Volume 25 (January 2015), 41–48

Herpetological Journal

FULL PAPER

Published by the British Herpetological Society

Effectiveness of protected areas in herpetofaunal conservation in Hidalgo, Mexico

Raciel Cruz-Elizalde[1], Aurelio Ramírez-Bautista[1], Larry David Wilson[2] & Uriel Hernández-Salinas[1,3]

[1]*Centro de Investigaciones Biológicas, Universidad Autónoma del Estado de Hidalgo, Mexico, A.P. 1-69 Plaza Juárez, C. P. 42001, Pachuca, Hidalgo, México*

[2]*Centro Zamorano de Biodiversidad, Escuela Agrícola Panamericana Zamorano, Departamento de Francisco Morazán, Honduras*

[3]*Instituto Politécnico Nacional, CIIDIR Unidad Durango, Sigma 119, Fraccionamiento 20 de Noviembre II, Durango, Durango 34220, México*

This study assesses the effectiveness of three Protected Natural Areas (PAs) in central Mexico (Parque Nacional El Chico, PNCH, Parque Nacional Los Mármoles, PNLM, and Reserva de La Biosfera Barranca de Metztitlán, RBBM), for the conservation of amphibians and reptiles. We also evaluate the conservation status of the concerned species assigned by the Mexican list for plants and animals, IUCN, as well as the species' Environmental Vulnerability Score. PNLM shows the highest richness and taxonomic diversity of both groups compared to those of PNCH and RBBM. We recorded a high number of endemic species, a high percentage of species (up to 88%) under risk categories, and a threat by environmental vulnerability for all species. We suggest that such analyses need to be expanded across a higher number of PAs in Mexico to determine their effectiveness in the protecting species of amphibians and reptiles and other biological groups.

Key words: amphibians, conservation, effectiveness, Hidalgo, natural areas, reptiles

INTRODUCTION

Loss and degradation of habitat due to anthropogenic activities represent a major threat to global biodiversity (Díaz et al., 2006; Magurran & McGill, 2011). Environmental deterioration results in decreasing numbers and abundance of species, changes in community composition and demographic patterns and a decrease in genetic diversity (Bell & Donnelly, 2006). The creation of protected areas (PAs) is a principal measure for the conservation of biodiversity (Ervin, 2003; Gaston et al., 2006, 2008; Greve et al., 2011). However, the establishment of PAs is not always reflecting an optimised measure to protect and manage biodiversity (Urbina-Cardona & Flores-Villela, 2010).

In Mexico, conservation strategies have involved habitat preservation by the creation of PAs (Ceballos, 2007). In 2007, 162 PAs were recognised by federal decree, which constituted 11.54% of the Mexican territory (CONANP, 2007). By 2013, the number had increased to 176, representing 13% of the country (CONANP, 2013). However, a large number of species and regions containing PAs are subject to management problems (Riemann & Ezcurra, 2005; Ramírez-Acosta et al., 2012). Existing PAs also do not necessarily maintain globally or regionally important biotic diversity through a preservation of ecosystem structure and function (Chape et al., 2005; Figueroa & Sánchez-Cordero, 2008; Urbina-Cardona & Flores-Villela, 2010). Conservation areas have been established based on the presence of charismatic umbrella species (Wilcox, 1984; Shafer, 1995), species indicative of environmental quality (Noss, 1990), or biodiversity hotspots (Myers, 1990). However, the number of species in an area does not reflect local higher-order phylogenetic diversity (Dinerstein & Wikramanayake, 1993; Pressey et al., 1993; Wiens et al., 2007; Cadotte et al., 2010).

A large number of PAs and other categories of reserves has been decreed in central Mexico (Flores-Villela et al., 2010), a poorly known region which is characterised by high species richness and high endemism for amphibians and reptiles (Ochoa-Ochoa et al., 2014). In the present study we evaluate the effectiveness of three PAs in the state of Hidalgo in the central region of Mexico for the protection of the herpetofauna by (i) measuring taxonomic distinctiveness of species, (ii) assigning these species to different conservation-related categories (IUCN, SEMARNAT, and the Environmental Vulnerability Score algorithm; Wilson et al., 2013a, b) and (iii) documenting the proportion of resident Mexican endemic species.

MATERIALS AND METHODS

Study area

The study area includes three PAs located in the state of Hidalgo in central Mexico (Fig. 1): Parque Nacional Los Mármoles (PNLM), Parque Nacional el Chico (PNCH) and

Correspondence: Aurelio Ramírez Bautista (ramibautistaa@gmail.com)

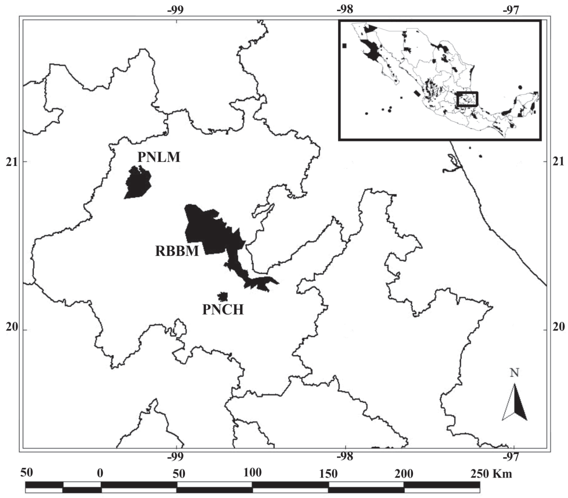

Fig. 1. Protected areas in Mexico (black areas on the top right inset). The map shows the three principal PAs in Hidalgo, Mexico (PNLM=Parque Nacional Los Mármoles, PNCH=Parque Nacional El Chico, RBBM=Reserva de la Biosfera Barranca de Metztitlán).

