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The Herpetofauna of the Chihuahuan Desert Biogeographic Province of Mexico: Diversity, Similarity to Other Provinces, and Conservation Status

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Abstract: The Chihuahuan Desert biogeographic province in Mexico is the largest of the fourteen biogeographic provinces of the country. This biogeographic province hosts a diverse array of amphibian and reptile species, with 262 native species, including 53 amphibians and 209 reptiles, accounting for a significant portion of Mexico's total amphibian (~12%) and reptile diversity (~21%). The Zacatecana subprovince exhibits the highest concentration of species for both groups (89% and 50% of Chihuahuan Desert amphibians and reptiles, respectively), indicating its importance for biodiversity within the Chihuahuan Desert. Comparative analyses with neighboring biogeographic provinces reveal substantial species overlap (48–55%), particularly with the Sierra Madre Oriental, the Transvolcanic Belt, and the Sierra Madre Occidental. These findings suggest strong ecological connections and corridors facilitating species exchange among these regions. Conservation assessments highlight the vulnerability of many species in the Chihuahuan Desert, with a notable percentage listed in the International Union for Conservation of Nature's (IUCN) Red List (~12%) and higher percentages categorized by the Mexican government as at risk according to their conservation status and the Environmental Vulnerability Score (~40%). Threats primarily stem from habitat loss, pollution, and other anthropogenic factors. In conclusion, the Chihuahua Desert emerges as a biogeographic province of significant biological richness and valuable evolutionary history for amphibians and reptiles. Its conservation is imperative for safeguarding the distinctive species and ecosystems that characterize this desert biome.

Keywords: biogeographic province; Chihuahuan Desert; Mexico; amphibians; reptiles; conservation

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1. Introduction

The portion of the Chihuahuan Desert (CD) biogeographic province that lies in Mexico is the largest of the fourteen Mexican biogeographic provinces, covering 578,002 km^2 that extends from 19.6545° N to 31.7837° N and from −98.7700° W to −111.5834° W. The Sierra Madre Occidental forms the western border and the Sierra Madre Oriental the eastern border of the CD; however, there is no clear definition of its northern and southern limits [1,2]. Here, we follow the delimitation of the CD proposed by [3,4], who considered the Transvolcanic Belt of central Mexico as the southern limit and the northern limit to be southern New Mexico and Texas in the US. Thus, the entirety of the Chihuahuan Desert encompasses extreme southeastern Arizona, southern New Mexico, and southwestern Texas in the US, and extreme northeastern Sonora and parts of Chihuahua, Coahuila, Nuevo León, Durango, Zacatecas, Guanajuato, San Luis Potosí, Querétaro, and Hidalgo (Figure 1).

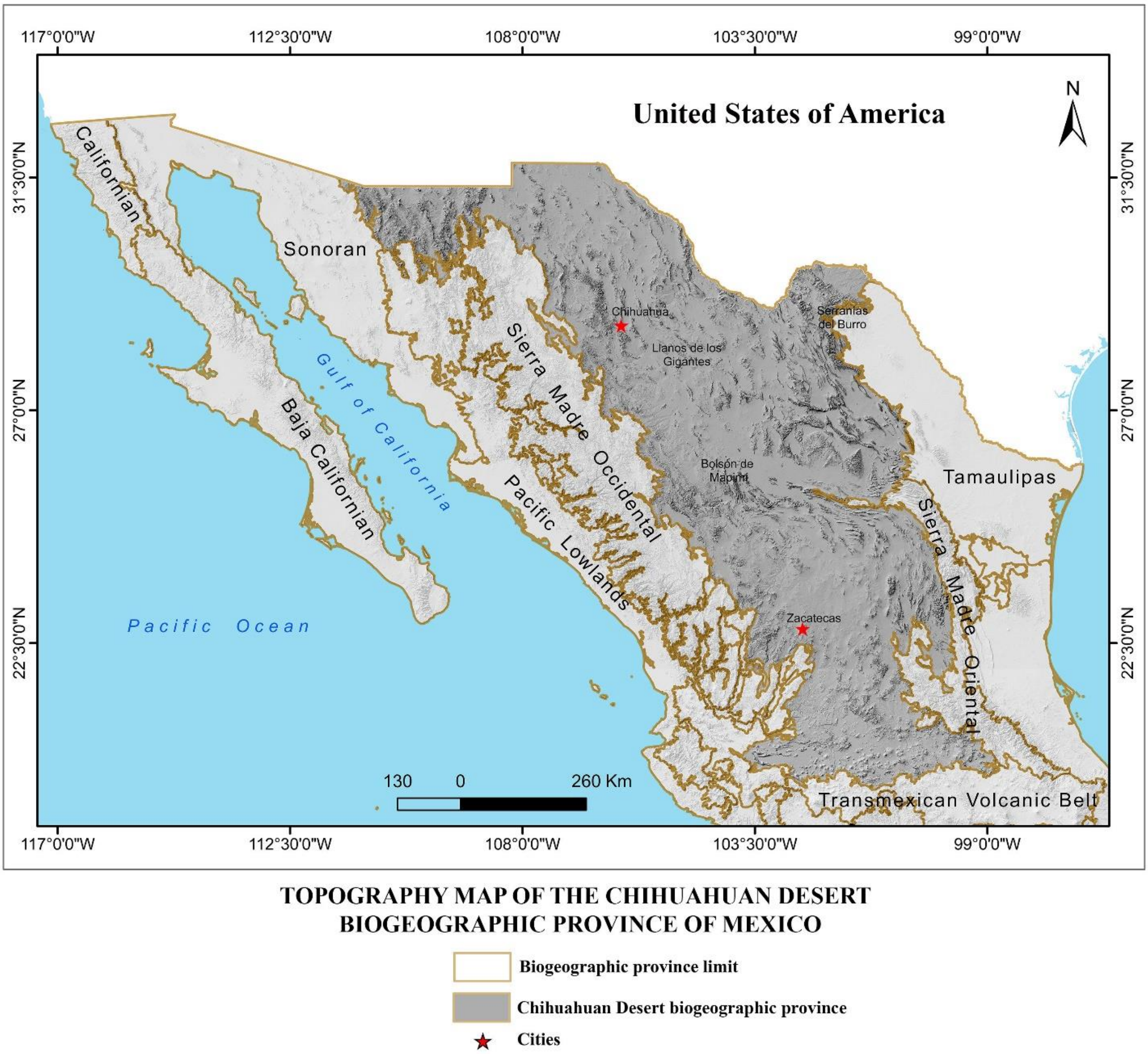

Figure 1. Topography map of the Chihuahuan Desert biogeographic province of Mexico [5].

Compared to the other thirteen biogeographic provinces of Mexico, the CD has a relatively low number of amphibian and reptile species; however, it has the highest biological and ecological diversity of the five Nearctic biogeographic provinces of Mexico (California, Baja California, Sonoran Desert, CD, and Tamaulipas) proposed by [4]. Its average altitude varies between 1000 and 2000 m, but in some parts along the Rio Bravo it reaches 350 m. This makes it a desert in which altitudes above 1000 m dominate, producing a unique climate and vegetation that influence its biological diversity. An enormous high-altitude plateau that is interrupted by isolated mountain ranges that create habitat islands runs throughout the CD. This habitat variation supports a high biodiversity with ≈4000 vascular plants, >1000 endemic plant taxa, 120 species of mammals, 300 species of birds, and 110 species of fish [1,6–8]. In addition, the CD is a transition zone between Southwestern and Southeastern provinces for North American turtles [9].

Here, we provide a checklist of the amphibians and reptiles of the CD Biogeographic Province in Mexico with a summary of their conservation status and similarity with six neighboring Biogeographic Provinces (Sonora, Tamaulipas, Sierra Madre Occidental, Sierra Madre Oriental, Transvolcanic Belt, and Pacific Lowlands). In addition, we consider how amphibian and reptile species are distributed between the two subprovinces in the CD, the Coahuilense and the Zacatecana, to determine if the herpetofauna of the CD is uniformly distributed across the CD or if there are differences in the distribution between the two subprovinces, which could help target conservation and management efforts in the CD. Examining how amphibians and reptiles are distributed among biogeographic provinces and how these species are shared between provinces can inform conservation plans for biological diversity in Mexico. We also summarize the distribution, conservation status, and threats faced by the species. We also evaluate what role geographic proximity, as estimated by the length of shared borders and the distance between geographic centroids of two provinces, affects the similarity between neighboring biogeographic provinces. Similarity would likely increase with proximity since biogeographic provinces that are closer together and that share a longer border are more likely to share some species that straddle the borders or the biogeographic provinces (see [10] for a similar analysis for Mexican states). Comparisons of species of neighboring provinces can help decide whether conservation planning at the biogeographic province level is best or if conservation planning incorporating multiple biogeographic provinces is necessary. Given they reflect ecologically relevant geographic units (e.g., [4,11]), biogeographic provinces may be a more appropriate level for planning than states, which are usually politically or culturally defined areas that are not necessarily ecologically relevant.

