

Diversity of Amphibian Communities In Four Vegetation Types of Hidalgo State, Mexico

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Abstract: The use of statistical tools to assess species richness in different biological groups has increased considerably in the recent years. In this context, during the wet and dry seasons of 2007 and 2008 (dry only), we evaluated the amphibian species richness (alpha and beta diversity) in four vegetation types: cloud forest (CF), pine-oak forest (POF), xeric scrub (XS), and tropical evergreen forest (TEF) in Hidalgo state, México. In this study, we sampled 16 sites in 9 months. The total species number recorded in the four vegetation types was 31. The CF was the vegetation type with the highest number of species. In contrast, the POF and the XS had the lowest alpha diversity. The POF had the highest number of exclusive species and the XS the lowest. The highest value of complementarity (beta diversity) was between the XS and the TEF. Our data reveals the conservation status of amphibian populations in different vegetation types in Hidalgo, and the high variation in species richness in each vegetation community suggests species habitat quality.

Keywords: Amphibians, Hidalgo, Species Richness, Diversity, Complementarity, Vegetation types.

1. INTRODUCTION

In recent years, regional species lists have more frequently been grounded in an explicit biogeographical and ecological context [1]. This has been the case for the distribution of amphibians, allowing a better approximation of the knowledge of species richness of this important animal group in many regions [2]. In the past 25 years, México has generated a significant amount of research on amphibians and reptiles, mainly focused on the distribution, species richness and higher-order diversity [2]. These efforts have revealed that at least 1204 species of amphibians and reptiles occur in México, one of the 12 megadiverse countries only after Brazil, Colombia and Australia [3]. Other authors indicate that richness of reptile species in Mexico is about 804 and 361 for amphibian species, occupying the second and fifth places worldwide, respectively [1].

In México, increased recognition of the diversity of its herpetofauna expanded the interest in biodiversity conservation, considering that this country is among the most diverse [4, 5]. However, this species diversity is not evenly distributed taxonomically, since México contains a relatively high number of orders, families and genera of birds, mammals, amphibians and (non-avian) reptiles relative to other mega-diverse countries [6]. Amphibian diversity is clearly high in Mexico, and studies have constituted the basis of important scientific contributions [2]. Nevertheless, there are still some large areas of México in which little is known about their amphibian diversity [1]. One case is Hidalgo state, where existing data confirm the occurrence of

amphibians in practically all vegetation types and elevations [7, 8], yet much of the state remains poorly surveyed.

Over the last few decades, many populations of amphibians in Hidalgo have decreased dramatically, mainly due to habitat destruction, for example, disturbance of forests, landscape fragmentation and pollution [9-11]. Other sources of decline include the targeted collection of certain species for the food or pet trades [12]. For example, the salamander *Ambystoma velasci*, the frogs *Lithobates berlandieri* and *L. montezume* have declined recently due to commercial exploitation as sources of meat, grease, oils, traditional medicines and pets [13, 14]. Many people in Mexico, particularly in Hidalgo, eat amphibians because some species represent a good source of protein, and healthy populations of certain species (especially *Lithobates* spp.) often contain large numbers of individuals, which can be collected relatively easy and in large numbers. For example, large populations of the leopard frog (*L. berlandieri*) are killed for human consumption, and also for their skin, art, and souvenirs [15]. These negative factors have contributed to amphibian population declines worldwide [16-18].

Amphibian diversity in Hidalgo is threatened with exploitation by human consumption. For example, it is well known that *A. velasci* is a common food item in the diet of people living near their aquatic habitats, despite concerns on the long-term persistence of these wild populations [19, 20]. At present, there is some information on the distribution and species richness of amphibians and reptiles in some vegetation types in Hidalgo; however, with the high rate of destruction of many natural environments, the decrease of amphibian populations is dramatic [18, 21]. There are very few studies on the ecology of amphibians in Hidalgo, particularly those that address the current diversity and species richness of amphibians among vegetation communities. One of such studies [7] found that the species

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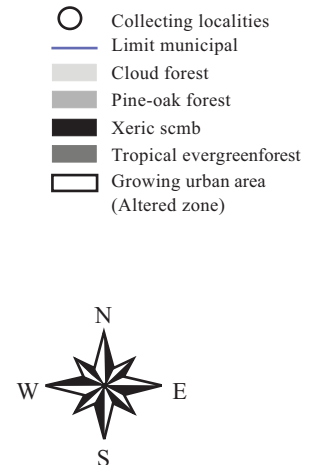


Fig. (1). Main vegetation types in the Hidalgo state, based on the nomenclature of [25]. The black points represent the sampling sites during the two seasons in the vegetation types.

richness was higher at higher elevations of cloud forest. [22] recorded a higher number of species in pine-oak forest than in the other vegetation types they examined. A study of arid tropical scrubland found reduced amphibian diversity relative to other vegetation types [23]. The limited data of amphibian richness in vegetation types points out that more information is needed in order to evaluate the current diversity of amphibians from Hidalgo, México.

