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ORIGINAL ARTICLE

Diversity and composition of anuran communities in transformed landscapes in central Mexico

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Abstract
Anthropized environments are associated with loss of biodiversity and have been listed as sites with low species richness for various biological groups. In this study, anuran amphibian species richness, community composition, and taxonomic and functional richness are analyzed for a highly anthropized region of central Mexico, the state of Querétaro, Mexico. A literature and database review found 25 species of anurans recorded in 13 types of environments varying from conserved to anthropized ones. Non-irrigated agricultural environments with annual seasonal harvests, such as submontane scrubland and low deciduous forest, presented the greatest species richness. Environments that had been transformed into crop fields, induced grassland and urban areas showed a greater similarity in their species composition compared to temperate environments without strong modification, i.e., montane cloud forest, pine–oak forest and oak–pine forest. The environments that presented a lower number of species also presented higher values of taxonomic diversity than those that presented the greatest species richness. The study showed that anthropized environments can maintain a different species composition than conserved environments, and maintain greater species and functional richness. This being so, further studies evaluating population density, endemism and conservation status of the species are necessary to evaluate anthropic effect on amphibian communities and other biological groups in the state of Queretaro and in other regions of Mexico.

Keywords Amphibians · Conservation · Transformed environments · Urbanization

Introduction

Habitat loss and fragmentation have been considered as the main factors that promote decreased biodiversity (Schelhas & Greenberg, 1996; Laurance & Bierregaard, 1997). This loss of biodiversity is reflected in a decrease in the size of natural populations, loss of genetic variability and high species replacement among communities (Saunders et al., 1991).

Both habitat loss and fragmentation are the result of anthropic processes, which have effects on the local and regional scales (Haila, 2002; Areendran et al., 2013; Huey et al., 2009), mainly in the populations of various biological groups such as amphibians, plants or mammals (Saunders et al., 1991; Laurance et al., 2002). The creation of human settlements, in addition to transforming the environment, also affects the biology and ecology of organisms (Clark et al., 1990), mainly by modifying their feeding patterns, sites and reproductive seasons, and by promoting new predators, such as domestic animals, as well as hunting and elimination of individuals by the inhabitants of these settlements (Dickman, 1987).

Among vertebrates, amphibians are a group that is highly vulnerable to changes in the structure of the environment, since they are highly dependent on bodies of water in conserved or low disturbance sites (Pineda et al., 2005; Wells, 2007). This being so, amphibians have served as bioindicators of environmental health (Wells, 2007), since they have

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aquatic and terrestrial life cycles, different stages of development, larval or direct phases (Duellman & Trueb, 1994), in addition to carrying out foraging activities (food search), hibernation and reproduction. They, therefore, are highly sensitive to environmental disturbance (Simon et al., 2009; Stuart et al., 2004).

Urbanization and modification of the natural landscape into agricultural areas represents the main promoter of change in the composition of species and their abundances in communities (Beebee & Griffiths, 2005; Sodhi et al., 2008). This change in the composition of species by community is a consequence of anthropic factors, which also modify the occurrence of functional traits of the species, which are defined as traits that can determine the species fitness and/or processes in the ecosystem where the species occurs (Weiher, 2011). Members of the anuran group show marked changes in species richness, composition and functional diversity when the environments where they occur suffer varying degrees of disturbance (Luja et al., 2017; Pereyra et al., 2018). For example, Clark et al. (2008) showed a notable decrease in individuals of *Ambystoma maculatum* and *Rana sylvatica* in environments with highways and high human population density. This effect was reflected in the small number of sites for reproduction, due to the presence of roads and pollution (Alberti et al., 2003; Clark et al., 2008). On the other hand, the tolerance presented by some species of anurans to transformed environments promotes changes in the diversity and composition of communities (Cruz-Elizalde et al., 2016a, b; Pereyra et al., 2018). Within these highly tolerant groups are species of the genera *Rhinella*, *Eleutherodactylus*, *Leptodactylus* and *Lithobates*, which use modified areas such as grazing areas or crop fields for maintenance of their populations, as well as foraging and reproduction activities (Cruz-Elizalde et al., 2016a). Pereyra et al. (2021) also reported that the communities of anurans in transformed environments are composed of species that are tolerant to changes in the environment, unlike species that are restricted to more conserved habitat conditions. This also brings with it the dominance of functional characters typical of tolerant species, and to the modes of reproduction presented by these species, which do not depend on conserved sites, unlike most species of the Hylidae family, which are representative of conserved environments (Duellman & Trueb, 1994; Wells, 2007; Crump, 2015; Aronson et al., 2016).

Various ecosystems in central Mexico are being heavily disturbed, which is reflected in considerable damage to the richness and diversity of various species of anuran amphibians that are currently in decline (Flores-Villela et al., 2010; Parra-Olea et al., 2014). Thus, although there are several studies that evaluate the richness and diversity of amphibians in this region (Flores-Villela et al., 2010; Cruz-Elizalde et al., 2016b), knowledge of the anthropic effect on the richness and composition of anuran communities at landscape level is scarce, and there is even less knowledge about their taxonomic and functional diversity in anthropized areas, such as agricultural areas, urban areas or remnants of natural vegetation. An example of this on the regional scale is the state of Querétaro, which has undergone significant changes in land use (Jones & Serrano Cárdenas, 2016), and where the study of amphibian fauna has been relatively scarce and where the study of the amphibian fauna has been relatively limited (Dixon & Lemos-Espinal, 2010; Parra-Olea et al., 2014; Cruz-Elizalde et al., 2016b, 2019). The state of Querétaro is located in central Mexico, a region with many urbanized areas, high population growth and dense human settlements (Esteller & Díaz-Delgado, 2002). However, in this state, several preserved environments can still be found, such as cloud forest and pine forest, sites with high richness and diversity of amphibian species (Flores-Villela et al., 2010).

