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Is geographical rarity frequent among the cacti of the Chihuahuan Desert?

¿Es la rareza geográfica frecuente entre las cactáceas del Desierto Chihuahuense?

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Abstract. With the aim of assessing the extent of geographical rarity of Mexican Cactaceae, we calculated the distribution size (area of occupancy) of 142 species from the Chihuahuan Desert. In addition, using 2 variables (number of localities and range size), we preliminarily assessed their conservation status using the current IUCN Red List criteria. The results showed enormous variation in the areas of occupancy, although from the biogeographic and conservation perspective the most exceptional group comprises the extremely narrow endemics (42 species), whose range is restricted to areas smaller than 10 km^2. Our results reinforce the reputation of this plant family as exceptionally rare geographically. We suggest that geographical rarity of Cactaceae in the Chihuahuan Desert is a natural phenomenon; however, we propose that the range of several species has been influenced by human activities. Regarding the conservation status of the species, 75 of them are categorized as Least concern. The remaining 67 species (47.2%) fall in 1 of the 3 categories of threat (27 Vulnerable, 11 Endangered, and 29 Critically endangered). These figures confirm the critical conservation status of Mexican Cactaceae.

Key words: areas of occupancy, cacti, Chihuahuan Desert, distribution size, Mexico, IUCN Red List.

Resumen. Se calculó el tamaño de la distribución (área de ocupación) de 142 especies de cactáceas del Desierto Chihuahuense, con el objeto de evaluar su grado de rareza geográfica. Además, mediante el uso de 2 variables (número de localidades y tamaño de distribución), se estimó de manera preliminar su estado de conservación usando los criterios actuales de la Lista Roja de la UICN. Los resultados mostraron gran variación en las áreas de ocupación. Sin embargo, desde una perspectiva biogeográfica y de la conservación, el grupo de especies más excepcional corresponde a las endémicas restringidas (42 spp.), cuyas áreas de distribución son menores de 10 km^2. Los resultados fortalecen la reputación de las cactáceas de ser una familia de plantas excepcionalmente rara geográficamente. Se sugiere que la rareza geográfica en cactáceas es un fenómeno natural; sin embargo, se propone que la distribución de algunas de las especies ha sido influenciada por actividades humanas. En lo que respecta al estado de conservación de las especies, 75 pueden ser consideradas bajo la categoría de Preocupación menor, mientras que las restantes 67 (47.2%) caen en alguna de las categorías de amenaza (Vulnerable = 27 spp., Amenazada = 11 spp., Críticamente amenazada = 29 spp.). Los resultados confirman el grave estado de conservación de las cactáceas mexicanas.

Palabras clave: áreas de ocupación, cactáceas, Desierto Chihuahuense, México, tamaño de distribución, Lista Roja de la UICN.

Introduction

Rare species are usually defined as those having low local abundance, small range size, and/or high habitat specificity (Rabinowitz, 1981; Gaston, 1994). Rarity and conservation are closely linked, because rare species have a greater likelihood of extinction than common ones (Gaston, 1994). In fact, the degree of rarity of the species has often been a useful parameter for their assignment to different categories of threat (IUCN, 2001). Investigations on the Cactaceae from the Chihuahuan Desert Region (CDR) have provided a considerable amount of quantitative and qualitative data suggesting that a significant number of cactus species is particularly rare geographically and ecologically (Hernández and Godínez, 1994; Hernández and Bárcenas, 1995, 1996; Bárcenas, 1999; Gómez-Hinostrosa and Hernández, 2000; Hernández et al., 2001, 2004, 2008; Hernández and Gómez-Hinostrosa, 2004; Goettsch and Hernández, 2006). Specifically, geographical rarity, recognized as the occurrence of particular species in relatively small areas, has been conceived as a recurring fact in Mexican Cactaceae. However, we are just starting to understand the real magnitude of this phenomenon and the way it is expressed in the CDR.

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Essentially confined to the New World, the cactus family comprises an estimated number of 1 500 species (Anderson, 2001; Hunt, 2006). Mexico has unequivocally been identified as the main centre of diversity of Cactaceae and a focal point for the conservation of members of this plant family. This country, primarily its dry areas, is home of almost 40% of the global diversity. In particular, the CDR, the largest desert region in North America, is home of the richest assemblage of Cactaceae worldwide. Hernández et al. (2004) reported 329 cactus species and 39 genera for the region, with 70% of the species and 43% of the genera being strictly endemic.