The objective of this study is to identify patterns of alpha, beta and gamma diversity of amphibians present in four different vegetation types: cloud forest (CF), pine-oak forest (POF), tropical evergreen forest (TEF), and xeric scrub (XS). These vegetation types represent an extensive area and a range of disturbances in Hidalgo.

2. METHODS

2.1. Study Area

Hidalgo state is located near the geographic center of México ($19^{\circ} 35' 52''$ to $21^{\circ} 25' 00''$ N, $97^{\circ} 57' 27''$ to $99^{\circ} 51' 51''$ W), with a mean elevation of 1660 m (18-3490 m.a.s.l) [24]. Within the state there are eight primary vegetation types from the ten recognized in México [25]. The four vegetation types selected in this study represent the more extensive vegetation types in the state (Fig. 1).

2.1.1. Cloud Forest (CF)

Hidalgo is the third state of Mexico with largest area of CF (212,595.54 ha), only after Oaxaca and Chiapas [25-28].

This vegetation type is found at elevations ranging from 500 to 1, 400 or 2000 meters above sea level [m.a.s.l.; 25, 26]. Mean annual temperature is 15°C with a maximum of 22°C . The CF consists of two floristic elements, one of temperate affinity and the other of tropical affinity; this combination of floristic elements is the result of a typical climate of humid and warm conditions [classified by 25, 27]. The areas where this vegetation type develops have high moisture and a climatic type *Cf* (temperate climate with rain throughout the year), but also *Cw* (temperate climate subhumid with summer rains), *Af* (hot and humid climate with rains throughout the year), and *Aw* [hot and subhumid climate with summer rains, 29]. Soils of CF are characterized by their acidity and pH [4 to 6; 26]. Floristic composition includes mainly epiphytes, shrubs, grasses and ferns [25]. Epiphytic bromeliads are abundant, e.g. *Tillandsia spp* and *Peperomia spp* [25]. Here, epiphytic ferns reach their greatest diversity, for example, the genera *Polypodium*, *Lycopodium* and *Selaginella* [26], the most representative are the tree ferns (Cyatheaceae) such as *Sphaeropteris horrida* and the endangered species *Cyathea mexicana* [26].

2.1.2. Pine-Oak Forest (POF)

This vegetation type is distributed in the mountain range, mainly in the Sierra de Pachuca, (469, 594. 45 ha) [25]. The most common pine species from Sierra de Pachuca are *Pinus rudis*, *P. teocote*, *P. patula*, and *P. montezumae*. While species of the genus *Quercus* are *Q. laurina*, *Q. affinis*, *Q. rugosa*, *Q. glabrecens*, *Q. crassifolia*, and *Q. frutex* [22].

[24, 25] mention that in Mexico, oak forests occupy 5.5% of the country's area and along with pine forests occupy 13.7%. This vegetation type establishes pioneer species after a human disturbance. Species of the genus *Pinus* and *Quercus* regenerate relatively quick, so this vegetation type is considered resistant to human influence, provided disturbance is not too intense and prolonged. It develops in dry, semi-dry, and temperate climates; variations in precipitations and temperature are due to the differences in altitude among the plains, valleys, and mountains in the provinces of the Transmexican Volcanic Belt and the Mexican Central Highlands. The Sierra de Pachuca is an area where there is an important species richness of pines and oaks in the state, with a temperate climate *Cw* (temperate subhumid with summer rains). This climate has two variants, whose differences are due to the amount of moisture and rainy patterns [25, 29].

2.1.3. Xeric Scrub (XS)

This vegetation type is found at altitudes between 1000 and 2400 m.a.s.l. in Hidalgo [23]. The annual average temperature ranges from 12 to 28°C. The most abundant genus of this vegetation type is *Larrea* [23, 25, 27, 29]. The xeric scrub has four to five well defined strata in which dominance is shared by several species of cactus and mesquite [25]. This community covers much of Hidalgo, and includes climbing plants, such as the vines *Ipomoea* sp. that grows on the genus *Opuntia*. On the other hand, the only epiphytic plant that becomes relatively abundant in this vegetation type is *Tillandsia recurvada* that inhabits shrubs and columnar cacti from Barranca of Metztitlán and Tolantongo, in Hidalgo, and in southern Tehuacan Valley, in

Puebla. Additionally, this species occurs in the arid lands of northern of Mexico (Chihuahua, Coahuila, and Baja California) [23, 25]. Lichens are also present in this vegetation type, mainly *Psora* spp and *Parmelia* spp; they occur on the surface of some rocks and can be associated with roots of trees or *Opuntia* sp., which provide water to lichens. Bryophytes and fungi are extremely rare in this vegetation type; however, fern genera such as *Notholaema*, *Cheilanthes*, *Pellaea* and *Sellaginella* occur in this vegetation type. These genera are related to an accumulation of moisture, usually in small rock crevices [26]. The climate type is defined as semi-warm *Bs* (dry or arid climate) and its mean annual temperature is 18.5°C with a maximum in June [25, 29].