In view of the accelerated rate of disturbance and loss of anuran populations in central Mexico (Flores-Villela et al., 2010), it is important to conduct studies that analyze species richness, similarity among communities, functional diversity and taxonomic diversity of communities at landscape level in conserved and disturbed environments in this region, as well as the anthropic effect on the composition of anuran communities. Analysis of the conservation status of the species specified in national and international regulations is also a priority, since many of these are in high risk categories (DOF, 2010; IUCN, 2021; Wilson et al., 2013).

The objective of this study is to analyze the richness, composition, functional richness and taxonomic diversity of amphibian communities in conserved and anthropic environments at landscape level in the state of Querétaro, as well as the conservation status of anuran species. Therefore, this study proposes to determine the contribution of conserved and disturbed environments to the composition of anuran communities in regions with a high degree of disturbance, as well as to identify functional traits and groups of species associated with different groups of environments (preserved and anthropized). Considering that amphibians are highly sensitive organisms to the transformation of the environment, in this study we hope to find that the greater the degree of disturbance in the analyzed environments, the lower the values in terms of species richness, as well as the values of taxonomic diversity and the values of functional richness.

Material and methods

Study area

The study area is the state of Querétaro, Mexico. The state is located in central Mexico (21° 40′, 20° 0′ N, 99° 0′, 100° 35′

E; Datum WGS84), an area highly urbanized by the creation of human settlements and agricultural areas. The state of San Luis Potosí adjoins it to the north, Guanajuato to the west, Michoacán to the south, Hidalgo to the east and the State of Mexico to the southeast (Fig. 1). It has an area of 11,769 km^2 (Bayona Celis 2016).

Data resources

Information on records of species presence and their location was obtained from various Mexican and foreign databases with records of amphibians for Mexico (Appendix 1), consultation of the Global Biodiversity Information Facility (GBIF, 2019) websites, and available databases of National Commission for the Knowledge and Use of Biodiversity (CONABIO) projects. Literature on richness and diversity of amphibians for the state was also consulted (Dixon & Lemos-Espinal, 2010; Cruz-Elizalde et al., 2016b, 2019). The records obtained from these resources were reviewed and georeferenced using the ArcMap 10.3 program (ESRI 2013). Because only the presence of species in previously established communities or environments is considered, the sources of information were considered sufficient. In this study, the abundances are not considered due to the difference in the sampling effort, or type of information source (databases and literature) between regions. The records of anuran species that showed doubtful distributions (Dixon & Lemos-Espinal, 2010; Frost, 2021) were removed from the analyses. The taxonomic update was based on the taxonomy followed by the Amphibian Species of the World website (Frost, 2021), where the most current taxonomic changes are summarized.

Characterization of the environments

The analyzed environments were established by consulting maps of land and vegetation use, Series VI (INEGI, 2017). The land use and vegetation maps were superimposed with the species records for Querétaro in the ArcMap 10.3 program (ESRI 2013). The environments analyzed were deciduous forest (DF), annual seasonal crop agriculture (ASCA), annual irrigated crop agriculture (AICA), pine–oak forest

