

## Research Article

# An analysis of the inter-state similarity of the herpetofaunas of Mexican states

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## Abstract

Mexico is a megadiverse country with high amphibian and reptile richness. Understanding how Mexico's herpetofauna is shared among Mexican states can contribute to developing conservation plans by figuring out which states may need to coordinate conservation actions. We generated species lists for the herpetofauna for all Mexican states, and used hierarchical clustering analyses to identify clusters of states on the basis of amphibian and reptile species separately. We also calculated pair-wise Jaccard distances for all Mexican states for amphibians, reptiles, and physiographic provinces and estimated the length of shared borders between states and the geographic (straight-line) distance between the centroids of pairs of states. We used these data to explore potential drivers of the cluster analysis results. Our cluster analysis for amphibians identified five clusters with nine subclusters, and for reptiles, resulted in four clusters with six subclusters. In general, the clusters for Mexican amphibians and reptiles have a similar composition of states. However, for amphibians, the states of Veracruz and Puebla form a cluster separate from a large cluster of northeastern Mexican states, whereas in reptiles Veracruz and Puebla cluster with northeastern Mexican states. Jaccard distances of amphibians and reptiles were highly, positively correlated. Both amphibian and reptile Jaccard distances were positively correlated with the physiographic provinces' Jaccard distance and shared border length and negatively correlated with the distance between centroids. Taken together, our results suggest that the pattern of the sharing of herpetofaunal species among Mexican states is a consequence of the states' proximity. Such a pattern is consistent with the underlying driver being the similarity of physiographic provinces (i.e., habitats and ecosystems) of these states (i.e., geographic proximity likely reflects, at least in large part, ecological similarity). Our results suggest clusters of states that should coordinate the conservation and management of their herpetofaunas. For example, clusters of states in southern Mexico share a high number of threatened amphibian species and clusters of states in northern Mexico share a high number of threatened reptile species. Oaxaca is also a state that has a unique herpetofauna and a high number of threatened species of both amphibians and reptiles.

**Key words:** Amphibia, hierarchical clustering, Jaccard's similarity, physiographic provinces, reptiles

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## Introduction

Mexico is a megadiverse country, with high species richness for a variety of taxa (Ramamoorthy et al. 1993). In addition, Mexico is the location for several conservation hotspots (Myers et al. 2000; Lira et al. 2002; Sosa and De-nova 2012; Contreras-MacBeath et al. 2014), as well as a country with high levels of endemism for several taxa (e.g., mosses, Delgadillo 1994; mammals: Escalente et al. 2009; vascular plants, Luna-Vega et al. 2013; birds, Bertelli et al. 2017; trees, Tellez et al. 2020). Much of Mexico consists of a transition zone (i.e., the Mexican Transition Zone) between the Nearctic and Neotropical zones (Villaseñor et al. 2020), giving rise to much of its diversity.

Mexico is also an area of high amphibian and reptile richness (e.g., Flores-Villela 1993; Flores-Villela and García-Vázquez 2014; Suazo-Ortuño et al. 2023), but also an area with high extinction debt and risk for these taxa (Chen and Peng 2017). Some amphibian and reptile taxa have centers of endemism in Mexico (Flores-Villela 1993; Suazo-Ortuño et al. 2023). For example, the Sierra Madre Occidental, Sierra Madre Oriental, and the Trans-Mexican Volcanic Belt are well known for being hotspots for differentiation of various Mexican reptiles and amphibians (e.g., Cisneros-Bernal et al. 2022), creating high levels of state endemics, even within the larger ecological province.

Mexico needs conservation approaches that focus on protecting specific areas (Bolam et al. 2023). Understanding how species are shared among ecological or biogeographical provinces is of critical importance to generating such conservation or management plans. Indeed, for amphibians and reptiles, ecoregions are particularly distinct (i.e., have distinct communities) (Smith et al. 2020). However, understanding how species are shared across political entities, such as states within a country, is also important to coordinating efforts among state-level governments (see Liu et al. 2020 for a broader discussion of transborder conservation). Indeed, it has been suggested that efforts to address the factors affecting biodiversity in Mexico will need to be shifted from the federal to state or even local levels (Sarukhán et al. 2015). It is therefore important to understand how the herpetofauna are distributed and shared among political entities within Mexico (i.e., among the Mexican states).

Previous efforts to examine similarity in the herpetofauna among Mexican states have been limited to cluster analyses of the states along both sides of the United States-Mexican border (Enderson et al. 2009; Smith and Lemos-Espinal 2015) and examinations of the number of species shared between focal states and their neighboring states (e.g., Lemos-Espinal and Smith 2020a, b, c; Lemos-Espinal et al. 2020). Here we explore how amphibian and reptile species are shared among Mexican states (including Mexico City) in order to determine how conservation efforts might best be coordinated among political entities. We also examine how similarities among states may be a function of the states' proximity (distance between centroids and length of shared border) and their similarities in physiographic provinces.

## Methods

Using the available literature, we collected species lists for amphibians and reptiles for all of the Mexican states, that we updated using additional literature

(see Table 1). We used hierarchical clustering analyses based on Jaccard's Similarity Coefficients for Binary Data as the distance metric with single linkage methods (nearest neighbor) to generate clusters of states on the basis of amphibian and reptile species separately. We identified clusters and subclusters for amphibians and reptiles separately by visually examining the resulting cluster tree and grouping states that shared common nodes, taking into account the Jaccard distances. Subclusters were groups of states that shared nodes within a larger cluster. We used the species' lists to calculate pair-wise Jaccard distances for all Mexican states for amphibians and reptiles, separately. We also generated pairwise Jaccard distances with respect to the physiographic provinces found in each state (see Table 2). In addition, we obtained two geospatial estimates: 1) the length of shared borders between the states using the Polygon Neighbors Tool and 2) the straight-line distance between the centroids of the states using the Feature to Point Tool and Point Distance on a Lambert Conformal Conic projection in Datum WGS84 in ArcGIS 10.3.1 (Environmental Systems Research Institute, Inc, Redlands, CA). We ran non-parametric Spearman's  $\rho$  tests to examine correlations among Jaccard distance estimates for amphibians, reptiles, physiographic regions, the length of shared borders, and the distance between the centroids of the states. Cluster analyses were performed using Systat 13.2 (Systat Software Inc., San Jose, CA) and all other statistical analyses were performed using JMP 16.2 (SAS Institute, Cary, NC).

## Results and discussion

### Cluster analysis

Our cluster analysis for amphibians generated five clusters, with subclusters apparent in some of the clusters (Figs 1A, 2A). Cluster AI consisted of Baja California and Baja California Sur. Cluster AII includes Tabasco and Chiapas and subcluster AIIa, which includes Yucatán, Quintana Roo, and Campeche. Cluster AIII consists of Veracruz and Puebla. Cluster AIV includes Durango and four subclusters: AIVa includes Morelos and México; AIVb includes Michoacán, Jalisco, and Colima; AIVc includes Nayarit and Sinaloa; and AIVd includes Sonora and Chihuahua. Cluster AV is made up of four subclusters: AVa includes Aguascalientes and Zacatecas; AVb includes Guanajuato and Querétaro; AVc includes San Luis Potosí and Hidalgo; and AVd includes Tamaulipas, Nuevo León, and Coahuila. Tlaxcala and Mexico City connect with a larger grouping of clusters AIII, AIV, and AV. Guerrero and Oaxaca then connect to this large grouping.

The cluster analysis for reptiles resulted in four clusters, again with subclusters within some clusters (Figs 1B, 2B). Cluster RI consists of Baja California and Baja California Sur. Cluster RII includes Chiapas and Tabasco, as well as subcluster RIIa that includes Campeche, Quintana Roo, and Yucatán. Cluster RIII includes Guanajuato and two subclusters: RIIIa consists of Coahuila, Nuevo León, Tamaulipas, San Luis Potosí, Hidalgo, and Querétaro; whereas RIIIb includes Veracruz and Puebla. Cluster RIV is a large cluster containing Mexico City and Tlaxcala and three subclusters: RIVa includes Aguascalientes, Zacatecas, Durango, Chihuahua, and Sonora; RIVb includes Sinaloa, Nayarit, Jalisco, Michoacán, and Colima; and RIVc includes Morelos and México. Guerrero and Oaxaca connect to a large group that consists of clusters RIII and RIV.

**Table 1.** Alphabetical list of Mexican States with the literature sources used to create the species lists of amphibians and reptiles used in the cluster analyses. State names are followed by the abbreviations used in Fig. 1. Source refers to the references from which the checklist for each specific state was obtained. Updates lists references used to update the original checklist we used for each state.