2.1.4. Tropical Evergreen Forest (TEF)

This vegetation type is located in an area of 205, 024.20 ha of Hidalgo [25], (Fig 1). There are also patches of tropical deciduous forest in the state, but it is restricted to small areas in Metztitlan, between 600 to 1200 m in altitude and in small patches of the northeast region of the state. Based on the classification of [30], climate is mainly *Am* (savanna or forest with rainfall throughout the year), but also *Af* (hot and humid weather with rain throughout the year) in more humid areas, and *Cw* (humid temperate climate with summer rainfall). The mean annual temperature of this vegetation type is 24.8°C, with a maximum of 31.5°C in July and August, and a minimum of 15.4°C in January [29, 30]. Flora is constituted by members of the genera *Quercus*, *Salix*, *Populus*, *Platanus*, and *Taxodium* [25]. It is also common *Manilkara zapota* (gum) and *Dioscorea composita*. The tropical rain forest is a complex vegetation community, in

Table 1. Surveys carried out throughout a year in the main vegetation types of Hidalgo state. The numbers below each month constitute the 16 samples made in each vegetation type: CF (cloud forest), POF (pine-oak forest), XS (xeric scrub), TEF (tropical evergreen forest)

Season	2007							
Dry (March-May)	Mach		April		May			
Surveys	1	2	3	4	5	6		
Vegetation types	CF	POF	XS	TEF	CF	POF		
Season	2007							
Rainy (June-September)	June		July		August		September	
Surveys	1	2	3	4	5	6	7	8
Vegetation types	CF	CF	POF	POF	XS	XS	TEF	TEF
Season	2008							
Dry (Mach-April)	Mach	April						
Surveys	1	1						
Vegetation types	XS	TEF						

which the dominant evergreen trees are over 25 m tall. However, not all trees are evergreen, as some of them lose their leaves during dry season, which coincides with flowering time of trees.

2.2. Sampling Methods

Amphibians were collected through direct searches in the above mentioned vegetation types, including their habitats and microhabitats. We carried out 16 three-day surveys in nine months during both the dry (March-May 2007, March 2008) and rainy seasons (June-September 2007, Table 1). We performed the last sampling survey in March-April 2008 (dry season) in XS and TEF to get the same number of samples (four for each vegetation type). Each three-day survey was carried out by three persons during six hours (11:00 – 14:00 hrs and from 20:00 to 23:00 hrs). All vegetation types were selected in a random way, considering the major original vegetation coverage. We walked during the established hours recording the number of amphibian species and their abundance in each vegetation type [31-33].

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Specimens were assigned to species by using dichotomous keys for each taxonomic group [34-39]. All collected specimens were deposited in the collection of amphibians and reptiles of the Biological Research Center of the Universidad Autónoma del Estado de Hidalgo (UAEH).

2.3. Data Analysis

A common statistical approach to evaluate plant and animal communities is the diversity index. Local diversity is described by alpha diversity [α , 40] and represents an estimate of all species within a given site. Beta diversity (β) is an estimate of complementarity, and measures the number of shared and unique species between sites. The species diversity of all sites within a larger region is described by gamma diversity (γ) [40, 41]. We have used different diversity indexes in order to estimate more accurately and comprehensively the species richness found in the four vegetation types studied.

To determine the maximum expected amphibian species richness in the four vegetation types, species accumulation curves were generated with EstimateS V.750 [42]. To infer whether the inventories were complete, we used Chao1 and Chao2 non-parametric estimators of species richness. We then assessed the degree of overlap of the curves of *singletons* (number of species represented by a single individual or present in one sample) and *doubletons* (two individuals of a species present in a single sample) [42].

Chao1 is an estimator based on the abundance of individuals belonging to a species in a sample, where S is the number of species in a sample, A_1 is the number of *singletons*, and A_2 is the number of *doubletons* ($^S\text{Chao1} = S_{\text{obs}} + A_1/2A_2$) [42-44].

Chao2 is a non-parametric estimator of incidence that requires frequency data for each species within the sample set. L is the number of species that occur only in one sample

(*singletons*) and M is the species number that occurs in exactly two samples ($^S\text{Chao2} = S_{\text{obs}} + L^2/2M$) [42-44].

Using estimates of abundance and incidence we can calculate the accumulation of species within a vegetation type based on sampling effort, and determine whether estimates of relative species diversity within each vegetation type are accurate.