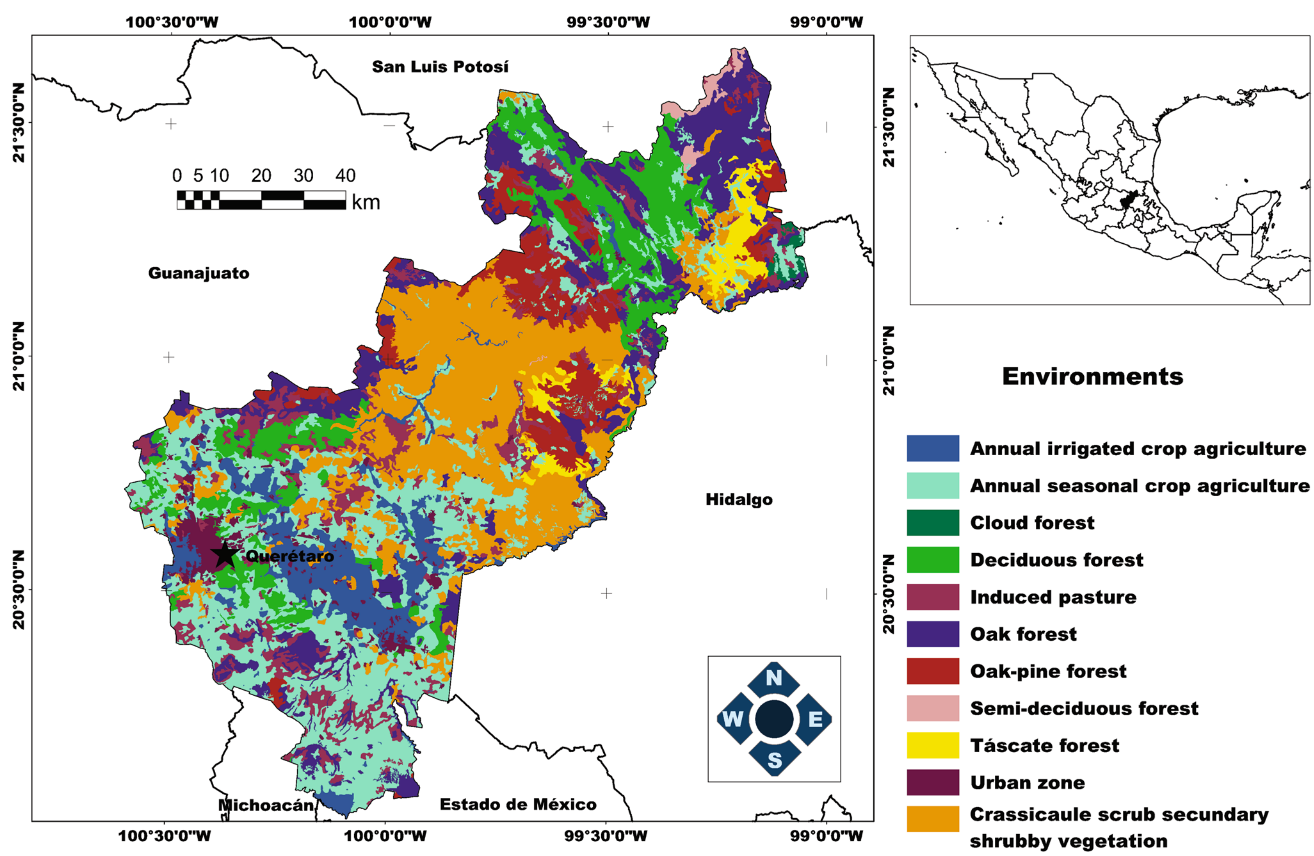


Fig. 1 Environments analyzed in Queretaro State, Mexico (deciduous forest = DF, annual seasonal crop agriculture = ASCA, annual irrigated crop agriculture = AICA, pine–oak forest = POF, submontane scrub = SS, urban zone = UZ, oak forest = OF, oak–pine forest = OPF, induced pasture = IP, crassicaule scrub secondary shrubby vegetation = CSSSV, táscate forest = TF, semi-deciduous tropical forest = SDTF, cloud forest = CF)

(POF), submontane scrub (SS), urban zone (UZ), oak forest (OF), oak–pine forest (OPF), induced pasture (IP), crassicaule scrub secondary shrubby vegetation (CSSSV), táscate forest (TF), semi-deciduous tropical forest (SDTF) and cloud forest (CF; Fig. 1) (INEGI, 2017).

Data analysis

Species richness

To estimate alpha diversity (number of species present in a geographic area; sensu Whittaker, 1972) of each community, the occurrences of the species in each of the analyzed environments were counted.

Functional richness

To assess functional richness (Fr), we collected information (based on literature and databases) about five specific traits: i) habit (terrestrial, arboreal or terrestrial/freshwater), ii) reproductive mode (eggs deposited in water with larval development, eggs deposited in vegetation, but with larval development in water, or eggs laid out of water, but with direct larval development), iii) diet (herbivore, carnivore, specialist, insectivorous or omnivorous), iv) activity (diurnal, nocturnal, diurnal/nocturnal) and v) foraging mode (active or sit and wait) (Laliberté & Legendre, 2010; Mason et al., 2005; Villéger et al., 2008). Functional richness was calculated using the FDIVERSITY program (Casanoves et al., 2010).

Similarity

We evaluated species similarity between environment types by non-metric multidimensional scaling (NMDS) in order to plot the relative position of the environment according to the similarity in species composition by means of the Jaccard index (Koleff et al., 2003). NMDS was carried out using STATISTICA (StatSoft, Inc. Tulsa, OK, USA).

Taxonomic diversity

To assess taxonomic diversity for each environment, the taxonomic distinctiveness of Warwick and Clarke (1995, 2001) was used, which calculates the mean (Delta = Δ^+) and the variance (Lambda = Λ;$^+$ sensu Clarke & Warwick, 1998) of the taxonomic diversity of the anurans from each environment. This method is based on the assumption that a community with high phylogenetic relationships among its species will be less diverse (phylogenetically) than a community with low phylogenetic relationships among its species (Clarke & Warwick, 1998; Moreno et al., 2009; Warwick & Clarke, 1995). The formulas are $\Delta^+ = [2\Sigma\Sigma_{i<j}\,\omega_{ij}]/[S\,(S-1)]$ and $\Lambda^+ = [2\Sigma\Sigma_{i<j}\,(\omega_{ij}-\Delta^+)^2]/[S\,(S-1)]$, where ω_{ij} is the taxonomic distance between each pair of species i and j, and S is the number of observed species in the sampling (Warwick & Clarke, 1995). A high value of Δ^+ reflects a low relationship among species, and therefore, it is a measure of taxonomic diversity. However, Λ^+ is not a measure of equity in the structure of the taxonomic diversity; thus, a high value of Λ^+ indicates under or over representation of the taxa in the sampling (environments).

To detect differences in taxonomic diversity between the environments, the samples were compared (species list per environment) and the regional species pool was used to generate a null model with 1000 resamplings (Clarke & Warwick, 1998). In this model, the average and variance of the sample numbers were used, and species were plotted with a confidence interval of 95% (Clarke & Warwick, 1998). We used communities with a minimum of 10 species to avoid the effect of high values of taxonomic diversity due to low species richness. To assess taxonomic diversity, we used the classification by Wilson et al. (2013), which includes five taxonomic categories: species, genus, family, order and class. The analysis was carried out with the PRIMER 5 program (Clarke & Gorley, 2001).