In a recent investigation (Hernández and Navarro, 2007), we calculated the distribution size of some Chihuahuan Desert cacti, confirming that some species have extremely limited geographical ranges; however, we still lack comprehensive information about the extent of geographical rarity of Cactaceae in the region. In this paper we estimate the area of occupancy (AOO) of a representative selection of Chihuahuan Desert cacti, ranging from widely distributed species to extremely narrowly endemic ones. The results allowed us to obtain a broad perspective of the nature and magnitude of geographical rarity of the Cactaceae in the Chihuahuan Desert. In addition, using 2 biogeographical variables (number of localities and AOO), we preliminarily assessed the conservation status of all of the studied species using the IUCN Red List current criteria.

Material and methods

Study area. The Chihuahuan Desert is a vast area extending from central Mexico, in the states of Guanajuato, Querétaro, and Hidalgo north to southern Texas, New Mexico, and a small part of Arizona. To the west and east, the region is bordered by the Sierra Madre Occidental and the Sierra Madre Oriental, and it has an approximate extension of 533 600 km^2 (the area was recalculated by us in this paper, but see Hernández and Gómez-Hinostrosa, 2005; Hernández, 2006). From the conservation perspective, the CDR stands among the 3 most remarkable deserts in the world, thanks to its relatively high biodiversity, numerous endemic species, and the existence of extensive well preserved areas (Dinerstein et al., 1999; Mittermeier et al., 2002). Thorough descriptions of the climatological, ecological, biogeographical, and vegetational characteristics of the CDR have been provided by numerous authors (e. g., Shreve, 1942; Johnston, 1977; Schmidt, 1979; Medellín-Leal, 1982; Henrickson and Johnston, 1986; Hernández and Gómez-Hinostrosa, 2005; Hernández, 2006).

Species selection. A total of 142 cactus species from the CDR were selected for this study, of which 129 (85.2%) are endemic to the region (Appendix 1). The species were chosen because they were reasonably well defined taxonomically and adequately represented by herbarium collections. We excluded several species from the analysis, either because they were taxonomically problematic or because they were underrepresented in the database. This was the case of several extremely wide-ranging species, such as *Opuntia lasiacantha*, *O. rastrera*, *O. streptacantha*, *Cylindropuntia imbricata*, and *C. tunicata*, as well as several narrowly distributed ones (e.g., *Coryphantha wohlschlageri, Mammillaria longiflora, M. stella-de-tacubaya, M. roseoalba*, etc.). Data on the general geographic distribution of all of the studied species may be found in Hernández et al. (2004) and are also summarized in the Appendix 1. Taxonomic nomenclature follows Hunt (2006).

Definitions. We followed the IUCN (2001) definition of area of occupancy, as the area occupied by a taxon within its more general extent of occurrence. The concept recognizes the fact that organisms usually are absent in some areas within its usually broader extent of occurrence, where uncolonized or unsuitable habitats exist. We consider AOO as a synonym of distribution or range size. Also, we define locality as a graphic point on a map, taken from a geo-referenced herbarium record, and separated by its nearest neighbour by at least 797.9 m, the radius of a 2-km^2 circle. Points located within this radius were considered part of the same locality. In concordance with the UICN (2001) convention, we considered a 2-km^2 area as a reasonable measure to quantify individual localities.

Data sources. Geo-referenced specimen data were taken from a database of cactus collections from North and Central America. The database contained at the time of this study over 26 300 herbarium records of Cactaceae from 35 herbaria, including our own collections resulting from extensive fieldwork conducted in the CDR over the last 15 years. A total of 6 496 geo-referenced records were taken from the database for this study (Fig. 1). The specimens included in the database had been collected between 1823 and 2007, with 35.4% collected between 1950 and 1989, and 41.9% since 1990 to the present. We estimate that in the CDR the collecting effort is one herbarium specimen of Cactaceae per every 61.1 km^2 (total area = 533 600 km^2).