2. Methods

2.1. Physiography

Reference [4] describes two subprovinces for the Chihuahuan Desert (CD) that broadly correspond to the northern (Coahuilense subprovince) and the southern (Zacatecana subprovince) halves. The Coahuilense extends from the Nazas River to the Big Bend region in the southern US. The Coahuilense subprovince is more arid and is characterized by an extensive high-altitude plateau that is traversed by relatively small mountain ranges that rise to >2000 m in altitude [4]. This subprovince was supported by [12] in a study of endemism in lizards in the CD and partially corresponds to the Mapimian subprovince of [1,2,13–18]. On this plateau there are isolated areas of quartz or gypsum sand dunes, including the Médanos de Samalayuca in north-central Chihuahua; Bolsón de Mapimí in southeastern Chihuahua, southwestern Coahuila, and northeastern Durango; Dunas de Bilbao in southwestern Coahuila; and Cuatrociénegas in east-central Coahuila [2,19,20]. These sandy systems are home to unique communities of amphibians and reptiles, where *Holbrookia* and *Uma* lizards are distinctive examples [21–23]. Important extensions of the Sierra Madre Occidental, such as the Sierra del Nido and El Hueso in central Chihuahua and the Sierra de San Luis in extreme northwestern Chihuahua, occur in the CD. The deep canyons of the Río Bravo in northeastern Chihuahua and northwestern Coahuila create a unique ecosystem whose altitude varies from 575 to 2401 m asl. This region is contiguous with the Big Bend region of Texas. Further to the east there is a rugged topography represented by mountains like El Burro, which reaches 2042 m in altitude. This mountain range, along with several satellite mountain ranges, is considered an extension of the Sierra Madre Oriental in northern Coahuila [11,14].

The southern portion of the CD makes up the Zacatecana subprovince [4], which corresponds, in part, with the Saladan subprovince of [2,13,14,16–18], and partially with the Mexican Plateau subprovince of [24]. The Zacatecana subprovince is less arid, with elevations that average 1800 m in the south to 1000 m in the far north [4]. This subprovince lacks dune systems but is traversed by a large number of small mountain ranges. The Sierra Madre Oriental extends into the CD in this subprovince in southeastern San Luis Potosí and northeastern Guanajuato [4]. Important relict species, such as the Queretaran Desert lizard (*Sceloporus exsul*), are found in the southeastern part of the Zacatecana subprovince ([25–27]).

Extremely arid climates are found in the northern and central parts of the CD, and arid and semiarid climates are near the foothills of the Sierra Madre Occidental, the Sierra

Madre Oriental, and the foothills of the mountain ranges that traverse the CD. However, in the southwestern part of the CD, a zone of semi-warm humid climate extends from the southern part of the Sierra Madre Occidental to the central part of the Transvolcanic Belt. In addition, there is a humid temperate climate in the extreme southeastern part of the CD and for most of its border with the Transvolcanic Belt. These variations in the climate of the southern CD allow some species of amphibians and reptiles with tropical and temperate affinities to extend their distributions into the province (Figure 2).

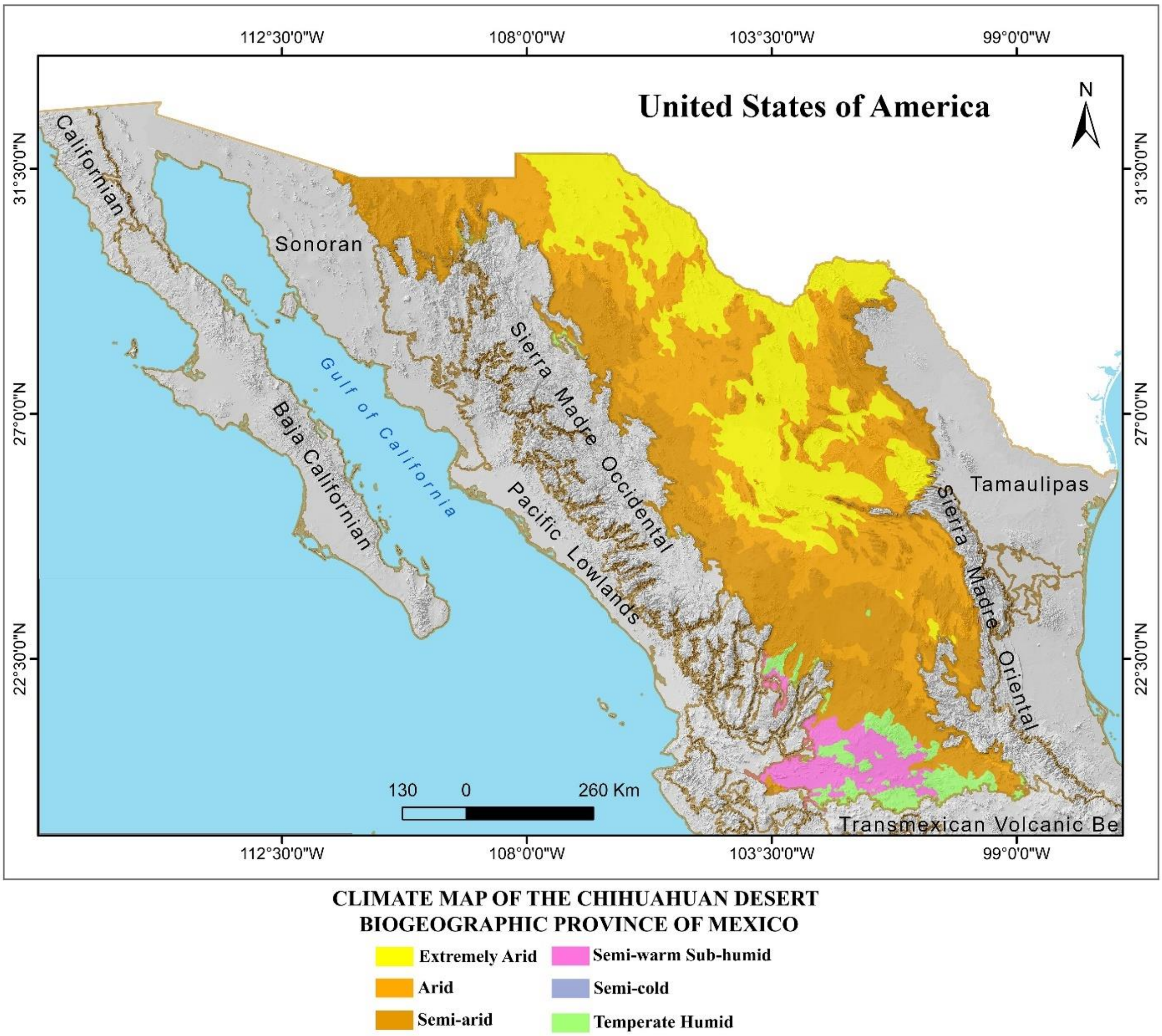

Figure 2. Climate map of the Chihuahuan Desert biogeographic province of Mexico [28].

The CD is home to a great diversity of plant species and vegetation types dominated by bushes and shrubs, including microphyllous desert scrub, rosetophilous desert scrub, crassicaule desert scrub, oak forest, grasslands, riparian vegetation, and stone pine forests (Figure 3; [3]). Grasslands are common, especially along the foothills of the Sierra Madre Occidental, whereas shrublands are more common along the foothills of the Sierra Madre Oriental. Livestock grazing is common in both grasslands and scrublands [2,29].

