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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 linkages 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 ρ 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); Montaño-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 AII and AIII and Oaxaca had particularly high numbers of threatened species and should be the focus of targeted conservation

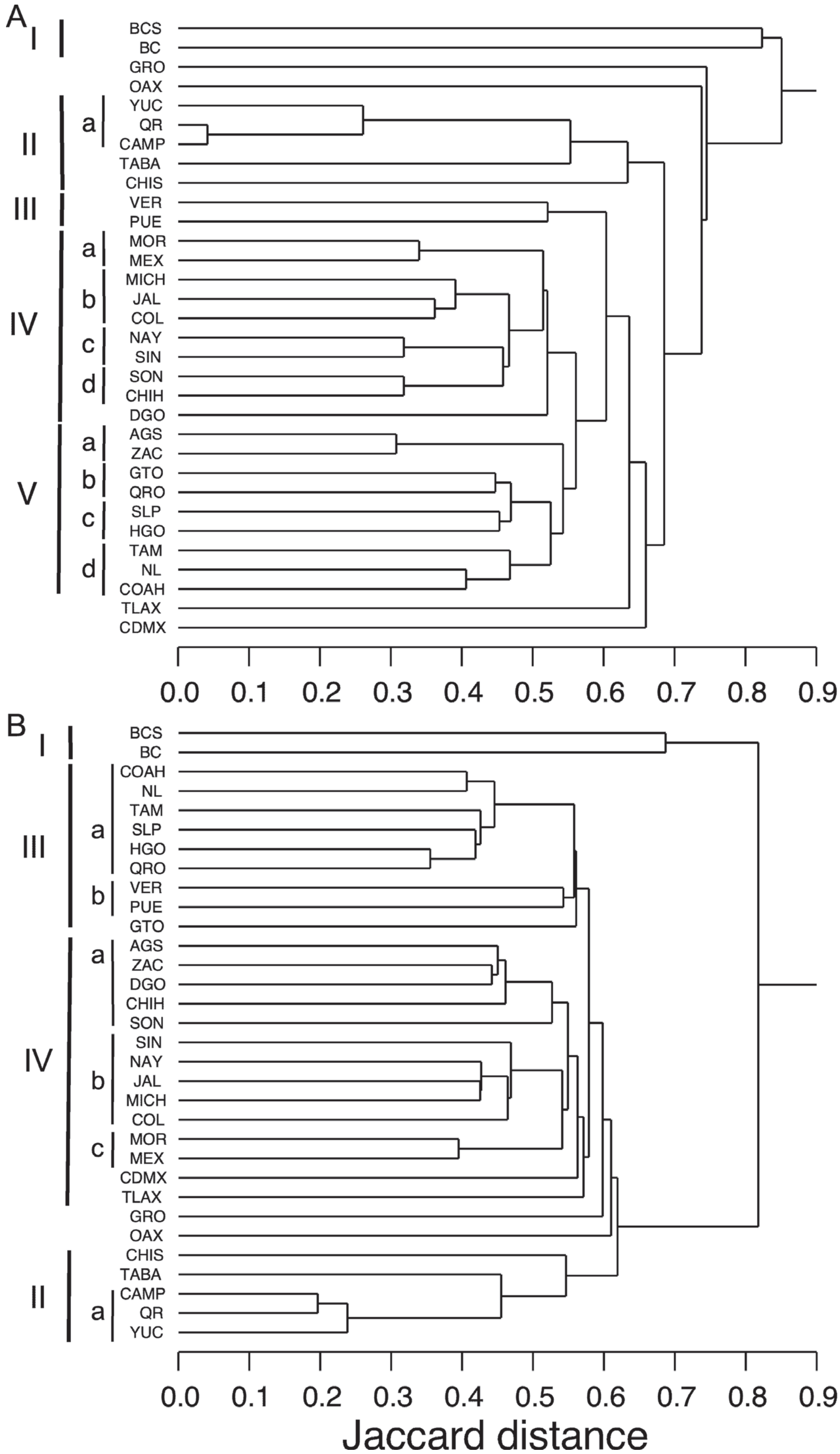

Figure 1. Cluster trees for A) amphibians and B) reptiles arising from a cluster analysis of the herpetofaunas of Mexican states. Main clusters are identified with Roman numerals and subclusters within clusters are identified with lower case letters. AGS = Aguascalientes, BC = Baja California, BCS = 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.

