Herpetofaunal diversity in Área Natural Protegida Las Musas, Guanajuato, Mexico

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Dryophytes eximius (Baird, 1854) is a hylid frog endemic to Mexico, where it has been recorded from 10 states and the Distrito Federal. In the following study, the authors examine herpetofaunal diversity in Área Natural Protegida Las Musas, in the state of Guanajuato. This treefrog is one of 12 amphibian species found in this natural protected area, where it was recorded in tropical dry forest, gallery forest, xerophytic scrub, and induced grassland. © J. Adrian Leyte-Manrique

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Herpetofaunal diversity in Área Natural Protegida Las Musas, Guanajuato, Mexico

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Abstract: Tropical dry forests are recognized as environments with high biological diversity marked by phenological patterns throughout the year, which define their species richness, composition, and abundance. Accordingly, knowledge on the diversity and abundance of species in a given area, and other aspects of their biology, is crucial for their conservation. In this context, we conducted a herpetofaunal survey in Área Natural Protegida Las Musas, a natural protected area (NPA) in the state of Guanajuato, Mexico. We compared species diversity between the seasons (wet and dry), and in five tropical vegetation types: gallery forest (GF), tropical deciduous forest (DF), xeric scrub (XS), induced grassland (IG), and associations of gallery forest and cornfields (G-C). We recorded a total of 40 species (27 from the field, 13 from the literature) in this NPA. The amphibians (12 species) are assigned to 10 genera and seven families, whereas the remaining herpetofauna (28 species of reptiles) are assigned to 20 genera and 10 families. We found species richness similar between the wet and dry seasons (17 species each), but species diversity was higher in the dry season than in the wet season. We also found the vegetation types DF, GF, and IG to be higher in species richness and diversity than G-C and XS. Our study adds to the knowledge of the herpetofauna at Las Musas, where the environment presently is threatened.

Key Words: Amphibians, conservation, diversity, reptiles, season, species richness, vegetation

Resumen: Los bosques tropicales caducifolios son reconocidos como ambientes con una alta complejidad marcada por patrones fenológicos a través del año, los cuales definen su riqueza específica, composición y abundancia. Por ello, el conocimiento sobre la diversidad y abundancia, entre otros aspectos, es crucial para la conservación de las especies en un área específica. En este contexto, conducimos un inventario herpetofaunístico en el Área Natural Protegida (ANP) Las Musas, en el estado de Guanajuato, México. Comparamos la diversidad de especies entre estaciones (lluvias y secas), y entre cinco tipos de vegetación: bosque de galería (BG), bosque tropical caducifolio (BTC), matorral xerófilo (MX), pastizal inducido (PI), y asociación de bosques de galería con cultivos de maíz (G-M). Registramos un total de 40 especies (27 registros en el campo y 13 de la literatura) en esta ANP. Los anfibios (12 especies) pertenecieron a 10 géneros y siete familias, mientras que el resto de la herpetofauna (28 especies de reptiles) pertenecieron a 20 géneros y 10 familias. Encontramos que la riqueza específica fue similar entre las lluvias y secas (17 especies en cada una), pero la diversidad de especies fue más alta en la estación de secas que en las lluvias. Encontramos que los tipos de vegetación de BTC, BG, y PI tuvieron una mayor riqueza de especies y diversidad que G-M y MX. Nuestro estudio se suma al conocimiento de la herpetofauna en Las Musas, donde el ambiente actualmente está amenazado.

Palabras Claves: Anfibios, conservación, diversidad, estación, reptiles, riqueza de especies, vegetación.

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INTRODUCTION

In recent years, studies focused on assessing species diversity among ecological communities or at different seasons of the year have helped elucidate the structure and dynamics of biological communities based on species richness (Cruz-Elizalde et al., 2012; Shaney and Marshall, 2013; Berriozabal-Islas et al., 2017). Studies based primarily on the use of diversity index values have allowed progress on the development and improvement of conservation strategies for various floral and faunal groups (García-Morales et al., 2011; Moreno et al., 2011). Among these groups, amphibians and reptiles have been shown to be useful models for understanding community functions (Cortés-Gómez et al., 2015), based on their ecological characteristics, intricate trophic webs, diversity of reproductive strategies, and taxonomic richness (Zug, et al., 2001; Ramírez-Bautista et al., 2014; Vitt and Caldwell, 2014).

The country of Mexico is well known for its high herpetofaunal species richness, which Johnson et al. (2017) reported as consisting of 1,292 native species, and represents 62% of the herpetofauna of Mesoamerica (www.mesoamericanherpetology.com; accessed 3 October 2017). Most taxa, however, are not found in protected areas, in part due to the limited distribution of many species (Medina-Aguilar et al., 2011; Macip-Ríos et al., 2015; Johnson et al., 2017). Although NPAs are beneficial for the protection of species, the actual number they protect remains unknown (Caballero-Cruz et al., 2016). With respect to the herpetofauna in the state of Guanajuato, the most recent species numbers have been estimated at 56, including 13 amphibians and 43 reptiles (Flores-Villela and García-Vázquez, 2014; Parra-Olea et al., 2014). Nonetheless, very few studies have addressed herpetofaunal richness and diversity in Guanajuato, while including such habitats as tropical dry forest and/or the occurrence of NPAs (Leyte-Manrique et al., 2016). Herpetofaunal surveys only have been conducted in a few of the 23 NPAs presently found in the state. In certain cases the surveys only have been partially completed, such as in Cerro de Arandas, located in the municipality of Irapuato (Uriarte-Garzón and Lozaya-Gloria, 2009), and in Cerro Amoles, Lago Crater La Joya y Área de Restauración Ecologíca, and Laguna de Yuriria and the surrounding area, Cerro el Culiacan, and La Gavia, in the municipalities of Moroleón, Yuriria, Cortazar, and Salvatierra (Arenas-Monroy, 2012; Reynoso et al., 2012). Las Musas is considered an "Area of Sustainable Use" that was reported to contain 26 herpetofaunal species (Chávez-Almanza, 2012); subsequently, however, the Instituto de Ecología of the state of Guanajuato (DOEG, 2013) reported 17 species.