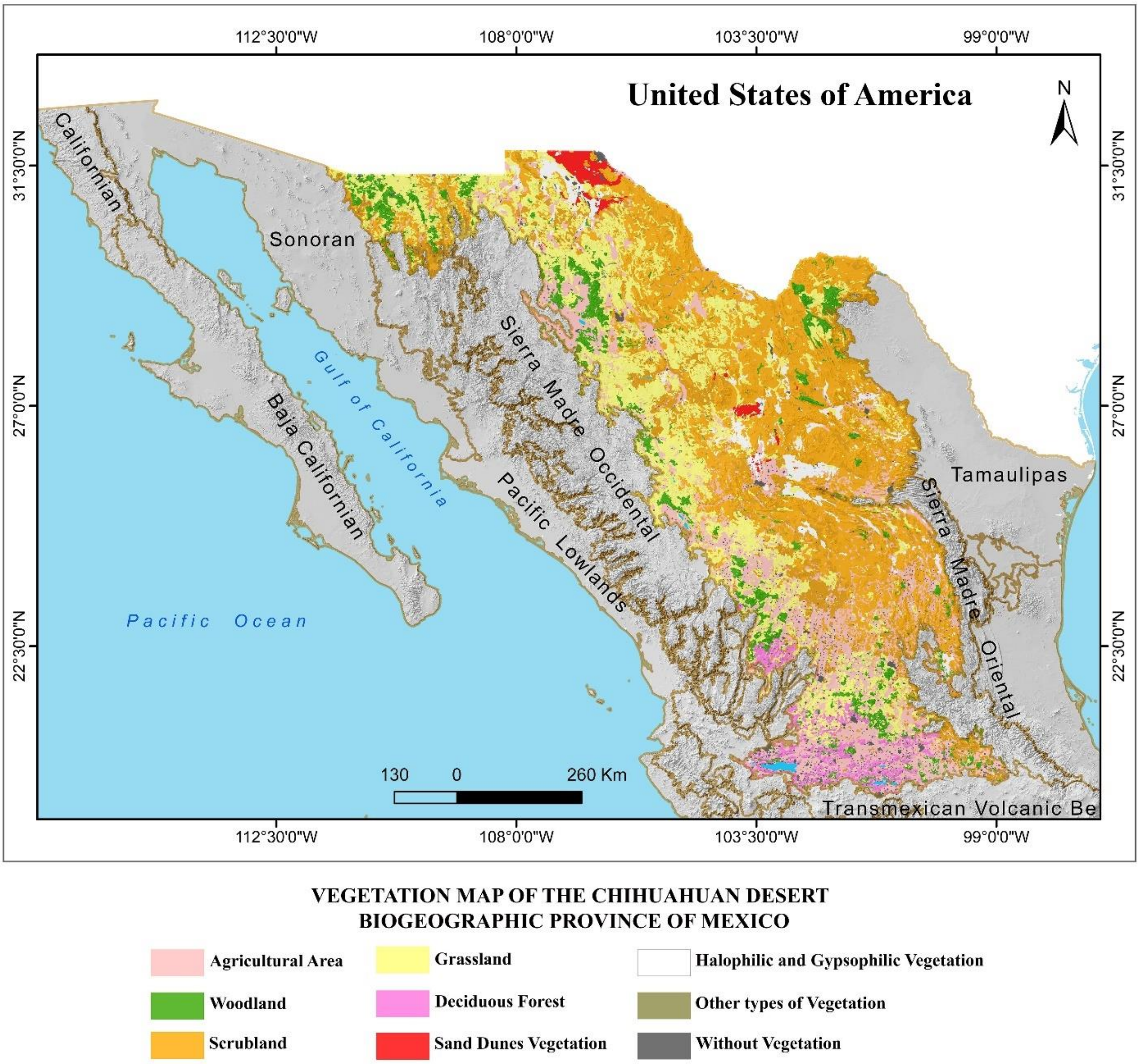

Figure 3. Vegetation map of the Chihuahuan Desert biogeographic province of Mexico [30].

2.2. Methodology

We collected and updated species lists for amphibians and reptiles for all of the Mexican states included in the Chihuahuan Desert (CD) biogeographic province (Sonora, Chihuahua, Coahuila, Nuevo León, Durango, Zacatecas, Guanajuato, San Luis Potosí, Querétaro, and Hidalgo) provided by [10] and updated with [31,32]. We follow Amphibian Species of the World [33] and AmphibiaWeb [34] for amphibian names and Reptile Database [27] for reptile names. We prepared the list of species of the CD and the six neighboring provinces (Sierra Madre Oriental, Transvolcanic Belt, Sierra Madre Occidental, Tamaulipas, Pacific Lowlands, and Sonoran Desert) following the areas proposed by [4,11,35,36] for each biogeographic province (see also [31]). In addition, we recorded the conservation status and population trends of each species based on the International Union for Conservation of Nature's (IUCN) Red List 2024 [37], the Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT) [38], and Environmental Vulnerability Scores (EVS; [39,40]). The IUCN Red List provides information on conservation status and population trends, SEMARNAT lists species at risk, and EVS assesses vulnerability based on a species' geographic distribution, ecological distribution, and anthropogenic impacts. We used hierarchical clustering analyses based on Jaccard's Similarity Coefficients for Binary Data as the distance metric and used the single-linkage method (nearest neighbor) to generate cluster trees of the CD and the neighboring biogeographic provinces for amphibians and reptiles separately. We also used the species lists to calculate pairwise Jaccard distances for the six neighboring biogeographic provinces and the CD for amphibians and reptiles separately (see Table 1). In addition, we obtained geospatial estimates using the map of biotic provinces of Mexico by [11] on a Lambert Conformal Conic projection in Datum WGS84 in ArcGIS 10.8.1 (Environmental Systems Research Institute, Inc., Redlands, CA, USA) for the length of shared borders between the biogeographic provinces using the Polygon Neighbors Tool and the straight-line distance between the centroids of the biogeographic provinces using the Feature to Point Tool and Point Distance (Table 2). We ran non-parametric Spearman's ρ tests to examine correlations between the Jaccard distance estimates of amphibians and reptiles between the 21 pairwise combinations of the CD and its neighboring provinces. We also used non-parametric Spearman's ρ tests to examine correlations between the pairwise Jaccard distance estimates of the biogeographic provinces and the length of shared borders and the distance between the centroids of the paired biogeographic provinces for amphibians and reptiles separately. We used chi-squared tests to compare the numbers of species considered to be in a category of conservation concern by each of the three methods (IUCN Red List, SEMARNAT, and EVS) for amphibians and reptiles separately, as well as compare the numbers of amphibians and reptiles listed in a category of conservation concern for each method separately. Cluster analyses were performed using Systat 13.2 (Systat Software Inc., San Jose, CA, USA), and all other statistical analyses were performed using JMP 16.2 (SAS Institute, Cary, NC, USA).

Table 1. Matrix of pairwise Jaccard distances for amphibians (above the diagonal) and reptiles (below the diagonal) among the Chihuahuan Desert province and its neighboring provinces. CD = Chihuahuan Desert, Son = Sonoran Desert, Tam = Tamaulipas, SMOcc = Sierra Madre Occidental, SMOri = Sierra Madre Oriental, TVB = Transvolcanic Belt, PL = Pacific Lowlands.

	CD	Son	Tam	SMOcc	SMOri	TVB	PL
CD		0.18	0.2	0.34	0.28	0.22	0.16
Son	0.12		0.1	0.29	0.052	0.067	0.19
Tam	0.26	0.11		0.12	0.15	0.08	0.12
SMocc	0.36	0.19	0.13		0.13	0.20	0.34
SMOri	0.30	0.05	0.19	0.14		0.51	0.14
TVB	0.27	0.06	0.10	0.28	0.43		0.22
PL	0.14	0.17	0.07	0.26	0.13	0.30	

Table 2. Surface area in km^2 of the Chihuahuan Desert and each of its six neighboring biogeographic provinces; length of shared border in km between the Chihuahuan Desert and each of its six neighboring biogeographic provinces; latitudinal centroid in degrees (°) of the Chihuahuan Desert and each of its six neighboring biogeographic provinces; distances between the centroid in km between the Chihuahuan Desert and each of its six neighboring biogeographic provinces; elevational range in m of the Chihuahuan Desert and each of its six neighboring biogeographic provinces; shared species between the Chihuahuan Desert and each of its six neighboring biogeographic provinces; and number of species of the Chihuahuan Desert and each of the neighboring provinces.

Neighboring Provinces	Surface Area (km^2)	Length of Shared Border (km)	Latitudinal Centroid (°)	Distance Between Centroids (km)	Elevational Range (m)	Shared Species	Number of Species
Chihuahuan Desert	578,001.50	-	26.1933	-	2600	-	262
Sierra Madre Oriental	51,897.30	3397	22.4605	582.1	3400	144	382

Table 2. *Cont.*

Neighboring Provinces	Surface Area (km^2)	Length of Shared Border (km)	Latitudinal Centroid (°)	Distance Between Centroids (km)	Elevational Range (m)	Shared Species	Number of Species
Transvolcanic Belt	82,839.90	1488	19.7368	781.9	5200	141	427
Sierra Madre Occidental	171,195.10	5120	25.7815	263.5	3000	126	217
Tamaulipas	106,829.70	1714	26.3657	408.7	2200	75	116
Pacific Lowlands	187,112.90	1709	20.3550	669.7	2200	73	325
Sonoran Desert	119,762.80	498	30.0701	939.9	1800	45	125

3. Results

3.1. Species Richness and Endemism

The Chihuahuan Desert (CD) of Mexico is home to 262 native species of amphibians and reptiles representing 30 families (10 amphibians and 20 reptiles) and 90 genera (21 amphibians and 69 reptiles). These include 53 species of amphibians (42 anurans and 11 salamanders) and 209 reptiles (92 lizards, 102 snakes, and 15 turtles) (Supplementary Table S1). The amphibian families with the highest species richness are Hylidae with 13 species and Bufonidae with 10. The reptile families with the highest species richness are Phrynosomatidae with 54 species and Colubridae with 46 species (Supplementary Table S1). Additionally, four species have been introduced to the CD biogeographic province: the common bullfrog (*Rana catesbeiana*), the common house gecko (*Hemidactylus frenatus*), the Mediterranean house gecko (*Hemidactylus turcicus*), and the Brahminy blindsnake (*Indotyphlos braminus*) (Supplementary Table S1). Another turtle reported as introduced in this province is the false map turtle (*Graptemys pseudogeographica*) [32] (Supplementary Table S1).