Cartographic method by conglomerates. For the calculation of the species geographic ranges, we used the cartographic method by conglomerates (CMC) proposed by Hernández and Navarro (2007). This method incorporates elements of the areographic and cartographic methods, previously used by different authors to calculate

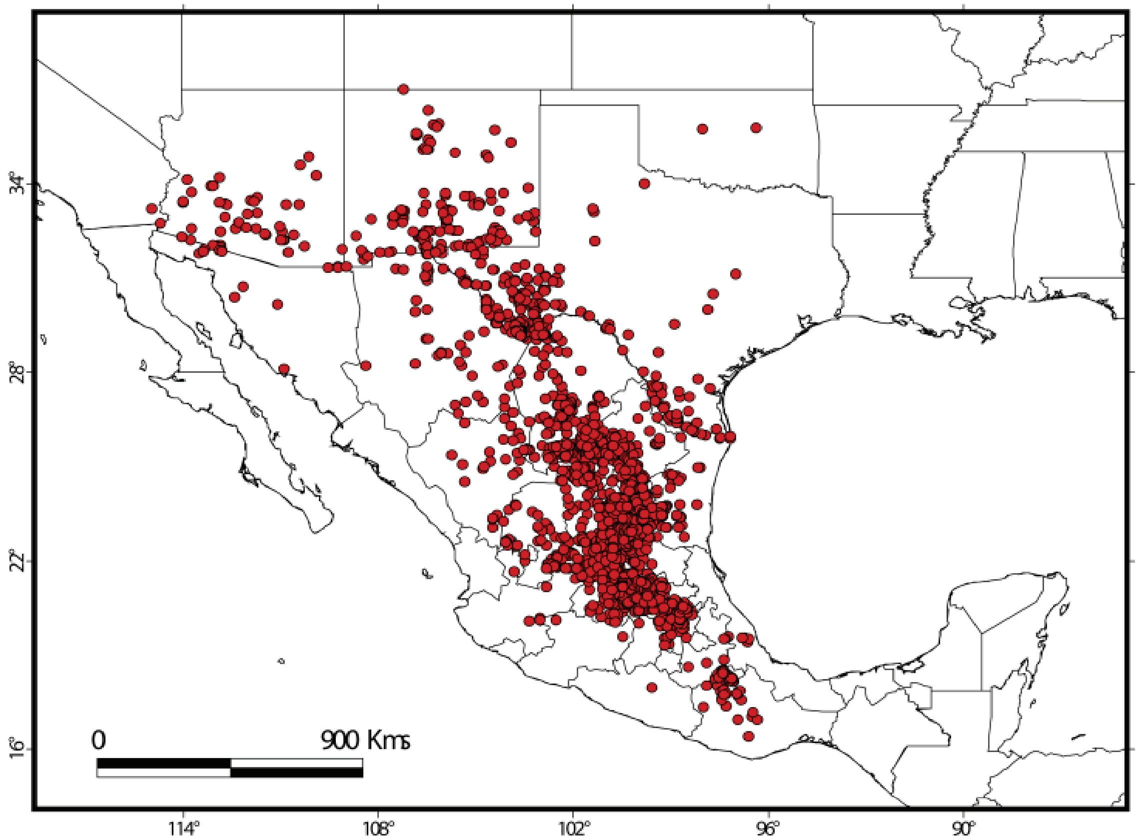

Figure 1. Point occurrences of the studied species. Each circle represents the occurrence of 1 or several species in a given locality.

distribution size. The CMC allows the recognition of discrete aggregations of 2 or more points (*conglomerates*) as well as isolated, single localities (*satellites*), both of which are clearly and objectively identifiable. The CMC procedure consisted of the following steps:

1. The geo-referenced data points of each species were plotted over a digital map. All available records of each species were used to plot the distribution maps.
2. Points were interconnected to form an open, minimum spanning tree (Rapoport, 1975), where all points were united by their shortest distance to their nearest neighbor. In minimum spanning trees all the points are interconnected and no loops should be formed (Fig. 2a).
3. Minimum distances between pairs of points were measured and the average distance (mean propinquity index) was calculated. The resulting average figure was used as a radius to trace a circle around each point (Fig. 2b). Thus, the size of the circles surrounding each point depended on the spatial configuration of the localities of each particular species.
4. At this stage of the procedure the disjunct conglomerates of 2 or more partially overlapping circles and the single, isolated satellites were clearly identifiable. In the example of Figure 2b, *Astrophytum capricorne* had 3 distinct conglomerates and 2 satellites.
5. The area of each conglomerate was calculated individually by superimposing a grid over the map containing the recorded localities. However, an appropriate scale (grid cell size) must be previously defined, due to the fact that area calculation is scale-dependent (see Hernández and Navarro, 2007). To determine the scale for each conglomerate, the distance between the 2 more distant points in that conglomerate was measured (Fig. 2c), and 10% of that maximum distance defined the grid cell size in each conglomerate. Thus, in the example of *Astrophytum capricorne* (Fig. 2d) the largest distance between points within each conglomerate (54.8, 98.3, and 19.96 km) determined 3 different scales: 5.48 for the