Species abundance and evenness were analyzed in each vegetation type and amphibian community generating abundance-dominance or rank-abundance curves. To plot the rank-abundance curves we calculated the logarithm of the proportion of each species as: $p(n/N)$. Species were then ordered from most to least abundant [44, 45].

β diversity was estimated as the complementarity of amphibian species between pairs of vegetation types [42]:

1. Combined species richness for two sites, where a is the number of species in site **A**, b is the number of species in site **B**, and c is the number of species common to sites A and B: $S_{AB} = a + b - c$.
2. Similarly, the number of species unique to each site is: $U_{AB} = a + b - 2c$.

This index varies from 0 (both sites are identical in species composition) to 1 (no shared species). The value has a meaning opposite to the similarity, indicating the rate of species turnover or β diversity [42-45]. Additionally, we estimated the degree of similarity between pairs of vegetation types by using the Jaccard similarity index [44]. This index also ranges from 0-1, where higher values indicate lower complementarity. The analysis of species complementarity was modelled using EstimateS V.750 [42], and we calculated the Jaccard's similarity index using BioDiversity Professional V2 [45].

3. RESULTS

3.1. Species Richness in Vegetation Types

We invested a total of 834 person-hour of sampling effort at sites representing all four vegetation types. A total of 244 individuals of 31 species were recorded (i.e., gamma diversity; Fig 1; Table 1), representing nine families and twenty genera. The family Hylidae was the most diverse (13 species), followed by the Plethodontidae (6), and Bufonidae (4) (Table 2; Fig. 2). In the CF, we found 19 species (alpha diversity) in 12 samples; five species were unique to this vegetation type (*Bromeliophyla dendroscarta*, *Ecnomiphyla miotympanum*, *Trachycephalus venulosa*, *Eleutherodactylus nitidus*, and *Tlalocohyla picta*). In the TEF, we found 14 species in 12 samples, four of these species were exclusive to this vegetation type (*Bolitoglossa platydactyla*, *Incilius nebulifer*, *Scinax staufferi*, and *Smimiscabaudinii*, Table 2; Fig. 2). The POF had the highest number of exclusive species (7, *Ambystoma velasci*, *Chiropterotriton dimidiatus*, *C. multidentatus*, *Hyla eximia*, *H. plicata*, *Plectrohyla robertsororum*, and *Pseudoeurycea altamontana*) out of a total of 13 species. The xeric scrub (XS) had the lowest number of species (6) (Table 1) and thus, the lowest diversity. None was exclusive for this type of vegetation (Table 2; Fig. 2).

Chao1 predicted a higher completeness in species richness in the CF, the POF and the XS, but not in the TEF.

Table 2. Number amphibians collected in the main vegetation types of Hidalgo state: CF (cloud forest), POF (pine-oak forest), XS (xeric scrub), and TEF (tropical evergreen forest)

Class	Species	Vegetation types				Species codes
		CF	POF	XS	TEF	
Order						
Family						
AMPHIBIA						
CAUDATA						
Ambystomatidae	<i>Ambystoma velasci</i>	0	9	0	0	S
Plethodontidae	<i>Bolitoglossa platydactyla</i>	0	0	0	1	DI
	<i>Chiropetrotriton dimidiatus</i>	0	2	0	0	X
	<i>C. multidentatus</i>	0	2	0	0	Z
	<i>Pseudoeurycea altamontana</i>	0	5	0	0	W
	<i>P. bellii</i>	1	2	0	1	Q
	<i>P. cephalica</i>	2	6	0	0	M
ANURA						
Bufonidae	<i>Incilius marmoreus</i>	2	0	0	7	K
	<i>I. nebulifer</i>	0	0	0	1	CI
	<i>I. valliceps</i>	7	0	4	15	D
	<i>Chaunus marinus</i>	8	0	0	11	C
Scaphiopodidae	<i>Spea multiplicata</i>	0	2	10	0	Y
Hylidae	<i>Bromeliohyla dendroscarta</i>	4	0	0	0	I
	<i>Charadrahyla taeniopus</i>	9	0	5	0	B
	<i>Ecnomiohyla miotympanum</i>	2	0	0	0	L
	<i>Hyla arenicolor</i>	1	0	1	0	P
	<i>H. eximia</i>	0	7	0	0	U
	<i>H. plicata</i>	0	8	0	0	T
	<i>Plectrohyla arborescandens</i>	1	0	0	1	R
	<i>P. charadricola</i>	5	0	0	11	G
	<i>P. robertsorum</i>	0	7	0	0	V
	<i>Scinax staufferi</i>	0	0	0	1	EI
	<i>Smilisca baudinii</i>	0	0	0	4	BI
	<i>Tlalocohyla picta</i>	5	0	4	2	H
	<i>Trachycephalus venulosa</i>	6	0	0	0	F
Leptodactylidae	<i>Leptodactylus melanonotus</i>	2	0	0	1	J
Craugastoriodae	<i>Craugastor decoratus</i>	2	0	0	0	N
	<i>C. rhodopis</i>	12	1	0	2	A
Eleutherodactylidae	<i>Eleutherodactylus nitidus</i>	2	0	0	0	Ñ
Ranidae	<i>Lithobates berlandieri</i>	6	7	7	13	E
	<i>L. spectabilis</i>	1	6	0	0	O
	Total	78	64	31	71	