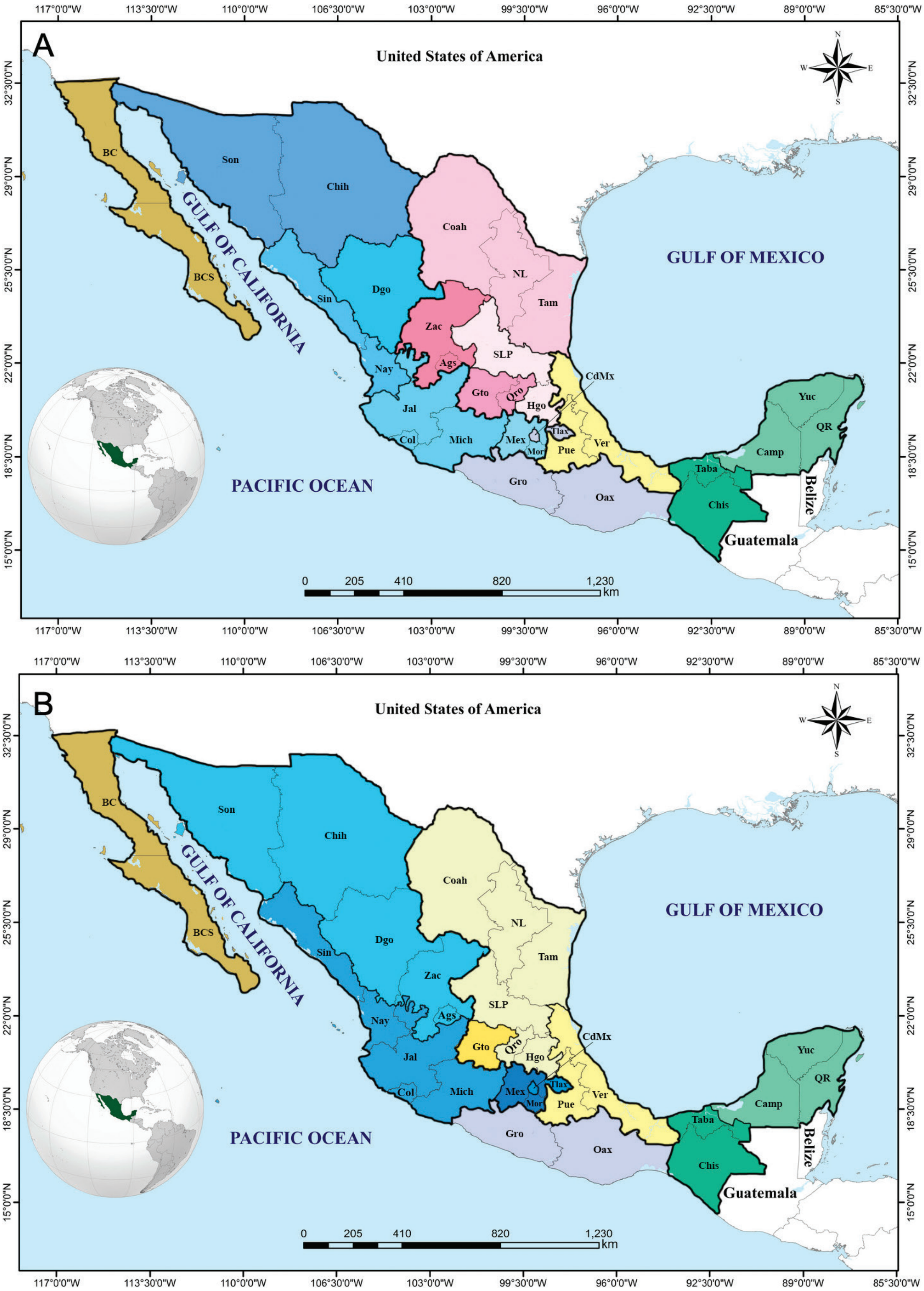

Figure 2. A map of Mexico showing the locations of the clusters of **A** amphibians and **B** reptiles identified by the cluster analyses found in Fig. 1. Different clusters are identified by color and surrounded by a thick border and subclusters within clusters are represented by different shades of 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		
Anaxyrus californicus	EN	LU, NNS, CC
Cluster AII VU: 21, EN: 21, CR: 5		
Charadrahyla chaneque	VU	LU, NNS
Craugastor amniscola	VU	LU, NNS, P
Craugastor brocchi	VU	LU, NNS, P, CC
Craugastor glaucus	EN	LU, NNS
Craugastor greggi	EN	LU, NNS, P, CC
Craugastor matudai	EN	LU, NNS, P, CC
Craugastor montanus	EN	LU
Craugastor palenque	VU	LU, NNS, P, CC
Craugastor pelorus	VU	LU
Craugastor pozo	CR	LU
Craugastor stuarti	VU	LU, NNS, P
Craugastor taylori	CR	LU
Dryophytes walkeri	VU	LU, NNS, CC
Duellmanohyla chamulae	EN	LU, NNS
Exerodonta bivocata	EN	LU
Exerodonta chimalapa	EN	LU
Incilius aurarius	EN	LU, CC
Incilius tacanensis	EN	LU, NNS, CC
Incilius tutelarius	VU	LU, NNS, P, CC
Plectrohyla acanthodes	EN	LU, NNS, P, CC
Plectrohyla avia	EN	LU, NNS, P, CC
Plectrohyla hartwegi	EN	LU, NNS, P, CC
Plectrohyla ixil	VU	LU, NNS, P, CC
Plectrohyla lacertosa	EN	LU, NNS
Plectrohyla pycnochila	CR (PE)	LU, NNS
Plectrohyla sagorum	VU	LU, NNS, P
Ptychohyla macrotympanum	VU	LU, NNS
Quilticohyla zoque	EN	LU
Rana macroglossa	VU	LU, P, CC
Bolitoglossa alberchi	VU	LU, NNS
Bolitoglossa engelhardti	EN	LU, NNS, P, CC
Bolitoglossa flavimembris	EN	LU, NNS, P, CC
Bolitoglossa flaviventris	EN	LU, NNS, P
Bolitoglossa franklini	VU	LU, NNS, P, CC