Reserva de la Biósfera Barranca de Metztitlán (RBBM; Table 1, Fig. 1). The PNLM forms part of the Sierra Gorda within the Sierra Madre Oriental. It comprises 23,150 ha, extends to a maximum of 2,800 m a.s.l. and exhibits subhumid climates with summer rains (CONANP, 2007). The vegetation types represented in the park are pine-oak forest, pine forest, oak forest, xerophytic scrub and pasturelands (Rzedowski, 1978; CONANP, 2007), with large areas being cultivated. PNCH is located 26 km from Pachuca city, and is part of the Transvolcanic Axis as well as the Sierra Madre Oriental (Zavala, 1995). This park comprises 2,739 ha that range from 2,350 to 3,086 m a.s.l. in elevation, and experiences a subhumid climate with summer rains and an average annual temperature of 10–14°C (maximum 36°C). Vegetation types include pine-oak forest, pine forest, fir forest and, to a lesser extent, cypress forest and xerophytic scrub in the south (Zavala, 1995; CONANP, 2007). RBBM, with an area of 96,043 ha, has a semi-dry climate and a mean annual temperature ranging between 16 and 22°C, (CONANP, 2003). It is located between the Sierra Madre Oriental and the Transvolcanic Axis, which allows for a high diversity of vegetation types as pine-oak forest, tropical deciduous forest, submontane scrub and xerophytic scrub (Rzedowski, 1978; CONANP, 2007).

Fieldwork

The fieldwork consisted of direct observations according to the methodology proposed by Casas-Andreu et al. (1991), involving both daily diurnal and nocturnal excursions from 1000 to 1400 hours and from 1900 to 2300 hours, respectively, in each vegetation community of each PA (see Table 1). Three observers participated in all sampling efforts and the same sampling effort was employed for all environments in each PA (3 persons x 8 hours of sampling = 24 person-hours by day in each vegetation type). Sampling in RBBM was undertaken in two periods (February–April and June–August 2007). Prior to this work, we undertook two additional sampling efforts in June and September 2006 (Vite-Silva et al., 2010); in total amounting to 960 person-hours. In the case of PNCH, we sampled in March, June, August and September 2005, and between May 2006 and June 2007 (2160 person-hours in 11 months). For PNLM, data were collected between May and November of 2007 and between June and September 2010 (1320 person-hours in 18 months).

We determined species in the field if possible, or collected specimens otherwise. All specimens were anesthetised in the laboratory by lowering body temperature and quickly killed by injection of a dose of 10% formalin behind the skull on the neck and fixed in 10% formalin (Casas-Andreu et al., 1991). For identification, individuals were transported to the Laboratorio de Ecología de Poblaciones, Centro de Investigaciones Biológicas, of the Universidad Autónoma del Estado de Hidalgo, and later deposited in their Herpetological Collection.

Data analysis

In order to estimate alpha diversity (α; number of species present in a community, *sensu* Whittaker, 1972) for each PA, we considered species occurrence in each of the areas and vegetation types analysed. In order to determine the species similarity among the PAs, we used the Jaccard similarity coefficient (Koleff et al., 2003) $J=c/(a+b)-c$; where a is the number of species present in site A, b is the number present in site B, and c the number of species present in both sites (A and B). The values for this coefficient range between 0 (when there are no species shared between the sites) and 1 (when both sites have the same species composition). The analysis was performed using the program EstimateS v.7.5 (Colwell, 2005). In order to evaluate the variation

Table 1. Description of the principal protected areas in Hidalgo, Mexico. PNLM=Parque Nacional Los Mármoles; PNCH=Parque Nacional El Chico; RBBM=Reserva de la Biosfera Barranca de Metztitlán. Pine-oak forest=POF, P=pastureland, XS=xerophytic scrub, PF=pine forest, OF=oak forest, FF=fir forest, TDF=tropical deciduous forest and SS=submontane scrub.

Protected Area Name	Category	Area (ha)	Vegetation types	Date of decree
PNLM	National Park	23,150	POF, P, XS, PF, OF	8 September 1936
PNCH	National Park	2,739	OF, FF, PF, POF, XS	6 July 1982
RBBM	Biosphere Reserve	96,043	TDF, POF, XS, SS	27 November 2000