State	Source	Updates
Aguascalientes (AGS)	Carbajal-Márquez and Quintero-Díaz (2016)	Cox et al. (2018);
Baja California (BC)	Grismer (2002); Hollingsworth et al. (2015)	Cox et al. (2018); Meik et al. (2018);
Baja California Sur (BCS)	Grismer (2002)	Cox et al. (2018); Meik et al. (2018);
Campeche (CAMP)	González-Sánchez et al. (2017)	Ortiz-Medina et al. (2020); Palacios-Aguilar and Flores-Villela (2020);
Chiapas (CHIS)	Johnson et al. (2015)	Hernández-Ordóñez et al. (2017); Clause et al. (2020); McCranie et al. (2020); Palacios-Aguilar and Flores-Villela (2020); Lara-Tufiño and Nieto-Montes de Oca (2021)
Chihuahua (CHIH)	Lemos-Espinal et al. (2017)	Burbrink and Guiher (2014); Montanucci (2015); Blair and Hansen (2018); Cox et al. (2018); Palacios-Aguilar and Flores-Villela (2020); Ramírez-Reyes et al. (2021b)
Coahuila (COAH)	Lemos-Espinal and Smith (2016); Lazcano et al. (2019)	Burbrink and Guiher (2014); Baeza-Tarin et al. (2018)
Colima (COL)	Lemos-Espinal et al. (2020)	Horowitz (1955); Montanucci (1979); Hillis et al. (1983); Platz (1991); Webb (2001); McCranie and Köhler (2004); Zaldivar-Riverón et al. (2004); Pérez-Ramos and Saldaña-de la Riva (2008); Lavin et al. (2014); Streicher et al. (2014); Campbell et al. (2018); Cox et al. (2018); Grünwald et al. (2018); O'Connell and Smith (2018); Ramírez-Reyes and Flores-Villela (2018); McCranie et al. (2020); Montaña-Ravalcaba et al. (2020); Palacios-Aguilar and Flores-Villela (2020); Reyes-Velasco et al. (2020a, b)
Durango (DGO)	Lemos-Espinal et al. (2018a, 2019b)	Montanucci (2015); Campbell et al. (2018); Caviedes-Solis and Nieto-Montes de Oca (2018); Campillo-García et al. (2021); Ramírez-Reyes et al. (2021b)
Guanajuato (GTO)	Leyte-Manrique et al. (2022)	
Guerrero (GRO)	Palacios-Aguilar and Flores-Villela (2018)	Ramírez-Reyes et al. (2017); Campbell et al. (2018); Caviedes-Solis and Nieto-Montes de Oca (2018); Cox et al. (2018); García-Vázquez et al. (2018); Palacios-Aguilar et al. (2018); Ramírez-Reyes and Flores-Villela (2018); Blancas-Hernández et al. (2019); Grünwald et al. (2019); Köhler et al. (2019); Kaplan et al. (2020); Palacios-Aguilar and Flores-Villela (2020); Palacios-Aguilar and Santos-Bibiano (2020); Everson et al. (2021); García-Vázquez et al. (2021); Grünwald et al. (2021a, b); Jameson et al. (2022)
Hidalgo (HGO)	Lemos-Espinal and Smith (2015); Lemos-Espinal and Dixon (2016)	Hansen et al. (2016); Badillo-Saldaña et al. (2018); Caviedes-Solis and Nieto-Montes de Oca (2018); Ramírez-Bautista et al. (2020); Valencia-Herverth et al. (2020); Bryson et al. (2021); Campillo-García et al. (2021); Tepos-Ramírez et al. (2021)
Jalisco (JAL)	Cruz-Sáenz et al. (2017)	Ramírez-Reyes et al. (2017); Campbell et al. (2018); Caviedes-Solis and Nieto-Montes de Oca (2018); Cox et al. (2018); Ramírez-Reyes and Flores-Villela (2018); Pazos-Nava et al. (2019); Ahumada-Carrillo et al. (2020); Cavazos-Camacho and Ahumada-Carrillo (2020); McCranie et al. (2020); Palacios-Aguilar and Flores-Villela (2020); Bryson et al. (2021); Campillo-García et al. (2021); Everson et al. (2021); Flores-Villela et al. (2022)
México (MEX)	Lemos-Espinal and Smith (2020d)	Campbell et al. (2018); Caviedes-Solis and Nieto-Montes de Oca (2018); Kaplan et al. (2020); Bryson et al. (2021); Campillo-García et al. (2021); Everson et al. (2021); Jameson et al. (2022)
Mexico City (CDMX)	Lemos-Espinal and Smith (2020c)	García-Alvarado (2016); Campillo-García et al. (2021); Everson et al. (2021)
Michoacán (MICH)	Alvarado-Díaz et al. (2013)	Mendoza-Hernández and Roth-Monzón (2017); Ramírez-Reyes et al. (2017); Campbell et al. (2018); Cox et al. (2018); Ramírez-Reyes and Flores-Villela (2018); McCranie et al. (2020); Palacios-Aguilar and Flores-Villela (2020); Bryson et al. (2021); Campillo-García et al. (2021); Everson et al. (2021); Hernandez et al. (2022)
Morelos (MOR)	Lemos-Espinal and Smith (2020b)	Campbell et al. (2018); Cox et al. (2018); Palacios-Aguilar and Flores-Villela (2020); Jameson et al. (2022)
Nayarit (NAY)	Woolrich-Piña et al. (2016)	Ramírez-Reyes et al. (2017, 2021a, b); Campbell et al. (2018); Cox et al. (2018); Loc-Barragán et al. (2018); Ramírez-Reyes and Flores-Villela (2018); Loc-Barragán and Woolrich-Piña (2020); McCranie et al. (2020); Palacios-Aguilar and Flores-Villela (2020); Flores-Villela et al. (2022)
Nuevo León (NL)	Lemos-Espinal et al. (2016); Nevárez de los Reyes et al. (2016)	Grünwald et al. (2018); Nevarez de los Reyes et al. (2019a, b); Campillo-García et al. (2021)

State	Source	Updates
Oaxaca (OAX)	Mata-Silva et al. (2015, 2021)	Gray et al. (2016); Parra-Olea et al. (2016); Campbell et al. (2016, 2018); Canseco-Márquez et al. (2017a, b); Ramírez-Reyes et al. (2017); Caviedes-Solis and Nieto-Montes de Oca (2018); García-Padilla et al. (2019); Mata-Silva et al. (2019); Carbajal-Márquez et al. (2020); McCranie et al. (2020); Sánchez-García et al. (2020); García-Vázquez et al. (2021); Grünwald et al. (2021a, b); Jameson et al. (2022); Nieto-Montes de Oca et al. (2022)
Puebla (PUE)	Woolrich-Piña et al. (2017)	Caviedes-Solis and Nieto-Montes de Oca (2018); Campbell et al. (2018); Cox et al. (2018); de la Torres-Loranca et al. (2020); Fernández-Badillo et al. (2020); Palacios-Aguilar and Flores-Villela (2020); Everson et al. (2021)
Querétaro (QRO)	Dixon and Lemos-Espinal (2010); Cruz-Elizalde et al. (2019)	Bryson et al. (2021); Tepos-Ramírez et al. (2021)
Quintana Roo (QR)	González-Sánchez et al. (2017)	
San Luis Potosí (SLP)	Lemos-Espinal et al. (2018b)	Guajardo Welsh et al. (2020); Palacios-Aguilar and Flores-Villela (2020); Arenas-Moreno et al. (2021); Campillo-García et al. (2021); Tepos-Ramírez et al. (2021)
Sinaloa (SIN)	Lemos-Espinal and Smith (2020a)	Campbell et al. (2018); Cox et al. (2018); Trageser and Schell (2018); Loc-Barragán et al. (2020a, b); Palacios-Aguilar and Flores-Villela (2020); Ramírez-Reyes et al. (2021b)
Sonora (SON)	Rorabaugh and Lemos-Espinal (2016); Lemos-Espinal et al. (2019a)	Cox et al. (2018); Meik et al. (2018); Barley et al. (2021); Ramírez-Reyes et al. (2021b)
Tabasco (TABA)	Barragán-Vázquez et al. (2022)	
Tamaulipas (TAM)	Farr (2015); Terán-Juárez et al. (2016)	Grünwald et al. (2018); Rautsaw et al. (2018); Sosa-Tovar et al. (2019); Campillo-García et al. (2021)
Tlaxcala (TLAX)	Fernández et al. (2006)	
Veracruz (VER)	Torres-Hernández et al. (2021)	Carbajal-Márquez et al. (2020); Schätti et al. (2020); Tepos-Ramírez et al. (2021)
Yucatán (YUC)	González-Sánchez et al. (2017)	Palacios-Aguilar and Flores-Villela (2020);
Zacatecas (ZAC)	Sigala-Rodríguez et al. (2020a, b); J.J. Sigala-Rodríguez, pers. comm.	