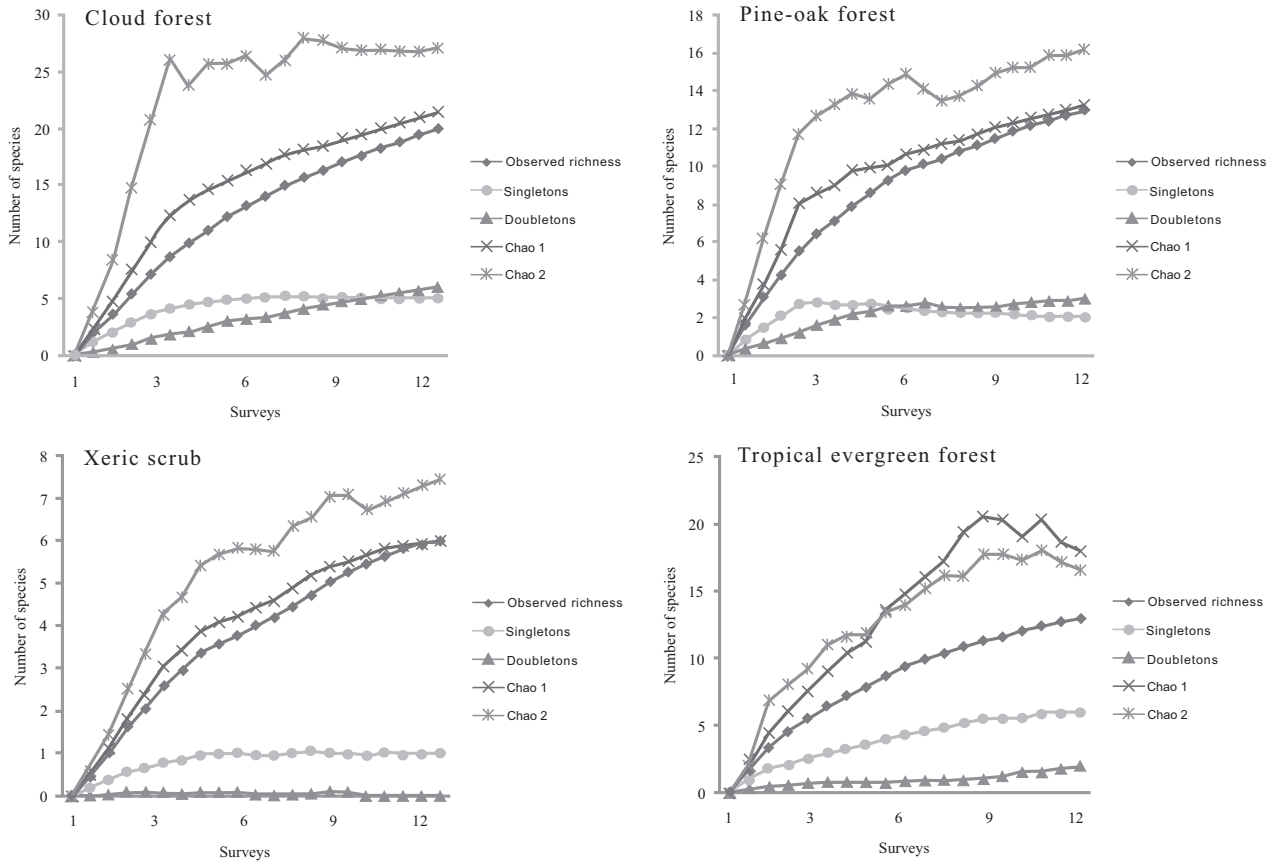


Fig. (2). Amphibian species accumulation curves in the main vegetation types of Hidalgo state. The Y axis represents the number of species collected and the X axis represents the number of samplings used in the collection of amphibians.

The observed species richness was higher in CF; however, our estimators predicted that between three (Chao1 = 91%) and eight (Chao2 = 74%) amphibian species were not detected in our surveys (Table 2 and 3; Fig. 2). The POF exhibited the highest percentage of completeness (Chao1 = 100%, Chao2 = 81%). According to Chao2, it is still necessary to add three to four species (Table 2 and 3; Fig. 2). The TEF is the second in species richness (Table 2 and 3; Fig. 2) and showed a completeness of 72 and 89%, respectively (Table 2 and 3; Fig. 2).

