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Recognizing chorotypes for terrestrial Mexican mammals: contrasting datasets and units of analysis, and ecological implications

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Chorotypes are groups of species that share a similar distribution within a study area. Their identification depends on the geographic units and the taxa analyzed. For the terrestrial Mexican mammals, identification of chorotypes has not been explored yet. Our objectives are (1) to identify chorotypes for the species of terrestrial Mexican mammals using two different datasets (Map of Life [MOL] and International Union for Conservation of Nature [IUCN]), (2) to compare the results using biogeographic provinces, and (3) to discuss the relevance of the chorotypes for ecological regionalization. More than 400 species of mammals were used to identify 33 chorotypes in four different analyses: MOL and IUCN with the whole Chihuahuan province, and MOL and IUCN splitting it into Northern and Southern Chihuahuan. For the 33 chorotypes, one was recovered in all analyses, one was shared by three analyses, seven were shared by two, and 24 were unique for one. We demonstrate the importance of the use of different datasets of geographic distribution of mammals, as well as pre-defined units of analyses, and their influence on the results of a chorotype analysis. Most of the chorotypes identified the mixture of Nearctic and Neotropical biotas in the Mexican territory, but more interestingly, the affinity of ecological patterns of lowland and highland areas.

Keywords: affinity, biogeography, pattern, process, regionalization.

Los corotipos son grupos de especies que comparten una distribución similar dentro de un área de estudio. La identificación de estos depende de las unidades geográficas y los taxones analizados. Para los mamíferos terrestres mexicanos aún no se ha explorado la identificación de corotipos. Nuestros objetivos son: (1) identificar corotipos para las especies de mamíferos terrestres mexicanos empleando dos conjuntos de datos diferentes (Map of Life [MOL] e International Union for Conservation of Nature [IUCN]), (2) comparar los resultados utilizando provincias biogeográficas, y (3) analizar la relevancia de los corotipos para la regionalización ecológica. Para ello, se utilizaron más de 400 especies de mamíferos para identificar 33 corotipos en cuatro análisis diferentes: MOL y IUCN con la provincia Chihuahuense completa, y MOL y IUCN separando el Norte y Sur de la misma. De los 33 corotipos, uno se recuperó en todos los análisis, uno estuvo compartido por tres análisis, siete de ellos por dos y 24 resultaron únicos para uno. Demostramos la importancia del uso de diferentes conjuntos de datos de distribución geográfica de mamíferos, así como de unidades de análisis predefinidas, y su influencia en los resultados de un análisis de corotipos. La mayoría de los corotipos identificaron la mezcla de biotas neárticas y neotropicales en el territorio mexicano, pero lo más interesante fue la afinidad de los patrones ecológicos de áreas de tierras bajas y altas.

Palabras clave: afinidad, biogeografía, patrón, proceso, regionalización.

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The term "chorotype" has a complex history (see Morrone 2014; Fattorini 2015; 2016; Passalacqua 2015). Fattorini (2015) clarified it, distinguishing between global and regional chorotypes. Global chorotypes correspond to "groups into which species with similar overall ranges can be classified" (Fattorini 2015, p. 2249), whereas regional chorotypes are "groups of species that have a similar distribution within a certain study area" (Fattorini 2015, p. 2250). Interestingly, Fattorini (2015) assimilated the former to "biotas" (taxa inhabiting a particular area) and the latter to "cenocrons" (sets of taxa that share the same biogeographic history, constituting identifiable subsets that dispersed in a given time frame and assembled to a biota) (Morrone 2009; 2014). The quantitative identification of chorotypes was proposed by Baroni-Urbani *et al.* (1978) as a biogeographic pattern of two or more species occupying a similar distributional area. For a brief discussion of Baroni-Urbani *et al.* (1978) algorithm, see Real *et al.* (1992) and Escalante *et al.* (2024).

Distributional patterns are fundamental to propose biogeographic regionalizations of the Earth, but they are dependent on the taxa analyzed, the data and the geographic context. Additionally, it has been found that ecological and biogeographical regions might not always match (Crisci *et al.* 2006). Recently, Zhang *et al.* (2025) suggested that the identification of chorotypes may help refine biogeographic regionalizations, especially for exploring transition zones.

The use of different geographic units and data sources has been briefly explored for chorotypes. Since their formulation, chorotypes have been identified using artificial units as grid-cells of a particular size (*v. gr.* 1 x 1° latitude-longitude), however, the use of natural units, as biogeographic provinces, could be preferable. Natural units may adjust better to the typical irregular form of the distributional areas, due to ecological and evolutionary barriers. Moreover, many databases of biodiversity try to recover the geographic distribution areas of the species in polygons that could be useful to identify biogeographic patterns. For mammals, which are one of the taxa with more data (Troudet *et al.* 2017) and public databases available (*v. gr.* Wilson and Reeder 2005; International Union for Conservation of Nature (IUCN) 2025; Map of Life [MOL] 2025; Global Biodiversity Information Facility [GBIF.org] 2026; iNaturalist 2026; Mammal Diversity Database 2026), many sources could be used to identify chorotypes (or other distributional patterns). Few analyses assess how different datasets for the same taxon affect the identification of their distributional patterns. Due to taxonomic updates or the use of different taxonomic and nomenclatural authorities based on different species concepts, the current datasets available may influence the chorotype results.