Leyte-Manrique et al. (2016) conducted herpetofaunal studies in tropical environments in the municipality of Irapuato, Guanajuato. These authors conducted a survey and assessed species richness and diversity during the wet and dry seasons, and found that reptiles are better represented than amphibians, and that species richness is greater in the rainy season than during the dry months. A similar pattern has been reported in other studies conducted in seasonal tropical environments in other areas of Mexico (García and Cabrera-Reyes, 2008; Vite-Silva et al., 2010; Rioja-Paradela et al., 2013; Fuentes-Castrejón and Maldonado-Gasca, 2015).

Given the importance of seasonal tropical ecosystems (Janzen, 1988; Golicher et al., 2012), as well as of NPAs in Mexico, our aim in this study was to obtain and evaluate herpetofaunal richness and diversity in five vegetation types during both the wet and dry seasons at Área Natural Protegida Las Musas, Guanajuato, Mexico. Prior to our study, we hypothesized that the least disturbed areas would show the most diversity.

METHODS

Study Area

Área Natural Protegida Las Musas is located in the municipality of Manuel Doblado, in the state of Guanajuato (20°37'18"N, 101°54'21"W; WGS 84; Fig.1); its surface area consists of 3,174.76 ha, with an elevational range from 1,740 to 1,810 m. The climate in this region is semi-warm subhumid, with an average annual temperature of 20°C, the highest average temperatures are recorded in summer (38.5°C) and the lowest in winter (12°C), and the average annual precipitation ranges from 700 to 800 mm (García, 1973; DOEG, 2013). The primary vegetation is tropical deciduous forest, with elements of gallery forest, xeric scrub, induced grassland, and agricultural fields (Rzedowski, 1978). We generated our herpetofaunal list based on fieldwork conducted from July of 2014 to August of 2015, from records obtained in the literature, and from electronic databases (www.VertNet.org; Museo Dugès; and Colección de Anfibios y Reptiles de la Facultad de Ciencias de la Universidad Nacional Autónoma de México). We used only the records from our fieldwork in the species diversity analyses, because of the availability of abundance values.

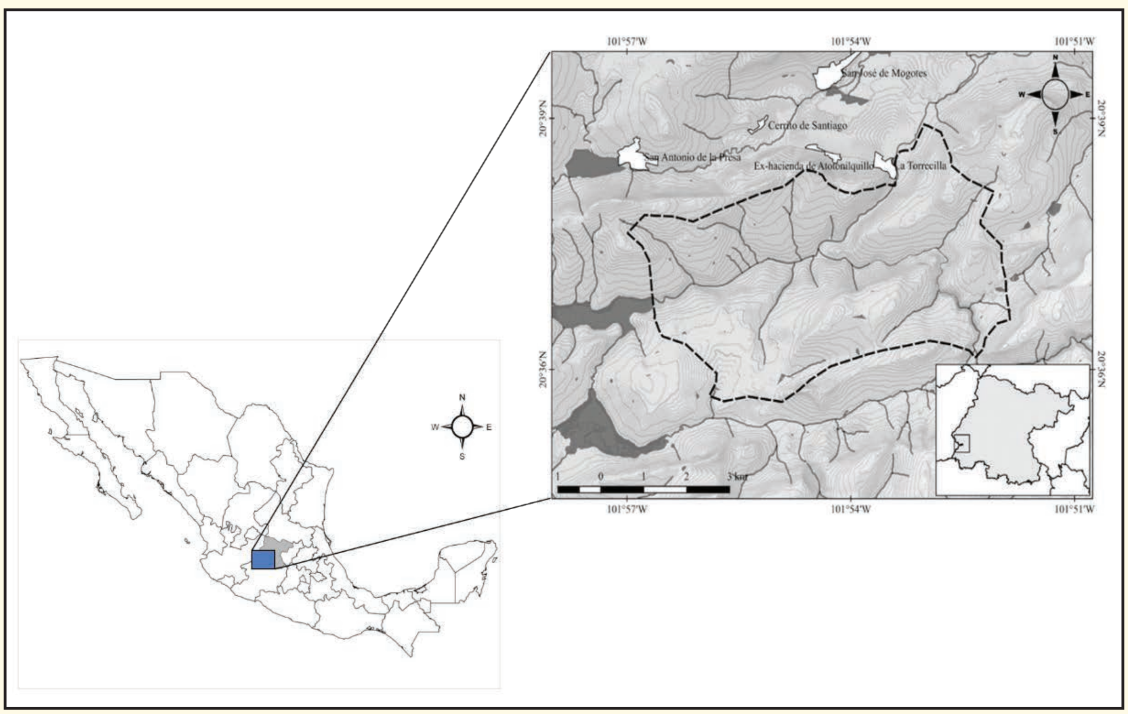

Fig. 1. Location of Área Natural Protegida Las Musas, Municipio de Manuel Doblado, Guanajuato, Mexico.

Fieldwork

We conducted sampling activities in five vegetation types: gallery forest (GF), tropical deciduous forest (DF), xeric scrub (XS), induced grassland (IG), and associations of gallery forest and cornfields (G-C) (DOEG, 2013). We made 12 trips to the study area, each lasting three days, and searched for herpetofauna in the five vegetation types. Sampling effort (hours/person) accounted for 13/3 = 39 h/day, resulting in a total of 117 h/person for three days, and 1,404 h/person for the entire period (Cruz-Elizalde and Ramírez-Bautista, 2012).

