

Variation of amphibian and reptile composition in forest fragments of Veracruz highlands, Mexico

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Abstract

Variation of amphibian and reptile composition in forest fragments of Veracruz highlands, Mexico. The central mountain region of Veracruz is one of the richest areas of herpetofauna in Mexico. The steep topographic gradient of this region is associated with climatic gradients that enable the occurrence of highly diverse herpetofauna communities. We tested differences among habitats to herpetofauna in an urban area, pine forest, oak forest, and riparian forest of municipality Camerino Z. Mendoza, Veracruz, Mexico. We conducted two-day monthly surveys between 2015 and 2017 in 69 sites from fragments of an urban area, riparian forest, *Quercus* forest, and *Quercus-Pinus* forest and tested for differences in herpetofauna species among these fragments. We found a total of 11 amphibian and 33 reptile species, and a high composition dissimilarity and species replacement among the sites. Our results amplified significantly the species-records within Camerino Z. Mendoza, and showed a great variation of amphibian and reptile composition among sites, highlighting the current role of these forests as a reservoir for herpetofauna and their importance for future conservation strategies in the region.

Keywords: Alfa diversity, beta diversity, herpetofauna, mountain region, richness.

Resumen

Variación de la composición de anfibios y reptiles en fragmentos de bosque del altiplano de Veracruz, México. La región montañosa del centro de Veracruz es una de las regiones con mayor riqueza herpetofaunística de México. El gradiente topográfico de esta región está asociado con diferencias climáticas que permiten la presencia de comunidades herpetofaunísticas muy diversas.

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Analizamos las diferencias en la diversidad herpetofaunística entre un área urbana, bosque de pino, bosque de roble y bosque de ribera del municipio Camerino Z. Mendoza, Veracruz, México. Realizamos censos mensuales de dos días entre 2015 y 2017 en 69 sitios de fragmentos de un área urbana, bosque ribereño, bosque de *Quercus* y bosque de *Quercus-Pinus* y analizamos las diferencias de especies de herpetofauna entre estos fragmentos. Encontramos un total de 11 especies de anfibios y 33 de reptiles, y una alta disimilitud en la composición y el reemplazo de especies entre los sitios. Nuestros resultados aumentaron los registros de especies dentro de Camerino Z. Mendoza, y mostraron una gran variación en la composición de anfibios y reptiles entre sitios, destacando el papel actual de estos bosques como reservorio de herpetofauna y su importancia para futuras estrategias de conservación en la región.

Palabras clave: diversidad alfa, diversidad beta, herpetofauna, región montañosa, riqueza.

Resumo

Variação na composição de anfíbios e répteis em fragmentos de floresta das terras altas de Veracruz, México. A região montanhosa de Veracruz central é uma das regiões herpetofaunísticas mais ricas do México. O gradiente topográfico dessa região está associado a diferenças climáticas que permitem a presença de comunidades herpetofaunísticas muito diversas. Analisamos as diferenças na diversidade da herpetofauna entre uma área urbana, uma floresta de pinheiros, uma floresta de carvalhos e uma mata ciliar no município de Camerino Z. Mendoza, Veracruz, México. Entre 2015 e 2017, realizamos censos mensais de dois dias em 69 fragmentos de uma área urbana, uma floresta ribeirinha, uma floresta de *Quercus* e uma floresta de *Quercus-Pinus* e analisamos diferenças em espécies entre estes fragmentos. Encontramos um total de 11 espécies de anfíbios e 33 espécies de répteis, e uma grande disparidade na composição e substituição de espécies entre locais. Nossos resultados aumentaram os registros de espécies dentro do município Camerino Z. Mendoza e mostraram uma grande variação na composição de anfíbios e répteis entre sítios, destacando o papel atual dessas florestas como reservatório de herpetofauna e a sua importância para futuras estratégias de conservação da região.

Palavras-chave: diversidade alfa, diversidade beta, herpetofauna, região montanhosa, riqueza.