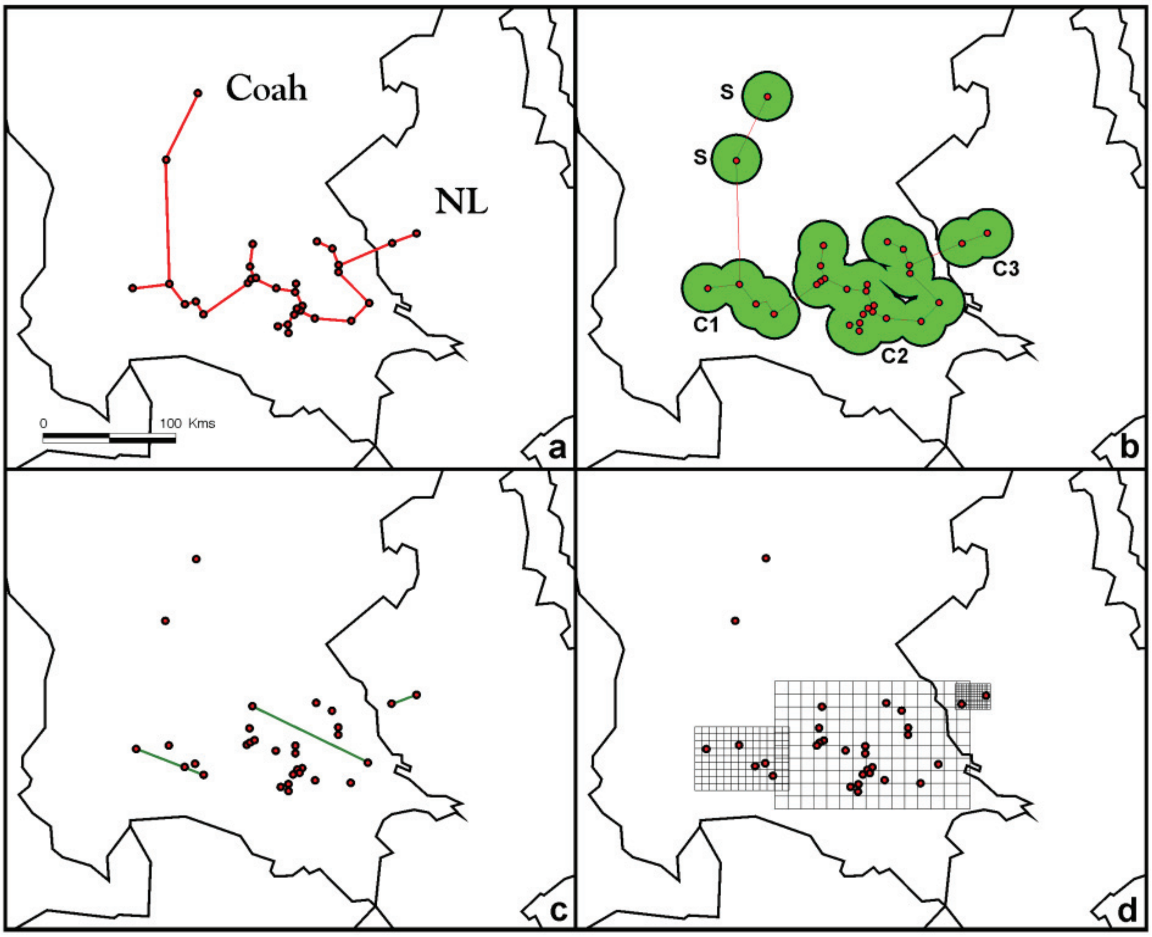

Figure 2. Cartographic method by conglomerates applied to *Astrophytum capricorne*. (a), minimum spanning tree. (b), the overlapping circles define 3 conglomerates (C) and distinguish them from the isolated satellites (S). (c), the distance between the most distant localities within each conglomerate is measured. (d), ten percent of that distance is the scale in each conglomerate.

western (C1) conglomerate (grid cell size = 5.48 x 5.48 = 30.03 km^2), 9.83 for the central (C2) conglomerate (grid cell size = 9.83 x 9.83 = 96.629 km^2), and 1.996 for the eastern (C3) one (grid cell size = 1.996 x 1.996 = 3.984 km^2).

