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ENDEMIC ANGIOSPERM LINEAGES IN MEXICO: HOTSPOTS FOR CONSERVATION

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ABSTRACT

As a megadiverse country, Mexico harbors 4 to 8% of the flora of the world and of this, 51% is endemic. There is concern because several factors are impeding its conservation. In this paper, areas of endemism for the flowering plants of Mexico are identified to prioritize regions for conservation. To categorize zones for preservation, the approach followed takes biodiversity, weighted endemism and evolutionary history into account. Lineages of angiosperms, families, genera, and formal or informal groups within genera previously retrieved as monophyletic are selected to represent evolutionary history in equivalent spatial units. A database with 9416 entries based on specimens of species belonging to 259 monophyletic groups of angiosperms from Mexico was compiled, and their presence-absence recorded for every unit area. Species richness and weighted endemism index was calculated for each of these units. The results indicate that the majority of the regions with the highest indices of endemism have a dry climate with xeric vegetation, with the exception of two areas of tropical and temperate forests. They are: the northeastern rosette scrub in Nuevo León and Coahuila, gypsum grasslands in San Luis Potosí, the Sierra Gorda in Queréraro, Tolantongo in Hidalgo, the Tehuacán-Cuicatlán Valley in Puebla and Oaxaca, El Salto in Durango, Sierra de Quila in Jalisco, a western portion of the Balsas River Basin in Michoacán, Guerrero, Morelos and State of Mexico, the Tehuantepec area in Oaxaca, the Central Depression of Chiapas and El Triunfo in Chiapas. Some of the areas of endemism in the Chihuahuan Desert, Balsas River Basin, the Central Depression of Chiapas and the southern area of Oaxaca are not sufficiently protected. Approximately 340 species

were microendemic, i.e. restricted to a single quadrat, and the Cactaceae account for the majority of the species on the Mexican Red List.

Key words: Cactaceae, Chihuahuan Desert, endemism, Mega-Mexico, xeric vegetation.

RESUMEN

México está considerado como uno de los países megadiversos y en su territorio se encuentran entre 4 y 8% del número de total de especies de plantas del mundo, de las cuales 51% son endémicas. Existe una gran preocupación sobre la conservación de la flora mexicana, ya que se han detectado varias actividades y factores que la amenazan. En este trabajo se identifican áreas de endemismo para las angiospermas de México con el objetivo de priorizar regiones para conservación. Para categorizar estas zonas se sigue el enfoque que toma en cuenta la biodiversidad, el índice de endemismo ponderado y la historia evolutiva. Se identificaron los linajes de angiospermas, ya sean familias, géneros, o grupos infragenéricos con o sin estatus taxonómico que previamente se habían determinado como monofiléticos para representar la historia evolutiva en unidades espaciales equivalentes. Se construyó una base de datos de 9416 registros de especies de 259 grupos monofiléticos de angiospermas restringidas a México y se registró su presencia en estas áreas. Para cada una se calculó la riqueza de taxones y el índice de endemismo ponderado. Los resultados muestran que la mayoría de las zonas de más alto endemismo están en climas secos, con vegetación xérica, con dos excepciones de vegetación tropical y templada. Los índices de endemismo ponderado más altos se localizaron en: el área norte de matorral rosetófilo en Nuevo León y Coahuila, matorrales gipsófilos en San Luis Potosí, la Sierra Gorda en Querérato, Tolantongo en Hidalgo, el Valle de Tehuacán-Cuicatlán en Puebla y Oaxaca, El Salto en Durango, la Sierra de Quila en Jalisco, la zona oeste de la Depresión del Balsas en Michoacán, Guerrero, Morelos y el Estado de México, la zona de Tehuantepec en Oaxaca y El Triunfo en Chiapas. Algunas áreas de endemismo en el Desierto Chihuahuense, en la Cuenca del Balsas y en la Depresión de Chiapas, así como del sur de Oaxaca no están suficientemente protegidas. Se registraron aproximadamente 340 especies con distribución restringida a un solo cuadrante y de éstas la mayoría de las que se incluyen en la lista de taxones amenazados de México pertenecen a las Cactaceae.

Palabras clave: Cactaceae, Desierto Chihuahuense, endemismo, Mega-México, vegetación xérica.

INTRODUCTION

Different criteria have been applied to prioritize areas for conservation and undoubtedly the most widely used is the concentration of endemic species undergoing increased habitat loss. The areas defined this way are known as "biodiversity hotspots" (Myers et al., 2000). Globally, thirty-five biodiversity hotspots, comprising 44% of the total number of species of vascular plants, have been identified and Mesoamerica is one of them (Myers et al., 2000; Mittermeier et al., 2011).

Other approaches for prioritizing areas for conservation have added the element of evolutionary history, because diversity and evolutionary history are unequally distributed in different areas of the world (Vane-Wright et al., 1991). Among these approaches, phylogenetic endemism uses phylogenetic diversity and weighted endemism as measures to identify areas for conservation based on equivalent spatial units (Rosauer et al., 2009). Additionally, attributes such as scarcity (Cadotte & Davies, 2010), local and global rarity of taxa (e.g. Crain et al., 2011), phylogenetic distinctiveness and isolation (e.g. Collen et al., 2011), phylogenetic diversity (Forest et al., 2007) and functional diversity (e.g. Devictor et al., 2010; Pio et al., 2011) have variously been incorporated to the evolutionary history approach.

In this paper, we identify areas of endemism for the flowering plants of Mexico to prioritize areas for conservation. The concept followed here for an area of endemism is that of a geographic region that includes the distributions of two or more monophyletic taxa with phylogenetic and distributional congruence (Harold & Mooi, 1994). Areas of endemism have several attributes: they have a single history, they are smaller than the entire study area, they do not overlap with other areas of endemism, they host at least two taxa with ranges restricted to the area and they are maximally congruent (Linder, 2001; Szumik et al., 2004; Ebach et al., 2008).