Our searching methods consisted of walking transects (500 × 10 m) with four replicates in each vegetation type (Lips et al., 2004; Cruz-Elizalde and Ramírez-Bautista, 2012; Rioja-Paradela et al., 2013; Leyte-Manrique et al., 2016). We maintained a gap of 50 m between the margins of the vegetation types to ensure interdependence of the data (Vite-Silva et al., 2010), and based our collection of specimens on Casas-Andreu et al. (1991). We searched for amphibians from 1900 to 2400 h, when most individuals were active, in bodies of water such as ponds and rivers and primarily in vegetation along the edges, and in logs and under rocks. We searched for lizards from 0900 to 1700 h, in rocky areas, shrubs, trees, and logs (Casas-Andreu et al., 1991), and for turtles from 1900 to 2400 h, primarily in bodies of water such as streams and their surrounding areas. As far as diurnal snakes, we carefully examined rocks, logs, shrubs, and trees, using a schedule similar to that of the diurnal lizards. Initially, we collected individuals by using rubber bands, tongs, hooks, or directly by hand to confirm their taxonomic identification. We deposited the specimens in the Laboratorio de Biología at the Instituto Tecnológico Superior de Salvatierra.

We identified individuals in situ to the species level, by using taxonomic keys and field guides (Vázquez-Díaz and Quintero-Díaz, 2005; Ramírez-Bautista et al., 2009), and based our scientific names on the constantly updated Taxonomic List available at <www.mesoamericanherpetology.com>.

Analysis

We determined species richness by using the estimators ACE and Chao 1, which generate predictive models based on accumulation curves for each type of vegetation, and considered species abundance throughout the sampling period. These models have proven beneficial for determining completion of species surveys (Moreno, 2001; Vellend, 2001; Magurran, 2004). We evaluated the incorporation of new species into the herpetofaunal list based on sampling effort and the observed and expected species in the area (Jiménez-Valverde and Hortal, 2003). Following Moreno and Halffter (1999) and Moreno (2001), we considered logarithms for rare species based on one or two samples as "singletons" or "doubletons," respectively. We generated species accumulation curves using the software EstimateS V. 9.1.0 (Colwell, 2006).

Species Diversity

We determined species richness between vegetation types by using the effective number of species (Jost, 2006). We obtained this number by using the following equation:

$$^{q}D = \left(\sum_{i=1}^{S} p_i^q\right)^{1/(1-q)}$$

where: ^{q}D is diversity, *pi* is relative abundance (proportional abundance) of *i* species, *S* is species number, and *q* is the order of diversity and defines the sensitivity of the index to the relative abundance of species; in this case, we considered $q = 1$, where all species are included and have a weight exactly proportional to their abundance in the community (Jost, 2006; García-Morales et al., 2011; Moreno et al., 2011). We also compared and evaluated the Jost's adjusted model with the Shannon-Wiener species richness index, using the program Species Diversity and Richness III.

Abundance-rank Curves or Whittaker's Curves

We generated abundance-rank curves or Whittaker's curves to compare species proportional abundance between the different vegetation types and between the wet and dry seasons (Moreno 2001; Rioja-Paradela et al., 2013).

Conservation Status of the Herpetofauna at Las Musas

We analyzed the conservation status of the herpetofaunal species found in Área Natural Protegida Las Musas according to SEMARNAT (2010), the IUCN Red List of Threatened Species (2017), and the Environmental Vulnerability Score (EVS) system (Wilson et al., 2013a, b).

RESULTS

Based on our fieldwork and records from the literature, we assembled a list of 40 herpetofaunal species (12 amphibians, 28 reptiles) occurring in Área Natural Protegida Las Musas, categorized in 17 families and 31 genera. Of these, the amphibians are grouped in seven families and 10 genera, and the reptiles in 10 families and 20 genera. For the species richness and diversity analyses, however, we included only 27 species (nine amphibians, 18 reptiles) found during our fieldwork (Tables 1, 2). The best-represented amphibian families were the Bufonidae and Hylidae (two species in each), whereas the best-represented reptile families were the Colubridae (nine species) and Phrynosomatidae (two species) (Fig. 2; Table 1).