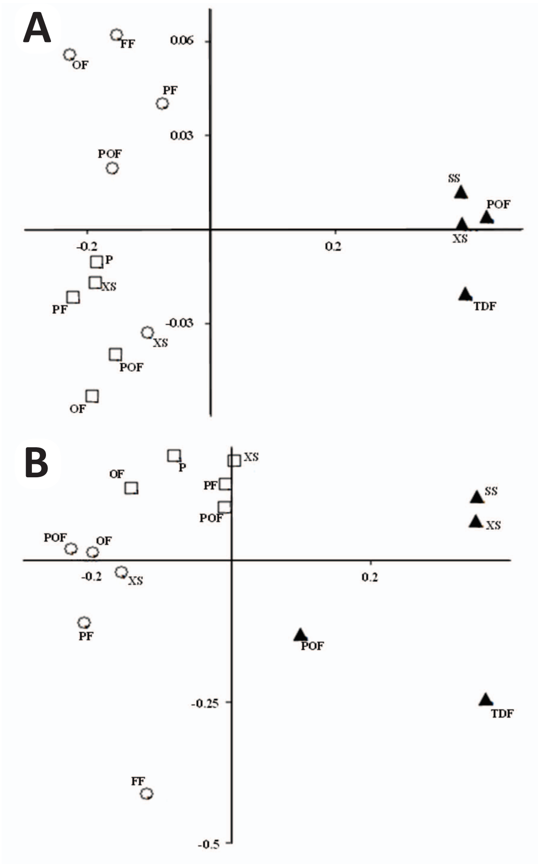

Fig. 2. Non-metric multidimensional scaling of vegetation types (POF=pine-oak forest, P=pastureland, XS=xerophytic scrub, PF=pine forest, OF=oak forest, FF=fir forest, TDF=tropical deciduous forest, and SS=submontane scrub) in the PAs (PNLM=square, PNCH=circles, RBBM=closed triangles) based on amphibian (A) and reptile (B) species composition in the PAs. The Stress value for amphibians was 0.593 and 0.114 for reptiles.

in species composition among the vegetation types of each PA, we applied a non-metric multidimensional scaling analysis (NMDS) to graphically represent the relative position of vegetation types in accordance with the similarity in species composition, using the Jaccard similarity coefficient (Koleff et al., 2003); the analysis was conducted using the program PAST (Hammer et al., 2001).

We further calculated the average (Delta=Δ^+) and the variance (Lambda=Λ^+; *sensu* Clarke & Warwick, 1998) of the amphibian and reptile taxonomic diversity in each PAs by using the measures proposed by Warwick & Clarke (1995, 2001). This method is based on the premise that a community with a high phylogenetic relationship among species is less diverse (in a phylogenetic sense) than a community with a low phylogenetic relationship among species. The formulas are represented by $\Delta^+=[2\Sigma\Sigma_{i<j}\,\omega_{ij}]/[S(S\text{-}1)]$, and $\Lambda^+=[2\Sigma\Sigma_{i<j}\,(\omega_{ij}\text{-}\Delta^+)^2]/[S(S\text{-}1)]$; where ω_{ij} is the taxonomic distance between each pair of species *i* and *j*, and *S* is the species number observed in the sample (Warwick & Clarke, 1995). A high value of Δ^+ reflects low relatedness among species, and is thus a direct measure of taxonomic diversity. Λ^+ is also a measure of the unevenness in the structure across

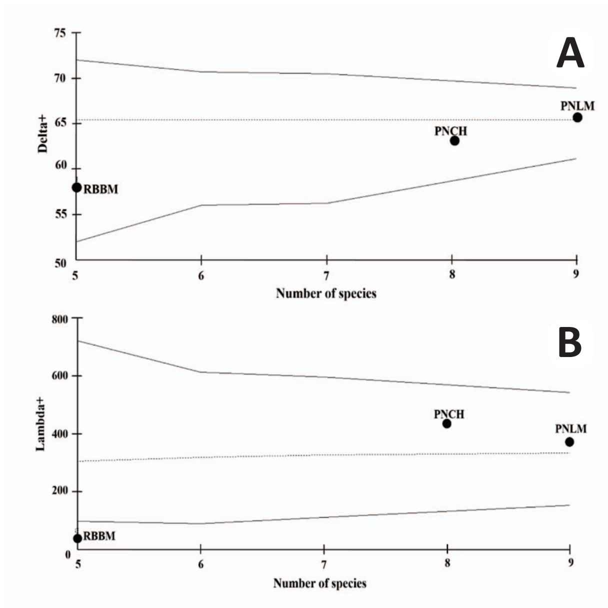

Fig. 3. Average taxonomic diversity (Delta+; A) and Variation in taxonomic diversity (Lambda+; B) by amphibian for analysed PAs (PNLM=Parque Nacional Los Mármoles, PNCH=Parque Nacional El Chico, and RBBM=Reserva de la Biosfera Barranca de Metztitlán) in Hidalgo state. Curved line represents confidence interval at 95% according to the null model.

taxonomic units. Thus, a high value of Λ^+ indicates over- or under- representation of taxa in the samples. To detect differences in the taxonomic distinctness at each PA we performed a randomisation test (Clarke & Warwick, 1998). This null model uses the theoretical mean and variance values, with 95% confidence intervals, obtained by taking 1000 random samples from the pool. Since the theoretical mean remains constant while the variance decreases with an increase in the number of species, the 95% confidence interval takes the form of a funnel (Clarke & Warwick, 1998).

We used the classification adopted by Wilson et al. (2013a, b), considering five taxonomic categories for amphibians and reptiles (species, genus, family, order and class). The analysis of taxonomic diversity was conducted using the program PRIMER 5 for Windows (Clarke & Gorley, 2001).

Species conservation status

We used the categories by the official Mexican list (NOM-059-SEMARNAT-2010) for plants and animals published by the Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT, 2010) and the International Union for Conservation of Nature and Natural Resources (IUCN, 2014). We also used the Environmental Vulnerability Score (EVS; Wilson et al. 2013a, b) that categorised as low (3 to 9 points), medium (10–13) and high (14–20). The score is the result of adding points assigned to species features based on (i) extent of geographic distribution, (ii) extent of ecological distribution (vegetation types used), and (iii) type of reproductive mode for amphibians and degree of human persecution for reptiles (see Wilson et al., 2013a, b for details).