Thus, to categorize areas for preservation we follow an approach that combines biodiversity, weighted endemism and evolutionary history. Lineages of Mexican angiosperms, families, genera or formal and informal groups within genera that have been previously recognized as monophyletic were selected to represent evolutionary history in equivalent spatial units.

As a megadiverse country, Mexico houses 4 to 8% of the flora of the world and there is concern because several factors are impeding its conservation. The greatest threats to the flora of Mexico are intensification of habitat loss, the adverse effects of climate change and the overexploitation of the majority of habitats (Dávila et al., 2011).

Angiosperms were chosen because they are one of the most diverse groups of organisms in Mexico. Their diversity has been estimated at 24,500-29,000 species

(Villaseñor, 2003; Espejo-Serna et al., 2004) and more than 50% are endemic to the country (Rzedowski, 1993). Furthermore, the genera distributed in Mexico have been documented (Villaseñor, 2004), and the floristic knowledge of the country has been recently summarized (Anonymous, 2009). The groups of angiosperms distributed in the area known as Mega-Mexico were used in this study. This biogeographic province was proposed by Rzedowski (1993) and includes, in addition to Mexico's current territory, the areas of the Sonoran Desert, the Chihuahuan Desert and the Tamaulipan scrub that lie in the United States of America, as well as those portions of Central America as far south as northern Nicaragua.

The families with the largest number of endemic Mexican genera are Cactaceae and Asteraceae (Turner, 1996-2010; Guzmán et al., 2003; Hernández & Gómez-Hinostrosa, 2011a,b). Setchellanthaceae, a monotypic family, only grows in Mexico (Iltis, 1999). In the monocots, a clade of geophyte genera in the Asparagaceae, the *Milla* clade, grows in Mega-Mexico (Gándara et al., 2009) and a group in the Crassulaceae, the *Acre* clade includes several genera exclusive to Mexico (Acevedo-Rosas et al., 2004; Carrillo-Reyes et al., 2010). Three related genera, *Morkilia, Sericodes* and *Viscainoa* in the Zygophyllaceae (Sheahan & Chase, 2006), and two genera in the Anacardiaceae, *Bonetiella* and *Pseudosmodingium* (Aguilar-Ortigoza et al., 2004) are found in this biogeographic province. In the Acanthaceae, nine genera and a clade within *Ruellia* are endemic to Mexico (Daniel, 1993; Tripp, 2010). In addition, among the more remarkable endemic groups of Mexico are clades of *Bursera* (Rzedowski et al., 2005; De-Nova et al., 2012), *Agave* and groups nested within this genus such as *Manfreda*, *Polianthes* and *Prochnyanthes* (García-Mendoza, 1995; Rocha et al., 2006, Good-Avila et al., 2006), the section *Physodium* in *Melochia* (Dorr & Barret, 1989), a clade in the *Zea diploperennis* group (Poaceae) (Buckler & Holtsford, 1996), and a clade of *Yucca* within the *Sarcocarpa* group (Pellmyr et al., 2007). *Fouquieria* and *Leucophyllum* are arid land groups in Mega-Mexico (Henrickson & Flyr, 1985; Schultheis & Baldwin, 1999). Enigmatic genera like *Velascoa* (Crossosomataceae) (Sosa & Chase, 2003), *Chiangiodendron* (Achariaceae) (Sosa et al., 2005), *Enriquebeltrania* (Euphorbiaceae) (De-Nova et al., 2006), *Cerdia* (Caryophyllaceae) (Sosa et al., 2006), *Olmeca* (Bambusoideae, Poaceae) (Dávila-Aranda et al., 2004; Ruiz-Sanchez et al., 2011), *Peltophorum* (Leguminosae) (Sousa, 2005), the parasitic *Eremitilla* (Orobanchaceae) (Yatskievych & Contreras-Jiménez, 2009), *Echinopterys* (Malpighiaceae) (Davis et al., 2001), *Nowickea* (Phytolaccaceae) (Martínez & McDonald, 1989), and *Mexipedium* (Orchidaceae) (Albert & Chase, 1992) are endemic to Mexico, to mention just a few examples. We recorded 259 monophyletic angiosperm groups endemic to Mega-Mexico.

The objectives of this paper are: 1) to identify the areas of endemism of the angiosperms of Mexico, using monophyletic groups to prioritize areas for conservation, and 2) to detect species from these natural groups with a restricted distribution to highlight the threatened taxa.

MATERIALS AND METHODS

Taxa

Mexican angiosperm lineages, families, genera, and infrageneric groups with or without formal taxonomic status were compiled based on the literature (Rzedowski, 1993; Villaseñor, 2004; Anonymous, 2009). Distribution records were obtained from herbarium specimens in ANSM, ENCB, HCIB, IBUG, IEB, MEXU, MO, NY, TEX, UAMIZ, US and XAL, and by consulting the Mexican Biodiversity Database (REMIB) (www.conabio.org).

Study area

The study area includes the entire country of Mexico. Even though the distribution of some groups extends into the south of the United States of America and northern Central America in Mega-Mexico, only the localities within Mexico were used. A system of land quadrats based on one degree squares was used to define arbitrary area units, resulting in a set of 237 area units with records of endemic taxa. The occurrence of every specimen of each monophyletic group in each quadrat was recorded. The data matrix had a total of 9416 georeferenced records. Quadrats with no records were eliminated. Species restricted to a single quadrat were identified as microendemics.

Areas of endemism

First, the number of species was added up for each quadrat to estimate its diversity (unweighted species richness, Pearson & Juliano, 1993; Kershaw et al., 1995). Then, the weighted endemism index, a method that weights species inversely to their distribution areas was also calculated (Linder, 2001).

Microendemic species

The species with a restricted distribution, i.e., those only found in a single quadrat, were recorded and of these the taxa on the Mexican Red List (Anonymous, 2010) were identified.