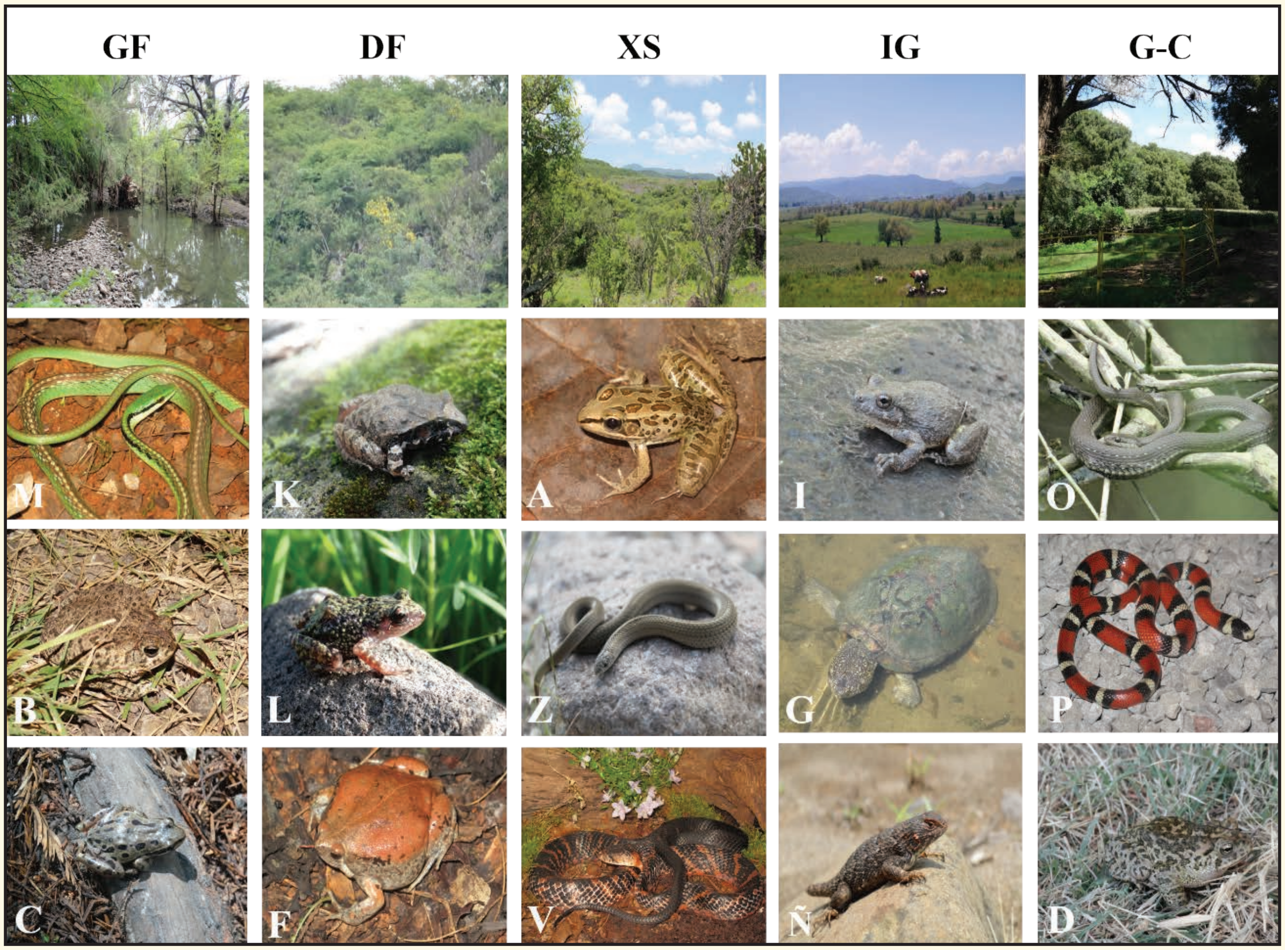

Fig. 2. Images of the vegetation types and species in the best-represented herpetofaunal families in Área Natural Protegida Las Musas. The letters for each species correspond to the ones in the abundance range curves. © J. Christian Berriozabal-Islas and Adrian Leyte-Manrique

With respect to the seasons, both amphibians and reptiles exhibited the same species richness (17 species in each). During the wet season, the taxonomic diversity consisted of nine species of amphibians and eight of reptiles. Fewer amphibians (five species) were recorded during the dry season, but more reptiles (12 species) were present in the wet season. With respect to the vegetation types, we obtained the following results (Table 1): GF = 16 species (seven amphibians, nine reptiles); DF = 14 species (nine amphibians, five reptiles); XS = 11 species (three amphibians, eight reptiles); IG = 14 species (six amphibians, eight reptiles); and G-C = six species (three amphibians, three reptiles).

Table 1. Checklist of the known herpetofauna in Área Natural Protegida Las Musas, Municipio de Manuel Doblado, Guanajuato. Abundance and vegetation types in their respective areas are as follows: GF = gallery forest; DF = tropical deciduous forest; XS = xeric scrub; IG = induced grassland; and G-C = gallery forest-cornfields. Conservation status categories are as follows: SEMARNAT (2010): A = Threatened, Pr = Special Protection, and Nc = Not evaluated; IUCN (2017): LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered, NE = Not Evaluated, and DD = Data Deficient; and EVS (Wilson et al., 2013a, b): L = Low, M = Medium, and H = High vulnerability. * = Species found during our fieldwork. With species reported in the literature ° = Chávez-Almanza (2012), likely occurrence, and • = IEE (2013).

	Vegetation Types					Conservation Status		
Species	**GF**	**DF**	**XS**	**IG**	**G-C**	**NOM 059**	**IUCN**	**EVS**
Amphibia								
Anura								
Bufonidae								
*°*Anaxyrus compactilis*	54	1	2	24	46	Nc	LC	14 = H
•*Anaxyrus punctatus*						Nc	LC	5 = L
*•*Incilius occidentalis*	20	2		1	2	Nc	NE	11 = M
•°*Rhinella horribilis*						Nc	LC	3 = L
Craugastoridae								
**Craugastor occidentalis*		1				Nc	DD	15 = H
Eleutherodactylidae								
**Eleutherodactylus guttilatus*		1				Nc	LC	11 = M
Microhylidae								
*°*Hypopachus variolosus*	8	5			4	Nc	LC	4 = L
Hylidae								
*•°*Dryophytes arenicolor*	13	11		1		Nc	LC	7 = L
*•°*Dryophytes eximius*	38	20	2	2		Nc	LC	10 = M
°*Smilisca fodiens*						Nc	LC	5 = L
Ranidae								
*•*Lithobates neovolcanicus*	68	19	3	17		A	NT	13 = M
Scaphiopodidae								
*°*Spea multiplicata*	11	8		1		Nc	LC	6 = L
Reptilia								
Testudines								
Kinosternidae								
*•°*Kinosternon integrum*	2	1		2	1	Pr	LC	11 = M
•°*Kinosternon hirtipes*						Pr	LC	10 = M
Squamata								
Dactyloidae								
•*Norops nebulosus*						Nc	LC	13 = M
Phrynosomatidae								
•*Sceloporus scalaris*						Nc	LC	12 = M
**Sceloporus spinosus*	1	2	1	2		Nc	LC	12 = M
*°*Sceloporus torquatus*	5	19	11	17		Nc	LC	11 = M

Teiidae								
**Aspidoscelis gularis*	8	2	7	3		Nc	LC	9 = L
Squamata								
Colubridae								
**Conopsis lineata*			1	1		Nc	LC	13 = M
•°Masticophis flagellum						A	NE	8 = L
**°Masticophis mentovarius*			1			A	LC	6 = L
**°Diadophis punctatus*				1		Nc	LC	4 = L
**Drymarchon melanurus*			1			Nc	NE	6 = L
•Lampropeltis mexicana						A	LC	15 = H
**Lampropeltis polyzona*					2	A	LC	7 = L
**•Leptophis diplotropis*	1					A	LC	7 = L
**°Oxybelis aeneus*	1					Nc	NE	8 = L
°Pituophis deppei						Nc	NE	10 = M
**Salvadora bairdi*			1			Pr	LC	15 = H
°Senticolis triaspis						Nc	NE	2 = L
**Trimorphodon tau*	1					Nc	LC	5 = L
Dipsadidae								
°Geophis petersii						Pr	DD	14 = H
•Rhadinaea hesperia						Nc	LC	10 = M
Natricidae								
**Thamnophis cyrtopsis*			1			A	LC	7 = L
**Thamnophis melanogaster*				1	1	A	EN	15 = H
•Thamnophis scalaris						A	LC	14 = H
Elapidae								
**Micrurus tener*		1		3		Nc	LC	11 = M
Viperidae								
**Crotalus molossus*	2					Pr	LC	8 = L
Typhlopidae								
**Indotyphlops braminus*	8					Nc	LC	2 = L
Total Individuals	241	93	31	76	56			
Total Species	16	14	11	14	6			