Bolitoglossa hartwegi	VU	LU, NNS
Bolitoglossa mulleri	VU	LU, NNS, P
Bolitoglossa stuarti	VU	LU, NNS, P

	IUCN Category	Threats
Bolitoglossa veracrucis	EN	LU
Bradytriton silus	EN	LU, NNS, P, CC
Cryptotriton alvarezdeltoroi	EN	LU, NNS
Dendrotriton megarhinus	VU	NNS, CC
Dendrotriton xolocalcae	VU	NNS, CC
Ixalotriton niger	EN	LU
Nyctanolis pernix	VU	LU, NNS, P, CC
Pseudoeurycea brunnata	CR	LU, NNS, CC
Pseudacris goebeli	CR	LU, NNS, CC
Pseudoeurycea rex	VU	LU, NNC, CC
Cluster AIII VU: 13, EN: 28, CR: 26		
Bromeliohyla dendroscarta	EN	LU, NNS
Charadrahyla nephila	EN	LU, NNS
Charadrahyla taeniopus	VU	LU, P
Craugastor galacticorhinus	EN	LU
Craugastor megalotympanum	EN	LU
Craugastor spatulatus	EN	LU
Craugastor vulcani	EN	LU
Duellmanohyla chamulae	EN	LU, NNS
Ecnomiohyla valancifer	CR	LU
Exerodonta bivocata	EN	LU
Exerodonta xera	VU	LU
Incilius cavifrons	EN	LU
Incilius cristatus	EN	LU, P
Megastomatohyla mixomaculata	EN	LU
Megastomatohyla nubicola	CR	LU
Ptychohyla zophodes	VU	LU, NNS
Quilticohyla zoque	EN	LU
Rana chichicuahutla	CR	LU, NNS
Rana chiricahuensis	VU	LU, NNS, P, CC
Rana johni	VU	LU
Rana pueblae	CR (PE)	LU
Sarcohyla charadricola	CR (PE)	LU
Sarcohyla pachyderma	CR (PE)	LU, NNS
Sarcohyla robertsorum	VU	LU, NNS
Sarcohyla siopela	CR (PE)	LU, NNS
Tlalocohyla godmani	VU	LU, P, CC
Ambystoma altamirani	EN	LU, NNS, P
Aquiloeurycea cafetalera	VU	LU, NNS, P
Aquiloeurycea praecellens	CR (PE)	LU
Aquiloeurycea quetzalanensis	CR	LU
Bolitoglossa alberchi	VU	LU, NNS
Bolitoglossa veracrucus	EN	LU
Chiropterotriton arboreus	CR	LU
Chiropterotriton aureus	CR	LU, NNS
Chiropterotriton casasi	CR (PE)	LU, NNS
Chiropterotriton chiropterus	CR	LU, NNS