RESULTS

Areas of endemism

The data matrix included the presence/absence data for 878 species belonging to 259 monophyletic groups for 237 area units. The highest unweighted species richness values for each quadrat are shown in Table 1 and Fig. 1. The areas with the highest number of endemic species are in Tehuacán-Cuicatlán, in the eastern of the Balsas River Basin, in Tolantongo and Tepeapulco, Hidalgo and in the Sierra Gorda.

The weighted endemism values are listed in Table 1 and shown in Fig. 2. Eleven areas with the highest weighted endemism values (10.657-34.819) were identified: 1) A northeastern area of rossette scrub in Nuevo León and Coahuila (Ramos Arizpe, Aramberri, Galeana and Zaragoza); 2) an area of gypsum grasslands in San Luis Potosí, 3) the Sierra Gorda, Querétaro (extending to San Luis Potosí); 4) Tolantongo in Hidalgo, 4) the area of Tehuacán-Cuicatlán, Puebla and Oaxaca; 5) El Salto, Durango; 6) the Sierra de Quila in Jalisco; 7) the western area of the Balsas River Basin (Michoacán, Guerrero, Morelos, State of Mexico); 8) the Tehuantepec area,

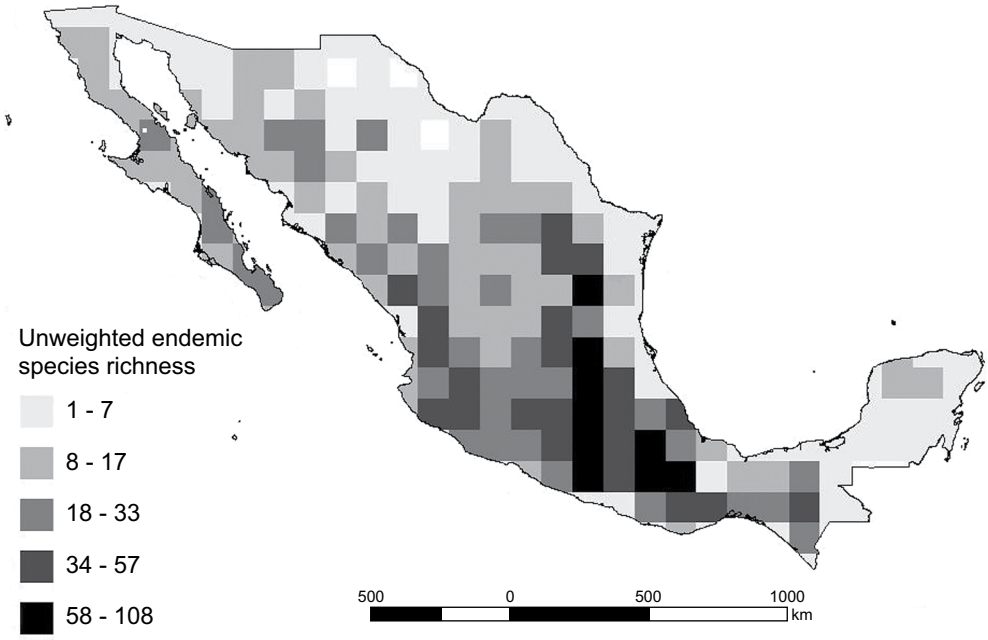

Fig. 1. Distribution map of the Mexican lineages of angiosperms (unweighted richness).

Table 1. Areas of endemism of the Mexican lineages of angiosperms with the highest species richness (number of species 23-108) and the highest indices of weighted endemism (6.61-34.81). Values for each land quadrat for every area of endemism are included.

Areas of endemism	Unweighted endemic species richness	Weighted endemism
Tehuacán-Cuicatlán	108	34.81888723
	94	30.53009253
Balsas River Basin	64	20.95559334
	66	19.20541089
Northeastern rosette scrub	61	18.9554685
Sierra Gorda	71	18.76557059
	64	16.97099585
Northeastern rosette scrub	53	16.89719931
Tolantongo	55	16.79210378
Balsas River Basin	74	16.68154352
Tehuacán-Cuicatlán	67	16.08813242
Balsas River Basin	47	15.86234919
	39	15.67449119
Sierra de Quila	57	14.40864616
Central Depression of Chiapas	39	15.67449119
Tehuantepec Region	50	14.27457894
Northeastern rosette scrub	39	13.88012541
El Triunfo	25	13.71388889
Northeastern rosette scrub	44	13.52460031
Balsas River Basin	52	12.92819513
El Salto	38	11.6864493
Gypsum grasslands	40	11.59780087
Sierra de Órganos	33	8.122629758
Baja California Sur	31	8.805300868
	24	7.578488054
	23	6.938598987
	23	6.618010751

Oaxaca; 9) the Central Depression of Chiapas; 10) El Triunfo, Chiapas. Among the areas with high weighted endemism indices is the southern area of Baja California and the Sierra de Órganos, Zacatecas (Fig. 2).