Introduction

Amphibian and reptile diversity are threatened by land use change and deforestation in several regions around the world (IUCN 2021). For example, urbanization replaces natural habitats with urban infrastructure, which decreases ecological niches for species (McDonnell and Pickett 1993, Hamer and McDonnell 2008), reducing the diversity and abundance of native species, as well as favors invasive fauna (Pickett *et al.* 2001, McKinney 2006). Currently, 41% of amphibians and 19% of reptiles worldwide are in a risk category by the IUCN and land change use and deforestation are among the principal causes (IUCN 2021).

Mexico has a variety of ecosystems that hold the second and seventh largest species richness of reptiles and amphibians in the world, respectively (Flores-Villela and Garcia-Vázquez 2014, Parra-Olea *et al.* 2014, AmphibiaWeb 2021). Most of this diversity is in Veracruz, which is the third state with the greatest herpetofauna diversity of Mexico (Guzmán-Guzmán 2011). This state hosts 25% (220 spp.) and 27% (103 spp.) of reptile and amphibian species of the country, respectively. Unfortunately, the transformation of forest habitats into agricultural areas or grazing such as coffee plantations, sugarcane crops and urban areas are threatening the herpetofauna habitats (Murrieta-Galindo *et al.* 2013a,b, Rivera-Hernandez 2015).

The central mountain region of Veracruz is considered one of the richest areas of herpetofauna in the state, harboring approximately 191 species of amphibians and reptiles (Almaraz-Vidal and Cerón de la Luz 2016). This region is located in eastern Mexico and is part of the mountain system where the eastern end of Trans-Mexican Volcanic Belt and the Sierra Madre Oriental meet. The extremely steep topographic gradient of this region, ranging from sea level to more than 5500 m a.s.l., is associated with climatic gradients that enable the occurrence of highly diverse communities of herpetofauna (Almaraz-Vidal and Cerón de la Luz 2016) in alpine grasslands, *Pinus* forest, *Abies* forest, *Quercus* forest, xeric shrublands, riparian vegetation, cloud forests, evergreen tropical forest and deciduous tropical forest (Rivera-Hernández *et al.* 2019).

Camerino Z. Mendoza municipality is in central Veracruz highlands from 1300 to 2380 m a.s.l., and harbored different habitats including pine forest, oak forest, and riparian forest. This municipality is within the Cañón del Río Blanco National Park, and includes 12 villages with different demographic growth and proximity to the forests (CONANP 2021). The municipality also belongs to a great industrial region with several effects on natural habitats such as water pollution and overexploitation of natural resources (Rivera-Hernández 2015). The region where Camerino Z. Mendoza is located has been previously studied (Ochoa-Ochoa and Flores-Villela 2006, 2011, Almaraz-Vidal and Cerón de la Luz 2016, Contreras-Calvario *et al.* 2019), finding high herpetofauna richness as well as differences in species richness and composition among altitude forests. For example, Almaraz-Vidal and Cerón de la Luz (2016) found in the region 191 species of amphibians and reptiles, of which only 50% of them are similar between two altitudinal regions of the Pico de Orizaba volcano. Despite the region where Camerino Z. Mendoza is located has been previously studied, to the best of our knowledge, none of these studies have

documented the diversity of this municipality along the different environments.

In this study we provide field sampling and records documentation of herpetofauna from Camerino Z. Mendoza, Veracruz, Mexico. Given that urban areas and their closeness to forests may influence amphibian richness, we hypothesized that forests affected by big human populations would show less richness than forests with low or null human impact. To test this, we examined differences in herpetofauna species among areas with different environments (riparian forest, oak forest, pine-oak forest, and an urban area) and different degrees of disturbance due to urbanization. Our results highlight the current role of fragment forests as a reservoir for herpetofauna that could be used for future conservation strategies.

Materials and Methods

Study Area

The Camerino Z. Mendoza municipality is located in the highlands region of central Veracruz (18°45'–18°49' N, 97°08'–97°12' W) (Figure 1). The region has an annual average precipitation of 900–1600 mm, a tropical wet climate with the lowest temperature at 14°C in winter and highest at 20°C in the summer season (INEGI 2009, CEIEG 2019). Camerino Z. Mendoza and surrounding areas comprise an admixture of habitats with significantly different forest structure and tree composition, including riparian forest, *Quercus* forest, *Quercus-Pinus* forest, and urban areas (Rivera-Hernández 2015) (Figure 1). Additionally, the municipality host four villages with different degree of urbanization: Mendoza City with 45,003 inhabitants and near a riparian forest, La Cuesta with 2,095 inhabitants and surrounded by oak forest, and Necoxtla with 2,890 inhabitants and surrounded by a pine forest (CEIEG 2019). According to the different environments and degree of urbanization that Camerino Z. Mendoza have, we compared the amphibian and