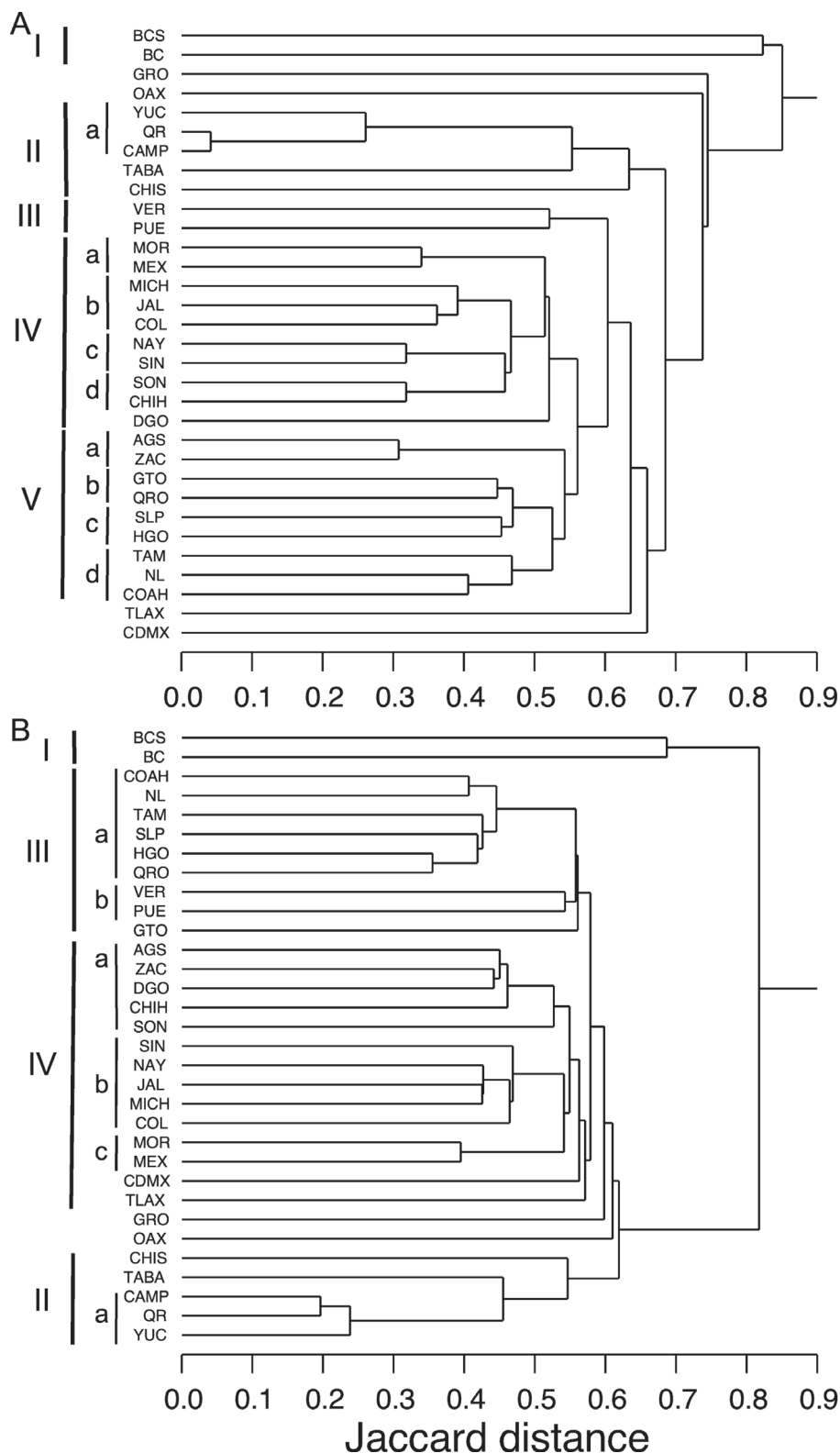
For the most part, the clusters for Mexican amphibians and reptiles are similar. One difference, however, is that in amphibians, Veracruz and Puebla form a cluster separate from the large cluster of the northeastern Mexican states, whereas in reptiles Veracruz and Puebla cluster with the northeastern Mexican states. Our clusters roughly correspond to the five environmental regions identified by Ochoa-Ochoa et al. (2014). The clusters we generated are generally similar to clusters generated for Mexico examining similarity in turtles in North America (Ennen et al. 2017), as well as for endemic Asteraceae, Poaceae, and Musci (Delgadillo et al. 2003). Our clusters show less similarity to the clusters for the plant families examined by Luna-Vega et al. (2013) and Lira et al. (2002), but there are still many commonalities. Much of the underlying similarity among states in our study, and the general commonalities in our cluster analysis and the clusters from the other cited studies above, likely reflects the distribution of biogeographic provinces in Mexico (e.g., Morrone et al. 2017). In other words, the environmental factors and ecosystems found in Mexican states drive the distribution of species, and those states sharing such ecosystems and habitats share more species than those that do not, and these similarities appear to generally hold for several taxa. Thus, the apparently geographic clusters we identified likely arise because of the correlation of geographic traits of states (e.g., latitude, longitude, elevation, proximity to oceans) and environmental traits of states (e.g., physiographic provinces, climate). In terms of conservation policies, such a finding suggests that policies should focus on addressing physiographic provinces rather than

**Table 2.** The distribution of physiographic provinces in all Mexican states. BCP = Baja California Peninsula; SP = Sonoran Plain; SMOc = Sierra Madre Occidental; SPN = Sierra and Plains of the North; SMOr = Sierra Madre Oriental; GPNA = Great Plains of North America; PCP = Pacific Coast Plain; NGCP = North Gulf Coastal Plain; CP = Central Plateau; VA = Volcanic Axis; YP = Yucatan Peninsula; SMS = Sierra Madre del Sur; SGCP = Southern Gulf Coastal Plain; SCG = Sierra of Chiapas and Guatemala; CAMR = Central American Mountain Range.

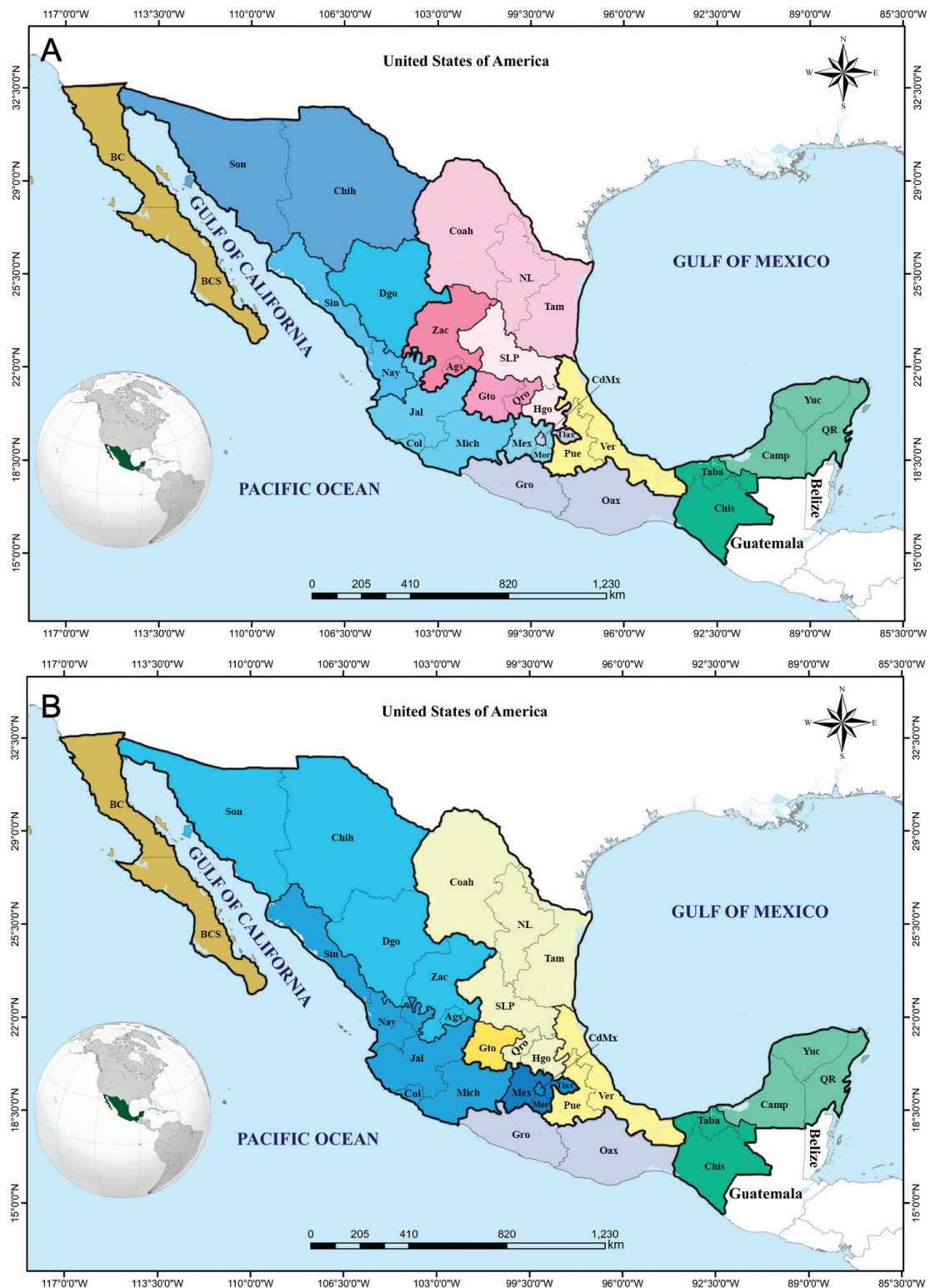
	BCP	SP	SMOc	SPN	SMOr	GPNA	PCP	NGCP	CP	VA	YP	SMS	SGCP	SCG	CAMR
Aguascalientes	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0
Baja California	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Baja California Sur	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Campeche	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
Chiapas	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Chihuahua	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Coahuila	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Colima	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Durango	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0
Guanajuato	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0
Guerrero	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Hidalgo	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0
Jalisco	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0
México	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Mexico City	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Michoacán	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Morelos	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Nayarit	0	0	1	0	0	0	1	0	0	1	0	1	0	0	0
Nuevo León	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0
Oaxaca	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1
Puebla	0	0	0	0	1	0	0	1	0	1	0	1	0	0	0
Querétaro	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0
Quintana Roo	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
San Luis Potosí	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0
Sinaloa	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Sonora	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0
Tabasco	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Tamaulipas	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0
Tlaxcala	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Veracruz	0	0	0	0	1	0	0	1	0	1	0	1	1	1	1
Yucatán	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Zacatecas	0	0	1	0	1	0	0	0	1	1	0	0	0	0	0

states per se. However, our clusters help identify the political entities that need to be involved in the discussions of the ecological entities that are the focus of conservation efforts.

For each cluster, we identified the species that are in a threatened category in the IUCN Red List (i.e., Vulnerable, Endangered, Critically Endangered) and summarized the major threats facing each species based on the IUCN Red List species accounts (IUCN 2022; see Table 3 for amphibians, Table 4 for reptiles). For amphibians, clusters All and AIII and Oaxaca had particularly high numbers of threatened species and should be the focus of targeted conservation



**Figure 1.** Cluster trees for A) amphibians and B) reptiles arising from a cluster analysis of the herpetofaunas of Mexican states. Main clusters are identified with Roman numerals and subclusters within clusters are identified with lower case letters. AGS = Aguascalientes, BC = Baja California, BCS = Baja California Sur, CAMP = Campeche, CHIS = Chiapas, CHIH = Chihuahua, COAH = Coahuila, COL = Colima, DGO = Durango, GTO = Guanajuato, GRO = Guerrero, HGO = Hidalgo, JAL = Jalisco, MEX = México, CDMX = Mexico City, MICH = Michoacán, MOR = Morelos, NAY = Nayarit, NL = Nuevo León, OAX = Oaxaca, PUE = Puebla, QRO = Querétaro, QR = Quintana Roo, SLP = San Luis Potosí, SIN = Sinaloa, SON = Sonora, TABA = Tabasco, TAM = Tamaulipas, TLAX = Tlaxcala, VER = Veracruz, YUC = Yucatán, ZAC = Zacatecas.