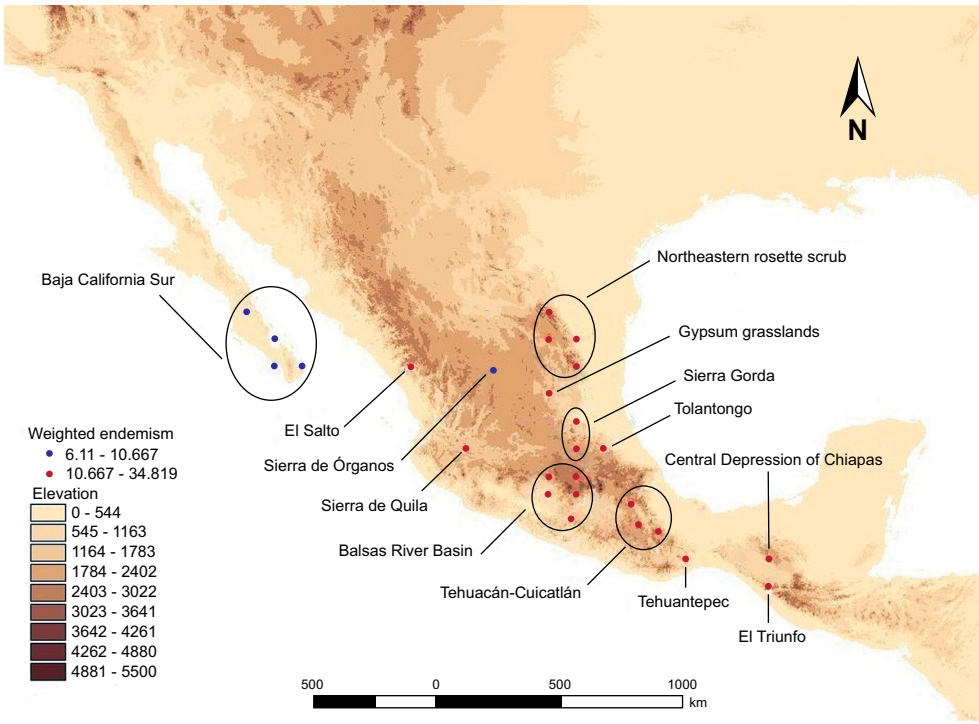

Fig. 2. Areas of endemism for the Mexican lineages of angiosperms (weighted endemism).

Microendemics

Appendix lists the 340 species whose distribution is restricted to a single quadrat, with their threatened status indicated when applicable.

DISCUSSION

Rzedowski (1993) pointed out that the distribution of areas with endemic species for the flora of Mexico does not coincide with the distribution of biodiversity. He indicated that the endemic taxa are concentrated in areas of dry climate and this conclusion was reached based on species richness alone, without taking the historical element into account. The latter has been included in this paper by identifying areas of endemism shared by at least two monophyletic groups. Our results indicate that majority of the areas: the northeastern rosette scrub, the gypsum grasslands,

the Sierra Gorda, the southern portion of the Chihuahuan Desert, the area of Tehuacán-Cuicatlán, the Sierra de Quila, the western area of the Balsas River Basin, the Tehuantepec area and the Central Depression of Chiapas, have a dry climate, corroborating Rzedowski's hypothesis. The endemic groups occur at low to middle elevations, in xeric vegetation. The only area with a tropical climate and a high weighted endemism index is El Triunfo in Chiapas, and El Salto in Durango has a temperate climate.

The Sierra Gorda was previously recognized as an area with significant endemism and it is included in the Mexican System of Natural Protected Areas, the SINAP (Arriaga-Cabrera et al., 2000). Additionally, the Tehuacán-Cuicatlán area is comprised of arid vegetation and is perhaps the most important biosphere reserve in Mexico (Arriaga-Cabrera et al., 2000). It is a floristic province, and an ecological island given the high number of endemics, estimated at 365 species (Méndez-Larios et al., 2004; Dávila et al., 2002).

The area of Metztitlán-Tolantongo was previously known for having high endemism and it was decreed as a biological reserve in 2000 (Hiriart-Valencia & González-Medrano, 1983; Arriaga-Cabrera et al., 2000). Furthermore, Sierra de Quila was earlier identified as a hotspot for conservation based on mammal distributional predictions as biodiversity surrogates (Sánchez-Cordero et al., 2005). In addition, the semiarid gypsum karstlands in north central Mexico characterized by a mosaic of shrubby communities and endemic gypsophile grasslands were formerly acknowledged as areas with elevated endemism and important to preserve (Henrickson & Johnston, 1986; Meyer et al., 1992; Huerta-Martínez & García-Moya, 2004).

The western area of the Balsas River Basin in Michoacán, Guerrero, Morelos and State of Mexico, is another region with high indices of endemism. Rodríguez-Jiménez et al. (2005) have identified 337 endemic species of vascular plants in this biogeographic province. Cañón del Zopilote and Infiernillo are two proposed areas for conservation in this province (Arriaga-Cabrera et al., 2000), yet they represent only a small area within the Balsas River Basin.

Several regions in Nuevo León harbor extremely large numbers of endemisms in the Cactaceae (Juárez et al., 2009), and a high concentration of narrowly distributed Asteraceae (González-Zamora et al., 2007; Alanís-Flores et al., 2011). Moreover, these regions coincided with one of the areas of high endemism identified in this study: the Northeastern rosette scrub.

Our results detected the Sierra La Laguna in Baja California Sur as a territory with high endemism. Plant diversity and endemism on the entire Baja California Peninsula have previously attracted attention (Riemann & Ezcurra, 2007).

The notable endemism in the Sierra La Laguna, Baja California, had also been pointed out (León de la Luz & Breceda, 2006) and resulted in the Sierra La Laguna reserve being decreed one of Mexico's biosphere reserves (Arriaga-Cabrera et al., 2000).

El Triunfo is a biosphere reserve with elevated endemism and richness, for which approximately 1000 species of vascular plants have been reported. The area includes several habitats such as cloud, oak and tropical forest (Martínez-Meléndez et al., 2008; Pérez-Farrera et al., 2012). It was decreed as a reserve because it is considered to be a Pleistocene refugium for several tropical species (Arriaga-Cabrerra et al., 2000). As well, the pine and oak forests in El Salto have provided suitable habitats for several gymnosperm relict species (Valenzuela-Núñez & Granados-Sánchez, 2009).

The Central Depression of Chiapas has been earlier identified as an area with seasonally dry tropical forests and tropical oak forests where approximately 3.4% of the total number of vascular plant species in Mexico are distributed (Reyes-García & Sousa, 1997). Furthermore, among the habitats of Tehuantepec, the tropical dry forests harbor the largest diversity including several taxa of endemic angiosperm (Acosta et al., 2003; Pérez-García et al., 2010).