reptile richness among: a riparian forest (RF) near to Mendoza City dominated by *Taxodium mucronatum* Ten. (= *Taxodium huegelii* hort. ex P.Lawson and C.Lawson) (18°47'44"–18°48'15" N, 07°10'57"–97°10'36" W; 1302–1330 m a.s.l.); an oak forest (QF) near to La Cuesta dominated by *Quercus* (18°47'43"–18°47'19" N, 97°10'43"–97°09'22" W; 1350–2000 m a.s.l.); a pine forest (PF) near to Necoxtla dominated by *Pinus patula* Schltdl. and Cham., *Quercus* sp., and *Cupressus* sp. reforestation (18°47'22"–18°45'51" N, 97°09'21"–97°09'12" W; 2000–2350 m a.s.l.); and the urban area of Mendoza City (UA) dominated by non-native species such as *Ficus benjamina* L., *Livistona chinensis* (Jacq.) R. Br. ex Mart.,

Jacaranda mimosifolia D. Don, *Araucaria heterophylla* (Salisb.) Franco, and *Eucalyptus globulus* Labill. (18°47'35"–18°48'39" N, 97°11'46"–97°10'29" W; 1310–1390 m a.s.l.) (Figure 1).

Data Collection

We conducted two-day monthly surveys between 2015 and 2017 in four environments: urban area (UA, 12 sites), riparian forest (RF, 13 sites), *Quercus* forest (QF, 33 sites), and *Quercus-Pinus* forest (QF, 11 sites) (Figure 1). Amphibians and reptiles were actively searched during the day in all microhabitats that might be occupied