Table 2. Amphibians and reptiles in the Protected Areas of Hidalgo, Mexico (X=presence, 0=absence; PNLM=Parque Nacional Los Mármoles; PNCH=Parque Nacional El Chico; RBBM=Reserva de la Biosfera Barranca de Metztitlán), risk category by SEMARNAT (Pr=Subject to special protection; A=Threatened; Nc=Not considered), IUCN (E=Endangered; VU=Vulnerable; NT=Near Threatened; LC=Least Concern; DD=Data deficient; NE=Not Evaluated), population status (U=Unknown; D=Decreasing; S=Stable; I=Increasing), endemism to Mexico (E=endemic; NE=not endemic), Environmental Vulnerability Score (EVS), and category of vulnerability (L=low, M=medium, H=high) according to Wilson et al. (2013a, b).

Taxa	PNLM	PNCH	RBBM	IUCN	Population Status	NOM-059-SEMARNAT-2010	Mexican Endemism	EVS
Amphibians								
Ambystoma velasci	0	X	0	LC	U	Pr	E	10 (M)
Chiropterotriton chondrostega	X	0	0	E	D	Pr	E	17 (H)
C. dimidiatus	0	X	0	E	D	Pr	E	17 (H)
C. mosaueri	X	0	0	DD	U	Pr	E	18 (H)
C. multidentatus	0	X	0	E	D	Pr	E	15 (H)
Pseudoeurycea altamontana	0	X	0	E	D	Pr	E	17 (H)
P. bellii	X	0	0	V	D	A	E	12 (M)
P. cephalica	X	X	0	NT	D	A	E	14 (H)
Craugastor augusti	X	0	0	LC	S	Nc	NE	8 (L)
Eleutherodactylus verrucipes	X	0	0	V	S	Pr	E	16 (H)
Incilius valliceps	0	0	X	LC	S	Nc	NE	6 (L)
Rhinella marina	0	0	X	LC	I	Nc	NE	3 (L)
Ecnomiohyla miotympanum	0	0	X	NT	D	Nc	E	9 (L)
Hyla arenicolor	X	0	0	LC	S	Nc	NE	7 (L)
H. eximia	0	X	0	LC	S	Nc	E	10 (M)
H. plicata	X	X	0	LC	S	A	E	11 (M)
Lithobates berlandieri	0	0	X	LC	S	Pr	NE	7 (L)
L. spectabilis	X	X	0	LC	D	Nc	E	12 (M)
Spea multiplicata	0	0	X	LC	S	Nc	NE	6 (L)
Reptiles								
Kinosternon integrum	X	0	0	LC	S	Pr	E	11 (M)
Abronia taeniata	X	X	0	V	D	Pr	E	15 (H)
Barisia imbricata	X	X	0	LC	U	Pr	E	14 (H)
Gerrhonotus infernalis	0	0	X	LC	S	Nc	E	13 (M)
G. ophiurus	X	0	0	LC	U	Nc	E	12 (M)
Phrynosoma orbiculare	X	X	0	LC	S	A	E	12 (M)
Sceloporus bicanthalis	0	X	0	LC	S	Nc	E	13 (M)
S. grammicus	X	X	X	LC	S	Pr	NE	9 (L)
S. minor	X	0	X	LC	S	Nc	E	14 (H)
S. mucronatus	0	X	0	LC	S	Nc	E	13 (M)
S. parvus	X	0	X	LC	S	Nc	E	15 H)
S. spinosus	X	X	X	LC	S	Nc	E	12 (M)
S. torquatus	X	0	X	LC	S	Nc	E	11 (M)
S. variabilis	X	0	X	LC	S	Nc	NE	5 (L)
Plestiodon lynxe	X	X	X	LC	S	Pr	E	10 (M)
Scincella gemmingeri	0	0	X	LC	S	Pr	E	11 (M)
Aspidoscelis gularis	X	0	X	LC	S	Nc	NE	9 (L)
Lepidophyma gaigeae	X	0	0	V	D	Pr	E	13 (M)
Boa constrictor	0	0	X	Nc	U	A	NE	10 (M)
Conopsis lineata	X	X	0	LC	S	Nc	E	13 (M)
Drymarchon melanurus	0	0	X	LC	S	Nc	NE	6 (L)
Ficimia hardyi	X	0	0	E	D	Nc	E	13 (M)
Masticophis schotti	X	0	0	LC	S	Nc	NE	13 (M)
Oxybelis aeneus	0	0	X	Nc	U	Nc	NE	5 (L)
Pantherophis emoryi	X	0	0	LC	S	Nc	NE	13 (M)
Pituophis deppei	X	X	0	LC	S	A	E	14 (H)
Salvadora bairdi	X	0	0	LC	S	Pr	E	15 (H)
Senticolis triaspis	0	0	X	LC	S	Nc	NE	6 (L)
Trimorphodon tau	0	0	X	LC	S	Nc	E	13 (M)
Diadophis punctatus	X	0	0	LC	S	Nc	NE	4 (L)
Geophis mutitorques	X	0	0	LC	S	Pr	E	13 (M)
G. semidoliatus	X	X	X	LC	S	Nc	E	13 (M)
Leptodeira septentrionalis	0	0	X	Nc	U	Nc	NE	8 (L)