It is noteworthy that the majority of the areas with the highest endemism indices, such as El Salto (Durango), the Central Depression of Chiapas, Tehuantepec, (Oaxaca), and Tolantongo in the southern area of the Chihuahuan Desert are not protected under the SINAP scheme (Arriaga-Cabrera et al., 2000).

Microendemic species

It is crucial to take the rarity of species into account when setting conservation priorities (Mooers & Redding, 2009). It has been mentioned that in areas of endemism the species with restricted distributions are usually on the red lists (e.g., Argentina, Szumik et al., in press). The same happens in Mexico where we found that a large number of the species whose distribution is restricted to a single quadrat in our study area are included on the Mexican List of Threatened Species (Anonymous, 2010).

Most of the species on this list with a limited distribution are cacti. More than 900 species of Cactaceae are present throughout Mexico (Ortega-Baes & Godínez-Álvarez, 2006). This is one of the groups that are most used as ornamental plants and so have been continuously extracted from their habitats, with the result that they are now the most threatened group in Mexico (Gómez-Hinostrosa & Hernández, 2000; Hernández & Gómez-Hinostrosa, 2011a,b).

CONCLUSIONS

Future research should examine the probable causes of diversification for the angiosperm lineages in the areas of endemism in Mega-Mexico. For other areas with high degrees of endemism, such as the Andes, isolation caused diversification, similar in many respects to the floras of remote oceanic islands (Särkinem et al., in press) or along elevational gradients (Kessler, 2000). Climate was the factor that promoted speciation in Australia's areas of endemism (Ladiges et al., 2011), while tectonic stability in central and southern China influenced the permanence of areas of plant endemism (López-Pujol et al., 2011). In Sub-Saharan Africa, elevation range and low seasonality were core environmental predictors for centers of endemism (Jetz et al., 2004). Diversification in hotspots of biodiversity and endemism in Brazil were attributed to the effect of fire on vegetation (Simon et al., 2009), while serpentine soils and a benign climate favored endemism in California (Anacker & Harrison, in press).

Our results suggest that various causes promoted the diversification of several groups of plants in the areas of endemism, and a dry climate together with isolation are probably the most remarkable. Nine areas of endemism have a dry climate. Furthermore, the Central Depression of Chiapas and the Balsas River Basin are two areas that remained isolated, bordered by mountain ranges. In contrast, El Triunfo in Chiapas probably acted as a refugium for angiosperm lineages that remained there throughout the Pleistocene. Gypsum soils probably favored endemism in the northeastern rosette scrub and the grasslands of San Luis Potosí. However investigation is needed to corroborate these hypotheses.

It should be emphasized that hotspots do not necessarily coincide with species richness, the degree of threat or areas of endemism (Orme et al., 2005). The areas of endemism identified in our study do not coincide with the areas with elevated diversity of the flora of Mexico, as Rzedowski (1993) pointed out, and some of the areas of endemism in the Chihuahuan Desert, Balsas River Basin and the southern area of Oaxaca are not sufficiently protected.

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APPENDIX

Microendemic species of the Mexican lineages of angiosperms. These are restricted to a single quadrat. Species that are on the Mexican Red List (Anonymous, 2010) are indicated with the following designations in parentheses: A = threatened, P = endangered, Pr = under special protection.

Acanthaceae
Gypsacanthus nelsonii E.J. Lott, V. Jaram. & Rzed.
Holographis anisophylla T.F. Daniel
Holographis argyrea (Leonard) T.F. Daniel **(Pr)**
Holographis caput-medusae T.F. Daniel
Holographis hintonii (Leonard) T.F. Daniel
Holographis pallida Leonard & Gentry
Holographis tamaulipica T.F. Daniel
Holographis tolantongensis T.F. Daniel
Ixtlania acicularis M.E. Jones
Mexacanthus mcvaughii T.F. Daniel
Mirandea andradenia T.F. Daniel
Mirandea huastecensis T.F. Daniel
Mirandea hyssopus (Nees) T.F. Daniel
Ruellia conzattii Standl.
Ruellia guerrerensis T.F. Daniel
Ruellia laslobasensis E.A. Tripp
Ruellia sarukhaniana Ramamoorthy
Ruellia sororia Standl.

Achariaceae
Chiangiodendron mexicanum T. Wendt

Achatocarpaceae
Phaulothamnus spinescens A. Gray

Amaryllidaceae
Sprekelia clintiae Traub

Anacardiaceae
Pseudosmodingium andrieuxii Engl.

Apiaceae
Eryngium humile Cav.
Eryngium mexicanum S. Watson

Apocynaceae
Thenardia gonoloboides Woodson

Asparagaceae
Beaucarnea purpusii Rose
Beschorneria tubiflora Kunth **(Pr)**
Dasylirion inerme S. Watson
Hemiphylacus mahindae L. Hern.
Hemiphylacus novogalicianus L. Hern.
Jaimehintonia gypsophila B.L. Turner
Milla magnifica H.E. Moore
Milla rosea H.E. Moore
Nolina humilis S. Watson
Nolina lindheimeriana S. Watson
Nolina pliabilis (Baker) Lundell
Nolina pumila Rose
Yucca baccata Torr.
Yucca capensis L.W. Lenz

Asteraceae
Ageratum albidum (DC.) Hemsl.
Ageratum conyzoides L.
Ageratum maritimum Kunth
Ageratum microcephalum Hemsl.
Ageratum munaense R.M. King & H. Rob.
Ageratum paleaceum (Gay ex DC.) Hemsl.
Ageratum tomentosum (Benth.) Hemsl.
Alomia hintonii R.M. King & H. Rob.
Alvordia angusta S.F. Blake
Amauria carterae A.M. Powell
Arnicastrum glandulosum Greenm.
Axiniphyllum pinnatisectum (Paul G. Wilson) B.L. Turner
Axiniphyllum sagittalobum B.L. Turner
Axiniphyllum tomentosum Benth.
Baeriopsis guadalupensis J.T. Howell
Bahiopsis carterae (E.E. Schill.) E.E. Schill. & Panero
Bahiopsis chenopodina (Greene) E.E. Schill. & Panero
Bahiopsis laciniata (A. Gray) E.E. Schill. & Panero

Appendix. Continuation.