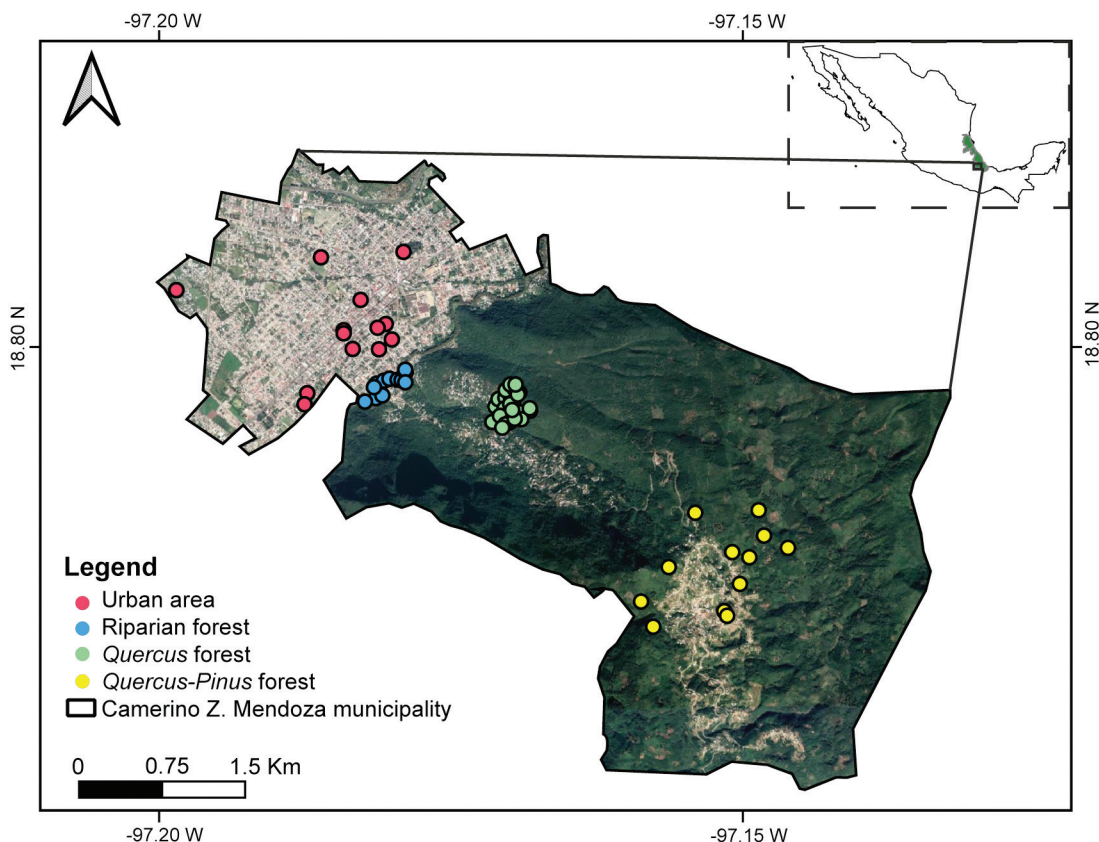


Figure 1. Map of the sites sampled in the urban area, riparian forest, *Quercus* forest and *Quercus-Pinus* forest of Camerino Z. Mendoza municipality.

by amphibians or reptiles. All individuals were collected by hand when encountered for identification, several species were photographed, and all individuals were returned to the collection site. Opportunistically surveys between 2015 and September 2020 also were added to our register.

In addition to our field surveys, we reviewed species reported from this municipality in the VertNet database (<http://portal.vertnet.org/search>), the Global Biodiversity Information Facility database (GBIF <https://www.gbif.org/>), and the Sistema Nacional de Información sobre Biodiversidad (SNIB) database to which contain records from scientific collections collected in Mendoza municipality.

Data Analysis

We analyzed the compositional differences among sites through species replacement and species richness differences applying the method proposed by Carvalho *et al.* (2012). Briefly, the compositional differences were measured at each two sites from the addition of species replacement and species richness differences (Appendix I). The species richness was defined as the number of species found during the study and in electronic databases. Differences in species richness between sites were tested with Kruskal-Wallis test the function 'kruskal.test' in R (R Core Team 2019). Replacement was defined as the substitution of n species in a given site by N species in another site. Finally, we obtained an overall measure of compositional dissimilarity among sites using the Jaccard dissimilarity index. To visualize richness and beta diversity, plots were carried using the ggplot2 package (Wickham 2016) in R (R Core Team 2019). Additionally, we determined which species are in a category of risk according to the Red List of Threatened Species (IUCN 2021) and the Mexican law (SEMARNAT 2010), to identify which environments host more species at risk which need conservation strategies.

Results

The total species for Mendoza was composed of four orders, 16 families, 36 genera and 44 species (33 reptiles and 11 amphibians) (Table 1, Figures 2 and 3). Seven amphibian species and 16 reptile species are endemic to Mexico (Table 1, Appendix II). Additionally, four species were found in our search of the HerpNet, GBIF and SNIB databases (Appendix II). One database species, *Scincella gemmingeri* (COPE, 1864), was not recorded during our sampling (Appendix II).

The number of species differed between sites, ranging from 13 in the urban area to 25 in *Quercus* forest (Figure 4A), but it was not statistically significant (Kruskal Wallis test, $\chi^2 = 3$, $df = 3$, $p = 0.3916$). The overall compositional dissimilarity among sites was 0.86 on average, ranging from 0.96 to 0.74. Replacement among sites was 0.64 on average, ranging from 0.87 to 0.39. The difference in species richness was 0.23 on average, ranging from 0.44 to 0.05 (Figure 4B, Appendix III).

According to the IUCN Red List (2021), 32 species were listed as Least Concern (LC), two as Endangered (EN), two as Near Threatened (NT), one as Vulnerable (VU), and one as Critically Endangered (CR). Meanwhile, according to the Mexican Law (NOM-059-SEMARNAT-2010), six species are Subject to Special Protection (Pr), and five are Threatened (A) (Table 1).

Discussion

Our results show that Mendoza municipality has a great variation of amphibian and reptile composition among sites of riparian forest, oak forest, pine-oak forest and urban area, offering suitable conditions for maintaining a portion of amphibian and reptile species of the region. The 44 amphibian and reptile species found in this study amplified significantly the species-records within Mendoza municipality. This highlights the current role of these forests as a reservoir for

Table 1. List of amphibians and reptiles found in Camerino Z. Mendoza. Sites where species were detected: UA, urban area; RF, riparian forest; QF, *Quercus* forest; QPF, *Quercus-Pinus* forest.