In the case of Mexico, chorotypes have been identified for 264 bird species of the Sierra Madre Oriental (Ferro *et al.* 2017) and for endemic taxa of the Transmexican Volcanic Belt (25 species of amphibians, 89 of insects, 15 mammals, one bird and 37 plants) (Escalante *et al.* 2024). Although there have been many attempts to identify distributional patterns of the terrestrial Mexican mammalian fauna, using numerical methods (Ramírez-Pulido and Castro-Campillo 1990), based on endemism (Escalante *et al.* 2007a; 2009), and diversity (Arita and León-Paniagua 1993; Rodríguez and Arita 2004), there are no analyses identifying chorotypes. For Mexico, some regionalizations have been proposed based on mammals (Ramírez-Pulido and Castro-Campillo 1990; Escalante *et al.* 2013), and they are dependent on the taxa analyzed, the data and the geographic context. For these reasons, our objectives are 1) to identify chorotypes for the species of Mexican mammals using two datasets, Map of Life (MOL 2025) and the IUCN Red List (IUCN 2025); 2) to compare the results using the Mexican biogeographic provinces; and 3) to discuss their implications for ecological distributional patterns.

Material and methods

We followed Fattorini (2015) to identify regional chorotypes. We divided the study area into geographical units and considered the species distributed within each unit; those that were grouped according to their distribution within a unit were considered a chorotype.

To compare two different data sources of mammalian species distributions, we obtained geographical distribution range areas from Map of Life (hereafter MOL; Map of Life 2025; https://mol.org/) and the IUCN Red List (hereafter IUCN; IUCN 2025; https://www.iucnredlist.org/), both in shapefile format. There are 772 mammal species registered in the geopolitical boundaries of Mexico in the MOL database, whereas 663 species are registered for the country in the IUCN database (a difference of 109 species). As both databases possibly overestimate the number of Mexican species (around 600 species according to the taxonomic list of Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO); Reséndiz-López 2025), we selected the MOL and IUCN species names following an updated list provided by García-Trujano and collaborators. Therefore, our final species lists have 487 species in MOL and only 416 species in IUCN, excluding the marine mammal species and species with uncertain taxonomy.

Polygons in shapefile format of distribution ranges for the selected species of both databases were intersected in QGIS 3.34 (QGIS Development Team 2023) with the complete boundaries of the 14 biogeographic provinces shapefiles of Mexico (Morrone *et al.* 2017; Escalante *et al.* 2025; https://americas.atlasbiogeografico.com/). The Chihuahuan province has the biggest surface of all provinces, and some authors have recognized at least two provinces or areas of endemism for mammals (Ramírez-Pulido and Castro-Campillo 1990; Escalante *et al.* 2003; 2007b) and other species (Morrone *et al.* 2022a). Thus, we decided to test the Chihuahuan province as a natural unit, dividing it into two sub-units, provisionally named Northern and Southern Chihuahuan. The limits used for this division correspond to Ramírez-Pulido and Castro-Campillo (1990) and applied with a shapefile provided by Reaño-Jiménez (pers. comm.). Therefore, two more intersections were carried out considering 15 provinces. All geographic analyses were done in QGIS 3.34.

For each of the four geographical intersections, we built a presence-absence matrix for all species, where a species' presence in each province was coded as '1' and its absence as '0'. Therefore, four matrices were analyzed and named: MOL - Chihuahuan, MOL - N & S Chihuahuan, IUCN – Chihuahuan, and IUCN - N & S Chihuahuan.

To identify the chorotypes, we used the RMACOQUI package for R software (Olivero *et al.* 2011; R Core Team 2023), which classifies distributional areas using Baroni-Urbani and Buser's (1976) index. The index provides a table of critical values which are used to perform exact randomization tests comparing the observed similarity values with all possible outcomes to detect significant similarities (Olivero *et al.* 2011). Then, a dendrogram was built with the agglomerative unweighted pair-group method using arithmetic averages (UPGMA) and branches that exhibited significant positive within-branch shared distributions and significantly disjunct from adjoining branches were identified. An index of internal homogeneity (IH) and distinctness was derived considering pairwise comparisons of the proportion of significant similarity and significant dissimilarity in every branch. A given branch was considered a chorotype if IH = 1 or positive, higher than subsequent nested clusters and statistically significant. Significance was evaluated comparing the frequency of significant similarities within a tested cluster and the most