Conservation status

Conservation status of the amphibians was analyzed according to the NOM-059-SEMARNAT-2010 (DOF, 2010) Red List of the International Union for the Conservation of Nature (IUCN; updated February 2021), and the vulnerability environmental score index (EVS; Wilson et al., 2013). The EVS considers a score from 3 to 9 as low vulnerability, from 10 to 13 as moderate vulnerability and from 14 to 20 as high vulnerability. The score uses information about the (1) geographic distribution, (2) extent of ecological distribution (vegetation types in which species occur) and (3) reproduction mode of amphibians (see Wilson et al., 2013).

Results

Species richness

The richness of anuran amphibians of Querétaro is 25 species (Table 1). Of the 13 types of environments analyzed, annual seasonal crop agriculture (ASCA), submontane scrub (SS), deciduous forest (DF) and induced pasture (IP), have the highest species richness, with 19, 18, 17, and 15, respectively (Table 1). Cloud forest (CF), semi-deciduous tropical forest (SDTF) and oak–pine forest (OPF) environments presented the lowest species richness, with 6, 4 and 3 species respectively (Table 1).

Table 1 List of anuran amphibians of the state of Querétaro present in the analyzed environments

Family/species	Analyzed environments												
	DF	ASCA	AICA	POF	SS	UZ	OF	OPF	IP	CSSSV	TF	SDTF	CF
Family Bufonidae													
Anaxyrus compactilis	X	X				X			X	X			
A. punctatus	X	X	X		X	X				X			
Incilius occidentalis	X	X	X	X	X	X	X	X	X	X			
I. valliceps	X	X	X		X		X		X		X	X	X
Rhinella horribilis	X	X	X				X						
Family Craugastoridae													
Craugastor augusti		X	X	X	X				X	X	X		
C. decoratus		X			X		X		X		X		X
Family Eleutherodactylidae													
Eleutherodactylus guttilatus					X								
E. longipes		X			X				X				
E. nitidus										X			
E. verrucipes	X	X		X	X	X	X		X		X		X
Family Hylidae													
Dryophytes arenicolor	X	X	X		X	X	X	X	X	X	X		
D. eximius	X	X	X		X	X	X		X		X		
Rheohyla miotympanum	X			X			X		X				
Scinax staufferi												X	
Smilisca baudinii	X	X		X	X		X		X	X	X		X
Tlalocohyla godmani	X	X		X	X		X		X				X
T. picta												X	
Family Microhylidae													
Hypopachus variolosus					X								
Family Ranidae													
Lithobates berlandieri	X	X	X	X	X	X	X	X	X		X	X	X
L. montezumae	X	X	X			X				X			
L. neovolcanicus	X	X	X		X	X			X		X		
L. spectabilis	X	X			X								
Family Scaphiopodidae													
Scaphiopus couchi	X	X			X						X		
Spea multiplicata	X	X	X		X	X	X		X	X			
Species richness	**17**	**19**	**11**	**7**	**18**	**10**	**12**	**3**	**15**	**9**	**10**	**4**	**6**

DF Deciduous forest, *ASCA* annual seasonal crop agriculture, *AICA* annual irrigated crop agriculture, *POF* pine–oak forest, *SS* submontane scrub, *UZ* urban zone, *OF* oak forest, *OPF* oak–pine forest, *IP* induced pasture, *CSSSV* crassicaule scrub secondary shrubby vegetation, *TF* táscate forest, *SDTF* semi-deciduous tropical forest, *CF* cloud forest, X = occurrence

Functional richness

The ASCA environment showed the highest value of functional richness (9.5), followed by SS (9.1), and induced pasture (IP) (8.7; Fig. 2). The lowest values were from CF (4.3), SDTF (4.1) and OPF (3.6; Fig. 2).

Similarity of species

The NMDS analysis and the Jaccard similarity index show a high similarity in the composition of species among communities of transformed environments, as well as in annual irrigated crop agriculture (AICA), ASCA, urban zone (UZ) and IP (Fig. 3). In contrast, communities in conserved environments, such as OPF, pine–oak forest (POF) and SDTF, presented a different species composition to the rest of the environments (Fig. 3).

Taxonomic diversity

Taxonomic diversity (Delta +) values show that the táscate forest (TF), oak forest (OF), IP and ASCA environments