**Figure 2.** A map of Mexico showing the locations of the clusters of **A** amphibians and **B** reptiles identified by the cluster analyses found in Fig. 1. Different clusters are identified by color and surrounded by a thick border and subclusters within clusters are represented by different shades of the cluster color and by intermediate line thicknesses. AGS = Aguascalientes, BC = Baja California, BCS = Baja California Sur, CAMP = Campeche, CHIS = Chiapas, CHIH = Chihuahua, COAH = Coahuila, COL = Colima, DGO = Durango, GTO = Guanajuato, GRO = Guerrero, HGO = Hidalgo, JAL = Jalisco, MEX = México, CDMX = Mexico City, MICH = Michoacán, MOR = Morelos, NAY = Nayarit, NL = Nuevo León, OAX = Oaxaca, PUE = Puebla, QRO = Querétaro, QR = Quintana Roo, SLP = San Luis Potosí, SIN = Sinaloa, SON = Sonora, TABA = Tabasco, TAM = Tamaulipas, TLAX = Tlaxcala, VER = Veracruz, YUC = Yucatán, ZAC = Zacatecas.



**Table 3.** A list of amphibian species from each cluster that are considered in a threatened category on the IUCN Red List, as well as the primary threats to each species based on the IUCN Red List species accounts (IUCN 2022). IUCN Categories: VU = Vulnerable, EN = Endangered, CR = Critically Endangered (PE = Possibly extinct). Threats: LU = Land use (urbanization, conversion to agriculture, resource extraction, deforestation), NNS = Non-native species and disease, P = Pollution (agricultural, industrial, domestic), CC = Climate change.

	IUCN Category	Threats
Cluster AI VU: 0, EN: 1, CR: 0		
<i>Anaxyrus californicus</i>	EN	LU, NNS, CC
Cluster AII VU: 21, EN: 21, CR: 5		
<i>Charadrahyla chaneque</i>	VU	LU, NNS
<i>Craugastor amniscola</i>	VU	LU, NNS, P
<i>Craugastor brocchi</i>	VU	LU, NNS, P, CC
<i>Craugastor glaucus</i>	EN	LU, NNS
<i>Craugastor greggi</i>	EN	LU, NNS, P, CC
<i>Craugastor matudai</i>	EN	LU, NNS, P, CC
<i>Craugastor montanus</i>	EN	LU
<i>Craugastor palenque</i>	VU	LU, NNS, P, CC
<i>Craugastor pelorus</i>	VU	LU
<i>Craugastor pozo</i>	CR	LU
<i>Craugastor stuarti</i>	VU	LU, NNS, P
<i>Craugastor taylori</i>	CR	LU
<i>Dryophytes walkeri</i>	VU	LU, NNS, CC
<i>Duellmanohyla chamulae</i>	EN	LU, NNS
<i>Exerodonta bivocata</i>	EN	LU
<i>Exerodonta chimalapa</i>	EN	LU
<i>Incilius aurarius</i>	EN	LU, CC
<i>Incilius tacanensis</i>	EN	LU, NNS, CC
<i>Incilius tutelarius</i>	VU	LU, NNS, P, CC
<i>Plectrohyla acanthodes</i>	EN	LU, NNS, P, CC
<i>Plectrohyla avia</i>	EN	LU, NNS, P, CC
<i>Plectrohyla hartwegi</i>	EN	LU, NNS, P, CC
<i>Plectrohyla ixil</i>	VU	LU, NNS, P, CC
<i>Plectrohyla lacertosa</i>	EN	LU, NNS
<i>Plectrohyla pycnochila</i>	CR (PE)	LU, NNS
<i>Plectrohyla sagorum</i>	VU	LU, NNS, P
<i>Ptychohyla macrotympanum</i>	VU	LU, NNS
<i>Quilticohyla zoque</i>	EN	LU
<i>Rana macroglossa</i>	VU	LU, P, CC
<i>Bolitoglossa alberchi</i>	VU	LU, NNS
<i>Bolitoglossa engelhardti</i>	EN	LU, NNS, P, CC
<i>Bolitoglossa flavimembris</i>	EN	LU, NNS, P, CC
<i>Bolitoglossa flaviventris</i>	EN	LU, NNS, P
<i>Bolitoglossa franklini</i>	VU	LU, NNS, P, CC
<i>Bolitoglossa hartwegi</i>	VU	LU, NNS
<i>Bolitoglossa mulleri</i>	VU	LU, NNS, P
<i>Bolitoglossa stuarti</i>	VU	LU, NNS, P

	IUCN Category	Threats
<i>Bolitoglossa veracrucis</i>	EN	LU
<i>Bradytriton silus</i>	EN	LU, NNS, P, CC
<i>Cryptotriton alvarezdeltoroi</i>	EN	LU, NNS
<i>Dendrotriton megarhinus</i>	VU	NNS, CC
<i>Dendrotriton xolocalcae</i>	VU	NNS, CC
<i>Ixalotriton niger</i>	EN	LU
<i>Nyctanolis pernix</i>	VU	LU, NNS, P, CC
<i>Pseudoeurycea brunnata</i>	CR	LU, NNS, CC
<i>Pseudacris goebeli</i>	CR	LU, NNS, CC
<i>Pseudoeurycea rex</i>	VU	LU, NNC, CC
Cluster AIII VU: 13, EN: 28, CR: 26		
<i>Bromeliohyala dendroscarta</i>	EN	LU, NNS
<i>Charadrahyla nephila</i>	EN	LU, NNS
<i>Charadrahyla taeniopus</i>	VU	LU, P
<i>Craugastor galacticorhinus</i>	EN	LU
<i>Craugastor megalotympanum</i>	EN	LU
<i>Craugastor spatulatus</i>	EN	LU
<i>Craugastor vulcani</i>	EN	LU
<i>Duellmanohyla chamulae</i>	EN	LU, NNS
<i>Ecnomiohyala valancifer</i>	CR	LU
<i>Exerodonta bivocata</i>	EN	LU
<i>Exerodonta xera</i>	VU	LU
<i>Incilius cavifrons</i>	EN	LU
<i>Incilius cristatus</i>	EN	LU, P
<i>Megastomatohyala mixomaculata</i>	EN	LU
<i>Megastomatohyala nubicola</i>	CR	LU
<i>Ptychohyala zophodes</i>	VU	LU, NNS
<i>Quilticohyala zoque</i>	EN	LU
<i>Rana chichicuahutla</i>	CR	LU, NNS
<i>Rana chiricahuensis</i>	VU	LU, NNS, P, CC
<i>Rana johni</i>	VU	LU
<i>Rana pueblae</i>	CR (PE)	LU
<i>Sarcohyala charadricola</i>	CR (PE)	LU
<i>Sarcohyala pachyderma</i>	CR (PE)	LU, NNS
<i>Sarcohyala robertsororum</i>	VU	LU, NNS
<i>Sarcohyala siopela</i>	CR (PE)	LU, NNS
<i>Tlalocohyla godmani</i>	VU	LU, P, CC
<i>Ambystoma altamirani</i>	EN	LU, NNS, P
<i>Aquiloerycea cafetalera</i>	VU	LU, NNS, P
<i>Aquiloerycea praecellens</i>	CR (PE)	LU
<i>Aquiloerycea quetzalanensis</i>	CR	LU
<i>Bolitoglossa alberchi</i>	VU	LU, NNS
<i>Bolitoglossa veracrucis</i>	EN	LU
<i>Chiropterotriton arboreus</i>	CR	LU
<i>Chiropterotriton aureus</i>	CR	LU, NNS
<i>Chiropterotriton casasi</i>	CR (PE)	LU, NNS
<i>Chiropterotriton chiropterus</i>	CR	LU, NNS

	IUCN Category	Threats
<i>Chiropterotriton chondrostega</i>	EN	LU, NNS
<i>Chiropterotriton lavae</i>	CR	LU
<i>Chiropterotriton nubilus</i>	CR	LU, NNS
<i>Chiropterotriton orculus</i>	VU	LU, NNS
<i>Chiropterotriton perotensis</i>	CR	LU, NNS
<i>Chiropterotriton terrestris</i>	CR	LU, NNS
<i>Chiropterotriton totonacus</i>	CR	LU, NNS
<i>Isthmura gigantea</i>	EN	LU, NNS
<i>Isthmura naucampatepetl</i>	CR	LU, NNS
<i>Notophthalmus meridionalis</i>	EN	LU, NNS, P
<i>Parvimolge townsendi</i>	VU	LU, NNS, P
<i>Pseudoeurycea firscheini</i>	EN	LU
<i>Pseudoeurycea gadovii</i>	VU	LU
<i>Pseudoeurycea lineola</i>	EN	LU, NNS
<i>Pseudoeurycea lynchi</i>	EN	LU
<i>Pseudoeurycea melanomolga</i>	EN	LU
<i>Pseudoeurycea mixteca</i>	VU	LU
<i>Pseudoeurycea nigromaculata</i>	EN	LU, NNS
<i>Pseudoeurycea orchimelas</i>	EN	LU
<i>Pseudoeurycea werleri</i>	EN	LU
<i>Thorius dubitus</i>	CR	LU, NNS
<i>Thorius lunaris</i>	CR	LU, NNS
<i>Thorius magnipes</i>	CR	LU, NNS
<i>Thorius maxillabrochus</i>	EN	LU, NNS
<i>Thorius minydemus</i>	EN	LU
<i>Thorius munificus</i>	CR	LU, NNS
<i>Thorius narismagnus</i>	CR	LU
<i>Thorius pennatulus</i>	EN	LU, NNS
<i>Thorius schmidtii</i>	CR	LU, NNS
<i>Thorius spilogaster</i>	CR	LU, NNS
<i>Thorius troglodytes</i>	EN	LU
Cluster AIV VU: 9, EN: 15, CR: 5		
<i>Craugastor vulcani</i>	EN	LU
<i>Eleutherodactylus erendirae</i>	EN	LU
<i>Eleutherodactylus floresvillelai</i>	VU	LU
<i>Eleutherodactylus grunwaldi</i>	EN	LU
<i>Eleutherodactylus jaliscoensis</i>	EN	LU
<i>Eleutherodactylus maurus</i>	VU	LU
<i>Eleutherodactylus nietoi</i>	EN	LU, NNS
<i>Eleutherodactylus rufescens</i>	VU	LU
<i>Eleutherodactylus teretistes</i>	VU	LU
<i>Eleutherodactylus wixarika</i>	EN	LU
<i>Incilius pisinnus</i>	EN	LU, P
<i>Rana chiricahuensis</i>	VU	LU, NNS, P, CC
<i>Rana dunni</i>	EN	LU, P
<i>Rana tarahumarae</i>	VU	LU, NNS, P, CC
<i>Rana tlaloci</i>	CR (PE)	LU, NNS, P