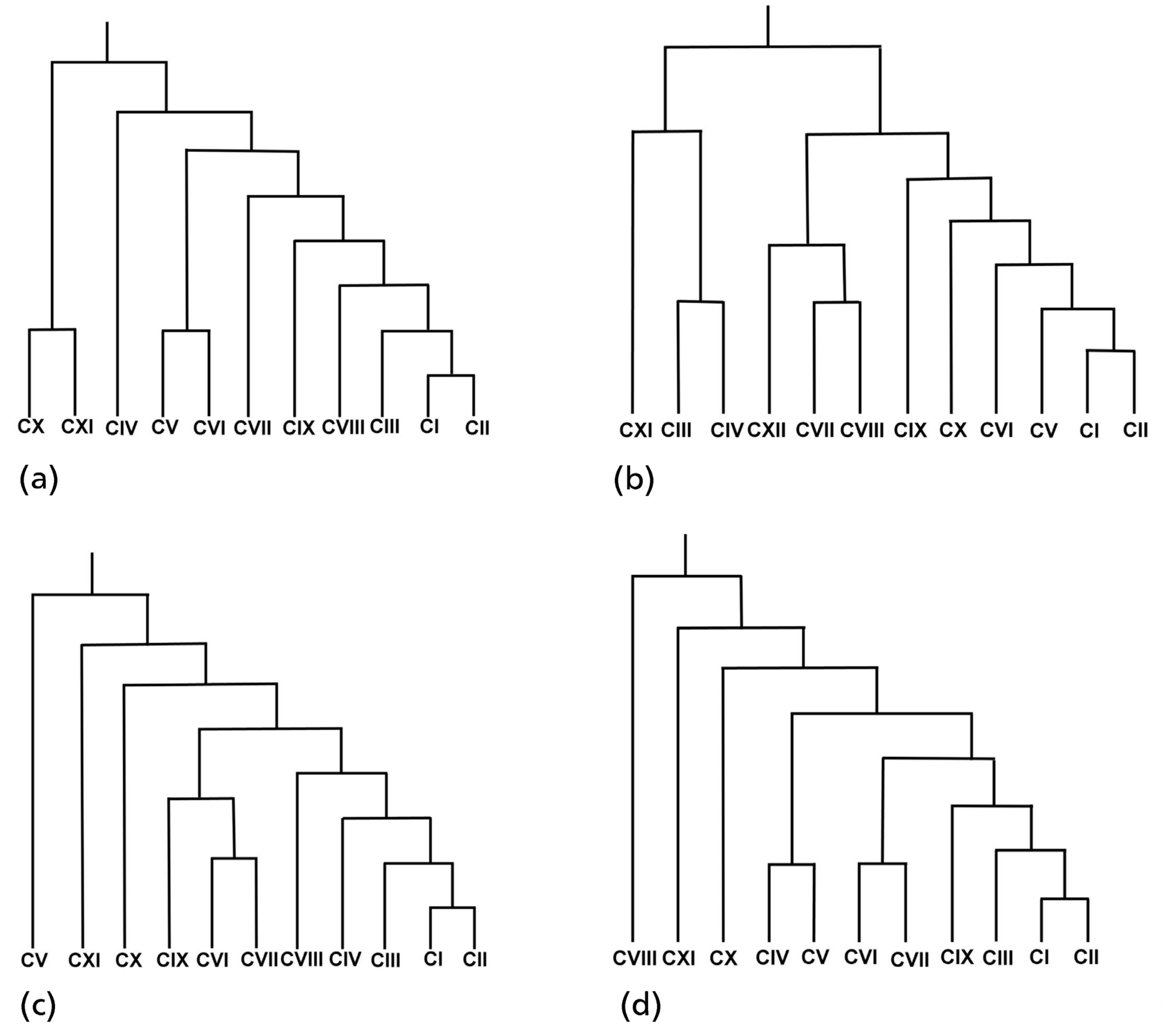

Figure 1. Dendrograms with the individual chorotypes obtained for the four datasets: (a) Map of Life (MOL) with the complete Chihuahuan province, (b) MOL with Northern and Southern Chihuahuan, (c) IUCN with the complete Chihuahuan, and (d) IUCN with Northern and Southern Chihuahuan.

similar branch of the dendrogram by means of a G-test of independence. Finally, a series of fuzzy logic parameters was computed based on the average of similarities between each species distribution and all the distributions in a chorotype, to evaluate the degree of membership of any particular distribution to every chorotype, the overlap between chorotypes and the degree to which a chorotype was included into another chorotype (Olivero *et al.* 2011).

We used the script provided by Ferro (2024) for the R 4.3.2 software (R Core Team 2023) and RStudio (Posit team 2025), based on the chorological affinity, which refers to the similarity between the geographic distribution areas of the taxa without reference to any predefined geographic area (Ferro *et al.* 2017). To identify the chorotypes, we consulted the output file named Chorotype Report, where the number of each chorotype is shown (C1, C2, C3, etc.) and the location of each one in the dendrogram is indicated, with the node number and the left branch as “A” or the right branch as “B” (Ferro 2024). If there were species whose distribution do not overlap significantly with another distribution (which means that they did not belong to any chorotype), their degree of membership in each chorotype was evaluated using the output file named Macoqui Degree of Membership. Because there is no formal procedure for the nomenclature of chorotypes, we followed Olivero *et al.* (2011) numbering the main chorotypes as they were shown in the output file.

Finally, we compared the provinces and species composition of all individual chorotypes (from each single analysis) obtained and summarized their coincidences. When we found the same chorotype in more than one analyses, they were grouped into a general chorotype, which was named with Roman numerals. Also, we used QGIS to select the polygons of the provinces of each chorotype species with significantly overlapping distribution and they were identified with the same color on a map.

Results

The results of the four different analyses of chorotypes, considering both datasets (MOL and IUCN) and two alternative numbers of provinces, are shown in Table 1. In Table 2, the individual chorotypes for each matrix are named with capital letter 'C' and Arabic numerals in the corresponding column with their number of species. From them, we identified 33 general chorotypes named with Roman numerals, regarding the numerical codes of the biogeographic provinces. The general chorotype IV was identical for all alternatives; chorotype I was shared by three matrices; seven chorotypes were shared by two datasets (V, XIII, XIV, XVI, XX, XXI, and XXXII; Table 2), all of which will be analyzed and discussed; and 24 were unique chorotypes for some datasets (which will not be described in detail).

The main features of each dendrogram with the relationship between their individual chorotypes are as follows:

For the MOL - Chihuahuan matrix, the dendrogram (Figure 1a) showed a first dichotomy segregating the mainly coastal provinces from the Pacific (C10) and the Baja Californian biogeographic provinces (C11). Then, the species distributed in the Chihuahuan and Tamaulipas provinces (C4) are separated from the rest. Next, provinces in northern and central Mexico (C5) and the Chiapas Highlands and Pacific Lowlands provinces (C6) are grouped together. The next division separates some highland and lowland provinces in southern Mexico (C7), followed by C9, which encompasses the Chihuahuan province with two central provinces. Then, a chorotype with all the provin-ces is separated (C8), C1 and C2 are the next, in a group with mostly lowland provinces. Finally, the last individual chorotype, C3, presents a mixture of highland and lowland provinces.