Bahiopsis lanata Kellogg
Bahiopsis tomentosa (A. Gray) E.E. Schill. & Panero
Brickellia adenolepis (B.L. Rob.) Shinners
Brickellia adontophylla A. Gray
Brickellia amblyoleopsis (B.L. Rob.) R.M. King & H. Rob.
Brickellia aramberrana B.L. Turner
Brickellia cardiophylla B.L. Rob.
Brickellia coahuilensis (A. Gray) Harc. & Beaman
Brickellia floribunda A. Gray
Brickellia frutescens A. Gray
Brickellia glabrata (Rose) B.L. Rob.
Brickellia glutinosa A. Gray
Brickellia hastata Benth.
Brickellia hebercarpa (DC.) A. Gray
Brickellia kellermanii Greenm.
Brickellia pedunculosa (DC.) Harc. & Beaman
Brickellia peninsularis Brandegee
Brickellia rusbyi A. Gray
Brickellia simplex A. Gray
Brickellia urolepis S.F. Blake
Brickellia vernicosa B.L. Rob.
Brickellia wislizeni A. Gray
Calanticaria brevifolia (Greenm.) E.E. Schill. & Panero
Conoclinium mayfieldii T.F. Patterson
Correllia montana A.M. Powell
Eryngiophyllum pinnatisectum Paul G. Wilson
Eryngiophyllum rosei Greenm.
Eupatoriastrum triangulare (DC.) B.L. Rob.
Faxonia pusilla Brandegee
Gonzalezia hypargyrea (Greenm.) E.E. Schill. & Panero
Gonzalezia rosei (Greenm.) E.E. Schill. & Panero
Gymnolaena serratifolia Rydb.
Gymnolomia scaposa Brandegee
Henricksonia mexicana B.L. Turner
Hofmeisteria gayleana B.L. Turner
Hybridella anthemidifolia (B.L. Rob. & Greenm.) Olsen
Hydropectis aquatica Rydb.
Jaliscoa goldmanii (B.L. Rob.) R.M. King & H. Rob.
Jaliscoa paleacea (Cronquist) R.M. King & H. Rob.
Jaliscoa pappifera S.F. Blake
Jefea gnaphalioides (A. Gray) Strother
Jefea pringlei (Greenm.) Strother
Lundellianthus breedlovei (B.L. Turner) Strother
Lundellianthus guatemalensis (Donn. Sm.) Strother
Lundellianthus salvinii (Hemsl.) Strother
Marshalljohnstonia gypsophila Henrickson
Mexerion sarmentosum (Klatt) G.L. Nesom
Nesomia chiapensis B.L. Turner
Otopappus acuminatus S. Watson
Otopappus pittieri (Greenm.) B.L. Turner
Paneroa stachyofolia (B.L. Rob.) E.E. Schill.
Perymenium ovalifolium (A. Gray) B.L. Turner
Philactis zinnioides Schrad.
Pittocaulon bombycophole (Bullock) H. Rob. & Brettell
Pleurocoronis gentryi (Wiggins) R.M. King & H. Rob.
Pleurocoronis pluriseta (A. Gray) R.M. King & H. Rob.
Psacaliopsis purpusii (Greenm. ex Brandegee) H. Rob. & Brettell
Psacalium brachycomum (S.F. Blake) H. Rob. & Brettell
Psacalium calvum (Brandegee) Pippen
Psacalium decompositum (A. Gray) H. Rob. & Brettell
Psacalium globosum (B.L. Rob. & Fernald) H. Rob. & Brettell
Psacalium hintonii (Pippen) H. Rob. & Brettell
Psacalium hintoniorum B.L. Turner
Psacalium pachyphyllum (Sch. Bip.) Rydb.
Psacalium paucicapitatum (B.L. Rob. & Greenm.) H. Rob. & Brettell
Psacalium peltigerum (B.L. Rob. & Seaton) Rydb.
Psacalium radulifolium (Kunth) H. Rob. & Brettell
Psacalium tussilaginoides (Kunth) H. Rob. & Brettell
Robinsonecio porphyresthes (T.M. Barkley) T.M. Barkley & Janovec
Squamopappus skutchii (S.F. Blake) R.K. Jansen, N.A. Harriman & Urbatsch
Sidneya tenuifolia (A. Gray) E.E. Schill. & Panero
Stenocarpha ritovegana B.L. Turner

Appendix. Continuation.

Stephanodoria tomentella Greene
Stevia chilapensis Soejima & Yahara
Stevia coahuilensis Soejima & Yahara
Stevia crassifolia Soejima & Yahara
Stevia ecatepecana Soejima, Yahara & K. Watan.
Stevia filodecaballoana Soejima, Yahara & K. Watan.
Stevia mascotensis Soejima & Yahara
Stevia mexicana Soejima, Yahara & K. Watan.
Stevia oaxacana Soejima & Yahara
Stevia oligophylla Soejima & Yahara
Stevia potosina Soejima, Yahara & K. Watan.
Stevia rotundifolia Soejima, Yahara & K. Watan.
Stevia scabrelloides Soejima & Yahara
Stevia viejoana Soejima, Yahara & K. Watan.
Steviopsis adenosperma (Sch. Bip.) B.L. Turner
Steviopsis amblyolepis (B.L. Rob.) R.M. King & H. Rob.
Steviopsis nesomii B.L. Turner
Steviopsis squamulosa (A. Gray) B.L. Turner
Steviopsis vigintiseta (DC.) R.M. King & H. Rob.
Stuessya apiculata (S.F. Blake) B.L. Turner & F.G. Davies
Stuessya perennans B.L. Turner & F.G. Davies
Tetrachyron chimalapanum B.L. Turner
Tetrachyron grayi (Klatt) Wussow & Urbatsch
Tetrachyron orizabensis (Klatt) Wussow & Urbatsch
Tuxtla pittieri (Greenm.) Villaseñor & Strother
Wamalchitamia appressipila (S.F. Blake) Strother
Wamalchitamia aurantiaca (Klatt) Strother
Wamalchitamia dionysi Strother
Zexmenia virgulta Klatt