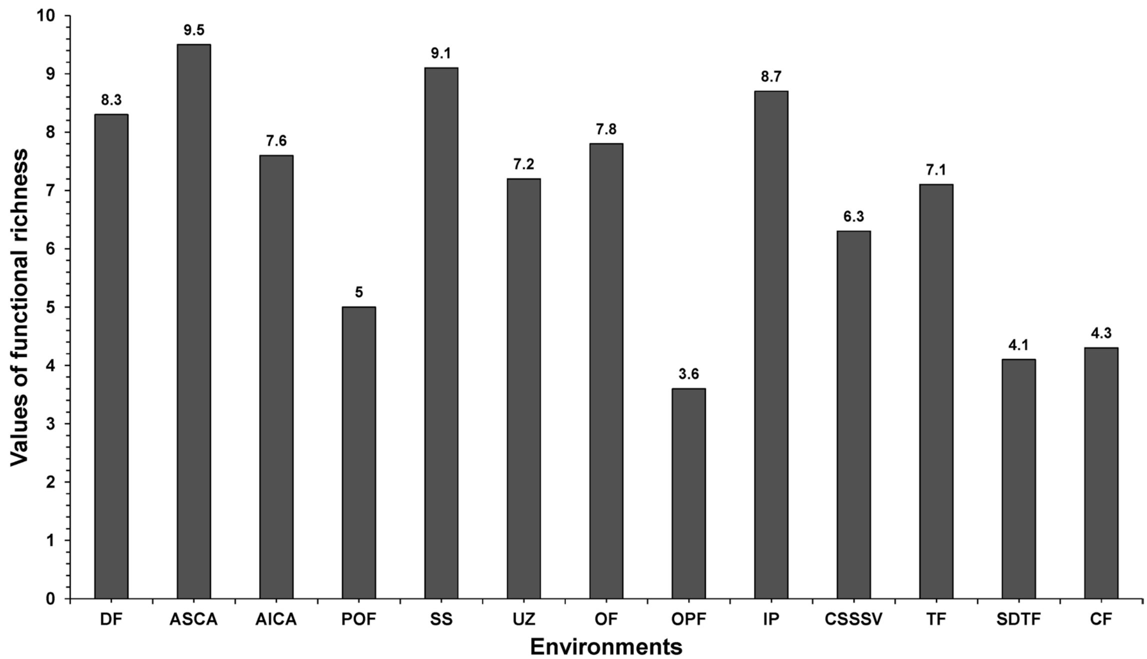
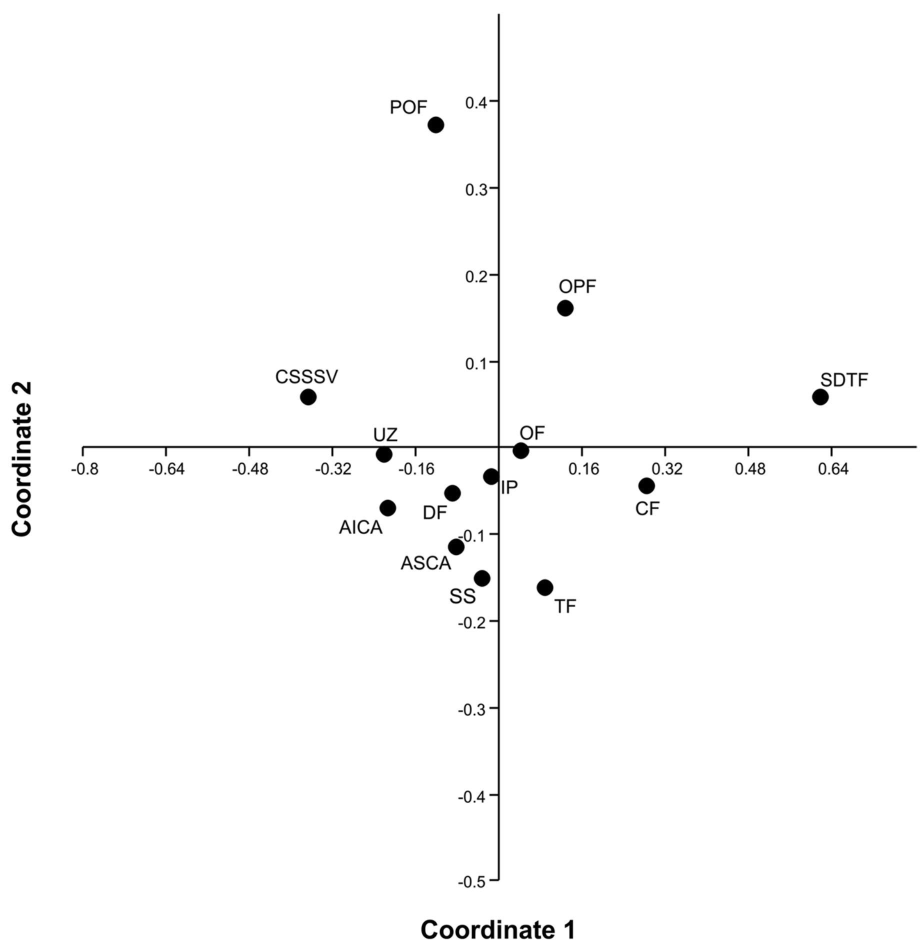


Fig. 2 Values of functional richness of amphibians in the analyzed environments

Fig. 3 Non-metric multidimensional scaling (NMDS) of the environments analyzed in the study (deciduous forest = DF, annual seasonal crop agriculture = ASCA, annual irrigated crop agriculture = AICA, pine–oak forest = POF, submontane scrub = SS, urban zone = UZ, oak forest = OF, oak–pine forest = OPF, induced pasture = IP, crassicaule scrub secondary shrubby vegetation = CSSSV, táscate forest = TF, semi-deciduous tropical forest = SDTF, cloud forest = CF). Stress value = 0.11



have taxonomic diversity values similar to the regional average (Fig. 4a). Environments such as the CF, POF and crassicaule scrub secondary shrubby vegetation (CSSSV) present higher values than average. According to the values of variation in taxonomic distinctiveness (Lambda +), all environments are within the 95% confidence interval generated by the model. The TF, OF, IP, SS and ASCA environments presented values similar to the average, and the UZ and AICA environments showed higher than average values (Fig. 4b).