Compared to the previous matrix, MOL - N & S Chihuahuan showed one more individual chorotype, resulting in 12 chorotypes (Figure 1b). Only two of these chorotypes are the same and the branches in the dendrograms are not completely equivalent. For this matrix, some chorotypes are recovered including only one of the two sub-units, Northern and Southern Chihuahuan, like in Southern Chihuahuan and Tamaulipan (C8), Southern Chihuahuan and Baja Californian (C11), Northern Chihuahuan, Pacific Lowlands and Sonoran (C4), and Northern Chihuahuan and other central provinces (C10). Although we expected to recover the chorotypes of the previous matrix, this did not happen, but some variations and nesting of the previous chorotypes were discovered. For example, C3 is similar to the previous C10; and C5 includes almost all the provinces of the previous C8 but excludes the complete Baja California Peninsula. All the differences and maps are shown in the Supplementary Material S1 and S2.

Table 1. Results of the four analyses of chorotypes, using the MOL and IUCN databases of geographic distribution areas, with the complete Chihuahuan province and its northern and southern parts. Individual chorotypes refer to the results of single analysis. MOL - Chihuahuan= Map of Life database with the complete Chihuahuan province, MOL - N & S Chihuahuan= Map of Life database with the Chihuahuan province divided in northern and southern parts, IUCN - Chihuahuan= IUCN database with the complete Chihuahuan province, and IUCN - N & S Chihuahuan= IUCN database with the Chihuahuan province divided in northern and southern parts.

Results / Tests	MOL - Chihuahuan	MOL - N & S Chihuahuan	IUCN - Chihuahuan	IUCN - N & S Chihuahuan
Number of species analyzed	487	487	416	416
Number of individual chorotypes	11	12	11	11
Number of species in no chorotype	178	7	158	111
Number of species in all chorotypes	309	480	258	305

For the IUCN - Chihuahuan matrix, the dendrogram (Figure 1c) showed a first dichotomy separating the Baja California province (C5) from the rest, and it was recovered in the MOL - Chihuahuan database. Next, C11 is separated from the rest, joining the Chihuahuan province with two lowland provinces and the Transmexican Volcanic Belt. The following individual chorotype includes the Sierra Madre del Sur and Veracruzan provinces (C10). Next, two groupings are formed: one including C6, C7 and C9, and other with C1, C2, C3, C4 and C8. In the first one the northern provinces are separated first (C9). Then, C6 and C7 are separated: C6 is similar to C9 but also includes highland provinces. Finally, C7 includes only the Pacific Lowlands and Sierra Madre del Sur provinces. On the second branch, two groups are discovered: the mainly lowland provinces (C8) and the other four chorotypes in another branch. Then, C4 is separated from the rest, grouping all the provinces together, similar to the chorotypes obtained in the MOL databases (C8 and C6). Finally, C3 is separated, having a mixture of lowland and highland provinces, the same as C2 but including mainly central provinces, and C1but including northern provinces.

When comparing the results of the IUCN - N & S Chihuahuan with the previous one, more similarities are noticed in the dendrogram (Figure 1d). Eight chorotypes are exactly the same (73%), being the branches in both dendrograms similar. The main differences are in C10, which includes the Balsas Basin, Sonoran and Veracruzan provinces; C2, which is very similar to C5 of the MOL - N & S Chihuahuan; and C5, which includes only the Californian, Northern Chihuahuan and Tamaulipan provinces. All the differences and maps are shown in the Supplementary Material S1 and S2.

We also compared the taxonomic composition and biogeographic provinces included in the chorotypes shared by four, three and two different analyses (Table 2). The only chorotype shared by the four analyses, chorotype IV, includes all the Mexican biogeographic provinces, but it is important to note that the chorotypes from the MOL and

Table 2. General chorotypes (Roman numerals) obtained through a consensus of the individual chorotypes, using the MOL and IUCN databases of geographic distribution areas, with the complete Chihuahuan province and its northern and southern parts. The name of each individual chorotype is shown in Arabic numerals, as the number of species in each chorotype per dataset, ordered by biogeographic provinces included. Biogeographic provinces: (1) Baja Californian, (2) Balsas Basin, (3) Californian, (4) Chiapas Highlands, (5) Chihuahuan, (5a) Northern Chihuahuan, (5b) Southern Chihuahuan, (6) Pacific Lowlands, (7) Sierra Madre del Sur, (8) Sierra Madre Occidental, (9) Sierra Madre Oriental, (10) Sonoran, (11) Tamaulipas, (12) Transmexican Volcanic Belt, (13) Veracruzan and (14) Yucatán Peninsula. MOL - Chihuahuan= Map of Life database with the complete Chihuahuan province, MOL - N & S Chihuahuan= Map of Life database with the Chihuahuan province divided in northern and southern parts, IUCN - Chihuahuan= IUCN database with the complete Chihuahuan province, and IUCN - N & S Chihuahuan= IUCN database with the Chihuahuan province divided in northern and southern parts.