Table 2. *(Continued)*

Taxa	PNLM	PNCH	RBBM	IUCN	Population Status	NOM-059-SEMARNAT-2010	Mexican Endemism	EVS
Rhadinaea gaigeae	X	X	0	DD	U	Nc	E	12 (M)
Micrurus tener	0	0	X	LC	S	Pr	NE	11 (M)
Rena dulcis	0	0	X	LC	U	Nc	E	13 (M)
Nerodia rhombifer	0	0	X	LC	S	Nc	NE	10 (M)
Storeria hidalgoensis	X	0	0	V	D	Nc	E	13 (M)
Thamnophis proximus	0	0	X	LC	S	A	NE	7 (L)
T. pulchrilatus	0	X	0	LC	U	Nc	E	15 (H)
Crotalus aquilus	X	X	0	LC	D	Pr	E	16 (H)
C. atrox	0	0	X	LC	S	Pr	NE	9 (L)
C. molossus	X	0	0	LC	S	Pr	NE	8 (L)
C. triseriatus	0	0	X	LC	S	Nc	E	16 (H)

RESULTS

The total species richness for the three PAs consists of 19 amphibian and 44 reptile species, representing 35.2% and 37% of the species known from the state of Hidalgo, respectively (Ramírez-Bautista et al., 2010; Table 2). PNLM contains the largest number of species (9 and 27, respectively), followed by amphibians for PNCH (8 species) and RBBM (5 species) and reptiles for the RBBM (23 species) and PNCH (14 species; Table 2). Vegetation types located in temperate environments harboured high species richness (Table 3), particularly pine-oak forest in PNLM and PNCH, followed by pine forest, fir forest and tropical deciduous forest in the case of RBBM (Table 3).

The similarity values for the species composition of both amphibians and reptiles for the three PAs are low. In the case of the amphibians, only the PNLM-PNCH pairing presents a value of 0.214 for three shared species. These results differ from those for reptiles, which in all combinations result in shared species. The values range between 0.367 for 11 shared species (PNLM-PNCH) species) to 0.125 for four shared species (PNCH -RBBM). Based on the Jaccard similarity coefficient, the NMDS analysis for amphibians and reptiles demonstrates a pattern in which identical vegetation types for each PA result in largely similar communities (Fig. 2, FF for reptiles as an exception).

Table 3. Species richness of amphibians and reptiles in Protected Areas (PNLM=Parque Nacional Los Mármoles; PNCH=Parque Nacional El Chico; RBBM=Reserva de la Biosfera Barranca de Metztitlán) in Hidalgo, Mexico, by vegetation types (POF=pine-oak forest, P=pastureland, XS=xerophytic scrub, PF=pine forest, OF=oak forest, FF=fir forest, TDF=tropical deciduous forest and SS=submontane scrub).

Protected Areas	Vegetation Types	Amphibians	Reptiles
PNLM	POF	8	21
	P	3	13
	XS	4	16
	PF	2	15
	OF	3	11
PNCH	OF	1	8
	FF	3	2
	PF	1	6
	POF	8	11
RBBM	XS	1	8
	TDF	3	12
	POF	2	8
	XS	2	8
	SS	3	4

With regard to taxonomic diversity, PNLM exhibits similar values for amphibian as well as reptile species (Fig. 3A and 4A). Regarding variation of taxonomic diversity, PNCH showed the highest overall value (above PNLM and RBBM for amphibians, and above PNLM for reptiles, Fig. 3B and 4B).

Of the total number of species of amphibians and reptiles reported for the PAs, 11 amphibians (57.9%) and 17 reptiles (38.6%) are listed with a risk status in the Norma Mexicana de Protección NOM-059-SEMARNAT-2010

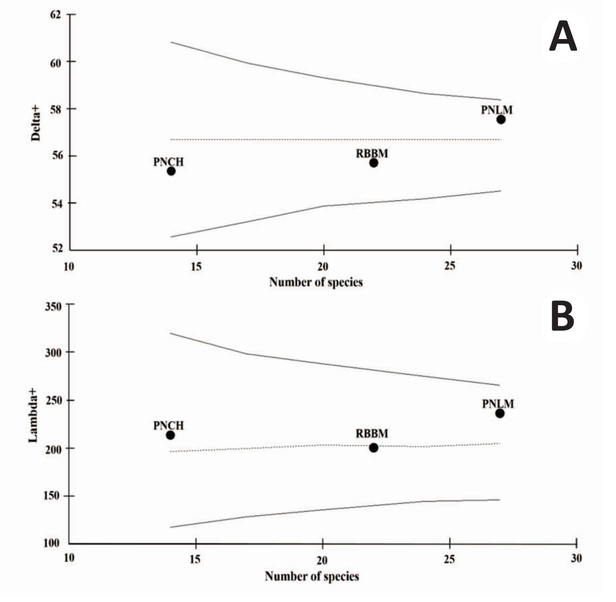

Fig. 4. Average taxonomic diversity (Delta+; A) and Variation in taxonomic diversity (Lambda+; B) by reptile for analysed PAs (PNLM=Parque Nacional Los Mármoles, PNCH=Parque Nacional El Chico, and RBBM=Reserva de la Biosfera Barranca de Metztitlán) in Hidalgo state. Curved line represents confidence interval at 95% according to the null model.

Table 4. Percentage species representation of amphibians and reptiles in protected areas according to IUCN and SEMARNAT categories.