	IUCN Category	Threats
<i>Sarcohyla floresi</i>	VU	LU, NNS
<i>Smilisca dentata</i>	EN	LU, P
<i>Ambystoma altamirani</i>	EN	LU, NNS, P
<i>Ambystoma amblycephalum</i>	CR	LU, NNS, P
<i>Ambystoma andersoni</i>	CR	LU, NNS, P
<i>Ambystoma dumerilii</i>	CR	LU, NNS, P
<i>Ambystoma lermaense</i>	EN	LU, NNS, P
<i>Ambystoma ordinarium</i>	EN	LU, NNS, P
<i>Chiropterotriton orculus</i>	VU	LU, NNS
<i>Isthmura sierraoccidentalis</i>	VU	LU, NNS
<i>Pseudoeurycea altamontana</i>	EN	LU
<i>Pseudoeurycea longicauda</i>	EN	LU, NNS
<i>Pseudoeurycea robertsi</i>	CR	LU, P
<i>Pseudoeurycea tlilicxiti</i>	EN	LU
Cluster AV VU: 10, EN: 9, CR: 5		
<i>Bromeliohyla dendroscarta</i>	EN	LU, NNS
<i>Charadrahyla taeniopus</i>	VU	LU, P
<i>Rana chiricahuensis</i>	VU	LU, NNS, P, CC
<i>Rana johni</i>	VU	LU
<i>Sarcohyla charadricola</i>	CR (PE)	LU
<i>Sarcohyla robertsorum</i>	VU	LU, NNS
<i>Smilisca dentata</i>	EN	LU, P
<i>Tlalocohyla godmani</i>	VU	LU, P, CC
<i>Aquiloerycea galeanae</i>	VU	LU
<i>Chiropterotriton arboreus</i>	CR	LU
<i>Chiropterotriton chico</i>	VU	NNS
<i>Chiropterotriton chiropterus</i>	CR	LU, NNS
<i>Chiropterotriton chondrostega</i>	EN	LU, NNS
<i>Chiropterotriton cieloensis</i>	VU	NNS, CC
<i>Chiropterotriton cracens</i>	VU	NNS, CC
<i>Chiropterotriton dimidiatus</i>	VU	NNS
<i>Chiropterotriton magnipes</i>	EN	LU, NNS
<i>Chiropterotriton miquihuanus</i>	EN	LU, NNS
<i>Chiropterotriton mosaueri</i>	CR	LU
<i>Chiropterotriton multidentatus</i>	EN	LU, NNS
<i>Chiropterotriton terrestris</i>	CR	LU, NNS
<i>Isthmura gigantea</i>	EN	LU, NNS
<i>Notophthalmus meridionalis</i>	EN	LU, NNS, P
<i>Pseudoeurycea altamontana</i>	EN	LU
Guerrero VU: 7, EN: 12, CR: 9		
<i>Craugastor guerreroensis</i>	EN	LU
<i>Craugastor saltator</i>	EN	LU, NNS
<i>Craugastor uno</i>	VU	LU
<i>Charadrahyla pinorum</i>	VU	LU, NNS
<i>Charadrahyla trux</i>	EN	LU, NNS, P
<i>Dryophytes arboricola</i>	VU	LU
<i>Exerodonta melanomma</i>	VU	LU

	IUCN Category	Threats
<i>Incilius cycladen</i>	VU	LU, NNS, P
<i>Incilius gemmifer</i>	EN	LU
<i>Quilticohyla erythromma</i>	VU	LU, NNS
<i>Rana omiltemana</i>	EN	LU, NNS
<i>Sarcohyla chryses</i>	EN	LU, NNS
<i>Sarcohyla floresi</i>	VU	LU, NNS
<i>Sarcohyla mykter</i>	EN	LU, NNS
<i>Sarcohyla thorectes</i>	EN	LU, NNS
<i>Sarcohyla toyota</i>	CR	LU, NNS
<i>Ambystoma altamirani</i>	EN	LU, NNS, P
<i>Isthmura maxima</i>	EN	LU
<i>Pseudoeurycea ahuitzotl</i>	CR	LU, NNS
<i>Pseudoeurycea amuzga</i>	EN	LU, NNS
<i>Pseudoeurycea kuautili</i>	CR	LU
<i>Pseudoeurycea mixcoatl</i>	CR	LU, NNS
<i>Pseudoeurycea tenchalli</i>	CR	LU, NNS
<i>Pseudoeurycea teotepec</i>	CR (PE)	LU, NNS
<i>Pseudoeurycea tlahcuiloh</i>	CR	LU, NNS
<i>Thorius grandis</i>	CR	LU, NNS
<i>Thorius infernalis</i>	CR	LU, NNS
<i>Thorius omiltemi</i>	EN	LU, NNS
Mexico City VU: 1, EN: 4, CR: 2		
<i>Eleutherodactylus grandis</i>	EN	LU, P
<i>Rana tlaloci</i>	CR (PE)	LU, NNS, P
<i>Ambystoma altamirani</i>	EN	LU, NNS, P
<i>Ambystoma mexicanum</i>	CR	LU, NNS, P
<i>Chiropterotriton orculus</i>	VU	LU, NNS
<i>Pseudoeurycea altamontana</i>	EN	LU
<i>Pseudoeurycea tlilicxiti</i>	EN	LU
Oaxaca VU: 15, EN: 36, CR: 28		
<i>Bromeliahyla dendroscarta</i>	EN	LU, NNS
<i>Charadrahyla altipotens</i>	EN	LU
<i>Charadrahyla chaneque</i>	VU	LU, NNS
<i>Charadrahyla esperancensis</i>	VU	LU, NNS
<i>Charadrahyla nephila</i>	EN	LU, NNS
<i>Charadrahyla pinorum</i>	VU	LU, NNS
<i>Charadrahyla sakbah</i>	EN	LU, P
<i>Craugastor spatulatus</i>	EN	LU
<i>Craugastor uno</i>	VU	LU
<i>Duellmanohyla chamulae</i>	EN	LU, NNS
<i>Ecnomiohyla echinata</i>	CR (PE)	LU, NNS
<i>Exerodonta chimalapa</i>	EN	LU
<i>Exerodonta melanomma</i>	VU	LU
<i>Exerodonta xera</i>	VU	LU
<i>Incilius cycladen</i>	VU	LU, NNS, P
<i>Incilius gemmifer</i>	EN	LU
<i>Incilius spiculatus</i>	EN	LU

	IUCN Category	Threats
<i>Incilius tutelarius</i>	VU	LU, NNS, P, CC
<i>Megastomatohyla mixe</i>	CR	LU
<i>Megastomatohyla pellita</i>	CR	LU, NNS
<i>Plectrohyla hartwegi</i>	EN	LU, NNS, P, CC
<i>Ptychohyla zophodes</i>	VU	LU, NNS
<i>Quilticohyla acrochorda</i>	CR	LU, NNS, P
<i>Quilticohyla zoque</i>	EN	LU
<i>Sarcohyla ameibothalame</i>	EN	LU, NNS
<i>Sarcohyla calvicollina</i>	CR (PE)	LU, NNS
<i>Sarcohyla cembra</i>	EN	LU, NNS
<i>Sarcohyla crassa</i>	CR	LU, NNS
<i>Sarcohyla cyanomma</i>	CR (PE)	LU, NNS
<i>Sarcohyla cyclada</i>	VU	LU, NNS
<i>Sarcohyla hazelae</i>	VU	LU, P
<i>Sarcohyla labeculata</i>	EN	LU, NNS
<i>Sarcohyla labedactyla</i>	CR	LU, NNS
<i>Sarcohyla pentheter</i>	VU	LU, NNS
<i>Sarcohyla psarosema</i>	CR (PE)	LU, NNS
<i>Sarcohyla sabrina</i>	CR (PE)	LU, NNS
<i>Sarcohyla siopela</i>	CR (PE)	LU, NNS
<i>Sarcohyla thorectes</i>	EN	LU, NNS
<i>Bolitoglossa alberchi</i>	VU	LU, NNS
<i>Bolitoglossa macrinii</i>	EN	LU
<i>Bolitoglossa oaxacensis</i>	EN	LU
<i>Bolitoglossa riletii</i>	EN	LU
<i>Bolitoglossa veracrucus</i>	EN	LU
<i>Bolitoglossa zapoteca</i>	EN	LU, NNS
<i>Isthmura boneti</i>	EN	LU, NNS
<i>Isthmura maxima</i>	EN	LU
<i>Ixalotriton niger</i>	EN	LU
<i>Ixalotriton parvus</i>	CR	LU
<i>Pseudoeurycea anitae</i>	CR (PE)	LU, NNS
<i>Pseudoeurycea aquatica</i>	CR	LU, NNS
<i>Pseudoeurycea aurantia</i>	CR	LU
<i>Pseudoeurycea cochranae</i>	VU	LU
<i>Pseudoeurycea conanti</i>	EN	LU
<i>Pseudoeurycea juarezi</i>	EN	LU, NNS
<i>Pseudoeurycea mixteca</i>	VU	LU
<i>Pseudoeurycea mystax</i>	EN	LU, NNS
<i>Pseudoeurycea obesa</i>	CR	LU
<i>Pseudoeurycea orchileucos</i>	EN	LU, NNS
<i>Pseudoeurycea papenfussi</i>	EN	LU, NNS, CC
<i>Pseudoeurycea ruficauda</i>	EN	LU
<i>Pseudoeurycea saltator</i>	CR	LU
<i>Pseudoeurycea smithi</i>	CR	LU, NNS
<i>Pseudoeurycea unguidentis</i>	CR (PE)	LU, NNS
<i>Pseudoeurycea werleri</i>	EN	LU