General horotype name	Biogeographic provinces	Individual chorotype names and number of species included in parentheses			
		MOL - Chihuahuan	MOL - N & S Chihuahuan	IUCN - Chihuahuan	IUCN - N & S Chihuahuan
I	1	C11 (9)		C5 (10)	C8 (10)
II	2, 5, 12	C9 (10)			
III	2, 7, 13				C10 (7)
IV	1, 2, 3, 4, 5a, 5b, 6, 7, 8, 9, 10, 11, 12, 13, 14	C8 (49)	C6 (107)	C4 (41)	C3 (85)
V	1, 3, 5, 6, 8, 9 10, 11			C6 (39)	C6 (36)
VI	1, 3, 5a, 5b, 6, 8, 10		C3 (38)		
VII	1, 3, 6, 8, 10, 11	C10 (48)			
VIII	1, 5b		C11 (11)		
IX	2, 4, 5, 7, 8, 9, 11, 12, 13	C3 (18)			
X	2, 4, 5a, 5b 6, 7, 8, 10, 12, 13, 14				C2 (14)
XI	2, 4, 5a, 5b, 6, 7, 8, 9, 10, 11, 12, 13, 14		C5 (105)		
XII	2, 4, 6, 7, 12, 13			C2 (14)	
XIII	2, 4, 6, 7, 13, 14			C8 (73)	C9 (73)
XIV	2, 5, 6, 12			C11 (12)	C11 (only 5b) (13)
XV	2, 5, 6, 7, 8, 9, 10, 12			C1 (15)	
XVI	2, 5, 6, 7, 9, 11, 12, 13			C3 (13)	C1 (only 5b) (14)
XVII	2, 5, 6, 7, 8, 9, 10, 12, 13, 14	C1 (26)			
XVIII	2, 5a, 5b, 6, 7, 8, 9, 10, 12, 13		C1 (28)		
XIX	2, 5b, 9, 12		C10 (10)		
XX	2, 6, 7, 12, 13	C2 (24)	C2 (24)		
XXI	3, 5, 8, 9, 10, 11, 13			C9 (29)	C4 (21)
XXII	3, 5a, 11				C5 (6)
XXIII	3, 5a, 5b, 8, 10, 11, 12		C12 (35)		
XXIV	3, 5a, 5b, 8, 9, 10, 11, 12, 13		C7 (24)		
XXV	4, 6	C6 (7)			
XXVI	4, 6, 7, 13, 14	C7 (75)			
XXVII	4, 6, 7, 9, 12, 13, 14		C9 (83)		
XXVIII	5, 11	C4 (9)			
XXIX	5, 6, 8, 9, 10, 11,12	C5 (34)			
XXX	5a, 11		C8 (10)		
XXXI	5a, 6, 10		C4 (5)		
XXXII	6, 7			C7 (7)	C7 (7)
XXXIII	7, 13			C10 (5)	

IUCN datasets were very similar using only the complete Chihuahuan province, with 49 and 41 species, respectively, and also using the partitioned Chihuahuan, with 107 and 85 species, respectively. We found 36 species shared by MOL and IUCN with the complete Chihuahuan province and 78 species shared between MOL and IUCN with the partitioned Chihuahuan province.

For the general chorotype I (Figure 2a), which was the only one shared by three matrices (except MOL - N & S Chihuahuan), almost 100% of the species were shared in all chorotypes, showing a high affinity to the Baja Californian province. The next seven general chorotypes were shared by two datasets. Chorotype V (Figure 2b) was diagnosed by both IUCN datasets, including eight biogeographic