6. Finally, the area occupied by the species in each conglomerate was calculated by adding the grid cell areas where the species was present. As for the satellites, each was assigned a constant area of 2 km^2. The AOO of the species was then calculated as the sum of the areas of all of its conglomerates and satellites.

The CMC was applied to all of the species whose distribution area was represented by at least 2 localities on a map. However, we found that our method was inapplicable to several species known to have extremely discontinuous distributions that very often inhabit extremely specialized habitats, such as gypsum and other unusual soil formations. These exceptional cases are exemplified by *Ariocarpus kotschoubeyanus*, a species known from some 35 discrete locations, in 6 different states, across a large portion of the CDR. This plant is an edaphic specialist growing almost exclusively in silty, dry lake beds, which are found widely scattered throughout the desert areas in northern Mexico. The indiscriminate application of our method to species such as *A. kotschoubeyanus* would produce unrealistically large AOO estimations, in this particular case AOO= 3 104.9 km^2. In cases such as this one we decided as an alternative to consider each individual locality as a 2-km^2 satellite. Consequently, the resulting area for *A. kotschoubeyanus* upon applying this criterion, and considering that some of the satellites overlap partially, is 67.95 km^2, a more convincing result for this rare and ecologically specialized species (see Hernández and Navarro, 2007). This same principle was also applied to the species known from a single locality. The species in Appendix 1 marked with a cross (†) are those to which all their localities were considered as satellites.

A Geographic Information System (ArcView 3.2) was used at all stages of the AOO calculation. This tool allowed us to plot the point distribution maps, measure all distribution parameters, and generate the grids with maximum accuracy. Minimum spanning trees were constructed with the aid of the ArcView extension "Trazos 2004" by Camilo Rojas (http://panbiog.infobio.net/?Software). For more information on the CMC application, readers are requested to see Hernández and Navarro (2007).

Results

Number of localities. The number of herbarium records available for a particular species depends on several factors, such as the size and accessibility of its geographical range, its local abundance, its visibility (small, cryptic species vs. large, conspicuous ones), and its maneuvrability (spineless or weakly-spined species vs. rigidly-spined species). In other words, the probability of a cactus plant reaching a herbarium cabinet is higher when it is geographically and ecologically common, conspicuous, and easy to process into a herbarium specimen. Considering these factors, the number of known localities per species showed substantial variation, ranging from a single locality, as was the case of 21 species, to 267 in the widespread, treelike *Myrtillocactus geometrizans* (Appendix 1). The average number of localities per species was 41.9 (± S.D. = 63.1, n = 142).

A good preliminary indicator of the degree of geographical rarity of the Cactaceae from the CDR is the number of localities known for each particular species. In fact, a simple linear regression model showed that there is a highly significant correlation between the number of localities (log_{10} transformed) of each particular species and their estimated log_{10} AOO ($r^2 = 0.789$, $F_{(1,140)} = 522.59$, $P < 0.001$), suggesting that the number of herbarium records may be used to predict range size. If the high correlation between the number of localities and AOOs is considered, our results suggest a clear tendency among cacti in the CDR to have restricted geographical ranges. Thus, almost half of the studied species (67 spp. or 47.8% of the sample) are known from 10 or less discrete localities (Fig. 3); of these, 33 species (23.2%) occur only in 3 or fewer localities, and 21 species (14.8%) in a single locality. In contrast, only 17 species (12%) are represented by a number of localities ranging from 100 to 200, and just seven wide-ranging species (4.9%) have been registered in 201 or more localities: *Echinocactus platyacanthus, Echinocereus pentalophus, Mammillaria crinita, M. formosa, Myrtillocactus geometrizans, Opuntia stenopetala,* and *Sclerocactus uncinatus*.