The greatest richness of amphibians in the CD was concentrated in the Zacatecana subprovince with 47 species (37 anurans and 10 salamanders) that represent 88.7% of the total amphibians that inhabit the CD (Supplementary Table S1). In the Coahuilense subprovince, 19 amphibians, 17 anurans, and two salamanders are found (Supplementary Table S1). Likewise, the greatest richness of reptiles was found in the Zacatecana subprovince with 146 species (58 lizards, 86 snakes, and two turtles) that represent 50.3% of the total reptile species that inhabit the CD. The Coahuilense subprovince houses 130 reptile species: 60 lizards, 55 snakes, and 15 turtles (Supplementary Table S1).

Twenty-eight of the 53 species of native amphibians registered in the CD are endemic to Mexico, and two species, the upland burrowing treefrog (*Smilisca dentata*) and the yellow-peppered salamander (*Ambystoma flavipiperatum*), are microendemic to the CD. Ninety-nine of the 209 native species of reptiles that inhabit the CD are endemic to Mexico; 16 of them are microendemic to the CD (Supplementary Table S1).

3.2. Comparison with Neighboring Provinces

The Chihuahuan Desert (CD) shares the largest proportion of its amphibian and reptile species composition with the Sierra Madre Oriental 55.0% (144 shared species), the Transvolcanic Belt 53.8% (141), and the Sierra Madre Occidental 48.1% (126) (Table 3; Supplementary Table S2).

The Jaccard distances of amphibians and reptiles were highly positively correlated (Figure 4; $n = 21$, Spearman's $\rho = 0.90$, $p < 0.0001$). Jaccard distances for amphibians were positively correlated with the shared border lengths (Figure 5A; $n = 21$, Spearman's $\rho = 0.66$, $p = 0.0012$) and negatively correlated with the distance between geographic centroids (Figure 5C; $n = 21$, Spearman's $\rho = -0.62$, $p = 0.0026$) between provinces. Jaccard distances for reptiles were positively correlated with shared border lengths (Figure 5B; $n = 21$, Spearman's $\rho = 0.62$, $p = 0.0028$) and negatively correlated with the distance between geographic centroids (Figure 5D; $n = 21$, Spearman's $\rho = -0.73$, $p = 0.0002$) between provinces.

Table 3. Summary of the number of species shared between the Chihuahuan Desert and neighboring biogeographic provinces (not including introduced species). The percent of the Chihuahuan Desert shared by neighboring provinces is given in parentheses. Total refers to the number of species found in the Chihuahuan Desert and six neighboring provinces (i.e., regional species pool), and the number in parentheses in this column is the percent of the regional species pool found in the Chihuahuan Desert. - indicates either the Chihuahuan Desert or their neighboring province has no species in the taxonomic group, or none of that specific taxon is shared between the provinces, thus no value for shared species is provided. Abbreviations of the Biogeographic Provinces are as follows: CD (Chihuahuan Desert); SMOr (Sierra Madre Oriental); TVB (Transvolcanic Belt); SMOc (Sierra Madre Occidental); Pacific (Pacific Lowlands); Sonoran (Sonoran Desert).

	CD	SMOr	TVB	SMOc	Tamaulipas	Pacific	Sonoran	Total
Amphibia	**53**	**38 (71.7)**	**38 (71.7)**	**28 (52.8)**	**13 (24.5)**	**18 (34)**	**11 (20.8)**	**241 (22)**
Anura	**42**	**30 (71.4)**	**30 (71.4)**	**26 (61.9)**	**13 (31)**	**18 (42.9)**	**10 (23.8)**	**156 (26.9)**
Bufonidae	10	8 (80)	5 (50)	8 (80)	4 (40)	6 (60)	5 (50)	23 (43.5)
Centrolenidae	-	-	-	-	-	-	-	1 (0)
Craugastoridae	2	1 (50)	2 (100)	2 (100)	1 (50)	2 (100)	-	19 (10.5)
Eleutherodactylidae	3	2 (66.7)	2 (66.7)	-		-	-	33 (9)
Hylidae	13	9 (69.2)	10 (76.9)	6 (46.2)	1 (7.7)	4 (30.8)	2 (15.4)	40 (32.5)
Leptodactylidae	2	2 (100)	2 (100)	1 (50)	1 (50)	2 (100)	1 (50)	3 (66.7)
Microhylidae	2	2 (100)	1 (50)	1 (50)	2 (100)	1 (50)	-	5 (40)
Phyllomedusidae	-	-	-	-	-	-	-	2 (0)
Ranidae	7	4 (57.1)	6 (85.7)	6 (85.7)	1 (14.3)	2 (28.6)	-	26 (26.9)
Rhinophrynidae	-	-	-	-	-	-	-	1 (0)
Scaphiopodidae	3	2 (66.7)	2 (66.7)	2 (66.7)	3 (100)	1 (33.3)	2 (66.7)	3 (100)
Caudata	**11**	**8 (72.7)**	**8 (72.7)**	**2 (18.2)**	**-**	**-**	**1 (9.1)**	**85 (12.9)**
Ambystomatidae	3	1 (33.3)	1 (33.3)	1 (33.3)	-	-	1 (33.3)	17 (17.6)
Plethodontidae	8	7 (87.5)	7 (87.5)	1 (12.5)	-	-	-	63 (12.7)
Salamandridae	-	-	-	-	-	-	-	1 (0)
Sirenidae	-	-	-	-	-	-	-	2 (0)
Dermophiidae	-	-	-	-	-	-	-	2 (0)
Reptilia	**209**	**106 (50.7)**	**103 (49.3)**	**98 (46.9)**	**62 (29.7)**	**55 (26.3)**	**34 (16.3)**	**627 (33.3)**
Crocodylia	-	-	-	-	-	-	-	**3 (0)**
Alligatoridae	-	-	-	-	-	-	-	1 (0)
Crocodylidae	-	-	-	-	-	-	-	2 (0)
Squamata	**194**	**103 (53.1)**	**101 (52.1)**	**94 (48.5)**	**57 (29.4)**	**53 (27.3)**	**30 (15.5)**	**582 (33.3)**
Lacertilia	**92**	**41 (44.6)**	**35 (38)**	**39 (42.4)**	**21 (22.8)**	**17 (18.5)**	**10 (10.9)**	**284 (32.4)**
Anguidae	9	7 (77.8)	6 (66.7)	4 (44.4)	-	2 (22.2)	-	20 (45)
Anolidae	**1**	-	1 (100)	1 (100)	-	1 (100)	-	22 (4.5)
Bipedidae	-	-	-	-	-	-	-	2 (0)
Corytophanidae	-	-	-	-	-	-	-	4 (0)
Crotaphytidae	3	1 (33.3)	-	1 (33.3)	1 (33.3)	-	1 (33.3)	8 (37.5)
Dibamidae	1	1 (100)	1 (100)	-	-	-	-	1 (100)
Diploglossidae	-	-	-	-	-	-	-	2 (0)
Eublepharidae	2		-	-	1 (50)	-	-	7 (28.6)
Gymnophthalmidae	-	-	-	-	-	-	-	1 (0)
Helodermatidae	-	-	-	-	-	-	-	4 (0)
Iguanidae	1	-	1 (100)	1 (100)	-	1 (100)	-	12 (8.3)
Phrynosomatidae	54	22 (40.7)	18 (33.3)	25 (46.3)	15 (27.8)	10 (18.5)	6 (11.1)	106 (50.9)
Phyllodactylidae	-	-	-	-	-	-	-	13 (0)
Scincidae	8	5 (62.5)	4 (50)	3 (37.5)	2 (25)	2 (25)	1 (12.5)	26 (30.8)
Sphaerodactylidae	-	-	-	-	-	-	-	3 (0)
Teiidae	10	4 (40)	3 (30)	4 (40)	2 (20)	1 (10)	2 (20)	28 (35.7)
Xantusidae	3	1 (33.3)	1 (33.3)	-	-	-	-	18 (16.7)
Xenosauridae	-	-	-	-	-	-	-	7 (0)
Serpentes	**102**	**62 (60.8)**	**66 (64.7)**	**55 (53.9)**	**36 (35.3)**	**36 (35.3)**	**20 (19.6)**	**298 (34.2)**
Boidae	-	-	-	-	-	-	-	4 (0)
Colubridae	46	27 (58.7)	22 (47.8)	29 (63)	23 (50)	19 (41.3)	11 (23.1)	107 (43)
Dipsadidae	21	13 (61.9)	19 (90.5)	9 (42.9)	3 (14.3)	9 (42.9)	1 (4.8)	85 (24.7)
Elapidae	3	1 (33.3)	3 (100)	1 (33.3)	1 (33.3)	2 (66.7)	1 (33.3)	14 (21.4)
Leptotyphlopidae	5	2 (40)	2 (40)	1 (20)	1 (20)	1 (20)	1 (20)	12 (41.7)
Loxocemidae	-	-	-	-	-	-	-	1 (0)
Natricidae	15	11 (73.3)	12 (80)	9 (60)	4 (26.7)	3 (20)	3 (20)	28 (53.6)
Typhlopidae	-	-	-	-	-	-	-	1 (0)
Viperidae	12	8 (66.7)	8 (66.7)	6 (12.5)	4 (33.3)	2 (16.7)	3 (25)	46 (26.1)
Testudines	**15**	**3 (20)**	**2 (13.3)**	**4 (26.7)**	**5 (33.3)**	**2(13.3)**	**4 (26.7)**	**42 (35.7)**
Cheloniidae	-	-	-	-	-	-	-	5 (0)
Dermochelyidae	-	-	-	-	-	-	-	1 (0)
Emydidae	7	-	-	1 (14.3)	2 (28.6)	-	1 (14.3)	14 (50)
Geoemydidae	-	-	-	-	-	-	-	2 (0)
Kinosternidae	5	2 (40)	2 (40)	3 (60)	1 (20)	2 (40)	2 (40)	15 (33.3)
Testudinidae	2	1 (50)	-	-	1 (50)	-	-	4 (50)
Trionychidae	1	-	-	-	1 (100)	-	1 (100)	1 (100)
Total	**262**	**144 (55)**	**141 (53.8)**	**126 (48.1)**	**75 (28.6)**	**73 (27.9)**	**45 (17.2)**	**868 (30.2)**