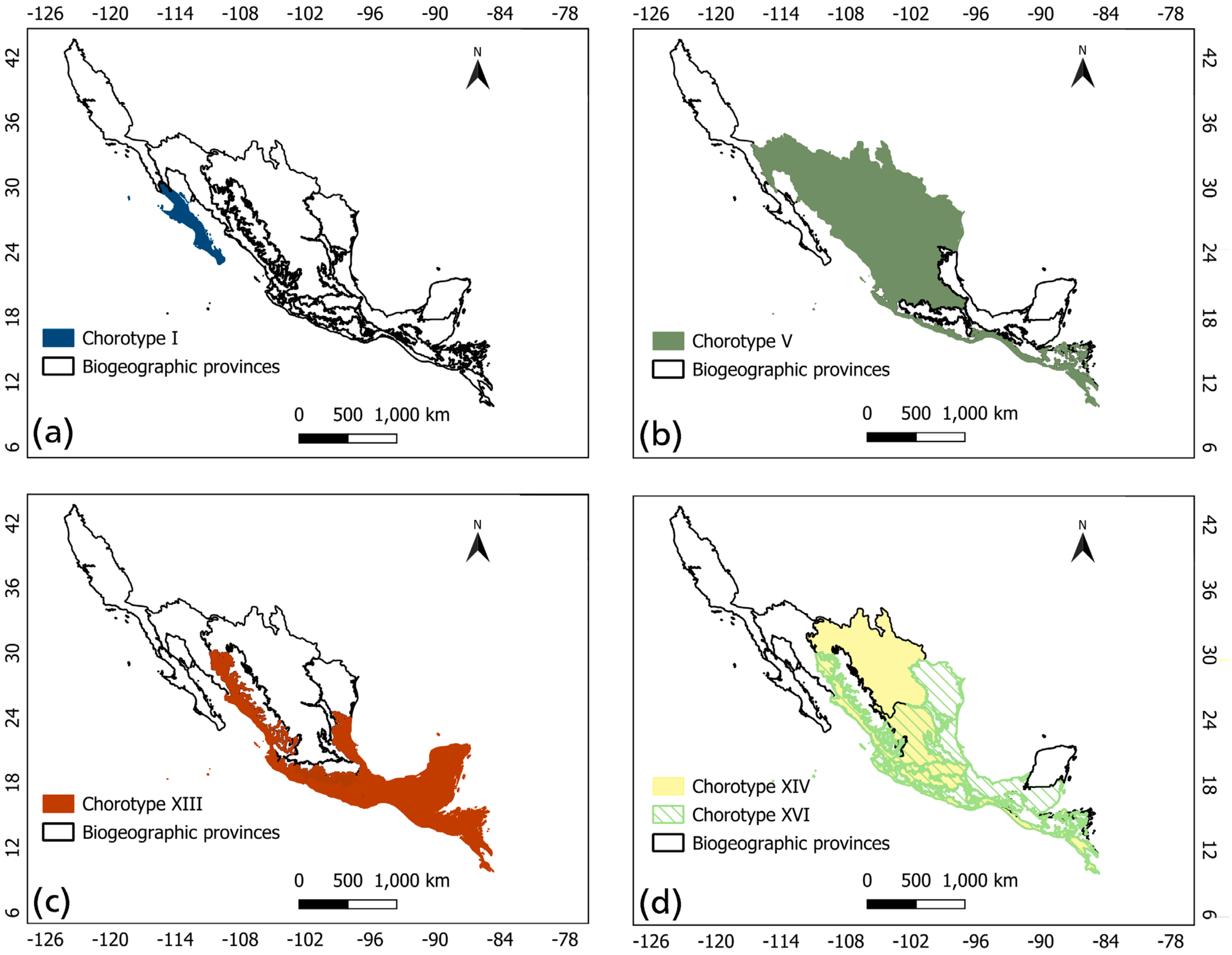

Figure 2. General chorotypes, which are shared by two or more analyses. (a) General chorotype I, shared by three analyses, represented by the individual chorotype C11 from the MOL database with the complete Chihuahuan province. (b) Chorotype V, shared by two analyses, represented by the individual chorotype C6 from the IUCN database with the complete Chihuahuan province. (c) Chorotype XIII, shared by two matrices, from both IUCN datasets. (d) Chorotypes XIV and XVI, shared by two IUCN matrices. Chorotype XIV is a subset of chorotype XVI.

provinces: the five Nearctic provinces, both mountainous chains that border those provinces at eastern and western sides, and a lowland province, the Pacific Lowlands. Chorotype XIII (Figure 2c) was also diagnosed by both IUCN datasets, but for central and southern provinces mainly, mixing Neotropical lowlands with highlands of the Mexican Transition Zone. The next general chorotypes shared by two datasets are XIV and XVI (Figure 2d), both chorotypes recognized by the IUCN matrix. Regarding the provinces involved in them, the chorotype XIV is a subset of XVI (with four and eight provinces, respectively), but in the IUCN - N & S Chihuahuan matrix, only the northern part of the Chihuahuan province was involved.

Chorotype XX, only identified by both MOL databases, occupies central Mexico, with lowland and highland provinces (Figure 3a). The next chorotype (XXI) was diagnosed by seven provinces in the IUCN - N & S Chihuahuan database (Figure 3b). The last chorotype, XXXII, was shared in two IUCN databases with only two biogeographic provinces: Pacific Lowlands and Sierra Madre del Sur (Figure 3c).

Discussion

Chorotypes are useful for organizing knowledge on the geographical distribution of taxa (Passalacqua 2015). When identifying chorotypes, as well as areas of endemism, the problem of using different datasets is not trivial. In this study, we show the relevance of using different datasets of geographic distribution of mammals, as well as pre-defined units of analyses, and their influence on the results of a chorotype analysis.

The differences among the four analyses led to the identification of a total of 33 different general chorotypes (coming from the individual chorotypes), but most of them were unique for one analysis. For the unique general chorotype (IV) obtained in the four analyses, MOL and IUCN had many species shared (~40 species); however, the use of a divided province (Chihuahuan) in two different units (Northern and Southern) duplicated the number of species (~80). These findings can reveal important implications for the universal application of data sources and units of analyses.