Species Richness

Using Chao 1 and ACE for all the vegetation types, the species cumulative curve for amphibians predicted completeness between 68 and 95% and between 70 and 100%, respectively; i.e., seven and nine species, similar to the number of species observed in the field (nine). Conversely, using Chao 1 and ACE the species cumulative curve for reptiles predicted completeness between 60 and 85% and between 75 and 90%, respectively; i.e., Chao1 estimated 18 species and ACE 19. The number of species for Chao1 was similar to that observed in the field (18), with a total of 27 species (nine amphibians, 18 reptiles) (Fig. 3, Table 2).

Table 2. Species completeness by vegetation type in Área Natural Protegida Las Musas.

Vegetation Type	% Completeness ACE Amphibians	% Completeness Chao 1 Amphibians	% Completeness ACE Reptiles	% Completeness Chao 1 Reptiles
GF	100	95	90	85
DF	95	90	80	75
XS	70	68	75	70
IG	85	80	75	60
G-C	85	80	85	80

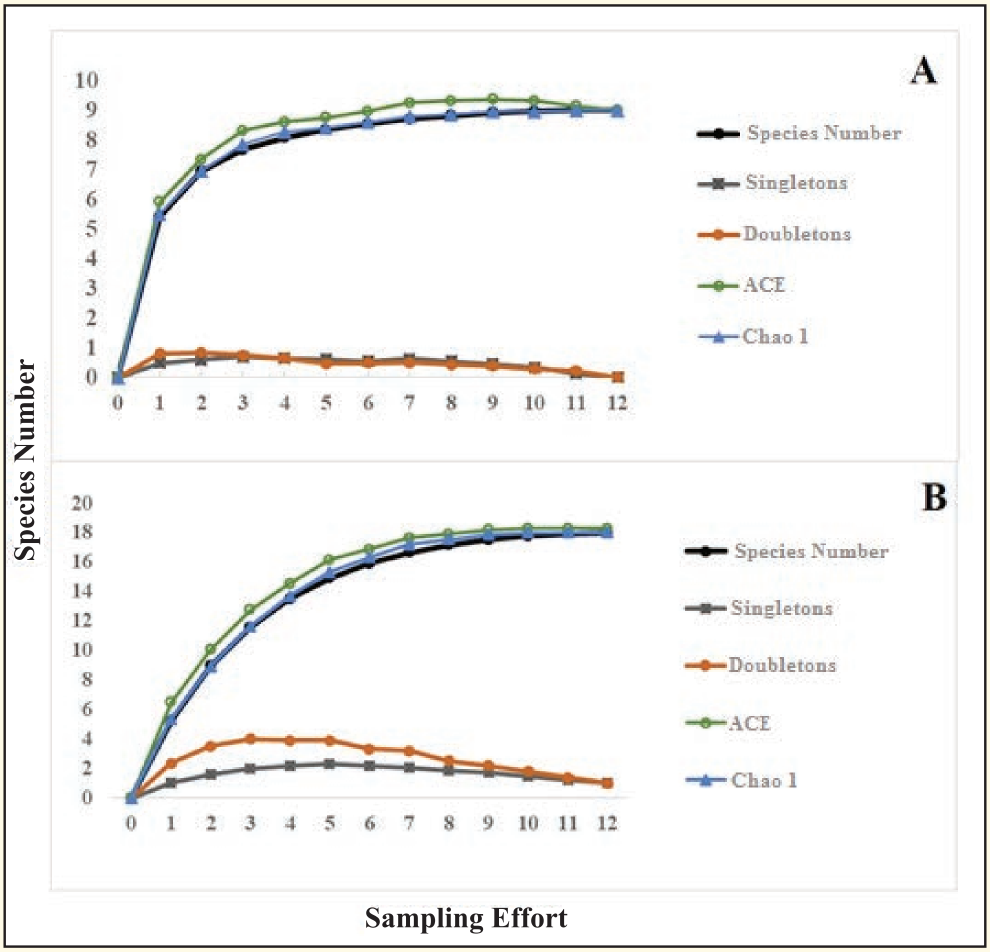

Fig. 3. Cumulative species curves for the herpetofauna of Área Natural Protegida Las Musas. A = amphibians, and B = reptiles.

Species Diversity

We found the estimated diversity (adjusted to the Jost value) for the five vegetation types highest in DF (qD = 8.09), followed by GF, XS, IG and G-C (qD = 7.60, 7.58, 6.50, and 1.82, respectively). As far as the Shannon-Wiener (H') index values, we found the highest for GF (1.99), followed by XS (1.95), and DF (1.82), and the lowest for IG (1.62) and G-C (1.06; Fig. 4).

Abundance-rank Curves or Whittaker's Curves

The abundance curves revealed greater abundance of rare species for both the wet and dry seasons. With regard to amphibians during the wet season, *Craugastor occidentalis* and *Eleutherodactylus guttilatus* were the least abundant species present in DF. Conversely, *Lithobates neovolcanicus* was present in GF, DF, XS, and IG; *Anaxyrus compactilis* in GF, XS, IG and G-C; and *Dryophytes eximius* in GF and DF. The last three species were the most abundant during both the wet and dry seasons. With regard to reptiles, snakes were the least abundant during both seasons, but *Indotyphlops braminus* was the most abundant snake during the dry season in GF. The lizard *Sceloporus torquatus* was more abundant than *Aspidoscelis gularis*, but both species were the most abundant during the wet season and in all the vegetation types, except for G-C (Fig. 5).