Conservation status

Few of the total recorded species are in conservation categories according to Mexican regulations (Table 2; NOM-059-SEMARNAT-2010). Of the 25 species, 12 are endemic to Mexico (48%). *Craugastor decoratus*, *Eleutherodactylus*

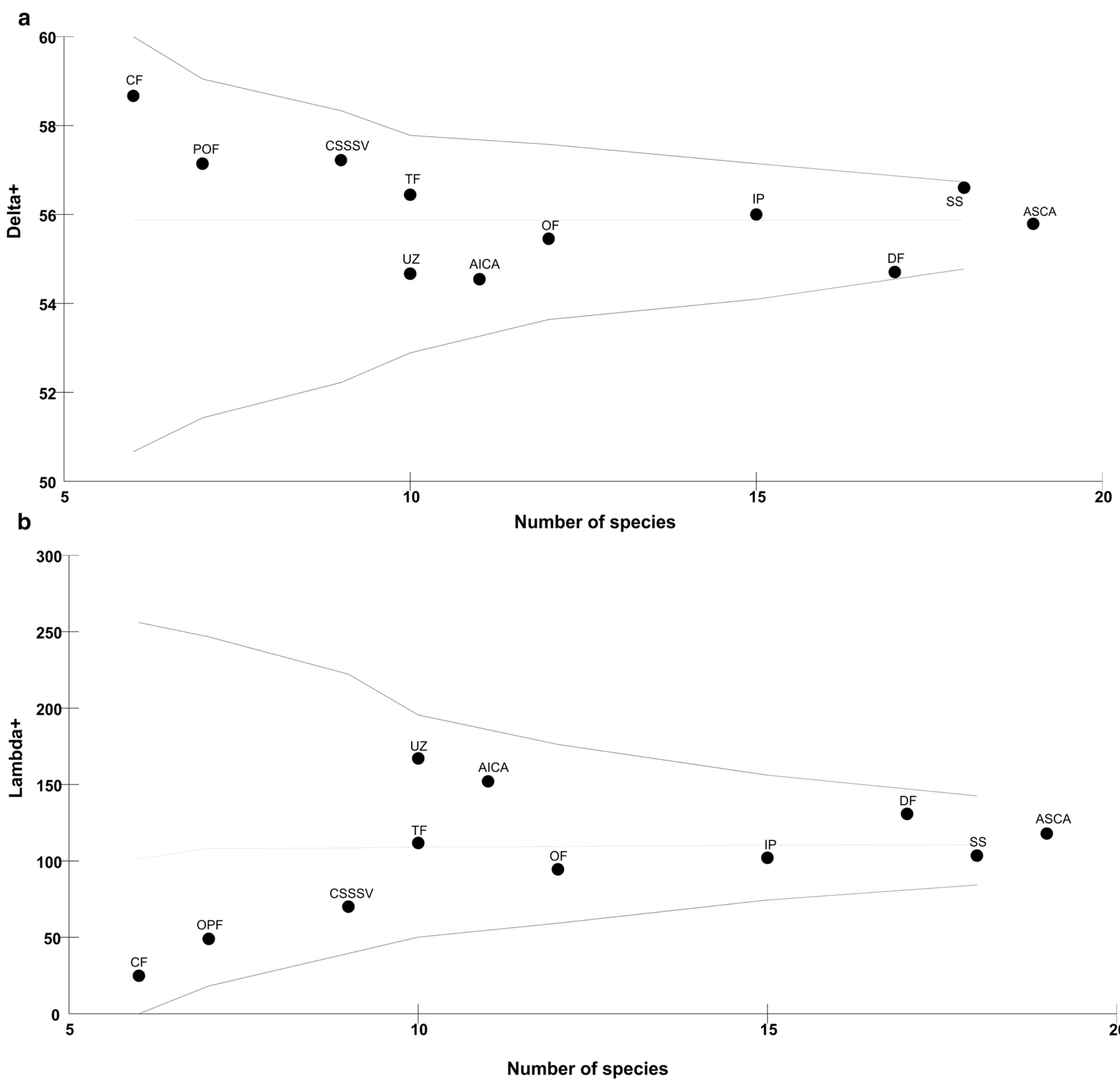


Fig. 4 Average (A; Delta^{+}) and variation (B; Lambda^{+}) of taxonomic diversity of the analyzed environments (deciduous forest = DF, annual seasonal crop agriculture = ASCA, annual irrigated crop agriculture = AICA, pine–oak forest = POF, submontane scrub = SS, urban zone = UZ, oak forest = OF, induced pasture = IP, crassicaule scrub secondary shrubby vegetation = CSSSV, táscate forest = TF, semi-deciduous tropical forest = SDTF, cloud forest = CF). The solid lines represent the 95% confidence interval according to the null model