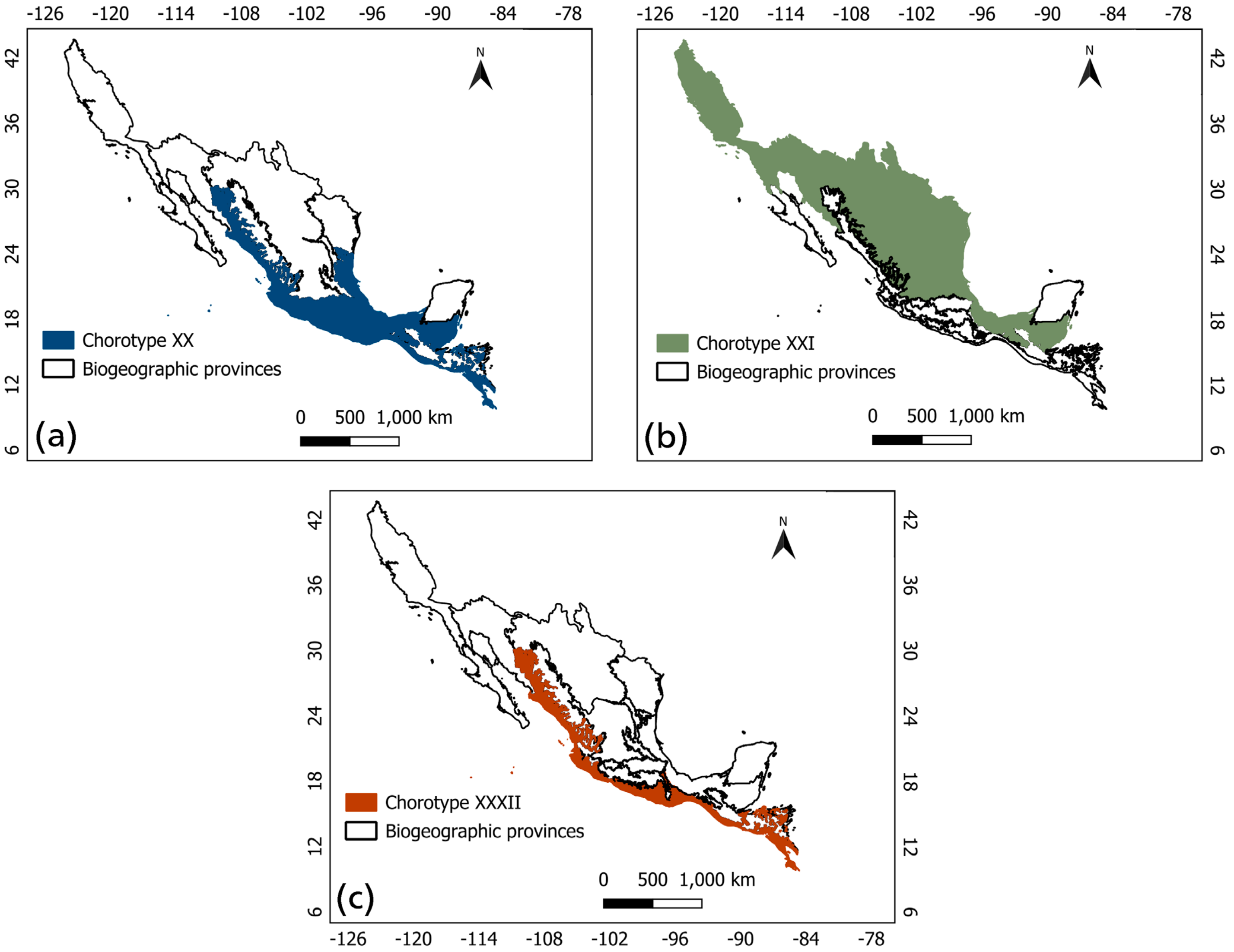

Figure 3. General chorotypes shared by two matrices. (a) General chorotype XX, identified by both MOL databases, (b) Chorotype XXI, shared by two matrices from the IUCN database, and (c) Chorotype XXXII, shared by two IUCN databases.

Chorotype IV, that includes all the Mexican biogeographic provinces, may result from the mixture of the Nearctic and Neotropical biotas in the Mexican Transition Zone. The biota of the Mexican Transition Zone was assembled through the successive dispersal of four cenocrons from North and South America that assembled to the original Paleoamerican biota (Morrone 2020): (1) the Mexican Plateau cenocron dispersed to southern North America from South America (Gondwana) in the Late Cretaceous-Paleocene; (2) the Mountain Mesoamerican cenocron dispersed from South America to the mountain forests of Central America and southern Mexico in the Oligocene-Miocene and then northward in the Pliocene; (3) the Nearctic cenocron dispersed from northern North America to the Mexican Transition Zone in the Miocene-Pliocene; and (4) finally, in the Pleistocene the Typical Neotropical cenocron dispersed from the Neotropical region. Some of the species defining chorotype IV are widely distributed in the country (distributed in at least two biogeographic provinces). For instance, *Lynx rufus, Myotis volans* and *Odocoileus hemionus* are distributed mainly in lowlands and highlands in the Nearctic region. These species, despite belonging to different orders, have high dispersal abilities and may constitute a "subchorotype" within a bigger one, as was defined by Flores *et al.* (2004). Other species can reach more southern areas, like *Eptesicus fuscus, Procyon lotor* and *Puma concolor*, the latter even exceeding the Neotropical region to the Andean region in South America. Their dispersal abilities have allowed them to colonize successfully lowlands and highlands, producing a mixture that could be useful in ecological regionalization, but would be useless for an evolutionary biogeographic regionalization.

Chorotype I (Figure 2a) confirmed the identity of the Baja California province biota, conformed by at least 10 species whose geographic distributions are not randomly shared: *Chaetodipus ammophilus, C. siccus, Neotoma insularis, Peromyscus caniceps, P. dickeyi, P. eva, P. guardia, P. sejugis, P. slevini* and *P. stephani*. Although it was not recovered in the MOL - N & S Chihuahuan database, in the C11 of this database, all of them are present together with *Myotis vivesi*, which is also distributed in the Sonoran province (Otárola-Ardila *et al.* 2013). The biota of the Baja California province is a result mainly of the geographical isolation of the peninsula, which had happened over the last 4 or 5 million years, as result of a complex tectonic origin and ecological transformation (Grismer 2000).

Chorotype V is based on 36 species distributed in nine provinces, most of them belonging to the order Rodentia. Moreover, three species were not shared by the two datasets, only diagnosed for the IUCN - Chihuahuan matrix: *Euderma maculatum*, *Perognathus amplus* and *Peromyscus boylii*. From them, in fact, *P. amplus* is distributed only in the Sonoran province, while the other two species diagnosed the whole Chihuahuan province. Other species, like *Neotoma albigula,* even avoid the Chihuahuan province, probably also representing subchorotypes, or *Callospermophilus madrensis*, which is exclusive to the Sierra Madre Occidental. Other species, like *Cynomys ludovicianus,* are only marginally distributed in this chorotype, which is an effect of the possible overestimation of the polygons. Other problems were shown for species with some uncertainty in their distributions and taxonomy, like *Neotamias durangae*. This species has only one continuous population in the MOL database, but two allopatric populations in the IUCN database. Therefore, this chorotype was not identified by the MOL analyses, even partitioning the Chihuahuan province. It is interesting that *N. durangae* is present in C5 of the MOL - Chihuahuan and C12 of the MOL - N & S Chihuahuan matrices (corresponding to general chorotypes XXIX and XXIII in Table 2). These chorotypes represent variations with 34 and 35 species, respectively, and variations between the provinces involved.