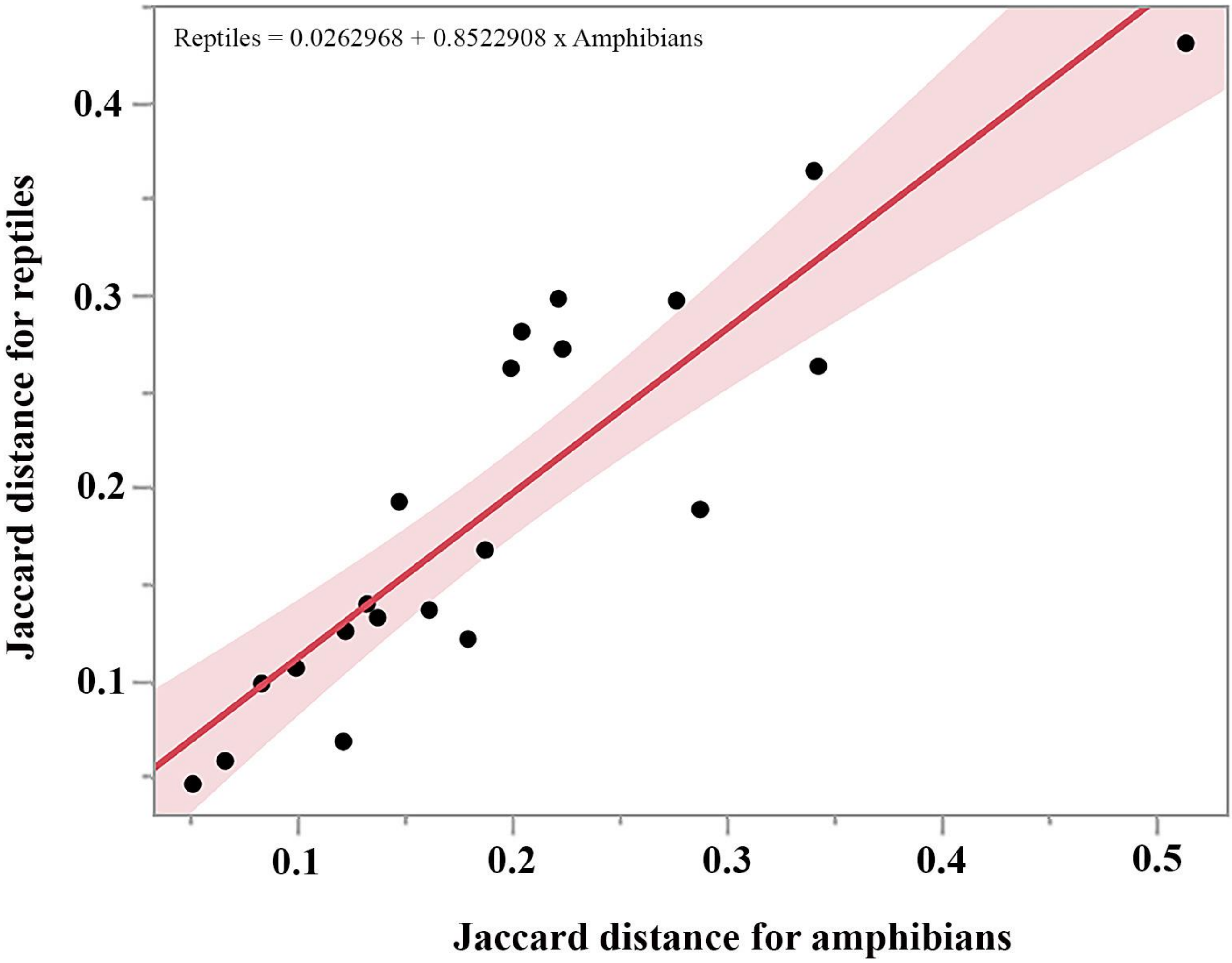

Figure 4. The correlation between the Jaccard distance of amphibians and reptiles among the Chihuahuan Desert and its neighboring biogeographic provinces, with the trend line and 95% confidence intervals.

The hierarchical cluster analysis for amphibians revealed distinct groupings among the biogeographic provinces (Figure 6A). One pair consists of the Transvolcanic Belt with the Sierra Madre Oriental. A second group includes the CD, the Pacific Lowlands, and the Sierra Madre Occidental. This group of three provinces joins the Sonoran Desert. This group of four provinces then combines with the group formed by the Transvolcanic Belt and the Sierra Madre Oriental. Finally, these two groups are joined by the Tamaulipas province, which is isolated from the others and exhibits the lowest similarity with them.

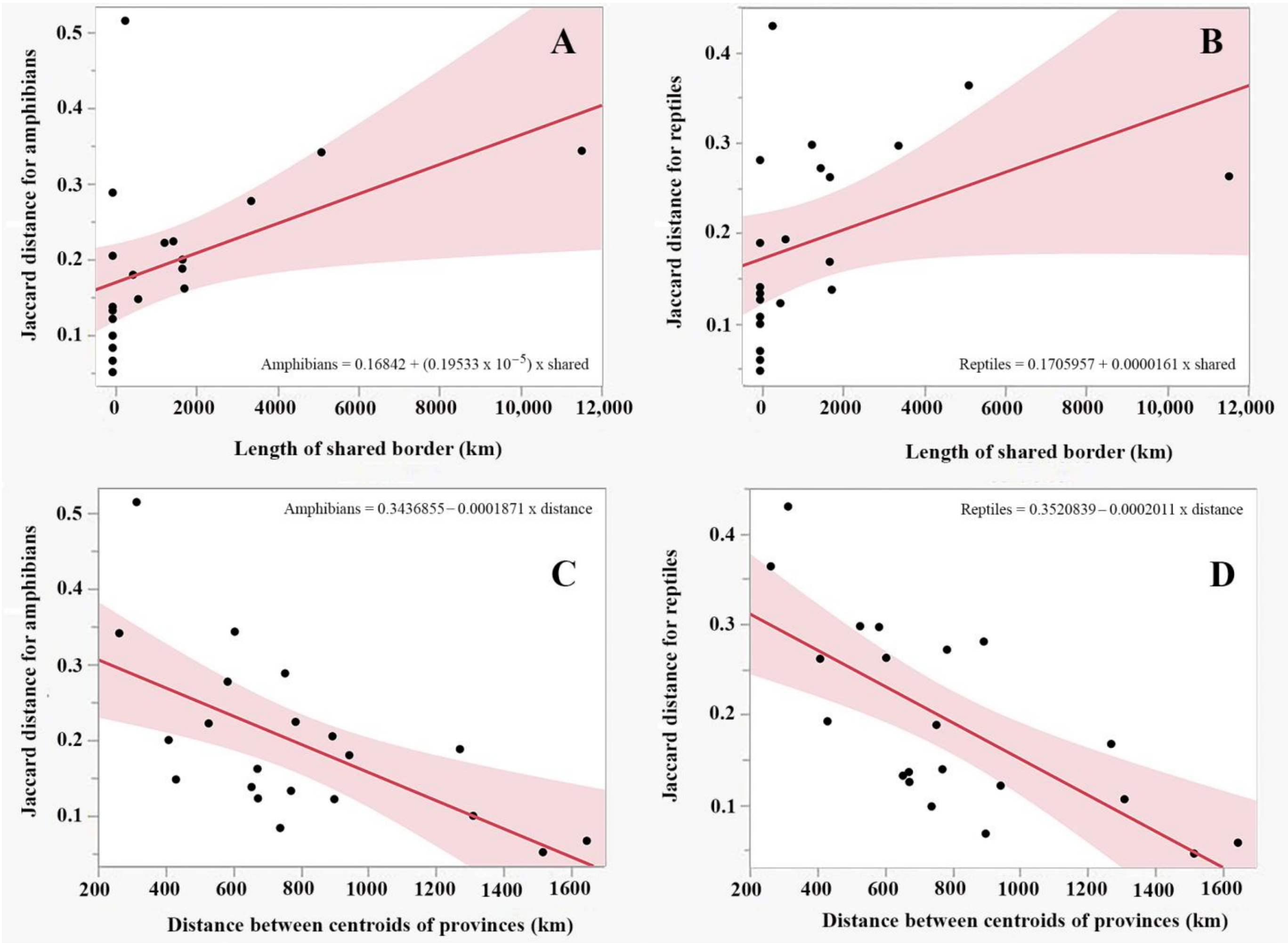

Figure 5. The correlation between the length of the shared border between neighboring biogeographic provinces and the Chihuahuan Desert and the Jaccard distance of (**A**) amphibians and (**B**) reptiles and the correlation between the distance between centroids of the Chihuahuan Desert and its neighboring biogeographic provinces and the Jaccard distance of (**C**) amphibians and (**D**) reptiles, with the trend line and 95% confidence intervals.