Table 2 Categories of conservation of anurans from Querétaro

Family/species	EVS	IUCN	Population trend	NOM-059	Endemism
Family Bufonidae					
Anaxyrus compactilis	14 (H)	LC	Unknown	NC	E
A. punctatus	5 (L)	LC	Stable	NC	NE
Incilius occidentalis	11 (M)	LC	Stable	NC	E
I. valliceps	6 (L)	LC	Stable	NC	NE
Rhinella horribilis	3 (L)	LC	Increasing	NC	NE
Family Craugastoridae					
Craugastor augusti	8 (L)	LC	Stable	NC	NE
C. decoratus	15 (H)	VU	Unknown	Pr	E
Family Eleutherodactylidae					
Eleutherodactylus guttilatus	11 (M)	LC	Unknown	NC	NE
E. longipes	15 (H)	VU	Unknown	NC	E
E. nitidus	12 (M)	LC	Stable	NC	E
E. verrucipes	16 (H)	VU	Stable	Pr	E
Family Hylidae					
Dryophytes arenicolor	7 (L)	LC	Stable	NC	NE
D. eximius	10 (M)	LC	Stable	NC	E
Rheohyla miotympanum	9 (L)	NT	Decreasing	NC	E
Scinax staufferi	4 (L)	LC	Stable	NC	NE
Smilisca baudinii	3 (L)	LC	Stable	NC	NE
Tlalocohyla godmani	13 (M)	VU	Unknown	A	E
T. picta	8 (L)	LC	Increasing	NC	NE
Family Microhylidae					
Hypopachus variolosus	4 (L)	LC	Stable	NC	NE
Family Ranidae					
Lithobates berlandieri	7 (L)	LC	Stable	Pr	NE
L. montezumae	13 (M)	NC	Unknown	Pr	E
L. neovolcanicus	13 (M)	NT	Decreasing	A	E
L. spectabilis	12 (M)	LC	Decreasing	NC	E
Family Scaphiopodidae					
Scaphiopus couchii	3 (L)	LC	Stable	NC	NE
Spea multiplicata	6 (L)	LC	Stable	NC	NE

EVS Environmental vulnerability scores, *L* low, *M* medium, *H* high. International Union for Conservation of Nature Status (*DD* data deficient; *LC* least concern, *VU* vulnerable, *NT* near threatened; *EN* endangered; *CE* =critically endangered; *NC* not considered). Population trend (increasing, stable, decreasing, unknown). Conservation status in Mexico according to SEMARNAT (2010) (A = threatened, *Pr* subject to special protection, *NC* not considered). Endemism in Mexico (*E* endemic, *NE* not endemic)

verrucipes, *Lithobates berlandieri* and *L. montezumae* are under special protection (Pr, Table 2). *Tlalocohyla godmani* and *L. neovolcanicus* are threatened (A), and the rest are not named in the legislation. According to the IUCN, 19 species are classified as Least Concern (LC; Table 2), two species (*Rheohyla miotympanum* and *L. neovolcanicus*) as Near Threatened and four species (*C. decoratus*, *E. longipes*, *E. verrucipes*, *Tlalocohyla godmani*) as Vulnerable (VU; Table 2). Fourteen species have stable populations, three species have decreasing populations (*Rheohyla miotympanum*, *L. neovolcanicus* and *L. spectabilis*), two (*Rhinella horribilis* and *T. picta*) have increasing populations, and the status of their populations is unknown for six of the species (Table 2). Thirteen species have low values of environmental vulnerability due to EVS, eight have medium vulnerability, and only four species (*Anaxyrus compactilis*, *C. decoratus*, *E. longipes* and *E. verrucipes*) have high environmental vulnerability (Table 2).

Discussion

The transformation of the environment brings with it modifications in the conformation of the wealth and composition of the communities (Simon et al., 2009). In the present study, a different composition is observed in terms of the richness and diversity of anuran species at the landscape scale between environments, with transformed environments being those with a high number of species, unlike environments with little disturbance. This result is contradictory to the general pattern where lower species richness has been recorded in environments with a certain degree of disturbance (Clark et al., 1990; Saunders et al., 1991; Laurance et al., 2002). As organisms highly dependent on environmental conditions, amphibians are restricted to a few environments (Pineda et al., 2005; Huey et al., 2009), and only those species that tolerate transformed environments could occupy diverse communities by their high tolerance to this kind on environment (Cruz-Elizalde et al., 2016a). This being so, in the agricultural use environments (ASCA and AICA), desert (shrub) and urban areas, species of the Bufonidae families were registered, such as *Anaxyrus punctatus*, *Incilius nebulifer*, *I. occidentalis* and *Rhinella horribilis*, which have a wider tolerance range for environmental variation, such as high or low temperatures, in addition to exploiting a high number of microhabitats and types of environments (Dayton et al., 2004; Schalk et al., 2015).

Also, in these environments several species of the genus *Lithobates* were registered, such as *L. berlandieri*, *L. spectabilis* and *L. montezumae*, which have high tolerance to pollution, in addition to clutch sizes exceeding 10,000 eggs per laying (Wells, 2007). This type of reproductive strategy (large clutch size) favors the occurrence of these species in conserved and disturbed environments, in addition to promoting greater abundance in their populations. This pattern of dominance of species highly tolerant to pollution, as well as low ecological restriction (e.g., microhabitats, laying sites, etc.), has been recorded for desert environments (Dayton et al., 2004), tropical (Pineda & Halffter, 2004) and other transformed environments, such as pastures and crop fields (Laurance et al., 2002; Pineda et al., 2005).