	IUCN Category	Threats
<i>Thorius arboreus</i>	CR	LU, NNS
<i>Thorius aureus</i>	CR	LU, NNS, CC
<i>Thorius boreas</i>	EN	LU, NNS, CC
<i>Thorius insperatus</i>	CR	LU, NNS
<i>Thorius longicaudus</i>	CR (PE)	LU, NNS
<i>Thorius macdougalli</i>	EN	LU, NNS
<i>Thorius maxillabrochus</i>	EN	LU, NNS
<i>Thorius minutissimus</i>	CR	LU, NNS
<i>Thorius narisovalis</i>	EN	LU, NNS
<i>Thorius papaloeae</i>	CR	LU, NNS
<i>Thorius pinicola</i>	EN	LU, NNS
<i>Thorius pulmonaris</i>	CR	LU, NNS
<i>Thorius schmidti</i>	CR	LU, NNS
<i>Thorius smithi</i>	CR	LU, NNS
<i>Thorius tlaxiacus</i>	EN	LU, NNS
Tlaxcala VU: 2, EN: 1, CR: 0		
<i>Sarcophyla robertsorom</i>	VU	LU, NNS
<i>Isthmura gigantea</i>	EN	LU, NNS
<i>Pseudoeurycea gadovii</i>	VU	LU

**Table 4.** A list of reptile species from each cluster that are considered in a threatened category on the IUCN Red List, as well as the primary threats to each species based on the IUCN Red List species accounts (IUCN 2022). IUCN Categories: VU = Vulnerable, EN = Endangered, CR = Critically Endangered (PE = Possibly extinct). Threats: LU = Land use (urbanization, conversion to agriculture, resource extraction, deforestation), NNS = Non-native species and disease, P = Pollution (agricultural, industrial, domestic), CC = Climate change, EXP = Exploitation, PER = Persecution, N/A = No threat listed.

	IUCN Category	Threats
Cluster RI VU: 9, EN: 3, CR: 2		
<i>Anniella geronimensis</i>	EN	LU
<i>Aspidoscelis catalinensis</i>	VU	NNS
<i>Aspidoscelis labialis</i>	VU	LU
<i>Sauromalus hispidus</i>	EN	LU, NNS, CC
<i>Sauromalus klauberi</i>	VU	NNS, CC
<i>Uta encantadae</i>	VU	N/A
<i>Uta lowei</i>	VU	N/A
<i>Uta tumidarostra</i>	VU	N/A
<i>Crotalus catalinensis</i>	CR	LU, NNS, EXP
<i>Caretta caretta</i>	VU	LU, NNS, P, CC
<i>Chelonia mydas</i>	EN	LU, EXP
<i>Dermodochelys coriacea</i>	VU	LU, P, CC, EXP
<i>Eretmodochelys imbricata</i>	CR	LU, P, CC, EXP
<i>Lepidochelys olivacea</i>	VU	LU, P, CC, EXP
Cluster RII VU:10, EN: 6, CR: 3		
<i>Crocodylus acutus</i>	VU	LU, NNS, CC, EXP
<i>Abronia matudai</i>	EN	LU
<i>Anolis barkeri</i>	VU	LU

	IUCN Category	Threats
<i>Anolis hobartsmithi</i>	EN	LU
<i>Anolis pygmaeus</i>	EN	LU
<i>Heloderma alvarezii</i>	VU	LU, CC, PER
<i>Lepidophyma lipetzi</i>	EN	LU
<i>Bothriechis aurifer</i>	VU	LU, EXP
<i>Bothriechis rowleyi</i>	VU	LU, EXP
<i>Cachryx defensor</i>	VU	LU, EXP
<i>Leptophis modestus</i>	VU	LU
<i>Rhadinella posadasi</i>	EN	LU
<i>Caretta caretta</i>	VU	LU, NNS, P, CC
<i>Chelonia mydas</i>	EN	LU, EXP
<i>Chelydra rossignonii</i>	VU	LU, EXP
<i>Dermatochelys mawii</i>	CR	LU, P, EXP
<i>Dermochelys coriacea</i>	VU	LU, P, CC, EXP
<i>Eretmochelys imbricata</i>	CR	LU, P, CC, EXP
<i>Lepidochelys kempii</i>	CR	LU, EXP
Cluster RIII VU: 18, EN: 22, CR: 5		
<i>Abronia chiszari</i>	EN	LU
<i>Abronia graminea</i>	EN	LU, EXP
<i>Abronia taeniata</i>	VU	LU, EXP
<i>Anolis barkeri</i>	VU	LU
<i>Anolis naufragus</i>	VU	LU
<i>Crotaphytus antiquus</i>	EN	LU
<i>Crotaphytus reticulatus</i>	VU	LU, NNS
<i>Gerrhonotus parvus</i>	EN	LU
<i>Lepidophyma gaigeae</i>	VU	N/A
<i>Lepidophyma micropholis</i>	VU	N/A
<i>Ophisaurus ceroni</i>	EN	LU
<i>Sceloporus chaneyi</i>	EN	LU
<i>Sceloporus cyanostictus</i>	EN	LU
<i>Sceloporus exsul</i>	CR	LU
<i>Sceloporus goldmani</i>	EN	LU
<i>Sceloporus maculosus</i>	VU	LU
<i>Sceloporus megalepidurus</i>	VU	LU
<i>Sceloporus oregon</i>	VU	LU
<i>Uma exsul</i>	EN	LU
<i>Xenosaurus grandis</i>	VU	LU
<i>Xenosaurus newmanorum</i>	EN	LU, PER
<i>Xenosaurus platyceps</i>	EN	LU, NNS
<i>Adelophis copei</i>	VU	LU
<i>Chersodromus rubriventris</i>	EN	LU
<i>Ficimia hardyi</i>	EN	LU
<i>Mixcoatlus melanurus</i>	EN	LU, PER
<i>Ophryacus undulatus</i>	VU	LU
<i>Rhadinaea marcellae</i>	EN	LU
<i>Rhadinaea montana</i>	EN	LU
<i>Storeria hidalgoensis</i>	VU	LU



	IUCN Category	Threats
<i>Tantilla shawi</i>	EN	LU
<i>Thamnophis melanogaster</i>	EN	P
<i>Thamnophis mendax</i>	EN	LU
<i>Thamnophis scaliger</i>	VU	LU
<i>Caretta caretta</i>	VU	LU, NNS, P, CC
<i>Chelonia mydas</i>	EN	LU, EXP
<i>Chelydra rossignonii</i>	VU	LU, EXP
<i>Dermatemys mawii</i>	CR	LU, EXP
<i>Dermochelys coriacea</i>	VU	LU, P, CC, EXP
<i>Eretmochelys imbricata</i>	CR	LU, P, CC, EXP
<i>Gopherus flavomarginatus</i>	CR	LU, EXP
<i>Lepidochelys kempii</i>	CR	LU, EXP
<i>Terrapene coahuila</i>	EN	LU
<i>Trachemys gaigeae</i>	VU	LU, P, CC, EXP
<i>Trachemys taylori</i>	EN	LU, NNS
Cluster RIV VU: 19, EN: 9, CR: 3		
<i>Crocodylus acutus</i>	VU	LU, P, CC, EXP
<i>Abronia deppii</i>	EN	LU
<i>Aspidoscelis martyris</i>	VU	N/A
<i>Barisia herrerae</i>	EN	LU, PER
<i>Barisia rudicollis</i>	EN	LU, PER
<i>Ctenosaura clarki</i>	VU	LU
<i>Ctenosaura conspicuosa</i>	VU	NNS, CC
<i>Ctenosaura nolascensis</i>	VU	NNS, CC, EXP
<i>Sauromalus varius</i>	VU	NNS, CC
<i>Sceloporus goldmani</i>	EN	LU
<i>Sceloporus maculosus</i>	VU	LU
<i>Sceloporus megalepidurus</i>	VU	LU
<i>Urosaurus auriculatus</i>	EN	NNS
<i>Urosaurus clarionensis</i>	VU	NNS
<i>Uta palmeri</i>	VU	N/A
<i>Adelophis copei</i>	VU	LU
<i>Crotalus pusillus</i>	EN	LU
<i>Crotalus stejneger</i>	VU	LU
<i>Masticophis thomasi</i>	CR	NNS
<i>Thamnophis melanogaster</i>	EN	P
<i>Thamnophis scaliger</i>	VU	LU
<i>Caretta caretta</i>	VU	LU, NNS, P, CC
<i>Chelonia mydas</i>	EN	LU, EXP
<i>Dermochelys coriacea</i>	VU	LU, P, CC, EXP
<i>Eretmochelys imbricata</i>	CR	LU, P, CC, EXP
<i>Gopherus evgoodei</i>	VU	LU, NNS, CC
<i>Gopherus flavomarginatus</i>	CR	LU, EXP
<i>Lepidochelys olivacea</i>	VU	LU, P, CC, EXP
<i>Terrapene coahuila</i>	EN	LU
<i>Trachemys gaigeae</i>	VU	LU, P, CC, EXP
<i>Trachemys yaquia</i>	VU	LU, P, CC, EXP