Areas of occupancy. As shown in the Appendix 1, the estimated AOOs vary continuously from tiny areas measuring less than 1 km^2 (e. g., *Ariocarpus bravoanus* and *Mammillaria carmenae*) to larger ones covering extensive portions of the CDR [e.g., *Cylindropuntia kleineae* (AOO= 132 702 km^2), *Peniocereus greggii* (AOO= 126 337 km^2), and *Sclerocactus uncinatus* (AOO= 102 881 km^2)]. The average AOO was 8 015 km^2 (± S.D. = 20 421; n = 142).

The great majority of the species (117 spp. or 82.4%) are restricted to areas smaller than 10 000 km^2, roughly the surface of a one-degree grid square at 35-36° latitude (Fig. 4). Among these, 59 spp. have ranges smaller than 100 km^2, representing 41.6% of the studied species. Remarkably, 42 species, nearly a third of the total sample (29.6%), are extremely narrow endemics whose geographic range is restricted to areas smaller than 10 km^2 (Appendix 1 and Fig. 4).

IUCN Red List. The data presented in the Appendix 1 are particularly useful in evaluating the conservation status of the species, using the Red List criteria (IUCN, 2001). In connection to this, we preliminarily categorized the conservation status of the 142 cactus species studied in this investigation. We accomplished this by comparing the AOO estimations and the number of known localities given in the Appendix 1 with the thresholds set by the IUCN (criterion B) for Vulnerable species (< 2 000 km^2, and < 10 localities), Endangered (< 500 km^2, and < 5 localities), and Critically Endangered (< 10 km^2, and 1 locality). Thus, according to these 2 variables, 75 species, those having the widest geographic ranges and the highest number of localities are categorized as Least concern. The remaining 67 species (47.2%) fall in any one of the 3 categories of threat (Vulnerable = 27 spp., Endangered = 11 spp., and Critically endangered = 29 spp.).

Discussion

Performance of the Cartographic method by conglomerates. Just as the typical cartographic (point-to-grid) method is greatly influenced by sampling effort, the method used here to calculate AOO also produced

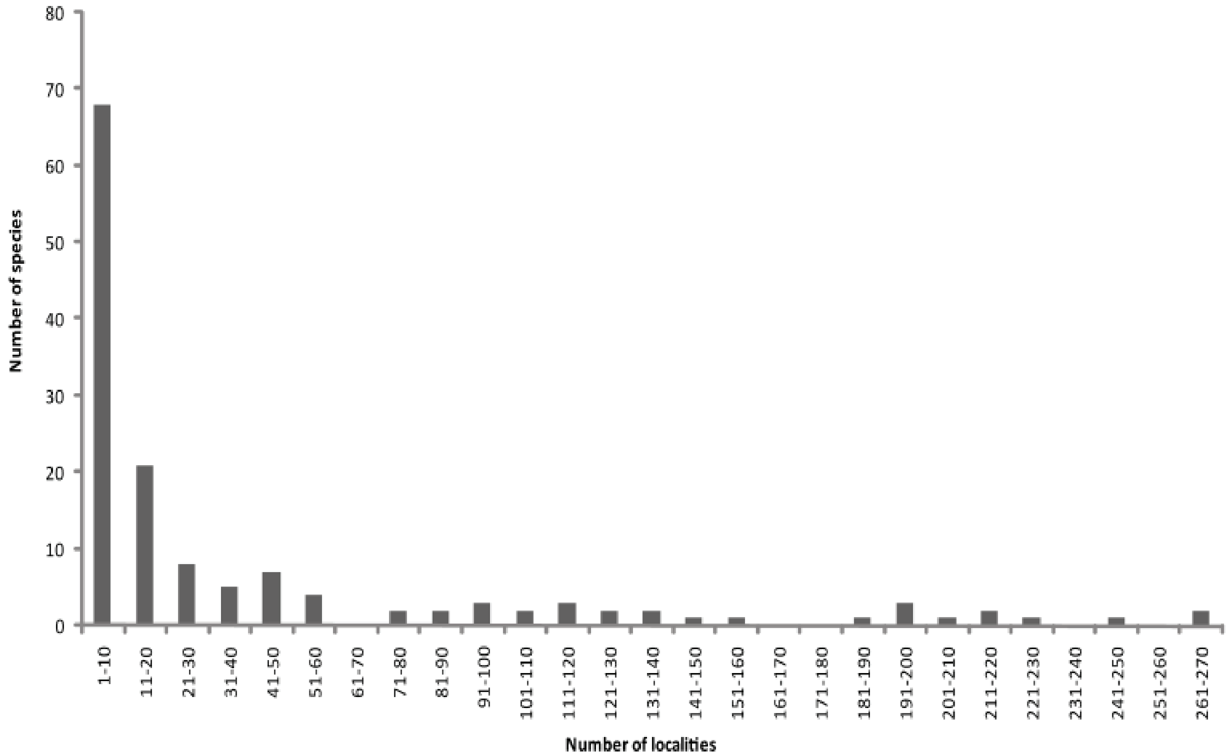

Figure 3. Frequency distribution of the number of known localities of cactus species in the Chihuahuan Desert Region (*n* = 142).