Taxon	UA	RF	QF	QPF	IUCN status	NOM-059	Endemic to Mexico
AMPHIBIANS							
BUFONIDAE							
<i>Incilius valliceps</i> (Wiegmann, 1833)	X	X			LC	-	
CRAUGASTORIDAE							
<i>Craugastor mexicanus</i> (Brocchi, 1877)			X	X	LC	-	X
<i>Craugastor pygmaeus</i> (Taylor, 1937)		X		X	VU	-	
ELEUTHERODACTYLIDAE							
<i>Eleutherodactylus cystignathoides</i> (Cope, 1877)	X				LC	-	-
<i>Eleutherodactylus nitidus</i> (Peters, 1870)			X		LC	-	X
HYLIDAE							
<i>Rheohyla miotympanum</i> (Cope, 1863)		X	X		NT	-	X
<i>Smilisca baudinii</i> (Duméril and Bibron, 1841)	X				LC	-	
PLETHODONTIDAE							
<i>Bolitoglossa platydactyla</i> (Gray, 1831)	X				NT	Pr	X
<i>Isthmura gigantea</i> (Taylor, 1939)				X	CR	-	X
<i>Pseudoeurycea firscheini</i> Shannon and Werler, 1955			X	X	EN	Pr	X
RANIDAE							
<i>Lithobates spectabilis</i> (Hillis and Frost, 1985)	X	X	X		LC	-	X
REPTILES							
ANGUIDAE							
<i>Abronia graminea</i> (Cope, 1864)			X	X	EN	A	X
<i>Gerrhonotus ophiurus</i> Cope, 1867			X		LC	-	X
COLUBRIDAE							
<i>Conopsis lineata</i> (Kennicott, 1859)			X	X	LC	-	X
<i>Drymarchon melanurus</i> (Duméril, Bibron, and Duméril, 1854)		X	X		LC	-	
<i>Ficimia olivacea</i> Gray, 1849			X		-	-	X
<i>Lampropeltis polyzona</i> Cope, 1860		X	X		LC	A	X
<i>Mastigodryas melanolomus</i> (Cope, 1868)			X		LC	-	
<i>Ninia diademata</i> Baird and Girard, 1853	X	X	X		LC	-	
<i>Pituophis deppei</i> (Duméril, 1853)	X				LC	A	X

Table 1. Continued.

Taxon	UA	RF	QF	QPF	IUCN status	NOM-059	Endemic to Mexico
<i>Pliocercus elapoides</i> Cope, 1860	X	X	X		LC	-	
<i>Stenorrhina degenhardtii</i> (Berthold, 1846)			X		LC	-	
<i>Thamnophis conanti</i> Rossman and Burbrink, 2005				X	-	-	X
DACTYLOIDAE							
<i>Anolis sericeus</i> Hallowell, 1856			X		-	-	
<i>Anolis laevis</i> (Wiegmann, 1834)			X		-	-	
<i>Anolis tropidonotus</i> Peters, 1863			X		-	-	
DIPSADIDAE							
<i>Coniophanes fissidens</i> (Günther, 1858)			X		LC	-	
<i>Chersodromus liebmanni</i> Reinhardt, 1861			X		LC	Pr	X
<i>Leptodeira annulata</i> (Linnaeus, 1758)			X		LC	-	
<i>Leptodeira polysticta</i> (Günther, 1895)		X				-	
ELAPIDAE							
<i>Micrurus diastema</i> (Duméril, Bibron, and Duméril, 1854)		X			LC	Pr	
GEKKONIDAE							
<i>Hemidactylus frenatus</i> Duméril and Bibron, 1836	X				LC	-	
KINOSTERNIDAE							
<i>Kinosternon integrum</i> Le Conte, 1854		X			LC	Pr	X
PHRYNOSOMATIDAE							
<i>Sceloporus formosus</i> Wiegmann, 1834				X	LC	-	X
<i>Sceloporus grammicus</i> Wiegmann, 1828				X	LC	Pr	
<i>Sceloporus mucronatus</i> Cope, 1885				X	LC	-	X
<i>Sceloporus variabilis</i> Wiegmann, 1834	X	X	X		LC	-	
SCINCIDAE							
<i>Plestiodon brevirostris</i> (Günther, 1860)				X	LC	-	X
<i>Scincella gemmingeri</i> (Cope, 1864)	X				LC	-	X
TYPHLOPIDAE							
<i>Amerotyphlops tenuis</i> (Salvin, 1860)	X				LC	-	-
VIPERIDAE							
<i>Crotalus ravus</i> Cope, 1865			X		LC	A	X
<i>Crotalus triseriatus</i> Wagler, 1830			X		LC	-	X
<i>Metlapilcoatlus nummifer</i> (Rüppell, 1845)			X		LC	A	X