Similarly in general chorotype XIII, which has 73 species, some are typically found in colder highlands (*v. gr.,* species of *Cryptotis*, *Habromys* or *Sorex*), whereas other species are typically from hotter lowlands (*v. gr.,* species of *Alouatta*, *Heteromys* or *Phyllostomus*). This chorotype also includes species with very restricted habitats and geographic distributions, but also species widely distributed.

General chorotype XIV is a subset of chorotype XVI. It is defined by 12 species, most of them belonging to the order Rodentia. In general, these species have distributional areas very restricted to mountainous chains (*v. gr.*, *Cratogeomys fulvescens*, *C. perotensis* and *Habromys delicatulus*). Some of them have been diagnosed as endemic taxa of one biogeographic province (*v. gr.*, *Romerolagus diazi* and *Sorex oreopolus* endemic to the Transmexican Volcanic Belt); however, the chorotype analysis was not able to identify these subtle differences. For the largest general chorotype XVI, there were also 12 species, but with a different composition, with the genus *Peromyscus* being the most representative. Some species are distributed in two or more mountainous provinces, but also the polygons could be overestimating the distributions to lowlands (*v. gr.*, *Peromyscus furvus* and *Sciurus oculatus*), like the Veracruzan province. Again, the chorotypes could identify patterns useful for ecological regionalization, diagnosing roughly species more restricted to lowland and highland environments.

General chorotype XX grouped 24 species distributed in central Mexico. Some of them are typical of lowlands (*Musonycteris harrisoni*, *Notocitellus annulatus* and *Tlacuatzin balsasensis*), and others typical of highlands (*Cryptotis magnus*, *Peromyscus melanurus* and *Sorex ixtlanensis*). In this chorotype, we may diagnose some sub-chorotypes, separating both sets of species; however, at this time, identification of this pattern is not clear.

Chorotype XXI was identified by 21 species, some of them distributed in north-central provinces (*v. gr.*, *Ammospermophilus interpres*, *Cratogeomys castanops* and *Myotis planiceps*) and others from northeastern provinces (*Nycticeius humeralis*, *Onychomys leucogaster* and *Sciurus alleni*). In general, these species are distributed in lowlands of the Nearctic provinces, although marginally extend to both mountain chains at eastern and western sides. In this chorotype there are species with Nearctic and Neotropical affinities that belong to the Mexican Plateau cenocron.

The last general chorotype, XXXII, encompasses seven species, three of them of the order Lagomorpha: *Lepus flavigularis*, *Sylvilagus graysoni* and *S. insonus*. In particular, *S. graysoni* is an insular species, belonging to the Pacific Lowlands province; moreover, its distribution is allopatric from lowland continental ones like *L. flavigularis*. Other species in this chorotype, like *Rheomys mexicanus* and *Peromyscus madrensis,* are distributed in the highlands of the Sierra Madre del Sur province.

Olivero *et al.* (2011) have suggested that chorotypes may result from environmental conditions shared by several species or from historical events biasing certain taxa to different areas. Thus, chorotypes may enhance the search for global processes influencing distribution of biodiversity. For the Mexican mammals, chorotypes were uninformative for evolutionary patterns mainly based on vicariance, which are used for evolutionary biogeographic regionalizations. In contrast, patterns influenced by dispersal or ecological processes are diagnosed herein, which could be useful for ecological regionalizations.

The biogeographical regionalization of Mexico currently recognizes the Nearctic and Neotropical regions, and the Mexican Transition Zone as an area of biotic assembly (*e.g.*, Morrone *et al.* 2017; 2022a; Morrone 2019). This mixture could be recognized, but more than the recovery of those patterns, chorotypes may identify mixed patterns based on environments associated with altitude. None of the identified mammal chorotypes corresponds to Morrone *et al.* (2022b) division of the Trans-Pecos and Mapimian districts within the Chihuahuan province; however, we found that this division affected the results, although not decisively. Also, only one biogeographic province was recognized (Baja Californian province), which allows in this particular case to integrate ecological and evolutionary processes in a natural regionalization. The incorporation of other taxa with different evolutionary and ecological histories as well as the temporal component, will allow to improve the understanding of the processes that produce the complex evolutionary and ecological biogeographic patterns of the country.

Conclusions

We demonstrate the possible effects of the use of different sources of geographic distributional data and operational units, where even small variations may modify the number of chorotypes obtained, and the species and units involved. In total, we identified 33 chorotypes, but subchorotypes also should be analyzed, to diagnose possible lowland and highland patterns within them. Finally, chorotypes seem to recognize more closely ecological patterns rather than evolutionary ones, even mixing species with different affinities in the same pattern, showing that the Mexican mammal fauna is a result of a complex history.

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Declaration of Artificial Intelligence use

No artificial intelligence tools were used in the preparation of this manuscript.

Author contributions

Conceptualization & Methodology: Tania Escalante, Juan J. Morrone. Investigation & Data Curation: Oscar Campos. Formal Analysis & Validation: Tania Escalante, Oscar Campos. Writing & Reviewing: Tania Escalante, Juan J. Morrone.

Supplementary data

S1. Similarities and differences between the 33 chorotypes obtained from each database, regarding the biogeographic provinces involved in each one.

S2. Maps of the 33 chorotypes resulting from the four datasets and the Mexican biogeographic provinces.

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