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

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

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

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

	IUCN Category	Threats
Thorius arboreus	CR	LU, NNS
Thorius aureus	CR	LU, NNS, CC
Thorius boreas	EN	LU, NNS, CC
Thorius insperatus	CR	LU, NNS
Thorius longicaudus	CR (PE)	LU, NNS
Thorius macdougalli	EN	LU, NNS
Thorius maxillabrochus	EN	LU, NNS
Thorius minutissimus	CR	LU, NNS
Thorius narisovalis	EN	LU, NNS
Thorius papaloae	CR	LU, NNS
Thorius pinicola	EN	LU, NNS
Thorius pulmonaris	CR	LU, NNS
Thorius schmidti	CR	LU, NNS
Thorius smithi	CR	LU, NNS
Thorius tlaxiacus	EN	LU, NNS
Tlaxcala VU: 2, EN: 1, CR: 0		
Sarcohyla robertsorum	VU	LU, NNS
Isthmura gigantea	EN	LU, NNS
Pseudoeurycea gadovii	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		
Anniella geronimensis	EN	LU
Aspidoscelis catalinensis	VU	NNS
Aspidoscelis labialis	VU	LU
Sauromalus hispidus	EN	LU, NNS, CC
Sauromalus klauberi	VU	NNS, CC
Uta encantadae	VU	N/A
Uta lowei	VU	N/A
Uta tumidarostra	VU	N/A
Crotalus catalinensis	CR	LU, NNS, EXP
Caretta caretta	VU	LU, NNS, P, CC
Chelonia mydas	EN	LU, EXP
Dermochelys coriacea	VU	LU, P, CC, EXP
Eretmochelys imbricata	CR	LU, P, CC, EXP
Lepidochelys olivacea	VU	LU, P, CC, EXP
Cluster RII VU:10, EN: 6, CR: 3		
Crocodylus acutus	VU	LU, NNS, CC, EXP
Abronia matudai	EN	LU
Anolis barkeri	VU	LU

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

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

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

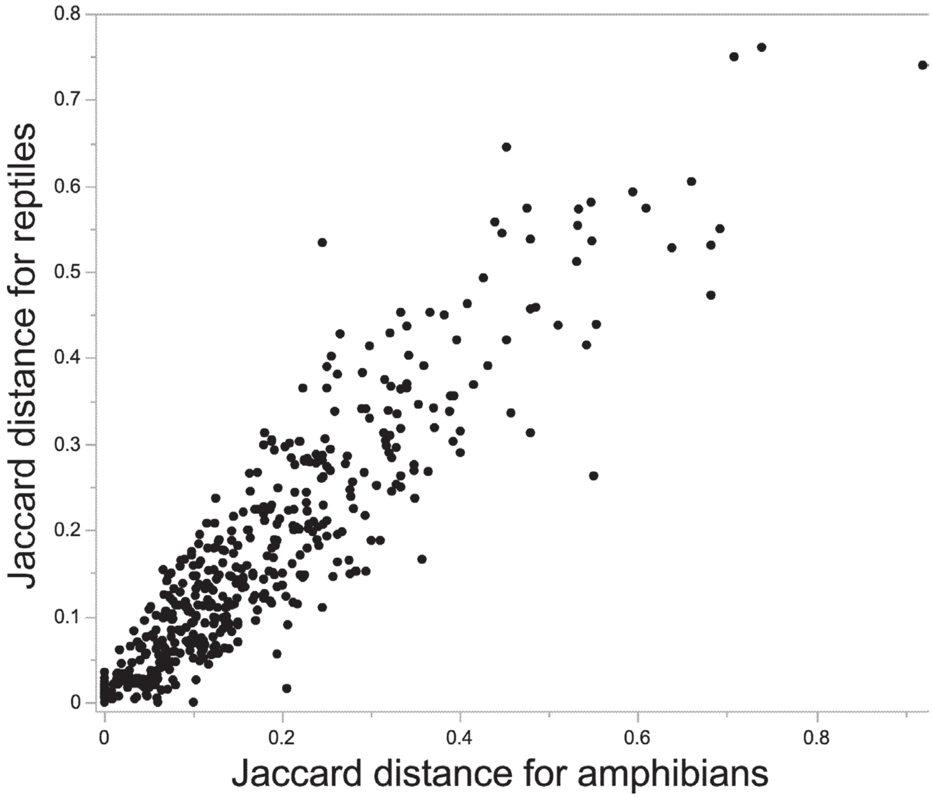

Figure 3. The correlation between the Jaccard distance of amphibians and reptiles among all pairs of Mexican states.