Protected Area	IUCN (2014)		NOM-059-SEMARNAT-2010	
	Amphibians	Reptiles	Amphibians	Reptiles
PNLM	7 (88.9%)	26 (96.3%)	6 (66.7%)	12 (44.4%)
PNCH	8 (100%)	13 (92.9%)	6 (75%)	7 (50%)
RBBM	5 (100%)	20 (87%)	1 (20%)	7 (31.8%)

(SEMARNAT, 2010). Among amphibians, plethodontid salamanders were mostly affected (Special Protection (Pr) category: *Chiropterotriton chondrostega*, *C. dimidiatus*, *C. mosaueri* and *C. multidentatus*; Threatened (A) category: *Pseudoeurycea bellii*, *P. cephalica*). Among anurans, only *Lithobates berlandieri* and *Hyla plicata* are listed as Pr and A, respectively (Table 2). In the case of the reptiles, 13 species are categorised as Pr, and four are in the A category (*Phrynosoma orbiculare*, *Boa constrictor*, *Pituophis deppei* and *Thamnophis proximus*). A high number of species is not considered in the NOM-059-SEMARNAT-2010 (Table 2).

Sixteen species of amphibians (84.2%) and 40 species of reptiles (91%) are classified by the IUCN, with 46 considered as of Least Concern (LC), five as Vulnerable (VU) and five as Endangered (EN; Tables 2 and 4). PNCH harbours the highest percentage of species in risk categories, followed by RBBM and PNLM; considering reptiles alone, PNLM harbours the highest percentage (Table 4). PNCH also contains six of the eight species represented in the SEMARNAT system, with reported, followed by lower numbers for PNLM and RBBM (Table 4).

The Environment Vulnerability Scores show that all species of amphibians and reptiles in the three PAs can be classified as proposed by Wilson et al. (2013a, b; Table 2). Seven amphibian species fall under the category of low vulnerability (LV: 36.84%), five show moderate vulnerability (MV: 26.32%), and seven species show highly vulnerable (HV: 36.84%). For reptiles, 11 species are LV (25%), 24 species are MV (55.5%), and 9 species are HV (20.5%; Table 2).

DISCUSSION

We demonstrate in this study that both species richness and taxonomic diversity are highest for amphibians and reptiles in the Parque Nacional Los Mármoles (PNLM), followed by the Parque Nacional El Chico (PNCH) and the Reserva de La Biosfera Barranca de Metztitlán (RBBM). The observed pattern reinforces the importance for a range of PAs, despite the observation of similar species linked to specific environments occurring in several areas (amphibians: *P. cephalica* and *H. plicata*, see also Flores-Villela et al., 2010; reptiles: lizards such as *Abronia taeniata*, *Barisia imbricata* and *Sceloporus grammicus*, and snakes such as *Conopsis lineata*, *P. deppei* or *Crotalus aquilus*). Lizards of the genus *Sceloporus*, for example, inhabit arid and semi-arid regions of Mexico (Leaché & Mulcahy, 2007) and are characteristic parts of the fauna for RBBM, PNLM and PNCH. Groups with broad phylogenetic relationship show high similarities in the use of niche, and therefore tend to occupy environments with similar resources (Raxworthy et al., 2003; Wiens et al., 2010). The elevated taxonomic diversity in the montane environments is consistent with other studies from central Mexico (Flores-Villela et al., 2010).

For central Mexico, CONANP (2007) recorded a total of 32 national parks, six biosphere reserves, four areas established for the protection of flora and fauna and two areas for natural resource protection. Most of these areas, however, have been subjected to a high degree of environmental deterioration caused by land use change, pollution, and habitat fragmentation (Ochoa-Ochoa et al., 2009). It is generally acknowledged that the taxonomic diversity of terrestrial vertebrates in PAs is compromised by the intensity of habitat fragmentation and the negative impact of human settlements (Deguise & Kerr, 2006). Urban activities, climate change and agricultural activities have already been shown to reduce phylogenetic diversity in zooplankton and plants (Knapp et al. 2008; Helmus et al., 2010).

The studied PAs harbour a high proportion of endemic amphibians, in line with the level of species richness and endemism revealed during other studies from Mexico (Flores-Villela et al., 2010; Vite-Silva et al., 2010; Cruz-Elizalde & Ramírez-Bautista, 2012; Hernández-Salinas & Ramírez-Bautista, 2012). Our findings suggest that it is important to monitor the population status of some species in RBBM in light of an increase in invasive *Rhinella marina* (Luja & Rodríguez-Estrella, 2010). The high proportion of species placed in threat categories of the IUCN and the NOM-059-SEMARNAT-2010 (SEMARNAT, 2010; IUCN, 2014) further emphasises the need to implement various protective measures.

This study illustrates the importance of PAs for the maintenance of species richness and taxonomic diversity of amphibians and reptiles in central Mexico, primarily in montane environments. Further studies are needed to explore the contributions of herpetofaunal species to functional diversity (Petchey & Gaston, 2002), alongside with an evaluation of legal measures and their implementation for conservation (Ramírez-Acosta et al., 2012; Cuevas Hernández et al., 2013). The impact of anthropogenic activities on the studied PAs should also be further assessed using wider taxonomic groups (Figueroa & Sánchez-Cordero, 2008).

ACKNOWLEDGEMENTS

The authors would like to thank V. Vite Silva and B. Stephenson for their assistance with fieldwork. We thank two anonymous reviewers, who greatly improved our manuscript. This study was supported by the projects Diversidad Biológica del Estado de Hidalgo FOMIX-CONACYT 43761, FOMIX-HGO-2008-95828, FOMIX 2012/191908, 191908–Diversidad Biológica del Estado de Hidalgo-3a Etapa, and CONABIO JM001. Specimens were collected under permit SEMARNAT08-017-A with the environmental register numbers (NRA) HESSX1304811, and SEMARNAT-SGPA/DGVS/02726/10 issued by SEMARNAT and assessed by Mexican environmental protection laws.