The hierarchical cluster analysis for reptiles generated a pair consisting of the Transvolcanic Belt and the Sierra Madre Oriental (Figure 6B). This pair of provinces is joined by the pair of the CD and the Sierra Madre Occidental. This group of four provinces is joined by the Pacific Lowlands. The Tamaulipas then joins this group of five provinces, followed by the Sonoran Desert province. The hierarchical clustering analysis for reptiles therefore reveals a different pattern to that for amphibians. For example, the Chihuahuan Desert province is grouped with the Sierra Madre Occidental, rather than with the Pacific Lowlands as observed with amphibians (Figure 6B).

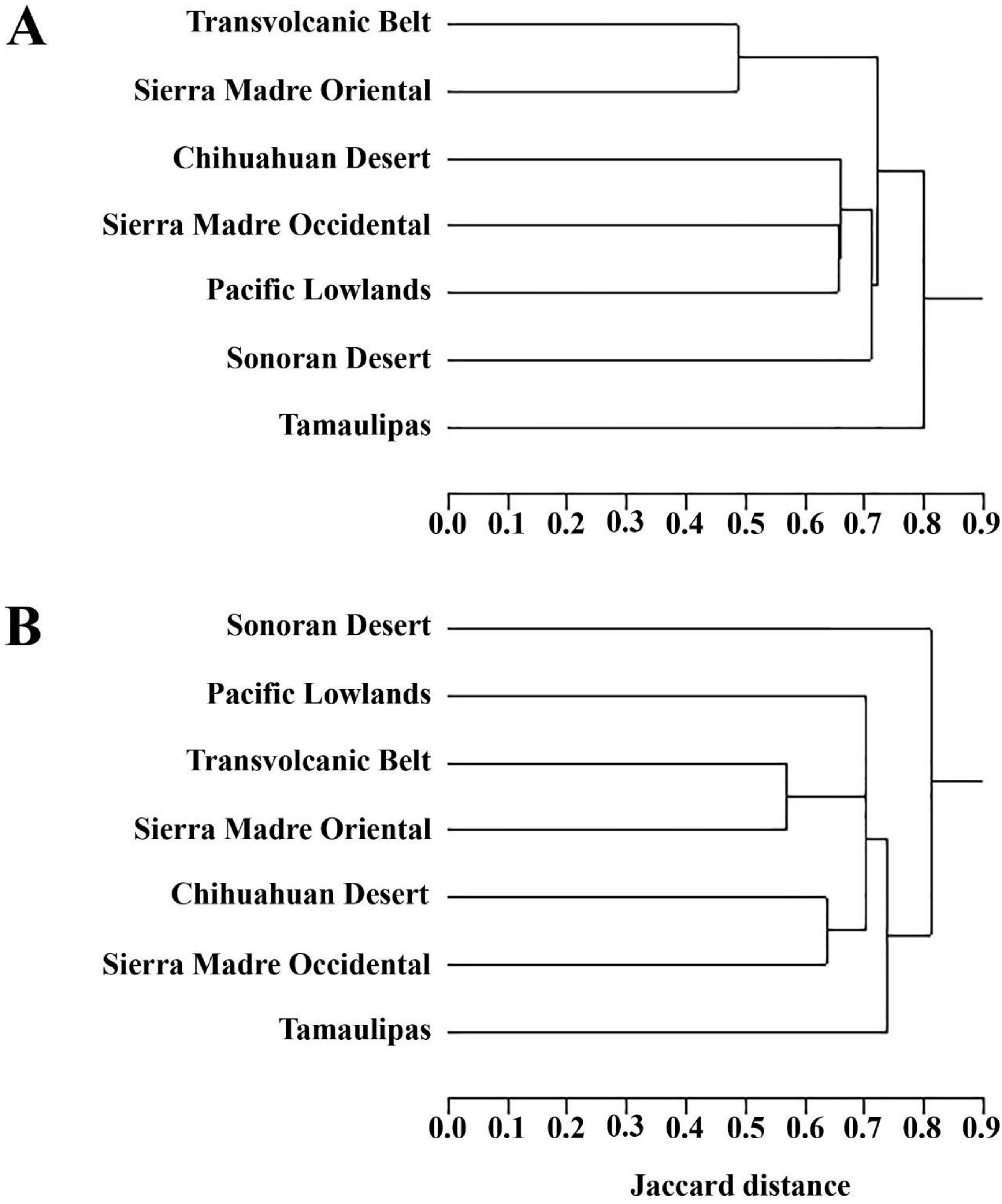

Figure 6. Cluster trees for (**A**) amphibians and (**B**) reptiles of the Chihuahuan Desert and its neighboring biogeographic provinces.

3.3. Conservation Status

Only 29 (12.4% = 29/234 evaluated) of the 262 native species of amphibians and reptiles that inhabit the Chihuahuan Desert (CD) are included in the International Union for Conservation of Nature's (IUCN) Red List (i.e., Vulnerable, Endangered, or Critically Endangered); 47 species (17.9% = 47/262) are placed in some category of risk by Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT), excluding NL (not listed) and Pr (subject to special protection); and 100 species (39.5% = 100/253 evaluated) are considered in the high-risk category by the Environmental Vulnerability Scores (EVS) (Figure 7, Table 4).

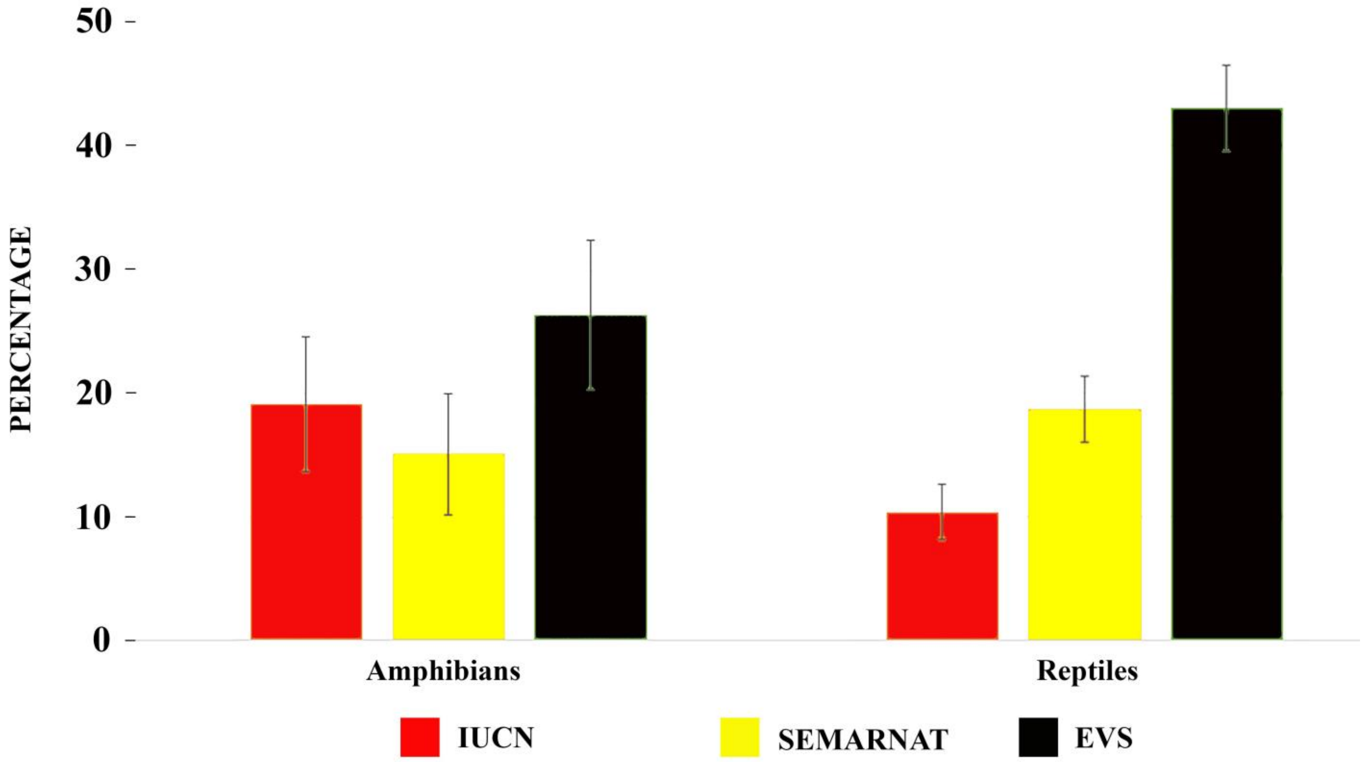

Figure 7. Percentage (±1 S.E.) of amphibian and reptile species with conservation concern status [37], categorized as threatened (A) or in danger of extinction (P) by the Mexican government [38], or deemed to have a high Environmental Vulnerability Score (EVS) [39,40], for the Chihuahuan Desert biogeographic province of Mexico.