Conservation Status of the Herpetofauna at Área Natural Protegida Las Musas

Of the 40 species indicated in this study, 13 have been placed in the Threatened (Amenazada [A]) or Special Protection (Protección Especial [Pr]) categories of NOM-059-SEMARNAT-2010. Of these species, one is the amphibian *Lithobates neovolcanicus* (A), and 12 are turtles and squamates: *Kinosternon hirtipes* (Pr), *K. integrum* (Pr), *Masticophis flagellum* (A), *M. mentovarius* (A), *Lampropeltis mexicana* (A), *L. polyzona* (A), *Lepthopis diplotropis* (A), *Salvadora bairdi*, *Thamnophis cyrtopsis* (A), *T. melanogaster* (A), *T. scalaris* (A) and *Crotalus molossus* (Pr). With regard to the IUCN Red List (2017), the amphibian *Lithobates neovolcanicus* is listed as Near Threatened (NT). With respect to the snakes, *Thamnophis melanogaster* is categorized as EN, and the remaining species are regarded either as Least Concern (LC) or Not Evaluated (NE) (Table 1). Finally, based on the EVS system (Wilson et al., 2013a, b), except for the exotic snake *Indotyphlops braminus*, all of the native species have been provided with a conservation status. According to the EVS system, five, four, and two amphibian species have been placed in the low, medium and high vulnerability categories, respectively. Of these, *Anaxyrus compactilis* and *Craugastor occidentalis* have been assessed high vulnerability values. Of the reptiles, 11, nine, and four species have been placed the low, medium and high vulnerability categories, respectively. Of these, the snakes *Lampropeltis mexicana*, *Salvadora bairdi*, *Thamnophis melanogaster*, and *T. scalaris* have been assessed in the high vulnerability category (Table 1).

DISCUSSION

The 40 species of amphibians and reptiles reported from Área Natural Protegida Las Musas represent 71.4% of the herpetofaunal species currently reported for the state (56 species [13 amphibians, 43 reptiles]; Parra-Olea et al, 2014; Flores-Villela and García-Vázquez, 2014; Table 1). In this study, we add 14 more species to the known herpetofauna of this NPA (Chávez-Almanza, 2012). We found turtles and squamates better represented than amphibians, which is a similar pattern to that found in tropical and temperate environments (Vite-Silva et al., 2010; Cruz-Elizalde and Ramírez-Bautista, 2012; Rioja-Paradela et al., 2013; Fuentes-Castrejón and Maldonado-Gasca, 2015; Leyte-Manrique et al., 2015; Mata-Silva et al., 2015). We found abundance relatively high for all the species of amphibians. Although we found species richness high for reptiles, some species were represented only by one or two individuals, as was the case for snakes. These differences were distinctive when compared to the lizards, where our results show *Sceloporus torquatus* and *Aspidoscelis gularis* with an abundance of 52 and 20 individuals, respectively. Species richness was the same for both seasons (17 species); however, amphibians were more diverse during the wet season and reptiles during the dry season. The latter pattern likely is associated with amphibian reproductive activity, which often is driven by rains, whereas reptiles are influenced mostly by habitat structure (Leyte-Manrique et al., 2016).

Contrary to the hypothesis we initially indicated for this study, we regard the species richness observed at Área Natural Protegida Las Musas as uncommon, inasmuch as we expected that amphibian species richness and abundance would increase during the wet season—but we found the same number of species during the dry season. This result likely was due to the presence of permanent water sources at the study site. We found amphibian species abundant along the Río Colorado, a river that might provide sufficient resources for their presence throughout the year. Vitt and Caldwell (2014) suggested that in seasonal environments, the presence of permanent bodies of water significantly benefits aquatic anurans, since they will not be affected by extreme environmental fluctuations of temperature and humidity. With respect to the vegetation types, XS and IG represented the highest species richness in reptiles, whereas GF, DF and G-C represented the highest for amphibians (Table 1). In this sense, the higher diversity of reptiles, especially with the snakes present in XS and IG, might have resulted from the complexity of the habitat, since the ground vegetation primarily was composed of grasses and huizaches (*Acacia farnesiana*). The structure created by these plants might have allowed the presence of these reptiles, as well as their respective prey. During this study we also observed a large number of rodents, lizards, and snakes, especially in XS and IG; however, we did not assess this variable. The high species diversity for reptiles we found in this study, particularly for IG, contrasts the results of Rioja-Paradela et al. (2013), where these authors reported a low species richness for the same vegetation type due to a low heterogeneity of the environment affecting availability of both food and shelter sources. The species richness in our site, however, might have been influenced by the presence of bodies of water, especially for amphibians (Fernández-Badillo et al., 2016).

Richness Estimates

The curve reached an asymptotic phase after sampling number 10 with 24 observed species, with Chao 1 and ACE predicting a species richness of 26 and 27 species, respectively. Given these results, to complete the survey two species were still needed, according to Chao 1, and three according to ACE (Fig. 3). In contrast, the estimators (singletons and doubletons) exhibited a high number of rare species across the 12 sampling events. The number of singletons and doubletons indicated that some species still needed to be included in the inventory; however, in this study, we regarded the herpetofaunal richness of Área Natural Protegida Las Musas as well-represented (Jiménez-Valverde and Hortal, 2003). The accumulation estimates for each vegetation type indicated that the observed species richness adjusted to the Chao1 and ACE estimators, by showing that in each case the species were represented, and thus we concluded that the surveys were complete (Jiménez-Valverde and Hortal, 2003; Cruz-Elizalde and Ramírez-Bautista, 2012).