REFERENCES

Bell, K.E. & Donnelly, M.A. (2006). Influence of forest fragmentation on community structure of frogs and lizards in northeastern Costa Rica. *Conservation Biology* 20, 1750–1760.

Casas-Andreu, G., Valenzuela-López, G. & Ramírez-Bautista, A. (1991). Cómo hacer una colección de anfibios y reptiles. Cuadernos del Instituto de Biología 10, Universidad Nacional Autónoma de México, México, D.F.

Cadotte, M.W., Davies, T.J., Regetz, J.S., Kembel, W., et al. (2010). Phylogenetic diversity metrics for ecological communities: integrating species richness, abundance and evolutionary history. *Ecology Letters* 13, 96–105.

Ceballos, G. (2007). Conservation priorities for mammals in megadiverse Mexico. The efficiency of reserve networks. *Ecological Applications* 17, 569–578.

Chape, S., Harrison, J., Spalding, M. & Lysenko, I. (2005). Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. *Philosophical Transactions of the Royal Society of London, Series B* 360, 443–455.

Clarke, K.R. & Warwick, R.M. (1998). A taxonomic distinctness index and its statistical properties. *Journal of Applied Ecology* 35, 523–531.

Clarke, K.R. & Gorley, R.N. (2001). PRIMER v5: user manual/tutorial. –PRIMER-E, Plymouth, United Kingdom.

Colwell, R.K. (2005). EstimateS: Statistical estimation of species richness and shared species from samples. Version 7.5.

CONANP. (2003). *Programa de manejo Reserva de la Biosfera Barranca de Meztitlán*. SEMARNAT. México, D.F.

CONANP. (2007). *Comisión Natural de Áreas Naturales Protegidas*. Available from: <http://www.conanp.gob.mx/sig/>. Accessed: 5 January 2013.

CONANP. (2013). *Comisión Nacional de Áreas Naturales Protegidas*, ¿Qué hacemos? Available from: <http://www.conanp.gob.mx/que_hacemos>. Accessed: 24 October 2013.

Cruz-Elizalde, R. & Ramírez-Bautista, A. (2012). Diversidad de reptiles en tres tipos de vegetación del estado de Hidalgo, México. *Revista Mexicana de Biodiversidad* 83, 458–467.

Cuevas Hernández, A.L., Sánchez-González, A. & Tejero-Díez, J.D. (2013). pteridophytes of a semiarid natural protected area in central Mexico. *Natural Areas Journal* 33, 177–188.

Deguise, I. & Kerr, J.T. (2006). Protected areas and prospects for endangered species conservation in Canada. *Conservation Biology* 20, 48–55.

Díaz, S., Fargione, J., Chapin, F.S. III. & Tilman, D. (2006). biodiversity loss threatens human well-being. *PLoS Biol*, 4, e277, doi:10.1371/journal.pbio.0040277.

Dinerstein, E. & Wikramanayake, E. D. (1993). Beyond “hotspots”: How to prioritize investments in biodiversity in the Indo-Pacific region. *Conservation Biology* 7, 53–65.

Ervin, J. (2003). Protected area assessments in perspective. *BioScience* 53, 819–822.

Figueroa, F. & Sánchez-Cordero, V. (2008). Effectiveness of natural protected areas to prevent land use and land cover change in Mexico. *Biodiversity and Conservation* 17, 3223–3240.

Flores-Villela, O., Canseco-Márquez, L. & Ochoa-Ochoa, L.M. (2010). Geographic distribution and conservation of the Mexican central highlands herpetofauna. In *Conservation of the Mesoamerican Amphibians and Reptiles*, 303–321. Wilson, L.D., Townsend, J.H. & Johnson, J.D. (eds). Eagle Mountain Publisher, L.C. Eagle Mountain, Utah, USA.

Gaston, K.J., Charman, K., Jackson, S.F., Armsworth, P.R., et al. (2006). The ecological effectiveness of protected areas: the United Kingdom. *Biological Conservation* 132, 76–87.

Gaston, K.J., Jackson, S.F., Cantú-Salazar, L. & Cruz-Piñón, G. (2008). The ecological performance of protected areas. *Annual Review of Ecology, Evolution and Systematics* 39, 93–113.

Greve, M., Chown, S.L., van Rensburg, B.J., Dallimer, M. & Gaston, K.J. (2011). The ecological effectiveness of protected areas: a case study for South African birds. *Animal Conservation* 14, 295–305.

Hammer, Ø., Harper, D.A.T. & Ryan, P.D. (2001). Past: Paleontological statics software package for evaluation and data analysis. *Paleontologica Electronica* 4, 9.

Helmus, M.R., Keller, W., Paterson, M.J., Cannon, C.H., et al. (2010). Communities contain closely related species during ecosystem disturbance. *Ecology Letters* 13, 162–174.

Hernández-Salinas, U. & Ramírez-Bautista, A. (2012). Diversity of amphibian communities in four vegetation types of Hidalgo State, Mexico. *The Open Conservation Biology Journal* 6, 1–11.

IUCN. (2014). *The IUCN Red List of Threatened Species v. 2013.2*. Available from: <http://www.iucnredlist.org>. Accessed 15 January 2014.

Knapp, S., Kuhn, I., Schweiger, O. & Klotz, S. (2008). Challenging urban species diversity: contrasting phylogenetic patterns across plant functional groups in Germany. *Ecology Letters* 11, 1054–1064.

Koleff, P., Gaston, K.J. & Lennon, J.K. (2003). Measuring beta diversity for presence-absence data. *Journal of Animal Ecology* 72, 367–382.