	IUCN Category	Threats
Guerrero VU: 6, EN: 4, CR: 1		
<i>Crocodylus acutus</i>	VU	LU, P, CC, EXP
<i>Abronia deppii</i>	EN	LU
<i>Abronia martindelcampoi</i>	EN	LU
<i>Abronia mixteca</i>	VU	LU, EXP, PER
<i>Ctenosaura clarki</i>	VU	LU
<i>Mixcoatlus barbouri</i>	EN	LU
<i>Ophryacus undulatus</i>	VU	LU
<i>Chelonia mydas</i>	EN	LU, EXP
<i>Dermochelys coriacea</i>	VU	LU, P, CC, EXP
<i>Eretmochelys imbricata</i>	CR	LU, P, CC, EXP
<i>Lepidochelys olivacea</i>	VU	LU, P, CC, EXP
Oaxaca VU: 14, EN: 7, CR: 3		
<i>Crocodylus acutus</i>	VU	LU, P, CC, EXP
<i>Abronia fuscolabialis</i>	EN	LU
<i>Abronia graminea</i>	EN	LU, EXP
<i>Abronia juarezi</i>	EN	LU
<i>Abronia mixteca</i>	VU	LU, EXP, PER
<i>Abronia oaxacae</i>	VU	LU
<i>Anolis pygmaeus</i>	EN	LU
<i>Ctenosaura oaxacana</i>	CR	LU, EXP
<i>Heloderma alvarezii</i>	VU	LU, CC, PER
<i>Sceloporus megalepidurus</i>	VU	LU
<i>Xenosaurus grandis</i>	VU	LU
<i>Bothriechis rowleyi</i>		LU, EXP
<i>Exiliboa placata</i>	VU	LU
<i>Micrurus ephippifer</i>	VU	LU
<i>Mixcoatlus melanurus</i>	EN	LU, PER
<i>Ophryacus undulatus</i>	VU	LU
<i>Tantilla flavilineata</i>	EN	LU
<i>Tantalophis discolor</i>	VU	LU
<i>Chelonia mydas</i>	EN	LU, EXP
<i>Chelydra rossignonii</i>	VU	LU, EXP
<i>Dermatemys mawii</i>	CR	LU, P, EXP
<i>Dermochelys coriacea</i>	VU	LU, P, CC, EXP
<i>Eretmochelys imbricata</i>	CR	LU, P, CC, EXP
<i>Lepidochelys olivacea</i>	VU	LU, P, CC, EXP

efforts. Unsurprisingly, the main threat to amphibians in these clusters, and indeed all clusters, is changes in anthropogenic land use, including conversion to agriculture, urbanization, and resource extraction. This result emphasizes the need for conservation and management policies that prevent habitat loss and fragmentation by human activity and that seek to restore lost or degraded habitats. Another common threat in these clusters is the specter of non-native species and diseases, primarily the potential for *Batrachochytrium dendrobatidis* and *B. salamandrivorans* to cause amphibian declines. In addition, introduction of non-native species appears to affect some species. The monitoring of

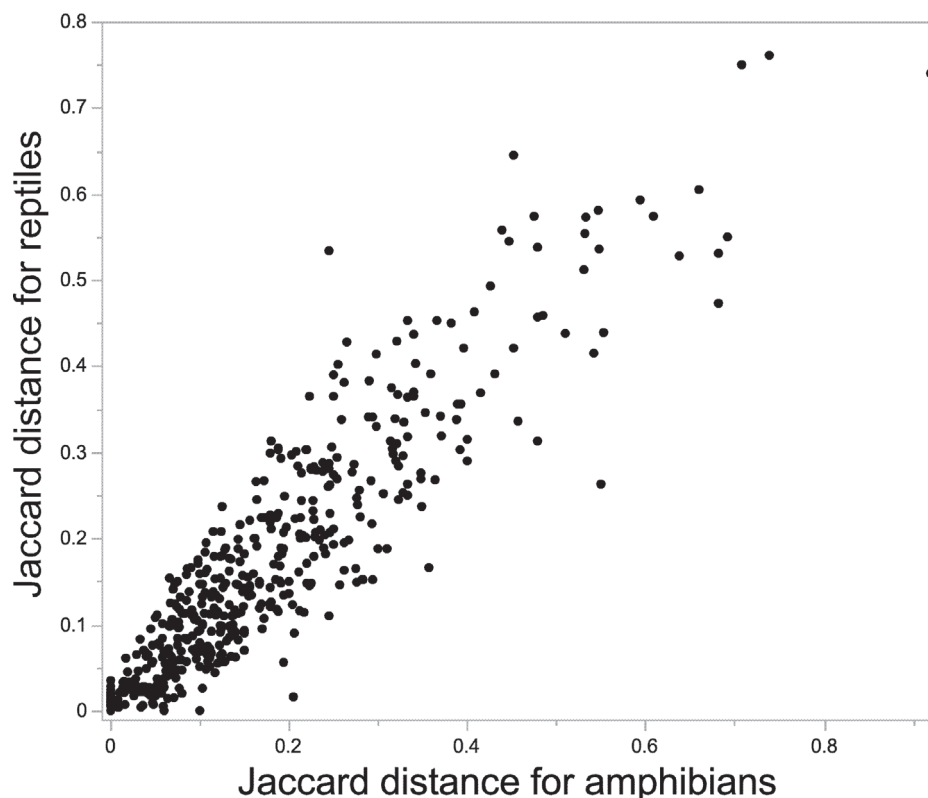
emerging diseases and policies to prevent the spread or introduction of non-native species, especially fish, should be pursued. Finally, climate change is listed as a threat to species in these clusters. The increased frequency of drought is of particular concern for many of the amphibian species in these clusters. Efforts to ensure water flow or sufficient aquatic habitats for amphibians are needed. Pollution, ranging from agricultural run-off, industrial contamination, mine or drilling waste, and domestic waste, is also another key threat for several species. Policies should be considered that minimize the input of pollutants into the aquatic or terrestrial habitats of amphibians.

For reptiles, cluster RIII has the highest number of threatened species, followed by cluster RIV and Oaxaca. As with amphibians, anthropogenic land use change in its many forms is ubiquitous as a threat to reptiles in each cluster. Again, efforts to minimize habitat loss and fragmentation are desperately needed, as are efforts to restore or reclaim habitats. For many species of reptiles, harvesting for the pet trade or for food, as well as persecution by humans, is another major threat. Establishment and enforcement of laws regulating the harvesting or killing of reptiles should be considered. In addition, education of local residents about the value and harmlessness of many of the persecuted species of reptiles could help to reduce persecution. Climate change, particularly through its effects on changing or shifting habitats, is also a potential threat to several species of reptiles, as is pollution. In addition, introduced species (e.g., rats, cats, and dogs) are important threats to island species in cluster RI.

When we consider the clusters of states that have high numbers of threatened amphibians and reptiles it is interesting to note that the states included in those clusters do not greatly overlap. For amphibians, the clusters with high numbers of threatened species are in southern Mexico whereas those for reptiles are in northern Mexico. However, Oaxaca has a high number of threatened species of both amphibians and reptiles, suggesting it needs to be a high priority of conservation efforts (see also Mata-Silva et al. 2015, 2021). The difference in the apparent distribution of high numbers of threatened species of amphibians and reptiles, as well as the secondary threats for each group (i.e., beyond anthropogenic land use change), suggested that each taxonomic group may need to be considered separately rather than as a single herpetofauna as conservation efforts are prioritized.

## Similarities

The Jaccard distances of amphibians and reptiles were highly, positively correlated (Fig. 3;  $n = 32$ , Spearman's  $\rho = 0.90$ ,  $P < 0.0001$ ). Amphibian Jaccard distances were positively correlated with the physiographic province Jaccard distance (Fig. 4A;  $n = 32$ , Spearman's  $\rho = 0.684$ ,  $P < 0.0001$ ) and shared border length (Fig. 4B;  $n = 32$ , Spearman's  $\rho = 0.498$ ,  $P < 0.0001$ ), and negatively correlated with the distance between centroids (Fig. 4C;  $n = 32$ , Spearman's  $\rho = -0.716$ ,  $P < 0.0001$ ). Reptile Jaccard distances were positively correlated with physiographic province Jaccard distances (Fig. 4D;  $n = 32$ , Spearman's  $\rho = 0.76$ ,  $P < 0.0001$ ) and shared border length (Fig. 4E;  $n = 32$ , Spearman's  $\rho = 0.536$ ,  $P < 0.0001$ ), and negatively correlated with distance between centroids (Fig. 4F;  $n = 32$ , Spearman's  $\rho = -0.779$ ,  $P < 0.0001$ ). The length of the shared border and the Jaccard distance for physiographic provinces were