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-

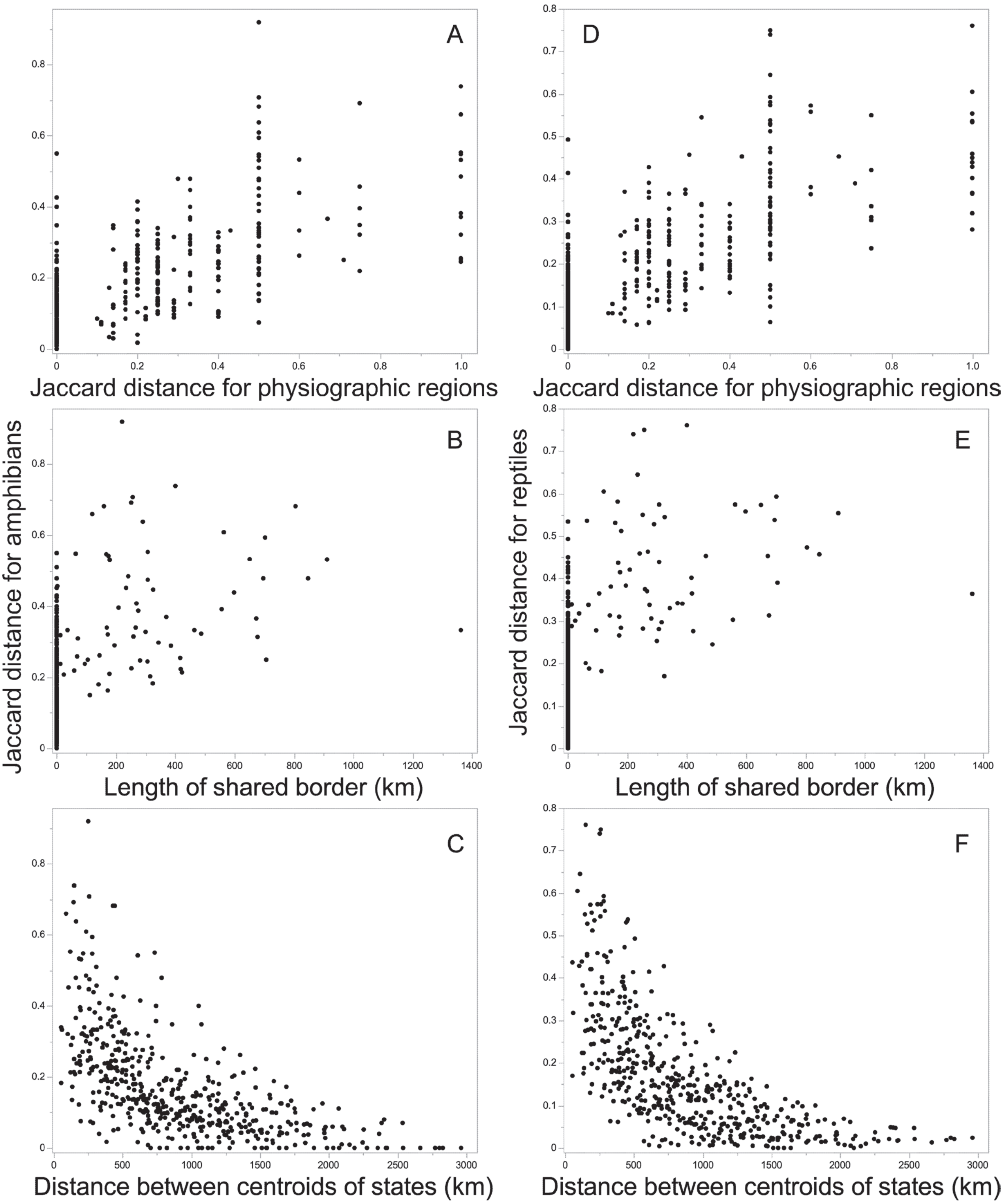

Figure 4. The relationships between Jaccard distances for physiographic regions, length of shared border, and distance between centroids of all pairs of Mexican states and the Jaccard distances of amphibians (**A, B, C** respectively) and reptiles (**D, E, F** respectively).