Leaché, A.D. & Mulcahy, D.G. (2007). Phylogeny, divergence times and species limits of spiny lizards (*Sceloporus magister* species group) in western North American deserts and Baja California. *Molecular Ecology* 16, 5216–5233.

Luja, V.H. & Rodríguez-Estrella, R. (2010). The invasive bullfrog *Lithobates catesbeianus* in oases of Baja California Sur, Mexico: potential effects in a fragile ecosystem. *Biological Invasions* 12, 2979–2983.

Magurran, A.E. & McGill, B.J. (2011). *Biological diversity: frontiers in measurement and assessment*. Oxford University Press.

Myers, N. (1990). The biodiversity challenge: Expanded hot spots analysis. *The Environmentalist* 10, 243–256.

Noss, R.F. (1990). Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* 4, 355–364.

Ochoa-Ochoa, L., Urbina-Cardona, J. N., Vázquez, L. B., Flores-Villela, O. & Bezaury-Creel, J. (2009). The effects of governmental protected areas and social initiatives for land protection on the conservation of Mexican amphibians. *PLoS ONE* 4, 9, e6878. doi:10.1371/journal.pone.0006878.

Ochoa-Ochoa, L., Campbell, J.A. & Flores-Villela, O.A. (2014). Patterns of richness and endemism of the Mexican herpetofauna, a matter of spatial scale? *Biological Journal of the Linnean Society* 111, 305–316.

Petchey, O.L. & Gaston, K.J. (2002). Functional diversity (FD), species richness, and community composition. *Ecology Letters* 5, 402–411.

Pressey, R.L., Humphries, C.J., Margules, C.R., Vane-Wright, R.I., & Williams, P.H. (1993). Beyond opportunism: key principles for systematic reserve selection. *Trends in Ecology and Evolution* 8, 124–128.

Ramirez-Acosta, J., Castellanos, A., Arnaud, G., Breceda, A. & Rojas-Soto, O. (2012). conservation of endemic terrestrial vertebrates in the protected areas of the baja california peninsula, Mexico. *Natural Areas Journal* 32, 15–30.

Ramírez-Bautista, A., Hernández-Salinas, U., Mendoza-Quijano, F., Cruz-Elizalde, R., et al. (2010). *Lista anotada de los anfibios y reptiles del estado de Hidalgo, México*. Universidad Autónoma del Estado de Hidalgo, Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México.

Raxworthy, C.J., Martínez-Meyer, E., Horning, N., Nussbaum, R.A., et al. (2003). Predicting distributions of known reptile species in Madagascar. *Nature* 426, 837–841.

Riemann, H. & Ezcurra, E. (2005). Plant endemism and natural protected areas in the peninsula of Baja California, Mexico. *Biological Conservation* 122, 141–150.

Rzedowski, J. (1978). *Vegetación de México*. Editorial Limusa, México.

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales). (2010). *Norma Oficial Mexicana NOM-059-SEMARNAT-2010, Protección ambiental Especies nativas de México de flora y fauna silvestres - Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio - Lista de especies en riesgo*. Diario Oficial de la Federación, segunda sección, 30 de diciembre, 1–78.

Shafer, C.J. (1995). Values and shortcomings of small reserves. *BioScience* 45, 80–88.

Urbina-Cardona, J.N. & Flores-Villela, O. (2010). Ecological niche modeling and prioritization of conservation-area networks for Mexican herpetofauna. *Conservation Biology* 24, 1031–1041.

Vite-Silva, V.D., Ramírez-Bautista, A. & Hernández-Salinas, U. (2010). Diversidad de anfibios y reptiles de la Reserva de la Biosfera Barranca de Metztitlán, Hidalgo, México. *Revista Mexicana de Biodiversidad* 80, 473–485.

Warwick, R.M. & Clarke, K.R. (1995). New biodiversity measures reveal a decrease in taxonomic distinctness with increasing stress. *Marine Ecology Progress Series* 129, 301–305.

Warwick, R.M. & Clarke, K.R. (2001). Practical measures of marine biodiversity based on relatedness of species. *Oceanography and Marine Biology: an Annual Review* 39, 207–231.

Whittaker, R.H. (1972). Evolution and measurement of species diversity. *Taxon* 21, 213–251.

Wiens, J.J., Parra-Olea, G., Garcia-Paris, M. & Wake, D.B. (2007). Phylogenetic history underlies elevational patterns of biodiversity in tropical salamanders. *Proceedings of the Royal Society of London, Series B* 274, 919–928.

Wiens J.J., Ackerly, D.D., Allen, A.P., Anacker, B.L., et al. (2010). Niche conservatism as an emerging principle in ecology and conservation biology. *Ecology Letters* 13, 1310–1324.

Wilcox, B.A. (1984). In situ conservation of genetic resources: determinants of minimum area requirements. In *National parks: conservation and development*, 639–647. McNeely, J.A. & Miller, K.R. (eds). Smithsonian Institution Press, Washington, D.C. USA.

Wilson, L.D., Mata-Silva, V., & Johnson, J.D. (2013a). A conservation reassessment of the reptiles of Mexico based on the EVS measure. *Amphibian and Reptile Conservation* 7, 1–47.

Wilson, L.D., Johnson, J.D., & Mata-Silva, V. (2013b). A conservation reassessment of the amphibians of Mexico based on the EVS measure. *Amphibian and Reptile Conservation* 7, 97–127.

Zavala, E. (1995). *Encinos Hidalguenses*. Universidad Autónoma de Chapingo, División de ciencias Forestales. México.

Accepted: 10 July 2014