Table 4. Summary of native species present in the Chihuahuan Desert by family, order or suborder, and class. Status summary indicates the number of species found in each IUCN conservation status in the order DD, LC, NT, VU, EN, CR (see Supplementary Table S1 for abbreviations; in some cases, species have not been assigned a status by the IUCN, and therefore these may not add up to the total number of species in a taxon). Mean EVS is the mean Environmental Vulnerability Score, scores ≥ 14 are considered high vulnerability [39,40] and categorized as at risk in Mexico according to [38] in the order NL, Pr, A, P (see Supplementary Table S1 for abbreviations).

Scientific Name	Genera	Species	IUCN DD, LC, NT, VU, EN, CR	$\bar{x}$ EVS	SEMARNAT NL, Pr, A, P
Class Amphibia					
Order Anura	**16**	**42**	**5, 31, 1, 2, 1, 1**	**9.6**	**27, 9, 6, 0**
Bufonidae	3	10	0, 9, 0, 0, 0, 0	8.8	9, 1, 0, 0
Craugastoridae	1	2	0, 2, 0, 0, 0, 0	10.5	2, 0, 0, 0
Eleutherodactylidae	1	3	0, 3, 0, 0, 0, 0	13.5	2, 1, 0, 0
Hylidae	5	13	0, 9, 1, 1, 1, 1	10	6, 3, 4, 0
Leptodactylidae	1	2	0, 2, 0, 0, 0, 0	5.5	2, 0, 0, 0
Microhylidae	2	2	0, 2, 0, 0, 0, 0	6.5	1, 1, 0, 0

Table 4. *Cont.*

Scientific Name	Genera	Species	IUCN DD, LC, NT, VU, EN, CR	x̄ EVS	SEMARNAT NL, Pr, A, P
Ranidae	1	7	5, 1, 0, 1, 0, 0	12	2, 3, 2, 0
Scaphiopodidae	2	3	0, 3, 0, 0, 0, 0	6.3	3, 0, 0, 0
Order Caudata	**5**	**11**	**0, 5, 0, 1, 3, 2**	**14.7**	**2, 7, 2, 0**
Ambystomatidae	1	3	0, 2, 0, 0, 1, 0	11.3	1, 2, 0, 0
Plethodontidae	4	8	0, 3, 0, 1, 2, 2	16	1, 5, 2, 0
Subtotal	**21**	**53**	**5, 36, 1, 3, 4, 3**	**10.7**	**29, 16, 8, 0**
Class Reptilia					
Order Squamata	**62**	**194**	**8, 141, 4, 8, 6, 1**	**12.4**	**122, 39, 30, 3**
Suborder Lacertilia	**23**	**92**	**2, 61, 3, 6, 4, 1**	**13.2**	**62, 17, 10, 3**
Anguidae	4	9	0, 6, 0, 1, 0, 0	12.8	4, 4, 1, 0
Anolidae	1	1	0, 1, 0, 0, 0, 0	13	1, 0, 0, 0
Crotaphytidae	2	3	0, 2, 0, 0, 1, 0	14	1, 1, 1, 0
Dibamidae	1	1	0, 1, 0, 0, 0, 0	10	0, 0, 1, 0
Eublepharidae	1	2	0, 2, 0, 0, 0, 0	14.5	0, 2, 0, 0
Iguanidae	1	1	0, 1, 0, 0, 0, 0	15	0, 0, 1, 0
Phrynosomatidae	7	54	1, 33, 3, 3, 3, 1	13.2	43, 3, 6, 2
Scincidae	2	8	0, 6, 0, 1, 0, 0	12.8	4, 4, 0, 0
Teiidae	2	10	0, 8, 0, 0, 0, 0	13	8, 2, 0, 0
Xantusidae	2	3	1, 1, 0, 1, 0, 0	15	1, 1, 0, 1
Suborder Serpentes	**39**	**102**	**6, 80, 1, 2, 2, 0**	**11.6**	**60, 22, 20, 0**
Colubridae	20	46	0, 42, 1, 0, 1, 0	11.3	34, 2, 10, 0
Dipsadidae	9	21	6, 13, 0, 0, 0, 0	11.8	13, 8, 0, 0
Elapidae	1	3	0, 3, 0, 0, 0, 0	11	1, 2, 0, 0
Leptotyphlopidae	2	5	0, 2, 0, 0, 0, 0	9.7	5, 0, 0, 0
Natricidae	4	15	0, 11, 0, 2, 1, 0	11.9	4, 2, 9, 0
Viperidae	3	12	0, 9, 0, 0, 0, 0	12.9	3, 8, 1, 0
Order Testudines	**7**	**15**	**1, 7, 3, 1, 2, 1**	**15.4**	**4, 5, 3, 3**
Emydidae	**4**	**7**	0, 2, 2, 1, 2, 0	16.8	2, 2, 2, 1
Kinosternidae	**1**	**5**	1, 3, 1, 0, 0, 0	12.6	2, 2, 0, 1
Testudinidae	**1**	**2**	0, 1, 0, 0, 0, 1	18.9	0, 0, 1, 1
Trionychidae	1	1	0, 1, 0, 0, 0, 0	15	0, 1, 0, 0
Subtotal	**69**	**209**	**9, 147, 7, 9, 8, 2**	**12.6**	**126, 44, 33, 6**
Total	**90**	**262**	**14, 183, 8, 12, 12, 5**	**12.2**	**155, 60, 41, 6**

Eight amphibian species (15.1% = 8/53) are listed in the risk categories of threatened (A) or in danger of extinction (P) by SEMARNAT, and fourteen species are considered of high risk by EVS (26.4% = 14/53). Only 10 amphibian species (19.2% = 10/52 evaluated) are included in the IUCN Red List: three listed as Vulnerable, four as Endangered, and three as Critically Endangered. Most of them have a decreasing population trend, and all of them, except the Chiricahua leopard frog (*Rana chiricahuensis*), are endemic to Mexico. These nine endemic and threatened species are only found in the Zacatecana subprovince. All of the listed species are threatened primarily by habitat loss [37]. For example, the common flat-footed salamander (*Chiropterotriton chiropterus*) is suffering from the loss of cloud forest [37]. In addition, *Rana chiricahuensis, Chiropterotriton chondrostega* (gristle-headed salamander), and *Chiropterotriton dimidiatus* (dwarf flat-footed salamander) are threatened by the amphibian chytrid fungus *Batrachochytrium dendrobatidis* [37]. *Rana chiricahuensis* is also threatened by introduced predators and competitors, such as bullfrogs, sport fish, and crayfish [37]. The proportion of species of amphibians in a category of conservation concern did not differ between the IUCN Red List, SEMARNAT, and EVS (Figure 7; $\chi^2_2 = 2.15$, $p = 0.34$).

Of the reptiles found in the CD, 10.4% (19/182 evaluated) are included in some category of conservation concern in the IUCN Red List, 18.7% (39/209 evaluated) are listed in the risk categories of threatened (A) or in danger of extinction (P) by SEMARNAT, and

43.0% (86/200 evaluated) are considered high risk by the EVS (Figure 7). The 19 species included in the IUCN Red List are threatened by urbanization, conversion of natural habitats to agriculture, resource extraction, and deforestation. Two are threatened by pollution of their habitats (the blackbelly garter snake [*Thamnophis melanogaster*] and the Big Bend slider [*Trachemys gaigeae*]), one by trade in the pet market (*Trachemys gaigeae*), one by hybridization with a different species (the Cuatrociénegas slider [*Trachemys taylori*]), and one is suffering from climate change and human consumption (the Bolson tortoise [*Gopherus flavomarginatus*]) [37]. Seventeen of these nineteen species are also categorized as high risk by the EVS, and only six of them are listed in the risk categories of threatened (A) or in danger of extinction (P) by SEMARNAT. The number of reptile species considered to be of conservation concern was considerably higher using the EVS method than either the IUCN Red List or SEMARNAT (Figure 7; $\chi^2_2 = 60.5$, $p < 0.0001$).

The proportions of amphibian and reptile species found in the CD that were considered in a category of conservation concern by the IUCN Red List did not differ (Figure 7; $\chi^2_1 = 2.88$, $p = 0.09$), nor did they differ for SEMARNAT (Figure 7; $\chi^2_1 = 0.36$, $p = 0.54$). However, the proportion of reptile species considered at high risk using the EVS method was greater than for amphibian species (Figure 7; $\chi^2_1 = 4.82$, $p = 0.028$).