Overall, estimates of completeness were higher in the XS and the POF (Fig. 2; Table 2), particularly in XS (Chao1=

100% and Chao2 = 86%; Table 2 and 3; Fig. 2). It could be due to the small number of species reported (6) in a relatively large number of samples (12). Overlap between singletons and doubletons curves show when the inventory is almost complete. When there is a complete intersection of these curves, species richness curve is asymptotic. Inventories in the CF and the POF are close to completion, which is reflected in a asymptotic curve well defined for XS and TEF (Table 2 and 3; Fig. 2).

3.2. Species Composition in Vegetation Types

Table 2 and Fig. (3) show the species richness (S) in the CF (S=19; 32%), the POF (S=13; 26%), the XS (S=6; 13%),

Table 3. Comparison of amphibian species richness between pairs of the main vegetation types of Hidalgo: CF (cloud forest), POF (pine-oak forest), XS (xeric scrub), and TEF (tropical evergreen forest)

Vegetation types (Observed richness)	Shared species	Complementarity	Similarity (Jaccard index)
CF-POF (19-13)	5	0.82	0.7
CF-XS (19-6)	4	0.82	0.49
CF-TEF (19-14)	10	0.58	0.63
POF-XS (13-6)	2	0.88	0.38
POF-TEF (13-14)	3	0.87	0.56
XS-TEF (6-14)	2	0.89	0.51

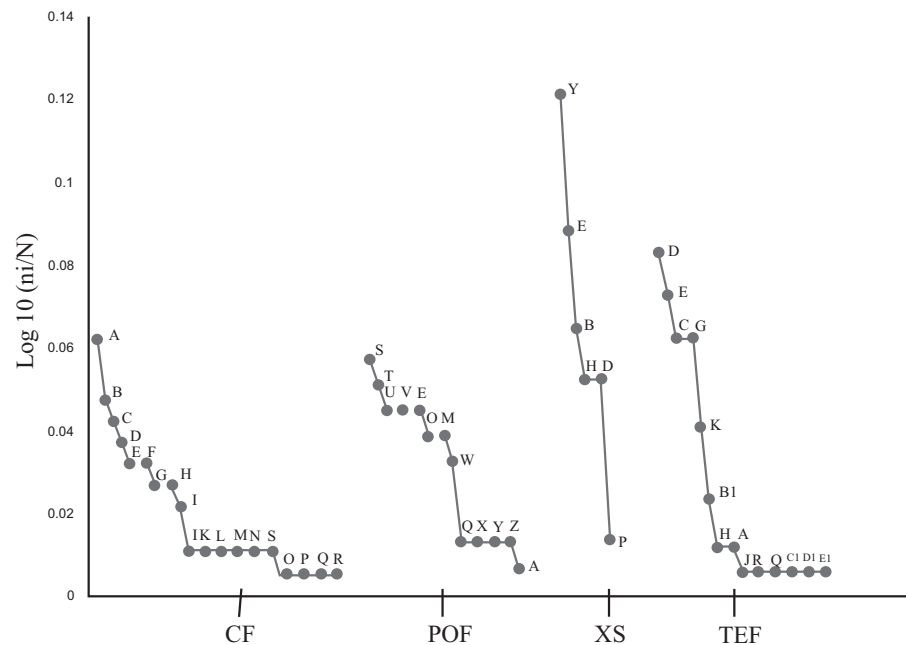


Fig. (3). Rank-abundance curves of amphibian species in the main vegetation types of Hidalgo state. The Y axis represents the abundance of each species transformed into Log 10, and the X axis groups the species by vegetation type: CF (cloud forest), POF (pine-oak forest), XS (xeric scrub), TEF (tropical evergreen forest). Species codes as shown in Table 2.

and the TEF ($S=14$; 29%). The ranid frog *Lithobates berlandieri* was the single most abundant species present in all vegetation types.

Rare species mainly occur in the CF, the POF and the TEF (Table 2; Fig. 3). A particular case was *Craugastor rhodopsis* which was dominant in the CF, rare in the POF and infrequent in the TEF (Table 2; Fig. 3). In the POF, *Ambystoma velasci*, *Hyla plicata*, and *H. eximia* were the most abundant and exclusive species, while *Chiropterotriton dimidiatus*, *C. multidentatus*, *Pseudoeurycea bellii*, and *Spea multiplicata* were less abundant or rare. The latter was the only dominant species in XS while *Hyla arenicolor* was an infrequent species (Table 2; Fig. 3). The most abundant species in TEF were *Cranopsis valliceps*, *Lithobates berlandieri*, *Chaunus marinus*, and *Plectrohyla charadricola*. This vegetation type held a considerable number of rare species as in the POF (Table 2; Fig. 3).

3.3. Complementarity

Complementarity of amphibian diversity was high among vegetation types, evidenced by the high species turnover (beta diversity) (Table 3). All possible pairings of vegetation types yielded greater than 50% in complementarity. The comparison of the CF and the TEF showed a low complementarity and a high similarity, which indicates low species turnover or few unique species for each vegetation type ($C = 0.58$, $ISj = 0.63$; Table 3).