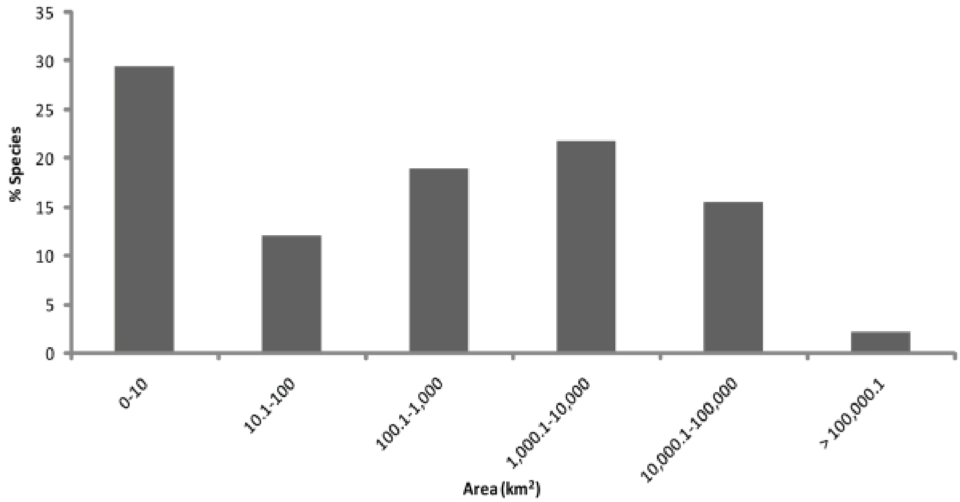

Figure 4. Frequency distribution of areas of occupancy (*n* = 142).

underestimates when sampling was poor or spatially biased (Graham and Hijmans, 2006). However, we believe that the relatively high number of records available for this study assure the relative accuracy of our AOO estimations (Fig. 1). As indicated in the methods, 6 496 geo-referenced records were used in our study, of which only 519 (8%) were redundant (same species, same locality); thus, we used in the mapping process 5 977 non-redundant records. On this basis, we consider that the database is complete enough to provide a reasonably accurate picture of the geographic ranges of the species, irrespective of whether they are widespread or narrow endemics. It has to be recognized, however, that there are extensive areas in the CDR that still are insufficiently explored (Fig. 1), as compared to intensively sampled regions such as Huizache and Mier y Noriega, for example (Hernández et al., 2001; Gómez-Hinostrosa and Hernández, 2000).

After using the CMC with a high number of species, we maintain Hernández and Navarro's (2007) argument that the results derived from the CMC are more accurate than the areographic (Rapoport, 1975) and cartographic methods. One of the limitations of the latter 2 methods is that they assume that the geographic range of the species is continuous (uninterrupted by disjunctions), which is rarely seen in nature (Brown and Lomolino, 1998; Gaston, 2003). As a result, these methods overestimate AOO calculations when compared to the CMC, because they incorporate extensive unoccupied areas. In their study of 10 cactus species, Hernández and Navarro (2007) reported that the average AOO calculated by the aerographic and cartographic methods was 3.5 and 5.5 times larger respectively than that estimated by the CMC.

Consequently, we believe that the CMC is more precise because it is sensitive to the presence of spatial disjunctions, excluding from the AOO calculation areas where the species are absent. In this respect, we have recently shown that geographical discontinuities are the rule among the Cactaceae in the CDR; these are expressed at different scales, from local patchiness to large geographical disjunctions (see Figs. 3 and 4 in Goettsch and Hernández, 2006, and Hernández et al., 2008, respectively).

Number of localities and areas of occupancy. We found a highly significant correlation between the number of localities and the estimated AOO. Thus, knowledge of the number of localities known for a particular species could be used as a predictor of their range size. Using this criterion, consideration of the locality data alone in this investigation (Appendix 1) suggested the high frequency of cactus species in the CDR with small AOO's.