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

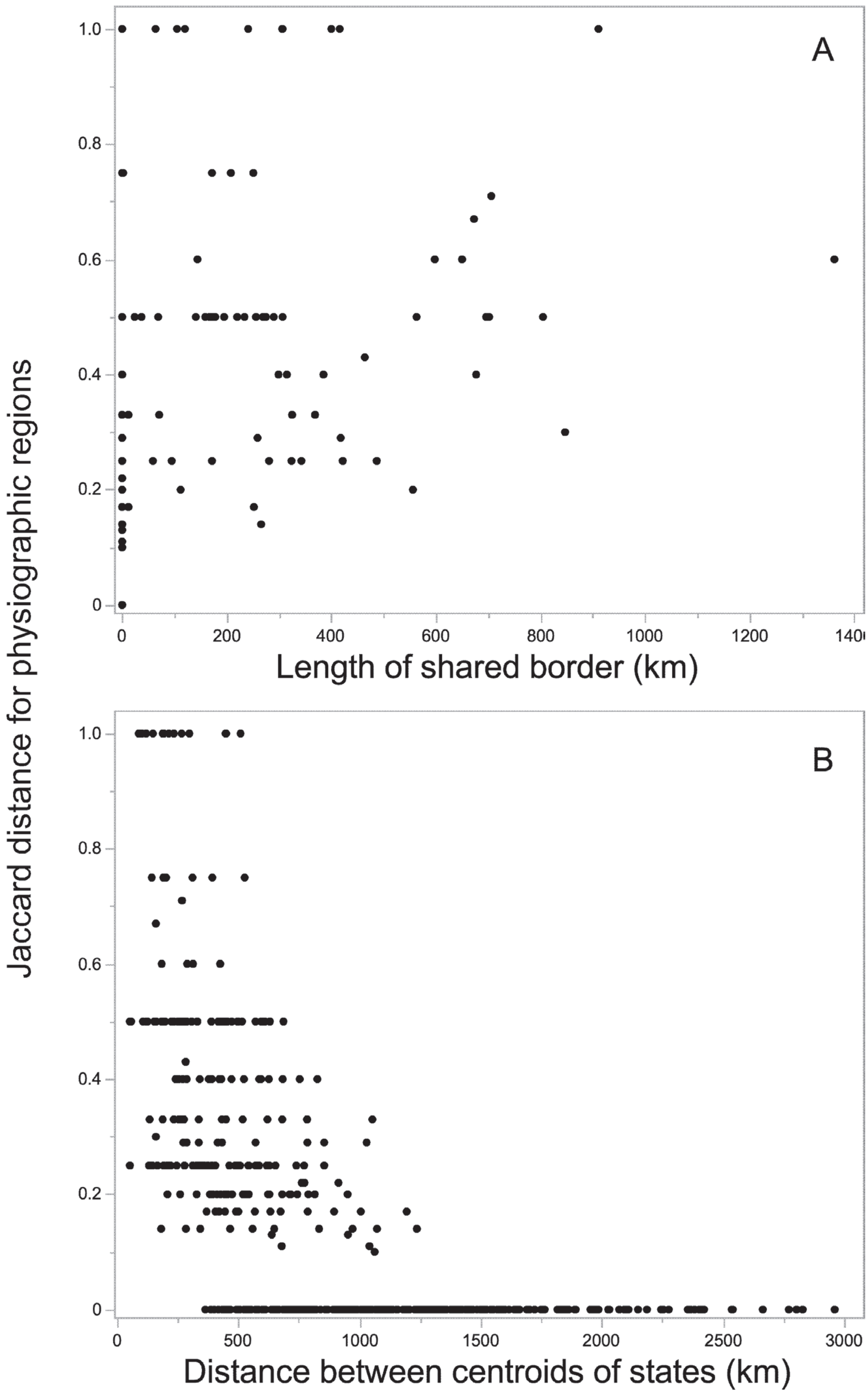

Figure 5. The relationship of length of shared border and distance between centroids with the Jaccard distance of physiographic provinces among all pairs of Mexican states.

(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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