The highest complementarity was between the TEF and the XS ($C = 0.89$; Table 3), representing a high species turnover. However, the latter had the lowest species richness and only *L. berlandieri* was present in both vegetation types; thus, replacement was close to 100%, in contrast to similarity value ($ISj = 0.51$; Table 3).

This pattern of high complementarity was very similar to the comparison between the POF and the TEF where

complementarity and similarity values were similar, although the abundance of individuals in each vegetation type was completely different (Table 3).

The value of complementarity in the comparison between the CF and the POF was $C = 0.82$ and a similarity value of $ISj = 0.70$ (Table 3). These values were higher when compared to the previous combination (CF and TEF) (Table 3). Low complementarity values mean high similarity values because there are a few exclusive species in each vegetation type, such as between the CF and the TEF ($C = 0.58$, $ISj = 0.63$; Table 3). It is important to emphasize that this comparison represents two vegetation types that share ecological characteristics, although they differ in species composition. However, there was not to have a strong difference in the choice of any of these vegetation communities, since similarity and species turnover were very similar (Table 3).

4. DISCUSSION

4.1. Species Composition

Amphibian diversity in Hidalgo represents 14.5% and 50% of the species and family diversity in Mexico, respectively [2, 7]. This is relevant from the perspective of the biodiversity in Hidalgo. In this study, we found 31 species of amphibians in the four main vegetation types of the state; however, this is likely to be a substantial underestimate of the true diversity of amphibians. Many areas of Hidalgo have not been surveyed exhaustively; therefore, they could hold new species or unrecorded species. For example, recent surveys [7] in remote areas of Hidalgo have revealed several new records of amphibians not previously recorded in the state. Modern taxonomy and studies on systematics of some groups of amphibian species, such as Hylidae are likely to result in the recognition of additional new species. Interestingly, no amphibian species

is endemic to the state [2, 7]. A study by [7] also reported 31 amphibian species in Hidalgo; however, in our study we report species that those authors did not recognize and almost a quarter of the species they reported are currently regarded as subspecies or synonyms of other species [46].

This study shows that a higher amphibian diversity exists in Hidalgo relative to several other Mexican states with similar area (e.g., Aguascalientes [47], Valle de México [12], or even some larger states such as Coahuila [48]). Such diversity could be explained by the occurrence of multiple biogeographic regions in Hidalgo (Sierra Madre Oriental, Transmexican Volcanic Belt, Mexican Plateau and the Gulf of Mexico) and the environmental heterogeneity they produce [49, 50]. Furthermore, this species richness may also be the result of the heterogeneity of habitats and microhabitats available for different species inhabiting the different vegetation types. This highlights the need to use specific techniques for collecting amphibians in otherwise inaccessible habitats such as the forest canopy [51-53].

4.2. Comparison of Species Richness by Vegetation Type

According to [54-57], alpha diversity is the measure of the number of species in a territorial sample that depends on the area for assessing local diversity [58, 59]. Habitat fragmentation leads to the reduction of biodiversity in an area or region, limiting the development of organisms by factors such as resources availability, competition, and predation [58, 60-62] have argued that fragmentation in southwestern Brazil severely damages anuran communities, leading to changes in temperature, precipitation and soil erosion, and therefore a decrease in alpha diversity [41, 63, 64].

The alpha diversity of each vegetation community examined in this study differed, although the POF and the TEF exhibited a similar number of species (13 and 14, respectively; Table 3). The highest species diversity (alpha diversity) was found in the TEF and the lowest in the XS. These differences in species richness could be due to the unique ecological conditions prevailing in each vegetation type. For example, the microclimatic conditions in the CF are more humid than in the POF and the XS. In the CF there is a higher accumulation of organic matter, greater canopy cover, and a warm-cold temperature constant, requirements necessary for the life of amphibians [7, 65, 66]. Environmental characteristics of the XS, such as high temperatures and low humidity are limiting factors for most amphibian species [67]. However, some species reported in this study have successfully adapted to arid environments, such as *Spea multiplicata* and *Hyla arenicolor*, two amphibians characteristic of the XS [12].

A number of authors have found even greater species diversity in the CF of Mexico. For example, [7] reported a greater number of amphibian species in the CF of Hidalgo; however, their sampling effort was significantly larger than ours. Similarly, [58] surveyed patches of CF in Veracruz state. They found five species more than in our study, but their sampling effort was also larger. We note that the CF in Hidalgo is the vegetation community with the highest degree of disturbance, yet was also the vegetation type supporting the highest number of amphibian species. This pattern is

similar to another study in a community of frogs in fragments of CF [68].