Figure 2. Some amphibians found in Mendoza municipality. (A) *Pseudoeurycea firscheini*, (B) *Isthmura gigantea*, (C) *Bolitoglossa platyductyla*, and (D) *Eleutherodactylus nitidus*. Photos: JLCJ (A), RAV (B-D)

herpetofauna and their importance for future conservation strategies.

The variation in species richness and species composition among sites suggest that each one offers particular conditions as a product of differences in environments and forest traits. Species richness tends to increase from urban areas to *Quercus* forest, reaching the highest number of species in this site, and then decreasing in the highest elevation site in the *Quercus-Pine* forest. However, *Quercus* forest is one of the most types of vegetation perturbed along Veracruz, and *Quercus-Pine* has changes in land use and forest species extraction (Castillo-Campos *et al.* 2011). Therefore, the species richness in these areas could be threatened.

The high composition dissimilarity and species replacement among the sites suggest that they are

a function of landscape heterogeneity, differences in elevation, and forest management (Meza-Parral and Pineda 2015, Almaraz Vidal and Cerón de la Luz 2016, Aldape-López and Santos-Moreno 2016, Illescas-Aparicio *et al.* 2016). For example, 29 species are only in one type of vegetation or altitude, and 15 of them are in the *Quercus* forest. Although the *Quercus* forest was the environment with more access sites which could have increased the possibility of finding species, this environment has the best forest management in the region, including selective firewood collection such as selection of small branches to leave large logs in the area that may be micro-habitats to herpetofauna (Aldape-López and Santos-Moreno 2016, Illescas-Aparicio *et al.* 2016). Other environments such as *Quercus-Pine* forest have a worse forest management without log size selection and



Figure 3. Some reptiles found in Mendoza municipality. (A) *Abronia graminea*, (B) *Plestiodon brevirostris*, (C) *Stenorrhina degenhartdii*, and (D) *Metlapilcoatlus nummifer*. Photos: ACC (A), RAV (B–C), JLCJ (D).

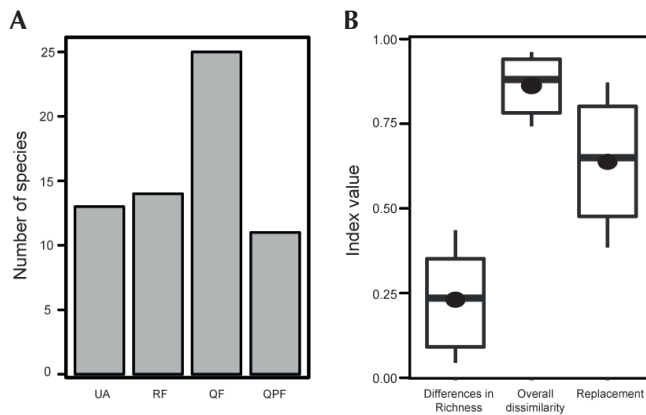



Figure 4. Number of species per site and compositional dissimilarity values between pairs of sites. (A) Herpetofauna richness in four sites of Mendoza municipality. (B) Overall dissimilarity (β_{cc}), replacement (β_{-3}), and differences in species richness (β_{rich}) are shown separately. Boxes represent 25 and 75 percentile, the horizontal line is the median, red point the mean, and whiskers are maximum and minimum values. Legend: UA, urban area, (RF) riparian forest, (QF) *Quercus* forest, (QPF) *Quercus-Pinus* forest.

deforestation to grow corn. Thus, the good practices in forest management may be maintaining several habitats for herpetofauna species.