As has been observed in other biological groups, such as mammals (Amori & Luiselli, 2013) and birds (Andrén, 1994), changes in the structure of the landscape affect the composition of their communities. In the environments analyzed here, there was remarkable similarity in the composition of species between environments with anthropic and preserved effects. For example, greater similarity was observed among agricultural areas, urbanized areas and induced pasture than between the mountain, pine–oak and oak–pine mesophilic forest environments (see Fig. 3), unlike species of the Bufonidae and Ranidae families in agricultural, temperate (CF, POF and OPF) and tropical environments (DF and SDTF) where anuran species with more stringent ecological requirements were recorded. These species were *Rheohyla miotympanum*, *Smilisca baudinii*, *Tlalocohyla godmani*, *T. picta* and *Craugastor decoratus*, which require unpolluted bodies of water, high humidity, broad tree cover and a wide variety of microhabitats to live in these environments (Duellman, 2001; Pineda & Halffter, 2004; Pineda et al., 2005).

Therefore, the different ecological and behavioral characteristics, in particular the reproductive modes used by the species registered in this study, promote different compositions in the anuran communities (Lieberman, 1986; Vitt & Caldwell, 2001). As can be seen in the numbers of species recorded per environment, and in the similarity in species composition among them, the agricultural and desert areas have a high number of species of certain families of anurans (Bufonidae, Ranidae or Eleutherodactylidae). This discrepancy between the number of species and the supraspecific taxonomic contribution (genera and families) is corroborated by the taxonomic diversity analysis. In this analysis, it is observed that communities with a low number of species, such as CF, POF and CSSSV, presented high values of taxonomic diversity; therefore, it is observed that both restricted species (e.g., *T. picta* and *C. decoratus*) and generalists (*I. occidentalis* and *L. berlandieri*) promote high complexity in the structure of communities (Dayton et al., 2004; Kerr & Deguise, 2004). Environments with anthropic effects, such as ASCA, IP and UZ, presented high values of functional richness. In these aspects, our results show a similar pattern to that of other studies, such as Riemman et al. (2017), who showed that environmental alteration does not affect functional richness of communities to a great degree. Despite presenting high values of functional richness in transformed environments, however, the negative effect of anthropized environments on the richness and diversity of different biological groups is widely recognized (Almeida et al., 2016; Ernst et al., 2006).

The composition of amphibian communities in the analyzed environments of Querétaro, as well as that of central Mexico, can be due to the complex orography that occurs in the area, since tropical, arid and semiarid environments occur in this region, as well as a high anthropic effect (Dixon & Lemos-Espinal, 2010; Flores-Villela et al., 2010). These transformed environments, such as agricultural areas, urban areas and induced grassland, in turn promote the occurrence of generalist species (Rothermel & Semlitsch, 2002). However, in terms of conservation, however, these species are less important than those with high ecological restrictions, such as those of the Hylidae, Craugastoridae or Eleutherodactylidae families (Duellman, 2001; Vitt & Caldwell, 2001).

The establishment of human-generated areas (anthropic effect) such as crop fields and urban areas is associated with a loss of richness and species diversity (Saunders et al. 1991; Haila, 2002). However, the pattern of low species richness in transformed environment was not reported in this study, since in the transformed environments, a greater number of species is observed; however, these species, mainly of the genera *Anaxyrus*, *Incilius* and *Lithobate*s have ecological characteristics that make them successful in a greater variety of environments (Cruz-Elizalde et al., 2016a). In terms of conservation, sites with a high number of species are a priority for their conservation. However, the anthropic effect on the composition of amphibian communities in the present study highlights the importance of also analyzing the taxonomic contribution and the functional role of the species, since in addition to conserving communities with high richness, supraspecific levels, such as genera or families, should also be considered as well as the diversity of functional features of the species in the communities (Lips, 1998; Wiens & Donoghue, 2004). An analysis of the structure and exchange of species between anthropized and conserved environments is important to determine the effect of loss and maintenance of biological diversity in different biological groups, in addition to devising and evaluating new strategies for the conservation of these species.

Appendix 1 National and foreign collections consulted with records of amphibians species from Querétaro, Mexico.

Collection	Country
Colección Herpetológica Centro de Investigaciones Biológicas, UAEH	Mexico
Comisión Nacional para el Conocimiento y Uso de la Biodiversidad CONABIO	Mexico
Colección Nacional de Anfibios y Reptiles de la Facultad de Ciencias del Instituto de Biología, UNAM	Mexico
Museo de Zoología de la Facultad de Ciencias de la Universidad Nacional Autónoma de México MZFC	Mexico
Collection of Vertebrates, University of Texas at Arlintong UTA	USA
Collection of Herpetology, University of California at Berkeley Museum of Vertebrate Zoology MVZ	USA
Collection Herpetology, Texas Cooperative Wildlife Collection, Texas A and M University TCWC	USA
Collection Herpetology, Oklahoma Museum of Natural History University of Oklahoma OMNH	USA
Collection of Herpetology, Zoology Section of Los Angeles Country Museum of Natural History LACM	USA
Collection of Herpetology, University of Illinois Museum of Natural History UIMNH	USA
Collection of Herpetology, Museum of Comparative Zoology, Harvard University MCZ	USA
The University of Michigan Museum of Zoology UMMZ	USA
Comisión Nacional para el Conocimiento y Uso de la Biodiversidad CONABIO	México

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Authors' contributions RCE and RPL conceived the idea. RCE and CBI analyzed the data. RCE wrote the paper. ARB reviewed the final version of the paper. All authors discussed the results and commented on the manuscript.

Availability of data and material Appendix 1, list of scientific collections consulted.

Declarations

Conflicts of interest The authors declare that they have no conflict of interest.

Ethics approval Not applicable.

Consent to participate All co-authors agree.

Consent for publication All co-authors agree.

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