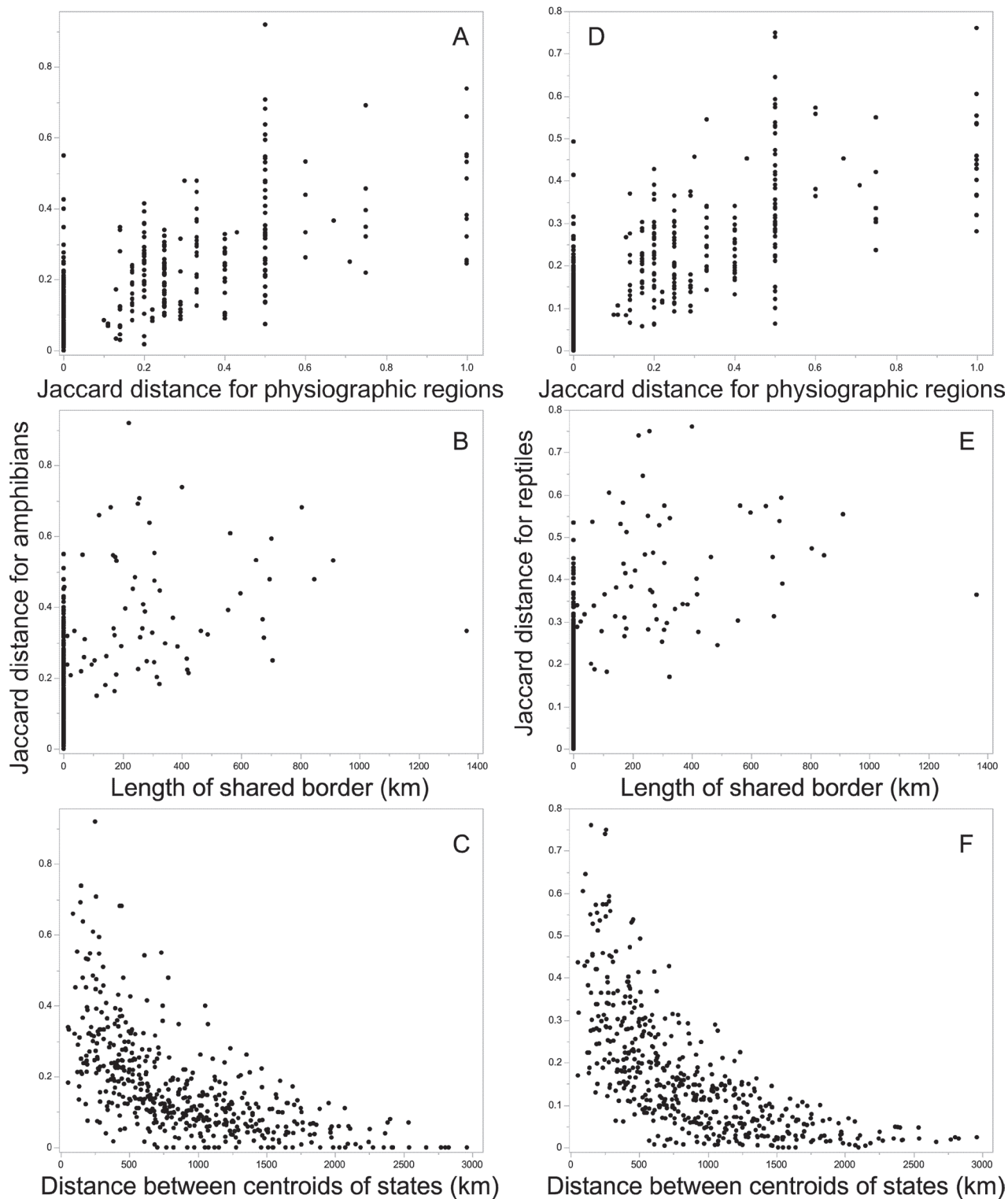


**Figure 3.** The correlation between the Jaccard distance of amphibians and reptiles among all pairs of Mexican states.

positively correlated (Fig. 5A;  $n = 32$ , Spearman's  $\rho = 0.543$ ,  $P < 0.0001$ ). The distance between centroids and the Jaccard distance for physiographic regions were negatively correlated (Fig. 5B;  $n = 32$ , Spearman's  $\rho = -0.778$ ,  $P < 0.0001$ ).

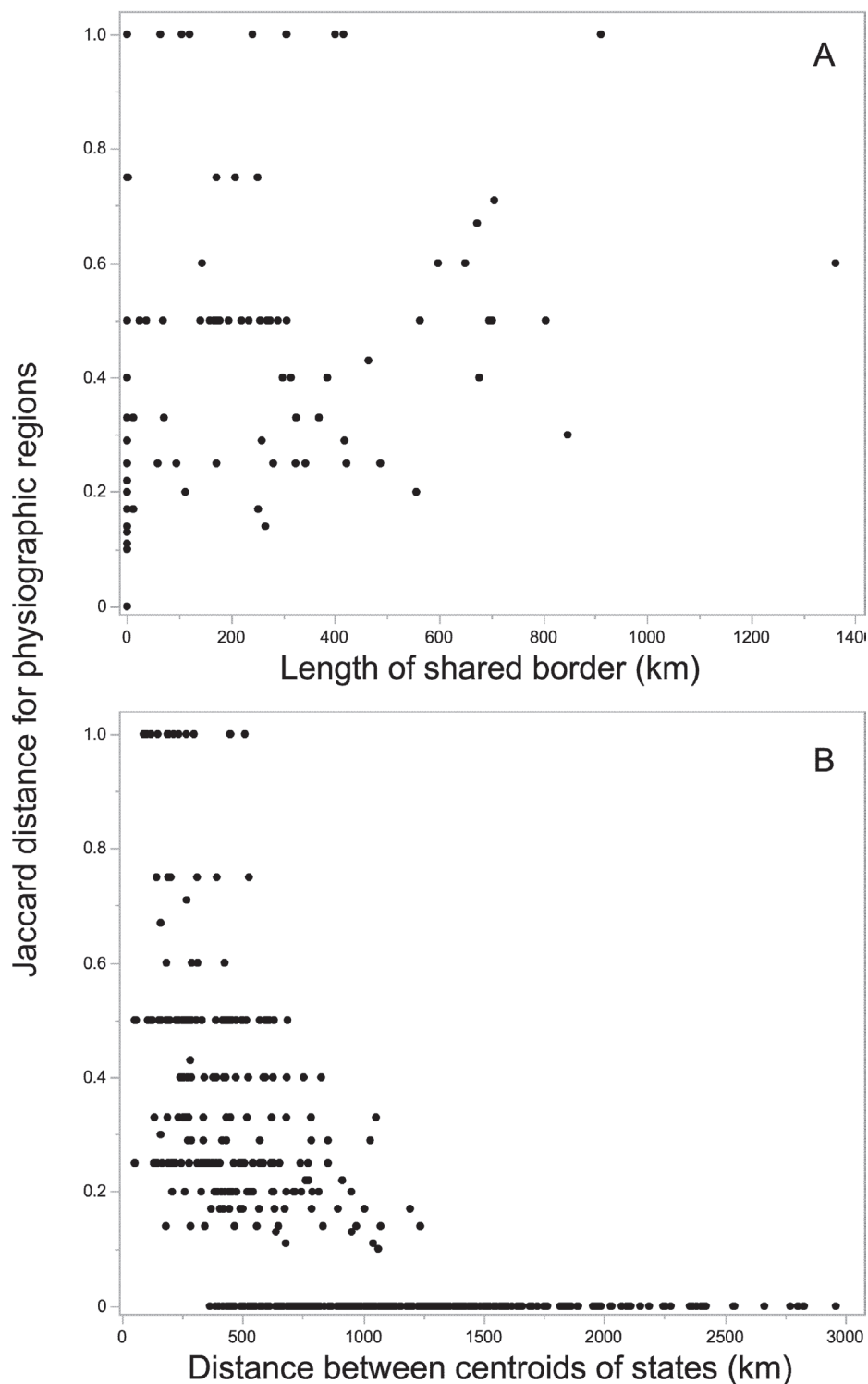
Taken together, our results suggest that many of the similarities and differences in the herpetofauna among Mexican states is a consequence of their proximity, at least in terms of the distance between the states. Such correlations are likely the result of such proximity on the similarity of physiographic provinces (i.e., habitats and ecosystems) of these states. These results are consistent with previous studies on similarities among communities or states of other taxa in Mexico and other geographic areas. For example, similarity of state-level floras and faunas typically decreases with the geographic distance between states (e.g., Qian and Ricklefs 2006). In addition, beta diversity of European reptiles increases with geographic distance between communities (Keil et al. 2012). In Mexico, similarity of flora among states is explained in good part by the proximity of the states, with neighboring states often sharing endemics and other species (Delgadillo et al. 2003).

The positive correlation between shared border length and Jaccard distances for reptiles, amphibians, and physiographic provinces deserves exploration. This result is, on the surface, counterintuitive: states that share a longer border would be expected to share more species or physiographic provinces (i.e., a negative correlation between Jaccard distances and shared border lengths). However, we used a shared border metric that is the absolute length of a shared border. Thus, a low value for shared border length could indicate a variety of things. First, a value of zero for shared border length clearly indi-



**Figure 4.** The relationships between Jaccard distances for physiographic regions, length of shared border, and distance between centroids of all pairs of Mexican states and the Jaccard distances of amphibians (A, B, C respectively) and reptiles (D, E, F respectively).

cates the states do not touch at all. Second, two small states that share much of their border would still have a relatively low value for shared border length (e.g., Mexico City, México, and Morelos; Aguascalientes and Zacatecas). Third, two states may be very close geographically but have either no shared border



**Figure 5.** The relationship of length of shared border and distance between centroids with the Jaccard distance of physiographic provinces among all pairs of Mexican states.

(e.g., Tlaxcala and Mexico City, Chiapas and Campeche) or a very short, shared border (e.g., Baja California and Baja California Sur, Zacatecas and Nayarit, Nayarit and Sinaloa). It may be more useful to look more carefully at Figs 4B and 4E. Visually, it looks as if there is only a weak correlation between the absolute length of a shared border and Jaccard distance. Thus, when considering

states that should work together for conservation, focus should be on other aspects, such as shared physiographic provinces or species rather than simply a shared border.

## Conclusions

Political borders can have significant effects on the abundance and diversity of populations and communities due to differing policies across the border (e.g., Shanas et al. 2006; Opermanis et al. 2012). It therefore should be a priority for states sharing species to work together for conservation rather than each state working in isolation (see also Dertien et al. 2020). Our results hopefully suggest clusters of states that would do well to work together to coordinate the conservation and management of their herpetofaunas (i.e., states in the same clusters or subclusters; see Fig. 2). This is especially true given the nature of the major threats to the Mexican herpetofauna are the type of threats that span across potential borders and would benefit from concerted efforts and elevated communication, including loss of habitats, pollution, harvesting and pet trade, invasive species, and climate change (Suazo-Ortuño et al. 2023).

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## Additional information

### Conflict of interest

The authors have declared that no competing interests exist.

### Ethical statement

No ethical statement was reported.

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### Author contributions

Conceptualization: GRS, JLE. Data curation: GRS, JLE. Formal analysis: JLE, GRS. Funding acquisition: GRS.

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## Data availability

All of the data that support the findings of this study are available in the main text.

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