Our results showed that 15 species have wide habitat distribution in more than one type of vegetation. This suggests that the high diversity of Mendoza Municipality is not only in one type of vegetation and is distributed over a wide range of elevations. Previous studies in Veracruz also have found high levels of dissimilarity and replacement in the composition of herpetofauna related to differences in elevation and the degree of heterogeneity (Wake *et al.* 1992, Pineda and Halfpter 2004, Murrieta-Galindo *et al.* 2013b, Meza-Parral and Pineda 2015, Almaraz-Vidal and Cerón de la Luz 2016). These results indicate that to preserve the herpetofauna of this region, the forest should be protected over a wide range of elevations.

We found 37 species in some category of risk according to the IUCN and the Mexican law (NOM-059). Despite Mendoza municipality being partially within the Río Blanco National Park, the *Quercus-Pine* forest is not within this protected area (CONANP 2017). Additionally, anthropogenic activities such as the pollution of Río Blanco river, forest fires, charcoal production, and irregular human settlements are increasing and threatening the species in the region inside and outside the protected area (Rivera-Hernandez 2015). Future studies should incorporate monitoring studies that allow us to know the current state of the populations to incorporate conservation strategies.

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Appendix I. Formula of compositional dissimilarity indexes.

Index	Formula	Description
Jaccard dissimilarity index	$\beta_{ec} = (b+c)/(a+b+c)$	a is the number of species in both sites, b is the number of species occurring only in the first site, and c is the number of species occurring only in the second site. min(b,c) is the minimum number of exclusive species in one of the two sites
Species replacement	$\beta_{-3} = 2 * \min(b,c)/(a+b+c)$	
Species richness differences	$\beta_{rich} = b-c / (a+b+c)$	

Appendix II. Checklist of amphibians and reptiles of Mendoza Municipality, Veracruz, Mexico, in scientific collections. Legend to Institutions: 1. UMMZ University of Michigan, Museum of Zoology; 2. IBUNAM Instituto de Biología, Universidad Nacional Autónoma de México; 3. ENCB-IPN Laboratorio de Cordados Terrestres, Departamento de Zoología, Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional; 4. Computarización de las colecciones de vertebrados terrestres de la Escuela Nacional de Ciencias Biológicas, IPN - Fases 2 y 3; 5. Colección Herpetológica de la Estación de Biología Tropical Los Tuxtlas, Veracruz.

Species	Longitude	Latitude	IUCN category	Endemic to Mexico	Catalog number	Institution	Source
<i>Stenorhina degenhardtii mexicana</i> (Steindachner, 1867)	-97.192	18.808	LC	-	119277	1	SNIB
<i>Scincella gemmingeri</i> (Cope, 1864)	-97.179	18.804	LC	X	18844	2	SNIB
<i>Sceloporus mucronatus</i> (Cope, 1885)	-97.179	18.805	LC	X	18803	2	SNIB
<i>Bolitoglossa platydactyla</i> (Gray, 1831)	-97.181	18.804	NT	X	7364	3	SNIB
<i>Bolitoglossa platydactyla</i> (Gray, 1831)	-97.181	18.803	NT	X	7364	4	GBIF
<i>Scincella gemmingeri</i> (Cope, 1864)	-97.179	18.804	LC	X	18844	5	GBIF
<i>Sceloporus mucronatus</i> (Cope, 1885)	-97.179	18.805	LC	X	18803	5	GBIF

Appendix III. Compositional dissimilarity values between pairs of study sites according to Carvalho et al. (2012).

A. Total dissimilarity values.	UA	RF	QF	B. Replacement values.				C. Difference in species richness values.			
	UA	RF	QF	UA	RF	QF	UA	RF	QF		
RF	0.75	-	-	RF	0.7	-	RF	0.05	-		
QF	0.88235	0.74194	-	QF	0.6	0.3871	QF	0.35294	0.35484		
QPF	0.95652	0.95834	0.875	QPF	0.86957	0.83333	QPF	0.08696	0.125		
						0.4375			0.4375		