4. Discussion

4.1. Species Richness and Distribution

Compared to the total amphibian richness of Mexico of 430 reported by [41] or 435 by [31], the CD is home to around 12% of the country's amphibian species. The CD is home to around 21% of the country's total reptile species as determined by [41] (975 species) or [31] (964 species). The distribution of amphibian and reptile richness is not homogenous in the CD, with the herpetofaunal species in the CD concentrated in the Zacatecana subprovince relative to the Coahuilense subprovince.

Over half of the amphibian species and just under half of the reptile species found in the CD are endemic to Mexico, but relatively few species (two amphibian species and 16 reptile species) are endemic specifically to the CD. Many of the herpetofaunal species in the CD are more broadly distributed across Mexico, as well as with the US.

4.2. Comparison with Neighboring Provinces

The Chihuahuan Desert (CD) shares around 50% of its amphibian and reptile species with the Sierra Madre Oriental, Transvolcanic Belt, and Sierra Madre Occidental biogeographic provinces and fewer species with the Tamaulipas, Pacific Lowlands, and Sonoran Desert provinces. The relatively high percentages of shared species between CD and the transition provinces, the Sierra Madre Oriental, Transvolcanic Belt, and Sierra Madre Occidental, likely reflect the fact that the transition provinces in Mexico serve as corridors where species with Nearctic and Neotropical affinities can mix and reach neighboring provinces, such as the CD [36]. In contrast, the lower percentages of species shared between the CD and the other neighboring provinces (all < 35%) may reflect a lower degree of proximity with these provinces, as suggested by the shorter shared borders and greater distances between centroids, which also likely reduce the extent of corridors through which species typical of these provinces can enter the CD.

The results of the hierarchical cluster analyses generally mirror the results of the analysis of shared species above. However, there are some differences in the amphibian and reptile trees (e.g., the placement of the Pacific Lowlands and the Sonoran Desert provinces). These differences in the trees between the two taxa may reflect differences in the ecological needs or characteristics of these two taxa. Indeed, patterns of richness and endemism among regions in Mexico differ between amphibians and reptiles [42]. Differences in how amphibians and reptiles are distributed among biogeographic provinces or regions may arise because the distributions of amphibians may be more influenced by humidity, temperature, or water quality requirements than are reptiles [43–45]. In addition, tolerance of a greater range of environmental conditions and greater mobility allow reptiles to have wider distributions than amphibians [46]. Diversification and extinction rates in different biogeographic provinces could also differ between amphibians and reptiles due to each province being more or less isolated, either physically or ecologically, depending on the taxon being considered [47–49].

4.3. Conservation Status

Several amphibian and reptile species in the CD are of conservation concern (>10% listed in IUCN, >15% are listed in the risk categories of threatened (A) or in danger of extinction (P) by SEMARNAT, and >39% in the high-risk category of the EVS). For amphibians, all three lists had similar assessments of the proportion of species in the CD that are of conservation concern. However, the EVS gave a substantially higher proportion of reptile species at high risk than the other two lists. In addition, the IUCN Red List and SEMARNAT lists suggest that the proportions of species of amphibians and reptiles at risk are similar, whereas the EVS suggests a higher proportion of reptile species in the CD are at high risk than the amphibians. One possible explanation for the difference between amphibians and reptiles in the EVS measure is that in general, Mexican salamanders, lizards, and turtles have higher proportions of species in the high EVS category [39]. Since there are very few salamanders in the CD but several lizards and turtles, some of the difference may reflect the relative degree of general conservation status in the types of amphibians and reptiles found in the CD.

The differences in the assessments across the three lists likely arise from the distinct criteria, geographic focus, and objectives of each evaluation system (see [50] for a discussion of differences between national and global Red Lists). The IUCN Red List provides global assessments based on expert-reviewed criteria that consider factors such as population size, geographic range, and the degree of fragmentation. However, these assessments are slow to change due to the time-intensive nature of expert consultations and data gathering (see [51]), and they may not reflect more recent information about species within the CD. In contrast, SEMARNAT focuses on assessing species' risk within Mexico, and its criteria prioritize national conservation issues, such as habitat loss and environmental degradation specific to the country. Since the SEMARNAT list has remained largely unchanged since 2010, it may not capture the most current evaluations of species, especially for those that have recently been identified as threatened or endangered globally. The EVS, on the other hand, is a more flexible, regionally oriented method that assesses species vulnerability based on their geographic distribution, ecological requirements, and exposure to anthropogenic impacts (see [39,40]). As a result, EVS can highlight species at high risk that may not yet be formally evaluated by IUCN or SEMARNAT but are nevertheless facing immediate or localized threats in the CD region. In addition, the EVS places greater weight on endemism when evaluating conservation status, which may contribute to the difference between the EVS measures and the IUCN [39,40]. Thus, the discrepancies between the three lists are a reflection of their different methodologies, with IUCN providing a global perspective, SEMARNAT focusing on national-level threats, and EVS emphasizing regional vulnerability. These differing frameworks result in variations in the number and categorization of species, reflecting the unique conservation priorities and environmental contexts considered by each assessment.

There are several threats to the CD, mostly leading to increased habitat loss. The growth of large urban populations in northern and central Mexico demands greater services, resulting in the loss of significant portions of natural habitat for amphibians and reptiles (e.g., [8,52]). In addition, conversion to cropland in the CD is a primary factor behind the decline of the Chihuahuan grasslands [53–56], which could significantly impact amphibian and reptile populations associated with these grasslands. Extensive livestock farming has drastically changed the landscape of northern Mexico through the consumption of large areas of bushes and grasslands [57]. Anthropogenic land use change and climate change will lead to restrictions in the distribution of *Uma exsul* and *Crotaphytus antiquus* by 2050 [58,59], and other species, such as *Urosaurus ornatus*, may not be able to successfully respond to climate change [60]. Climate change is predicted to cause a drastic reduction in the distribution of *Uma paraphygas* and *Sceloporus gadsdeni* [58,59]. In addition, agriculture, with its associated use of agrochemicals, and industrial activities are contaminating soils and bodies of water, increasing salinity, and causing habitat loss and negative effects for aquatic organisms [61]. Illegal collection (i.e., poaching) on species of amphibians and reptiles in the CD is harming some populations of amphibians and reptiles [37,62].

Another serious problem in the conservation of the herpetofauna of the CD is the construction of the border fence between Mexico and the United States that affects the largest remaining virgin area of borderlands, the Trans-Pecos portion of the CD [63].

The construction of the U.S.-Mexico border fence not only affects large-bodied, high-mobility species, such as jaguars [64], but also threatens the survival of smaller, often overlooked species, such as amphibians and reptiles, whose habitats are highly impacted by these walls or fences [65,66]. In the CD, many amphibians and reptiles depend on the connectivity between ecosystems for dispersal, gene flow, and access to essential resources like water. The increasing fragmentation of these habitats exacerbates the challenges faced by these species, particularly in regions with high biodiversity, such as the Trans-Pecos area [67–69]. These amphibians and reptiles, which play crucial ecological roles, are being isolated on either side of the border, leading to disrupted gene flow, reduced population viability, and increased risk of local extinctions [67,70,71]. Moreover, the environmental barriers posed by the border wall compound the challenges these species already face, including habitat destruction due to agriculture, urbanization, and livestock farming (e.g., [67,68,71]). Without adequate mitigation efforts like wildlife corridors and wildlife-friendly fencing, these species are likely to experience further population declines, significantly altering the fragile balance of the CD's ecosystems [69].

5. Conclusions

The Chihuahuan Desert (CD) in Mexico has a rich diversity of native amphibian and reptile species, with 262 species, including 53 species of amphibians and 209 species of reptiles. Compared to the total diversity of Mexico, the CD is home to a significant number of the amphibian and reptile species of the country. The distribution of species within the CD shows a concentration of diversity in the Zacatecana subprovince found in the southern CD for both amphibians and reptiles. This subprovince hosts the majority of species, indicating its importance for biodiversity in this biogeographic province. The CD shares a large proportion of its amphibian and reptile species with the Sierra Madre Oriental, the Transvolcanic Belt, and the Sierra Madre Occidental. These similarities suggest strong connections between these regions, with corridors allowing for species exchange.

Conservation assessments highlight the vulnerability of many species in the CD. Several species in the CD are included in the International Union for Conservation of Nature's (IUCN) Red List, primarily due to habitat loss, pollution, and other human-induced threats. In summary, the CD stands out as a biogeographic province of considerable biological diversity for amphibians and reptiles. Its conservation is crucial to protect the unique species and ecosystems that characterize this desert biome.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/d16120771/s1, Table S1 (Supplementary Table S1): Amphibians and reptiles of the Chihuahuan Desert (CD) biogeographic province of Mexico; Table S2 (Supplementary Table S2): Amphibians and reptiles shared between the Chihuahuan Desert and its six neighboring biogeographic provinces.

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