Boraginaceae
Lasiarrhenum confundum B.L. Turner
Lashiarrhenum pinetorum I.M. Johnst.
Mimophytum omphalodoides Greenm.

Brassicaceae
Lexarzanthe mexicana (Iltis & Al-Shehbaz) Diego & Calderón
Raphanorhyncha crassa Rollins

Burseraceae
Beiselia mexicana Forman
Bursera rzedowskii C.A. Toledo

Cactaceae
Astrophytum asterias Lem. **(P)**
Aztekium hintonii (Glass & W.A. Fitz Maur.) **(Pr)**
Aztekium ritteri Boed. **(A)**
Cumarinia odorata (Boed.) Buxb. **(Pr)**
Geohintonia mexicana Glass & W.A. Fitz Maur. **(Pr)**
Leuchtenbergia principis Hook. **(A)**
Neobuxbaumia multiareolata (Daws.) Bravo, Scheinvar & Sánchez-Mej.
Obregonia denegrii Frič & A. Berger **(A)**
Pachycereus tepamo S. Gama-López & S. Arias
Pelecyphora aselliformis Ehrenb. **(Pr)**
Pelecyphora strobiliformis (Werderm.) Frič & Schelle ex Kreuz. **(A)**
Thelocactus hastifer (Werderm. & Boed.) F.M. Knuth **(A)**
Turbinicarpus alonsoi Glass & S. Arias
Turbinicarpus hoferi Lüthy & A.B. Lau **(A)**
Turbinicarpus lophophoroides (Werderm.) Buxb. & Backeb. **(Pr)**
Turbinicarpus pseudopectinatus (Backeb.) Glass & R.A. Foster **(Pr)**

Caryophyllaceae
Cerdia virescens Moc. & Sessé

Convolvulaceae
Ipomoea decemcornuta O'Donell

Crassulaceae
Cremnophila linguifolia (Lem.) Moran
Cremnophila nutans (Rose) Rose
Graptopetalum amethystinum E. Walther
Graptopetalum bartramii Rose
Pachyphytum amethystinum Rose
Pachyphytum brachetii J. Reyes, O. González & A. Gut.
Pachyphytum brevifolium Rose
Pachyphytum caesium Kimnach & Moran
Pachyphytum coeruleum J. Meyrán
Pachyphytum contrerasii Pérez-Calix, I. García & Cházaro
Pachyphytum fittkaui Moran

Appendix. Continuation.

Pachyphytum garciae Pérez-Calix & Glass
Pachyphytum hookeri A. Berger
Pachyphytum kimnachii Moran
Pachyphytum longifolium Rose
Pachyphytum machucae I. García, Glass & Cházaro
Pachyphytum oviferum J.A. Purpus
Pachyphytum rzedowskii I. García, Pérez-Calix & J. Meyrán
Pachyphytum saltense Brachet, J. Reyes & Mondragón
Pachyphytum werdermannii Poelln.
Thompsonella garcia-mendozae P. Carrillo & Pérez-Calix
Thompsonella mixtecana J. Reyes & L. López
Thompsonella spathulata Kimnach
Thompsonella xochipalensis M. Gual Diaz, S. Peralta & Pérez-Calix

Crossosomataceae
Velascoa recondita Calderón & Rzed.

Cucurbitaceae
Cucurbita fraterna L.H. Bailey
Cucurbita pedatifolia L.H. Bailey
Apatzingania arachoidea I.M. Johnston
Vaseyanthus brandegeei Rose

Cyperaceae
Cypringlea evadens (C.D. Adams) Reznicek & S. González

Euphorbiaceae
Euphorbia coalcomanensis (Croizat) V.W. Steinm. **(A)**
Euphorbia cyri V.W. Steinm. **(E)**
Euphorbia dressleri V.W. Steinm. **(E)**
Euphorbia finkii (Boiss.) V.W. Steinm. **(A)**
Euphorbia peritropoides (Millsp.) V.W. Steinm.
Euphorbia personata (Croizat) V.W. Steinm.
Euphorbia tehuacana (Brandegee) V.W. Steinm. **(A)**
Euphorbia tithymaloides L.

Fabaceae
Acaciella barrancana (Gentry) L. Rico
Acaciella goldmanii Britton & Rose
Acaciella igualensis Britton & Rose
Acaciella sotoi L. Rico
Calliandropsis nervosus (Britton & Rose) H.M. Hern. & P. Guinet
Dalea laniceps Barneby
Dalea parrasana Brandegee
Hesperothamnus ehrenbergii (Harms) Harms
Hesperothamnus littoralis (Brandegee) Brandegee
Hesperothamnus purpusii (Harms) Harms
Marina brevis León de la Luz
Marina capensis Barneby
Marina catalinae Barneby
Marina divaricata (Benth.) Barneby
Marina interstes Barneby
Marina oculata (Rydb.) Barneby
Mariosousa acatlensis (Benth.) Seigler & Ebinger

Fagaceae
Quercus clivicola Trel. & C.H. Mull.
Quercus radiata Trel.
Quercus tarahumara Spellenb., J.D. Bacon & Breedlove
Quercus verde C.H. Mull.