In the POF we recorded 13 species of amphibians, but other studies have reported different results. For example, [22] recorded only seven of the 13 species reported in this study, although the size of their study area was less extensive. [69] also reported fewer species (six) in this vegetation type, but they recorded two species (*Eleutherodactylus longipes* and *E. verrucipes*) not found in our work. This might represent the missing species that Chao2 detected.

4.3. Abundance Patterns

Of the four vegetation types studied, the CF held the highest number of species, being the frog *Craugastor rhodopis* the dominant species, as found in other studies [59]. This species also occurs in the POF and the TEF, but it is rare, suggesting that the CF constitutes the main habitat for *C. rhodopis* [68]. Another dominant species in the CF was *Trachycephalus venulosa*, a species that was not dominant in the POF and the TEF. The composition of rare species in the CF we studied was similar to that found in other studies of anuran communities in fragmented environments of CF in Veracruz [58], where many of the species are rare or secretive. Some authors [64] have also suggested that comprehensive amphibian surveys in the CF require a larger sampling effort than that in other environments, including the use of specialized sampling techniques in hard-to-access habitats, such as the canopy or bromeliads that are known to harbour many of these amphibians [70, 71].

The TEF was the vegetation type that supported the second highest number of species (14 of 31; Table 2). In this vegetation community, *Incilius valliceps*, *Lithobates berlandieri*, *Chaunus marinus* and *Plectrohyla charadricola* were the most abundant species. These species have been reported in other localities of Hidalgo and other Mexican states with this vegetation type [58, 72]. The difference between species in the CF and the TEF is evident; however, these vegetation communities contain the largest number of species, which is probably due to similar environmental conditions prevailing in both vegetation types [65].

4.4. Complementarity

Overall, complementarity between vegetation types was high, more than 70% (Table 3). However, the single lowest level of complementarity in vegetation types was found between the CF and the TEF, showing that there is little heterogeneity in terms of exclusive species composition. In contrast, we found an approximate mean value of 40% in similarity, showing that in the four vegetation types there are several exclusive or unique species (Table 4). These differences in the values of complementarity and similarity are also seen in other sites with different vegetation types [5, 46, 59] and in other animal groups [73].

The CF and the TEF share the highest number of species (10), a pattern that could be explained by the presence of similar environmental conditions, such as precipitation and temperature, which are factors that allow the establishment of species [66]. This pattern was previously found in the CF and the TEF of México, these vegetation types have

relatively homogeneous environmental characteristics, which allow the establishment of a large number of endemic species [6, 12].

The high species turnover between vegetation types shown in this study is consistent with that reported by [74-76] in different animal groups in Mexico. These authors argue that México is a country with a low alpha diversity but with a high beta diversity. The results of this study follow the same pattern since the values of alpha diversity are not high, but replacement of species with values close to 90% show a high beta diversity.

Beta diversity is a powerful tool that measures species turnover based on unique species in a site, region or landscape [56]. This tool is used in biogeographic studies to generate results that better explain the choice and design of protected natural areas. For example, [8] modelled the distribution of amphibians and reptiles in order to locate areas with high diversity in Hidalgo, by using diversity indexes and biogeographical data. The use of statistical tools (analysis of diversity) as well as methods used in historical biogeography (PAE) can substantially help us to evaluate protected areas [49]. Even though the use of different methodologies (species richness and biogeography) can locate areas with high species richness, this approach has so far been poorly used to the urgent need to preserve areas with significant numbers of species in some category of conservation risk (e.g., endemics with restricted distribution). It is fundamental that the design and implementation of conservation strategies should be based on the use of various tools such as diversity indexes and biogeographical tools at different scales, since this would allow us to have a broader view of the conservation status of amphibians and reptiles, and of other groups occurring in different environments of Hidalgo and México.

CONCLUSIONS

Hidalgo has a high amphibian diversity with 31 species distributed in 20 genera and 7 families, even though it is located in central México with a large proportion of arid environments. This species richness coincides with the number of species reported by [34, 77] for the state, but we also found species not mentioned by these authors.

Our results suggest that future surveys should apply a greater sampling effort in each vegetation type, because our diversity estimators indicated that none of these four vegetation types had complete inventories. The highest recorded number of species was in the CF with 19, followed by the TEF (14), the POF (13), and the XS (6). In the POF we recorded the highest number of exclusive species (seven), followed by the CF (five), and the TEF (four).

Amphibian communities are dominated mostly by rare or uncommon species. *Lithobates berlandieri* was the only abundant species in all vegetation types studied. In the CF, *Craugastor rhodopis* was the most abundant species, but this species was rare in the POF and the TEF.

Beta diversity or complementarity was 80% in most of the comparisons; however, in the comparison between the CF and the TEF, we found a low value of complementarity and a high value of similarity, indicating that the amphibian species in these two vegetation types are similar.

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CONFLICT OF INTEREST

None declared.

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