Species Diversity

The Shannon-Wiener adjusted equation for Jost (${}^{q}D$) or effective number of species indicated that the DF and GF vegetation types showed high richness and diversity, while G-C was the least diverse (Fig. 4). The differences we observed between these vegetation types might correspond to ecological factors that specifically influence the species richness values (García-Vázquez et al., 2006). The vegetation structure, environmental characteristics during each season, different reproductive strategies among species, and the behavior and food availability for each species

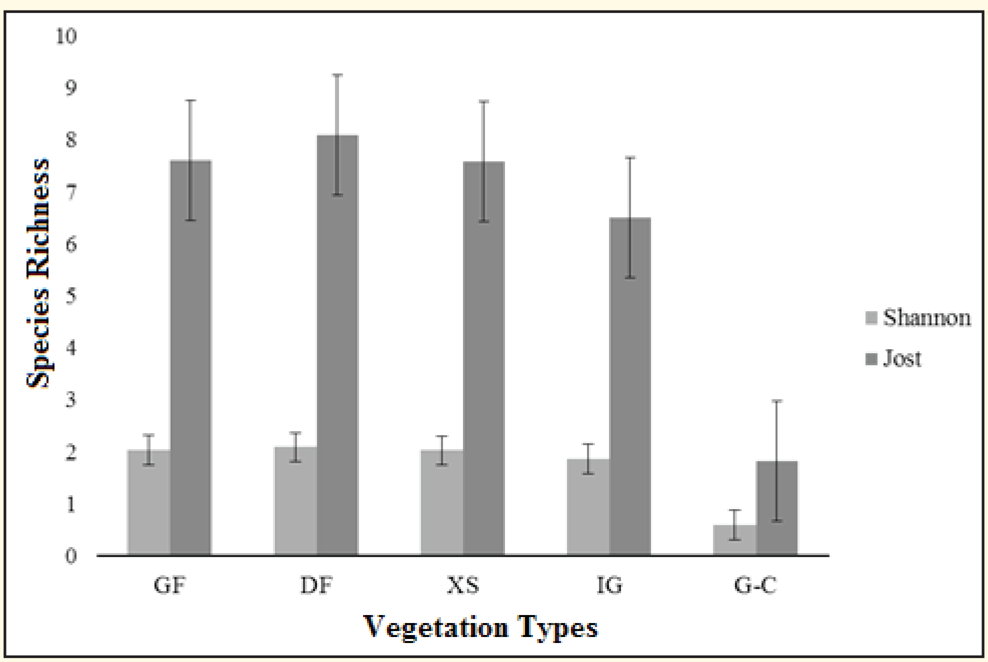

Fig. 4. Species richness by vegetation type with Jost adjusted values (qD) and Shannon-Wiener (H'). GF = gallery forest; DF = tropical deciduous forest; XS = xeric scrub; IG = induced grassland; and G-C = gallery forest-cornfield.

must influence species richness significantly, as we recorded high values in GF, DF and IG. With respect to G-C, a low presence of herpetofaunal species might have resulted from the constant change in the composition of the vegetation, i.e., the drastic change in habitat when growing and harvesting corn likely prevents more species from becoming established (Gardner et al., 2007; Rais et al., 2015). For example, Berriozabal-Islas et al. (2017) suggested that a decrease of lizard diversity in disturbed environments mostly is due to a reduction in the number and quality of microhabitats, because microhabitat complexity apparently plays an important role (Pianka, 1966). With respect to DF, the observed species richness can be considered within the normal patterns for this vegetation type, because high abundance has been reported in tropical deciduous vegetation in association with perennial vegetation and cloud forest (Bullock and Solis-Magallanes, 1990; García-Morales et al., 2011; Ramírez-Bautista and Moreno, 2006; Ramírez-Bautista et al., 2014).

Abundance Rank Curves or Whittaker's Curves

The abundance patterns revealed a dominance of rare species, and a few abundant species. The curves are biased toward a major occurrence and abundance of amphibians in almost every vegetation type. Three of the species with high abundance, particularly in GF and DF, were *Lithobates neovolcanicus*, *Anaxyrus compactilis*, and *Dryophytes eximius*. Their presence in these vegetation types can be explained by such factors as humidity, temperature, and water availability (Cruz-Elizalde and Ramírez-Bautista, 2012). With regard to GF, this vegetation type is humid and contains bodies of water throughout the year, thereby providing anurans with shelter, food, and reproductive sites (Zug et al., 2001; Vitt and Caldwell, 2014). The most abundant species in G-C was *A. compactilis*, followed by *Hypopachus variolosus* and *Incilius occidentalis*. We observed these species primarily in watered cornfields, where we found *H. variolosus* actively reproducing. In this context, we concluded that although we encountered these species in highly disturbed areas, they still were able to find conditions that allowed them to reproduce (Blaustein and Wake, 1995; Ramírez-Bautista et al., 2014; Berriozabal-Islas et al., 2017; Fig. 5). With respect to GF, the species *Dryhopytes arenicolor*, *D. eximius*, and *L. neovolcanicus* were present during the entire study period. The latter likely was due to the permanent waters of the Río Colorado, which influence the vegetation cover along the banks and indirectly the reproductive patterns of these amphibians. For example, we found eggs of *L. neovolcanicus* early (spring) and late (fall) in the year. Another factor that might significantly influence this distribution pattern is the fact that some species, such as *Craugastor occidentalis* and *Eleutherodactylus guttilatus*, only were present in DF during the wet season, but with low abundance (one and two individuals, respectively). With regard to XS and IG, both showed a similar diversity for reptiles, particularly snakes. The high reptile diversity (but low abundance) shown by both vegetation types, however, probably was due to the relative success of reptiles in utilizing a variety of habitats and reproductive strategies, when compared to amphibians (Vitt and Caldwell, 2014). For instance, reptile embryonic development cycles speed up with increasing temperatures, which improves their chances of survival and reproduction (Gardner et al., 2007; Vitt and Caldwell, 2014; Rais et al., 2015).