Fouquieriaceae
Fouquieria leonilae Miranda **(Pr)**
Fouquieria purpusii Brandegee **(P)**

Gentianaceae
Geniostemon atarjanus B.L. Turner
Geniostemon rotundifolius Rzed. & Calderón

Gesneriaceae
Achimenes candida Lindl.
Achimenes hintoniana Ramírez Roa & L.E. Skog
Achimenes nayaritensis L.E. Skog
Achimenes occidentalis C.V. Morton
Achimenes pedunculata Benth.
Smithiantha aurantiaca Wiehler

Iridaceae
Ainea conzattii (R.C. Foster) Ravenna **(A)**

Iteaceae
Pterostemon bravoanus J. Jiménez Ram. & M. Martínez

Appendix. Continuation.

Lamiaceae
Salvia canescens C.A. Mey.
Salvia dolichantha E. Peter
Salvia univerticillata Ramamoorthy ex Klitg.

Lauraceae
Mocinnodaphne cinnamomoidea Lorea-Hern.

Liliaceae
Hesperaloe tenuifolia G.D. Starr

Loasaceae
Schismocarpus matudae Steyerm.
Schismocarpus pachypus S.F. Blake

Malphighiaceae
Lasiocarpus multiflorus Nied.
Lasiocarpus ovalifolius Nied.

Malvaceae
Bastardiastrum tarasoides Fryxell
Bastardiastrum tricarpellatum (B.L. & Rob. & Greenm.) D.M. Bates
Periptera lobelioides Fryxell & S.D. Koch
Periptera trichostemon Bullock

Nyctaginaceae
Grajalesia fasciculata (Standl.) Miranda
Grajalesia ferruginea Miranda

Oleaceae
Hesperelaea palmeri A. Gray **(P)**

Onagraceae
Lopezia clavata Brandegee
Lopezia lopezioides (Hook. & Arn.) Plitmann, P.H. Raven & Breedlove
Lopezia ovata (Plitmann, P.H. Raven & Breedlove) Plitmann, P.H. Raven & Breedlove
Lopezia smithii Rose
Lopezia suffrutescens Munz
Megacorax gracielanus S. González & W.L. Wagner

Orchidaceae
Hagsatera rosilloi R. González
Mexipedium xerophyticum (Soto Arenas, Salazar & Hágsater) V.A. Albert & M.W. Chase **(P)**
Nezahualcoyotlia gracilis (L.O. Williams) R. González
Physogyne garayana R. González & Szlach.
Physogyne sparsiflora (C. Schweinf.) Garay
Svenkoeltzia luzmariana R. González
Svenkoeltzia pamelae Szlach., Rutk. & Mytnik

Orobanchaceae
Castilleja filiflora G.L. Nesom
Castilleja hidalgensis J.M. Egger
Castilleja macrostigma B.L. Rob.
Castilleja ornata Eastw.
Castilleja perelegans G.L. Nesom
Castilleja sphaerostigma Eastw.
Castilleja stipifolia G.L. Nesom
Castilleja tancitaroana G.L. Nesom
Eremitilla mexicana Yatsk. & J.L. Contr.
Lamourouxia brachyantha Greenm.
Lamourouxia macrantha M. Martens & Galeotti
Lamourouxia nelsonii B.L. Rob. & Greenm.

Phytolaccaceae
Nowickea glabra J. Martínez & J.A. McDonald
Nowickea xolocotzii J. Martínez & J.A. McDonald

Poaceae
Muhlenbergia brevis C.O. Goodd.
Muhlenbergia majalcensis P.M. Peterson
Olmeca clarkiae (Davidse & R.W. Pohl) Ruiz-Sanchez, Sosa & Mejía-Saules
Olmeca zapotecorum Ruiz-Sanchez, E., Sosa & Mejía Saules
Otatea glauca L.G. Clark & G. Cortés
Otatea ramirezii Ruiz-Sanchez
Otatea transvolcanica Ruiz-Sanchez & L.G. Clark
Otatea ximenae Ruiz-Sanchez & L.G. Clark

Rhamnaceae
Karwinskia calderonii Urb.
Karwinskia johnstonii R. Fernandez

Appendix. Continuation.

Rubiaceae
Carterella alexanderae (A.M. Carter) Terrell
Habroneuron radicans (Wernham) S.P. Darwin
Omiltemia parvifolia Borhidi & K.Velasco
Placocarpa mexicana Hook. f.
Stenotis gracilenta (I.M. Johnst.) Terrell
Stenotis peninsularis (Brandegee) Terrell
Stylosiphonia glabra Brandegee

Rutaceae
Ptelea baldwinii Torr. & A. Gray
Ptelea confinis Greene
Ptelea megacarpa Rose ex Greene
Ptelea obscura Greene
Ptelea obtusata Greene
Ptelea subintegra Greene

Sapindaceae
Balsas guerrerensis Cruz Durán & K. Vega

Scrophulariaceae
Leucophyllum alejandrae G.L. Nesom
Leucophyllum flyrii B.L. Turner
Leucophyllum hintoniorum G.L. Nesom
Leucophyllum langmaniae Flyr
Leucophyllum lanosum Flyr
Leucophyllum mojinense Henrickson & T. Van Devender
Leucophyllum ultramonticola Flyr
Leucophyllum virescens I.M. Johnst.

Solanaceae
Physalis heterophylla Nees
Physalis virginiana Mill.
Physalis walteri Nutt.
Solanum johnstonii Whalen
Solanum morelliforme Bitter & Münch
Solanum tribulosum S. Schauer
Tzeltalia amphitricha (Bitter) E. Estrada & M. Martínez
Tzeltalia calidaria (Standl. & Steyerm.) E. Estrada & M. Martínez

Zygophyllaceae
Morkillia acuminata Rose & Painter
Viscainoa pinnata Gentry