Conversely, reptiles showed greater species diversity in XS and IG, but with low abundance. The lizard *Sceloporus torquatus* was present in DF, IG and XS, while *Aspidoscelis gularis* was found in GF, DF, and XS. The presence of these two species in these vegetation types could be associated with their ability to adapt to different environments (Fernández-Badillo et al., 2016). Except for *Indotyphlops braminus* in DF, snakes showed a low abundance in all the vegetation types. We found most snakes in XS and IG. An explanation for their low abundance might involve their more cryptic and fossorial habits, when compared to lizards, which made their observation more difficult. With regard to the turtle *Kinostenon integrum*, although we found this species present in almost all the vegetation types it was never abundant, a pattern likely due to its own behavior, and also made observation difficult (Ramírez-Bautista et al., 2009; Leyte-Manrique et al., 2014). The results we found in this study might be regarded as atypical when compared to previous studies in vegetation types similar to DF, XS, and IG, which showed low abundance and high diversity (Medina-Aguilar et al., 2011; Rioja-Paradela et al., 2013).

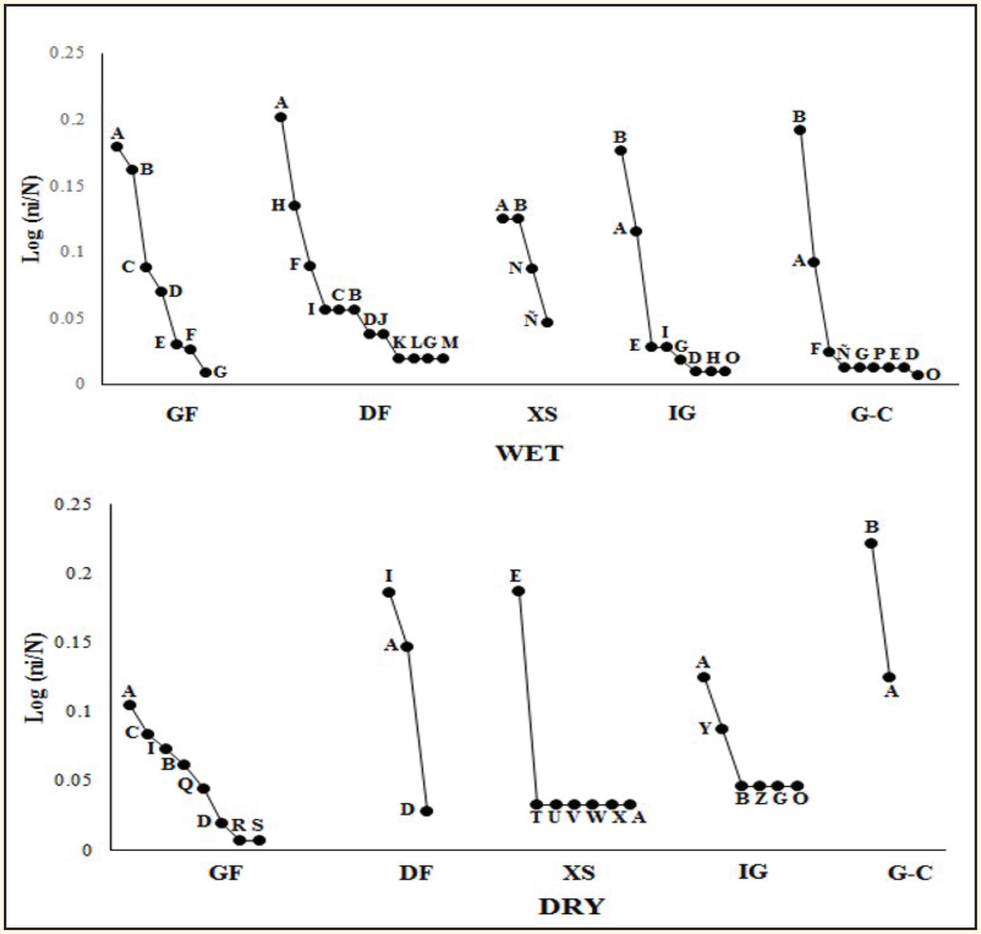

Fig. 5. Species composition by vegetation type and season arranged in order from the most abundant to the least. Species are represented by a capital letter, as follows: A = *Lithobates neovolcanicus*; B = *Anaxyrus compactilis*; C = *Dryophytes eximius*; D = *Incilius occidentalis*; E = *Aspidoscelis gularis*; F = *Hypopachus variolosus*; G = *Kinosternon integrum*; H = *Spea multiplicata*; I = *D. arenicolor*; J = *Crotalus molossus*; K = *Craugastor occidentalis*; L = *Eleutherodactylus guttilatus*; M = *Leptophis diplotropis*; N = *Sceloporus torquatus*; Ñ = *S. spinosus*; O = *Thamnophis melanogaster*; P = *Lampropeltis polyzona*; Q = *Indotyphlops braminus*; R = *Trimorphodon tau*; S = *Oxybelis aeneus*; T = *Masticophis mentovarius*; U = *Diadophis punctatus*; V = *Drymarchon melanurus*; W = *T. cyrtopsis*; X = *Salvadora bairdi*; Y = *Micrurus tener*; and Z = *Conopsis lineata*.

Implications for Conservation

In this study we provided information on the diversity and distribution of 27 species (fieldwork records) of amphibians and reptiles in a seasonal tropical environment at Área Natural Protegida Las Musas. We also provided an update on the total number of recorded herpetofaunal species (40) found in this NPA. As expected, the least disturbed sites within this area showed the higher diversity. Currently, the conservation status of these species has been assessed by SERMARNAT, the IUCN, and by use of the EVS measure. Of these, the EVS proved to be the most informative, because it provided a conservation status for all the native species involved in our study. We recommend future search efforts to attain more accurate representation of the biodiversity in the area, and which focus primarily on the species we rarely encountered in this study. As tropical dry forests are being confronted with an increasing number of global and local threats (Janzen, 1988; Golicher et al., 2012), so is their herpetofauna (Wilson et al., 2013a, b; Johnson et al., 2017). The information we provide herein, therefore, can be used for developing conservation strategies for the herpetofauna of NPAs. We recommend for such studies to be conducted in the NPAs of this state as soon as possible, with a goal of increasing our tools for ensuring the continued presence of the species living in these areas, so presumably they can be "saved" from the impact of human activities.

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