The use of this model could prove to be practical for estimating range size of other groups of plants and other organisms inhabiting desert and semi-desert regions. However, convincing results would be produced only if the most complete set of documented data of the global distribution of the species is used. Obviously, incomplete sets of information would result in erroneous conclusions.

Conservation status. The proportions given in the results for the different Red List categories are an indication of the conservation status of the Cactaceae of the CDR, and probably reflect the extent of endangerment of the entire family in Mexico, at least for the species inhabiting desert and semi-desert areas. In connection to this, it is worth noticing that the percent of threatened Cactaceae calculated here (47.2%) is similar to that reported for the cycads of the world (51.9%) in the 2007 version of the IUCN Red List (www.RedList.org). The cycads are an assemblage of 3 plant families (Cycadaceae, Stangeriaceae, and Zamiaceae), entirely evaluated for the Red List, having the reputation of being highly endangered. Unfortunately we do not know how the conservation status of Mexican Cactaceae compares to that of other critical groups of the Mexican succulent flora (e. g., Agavaceae, Crassulaceae, Nolinaceae, etc.) as no comprehensive information on their status exists for these groups.

A total of 43 species in the Appendix 1 has been previously evaluated for the Red List (www.RedList.org) by various advisors, using different sets of data. Of these, 39 are categorized as threatened (VU, EN or CR), and it is interesting that 34 of them (89.5%) are also classified as threatened according to our data. However, 1:1 coincidences (either VU, EN or CR) decrease to 38.5%. We judge that this level of correspondence with the current Red List is a confirmation that our approach harmonizes reasonably well with the Red List criteria established by the IUCN (Hernández and Navarro, 2007).

The influence of man. There are numerous documented cases of natural populations being virtually eliminated as a consequence of habitat destruction, unsustainable use, or poaching, resulting in the reduction of the species geographical range (del Castillo and Trujillo, 1991; Anderson et al. 1994). However, some cactus species are able to tolerate moderate amounts of disturbance (Martorell and Peters, 2005, 2009), and what is more, it is likely that the geographic range of several species has been enlarged by human activities.

For example, evidence exists that the AOO of some species of prickly pears (e. g., *Opuntia megacantha, O. hyptiacantha, O. robusta, O. streptacantha,* etc.) has been expanded in the CDR by the widespread dissemination of their seeds by man and his domestic animals. Edible fruits of *Opuntia* have been consumed by the inhabitants of the CDR since prehistoric times (Pimienta, 1990; Casas and Barbera, 2002). In addition, since their introduction to this region more than 3 centuries ago, cows, horses, and burros very likely have contributed to the dispersal of these species. A similar process of range expansion probably has occurred in the widespread *Myrtillocactus geometrizans*, a large columnar species that produces edible fruits. Furthermore, cholla species (*Cylindropuntia leptocaulis, C. kleineae, C. tunicata*, and *C. imbricata*) evidently have enlarged their range as a consequence of human activities. They even behave like weeds, in cases becoming extremely abundant after disturbance. The first 3 cholla species have detachable stem segments facilitating vegetative reproduction and dispersal.

How rare are cacti? The results presented in the Appendix 1 confirm previous statements suggesting that cacti very often inhabit small, frequently extremely restricted, areas of the CDR (Gómez-Hinostrosa and Hernández, 2000; Hernández et al., 2001, 2004, 2008; Hernández and Gómez-Hinostrosa, 2004; Goettsch and Hernández, 2006), and reinforce the reputation of this plant family as exceptionally rare geographically. Unfortunately, however, we lack comparative data allowing us to test whether geographical rarity, as seen in the Cactaceae, is shared with other plant groups inhabiting dry regions in Mexico and elsewhere.

Our perception of a high number of narrowly endemic cactus species in the CDR is not an artefact created by poor or spatially biased collecting. The presence of geographically rare cactus species has been corroborated by decades of exploration by amateur and professional botanists, including our systematic collecting programs carried out during more than 15 years. Geographical rarity in the CDR obviously is a natural phenomenon, likely produced by drastic climatic changes during the last 15 000 years (Van Devender, 1990), coupled with the fact that many of the species appear to have extremely limited dispersal abilities (Goettsch and Hernández, 2006; Hernández et al., 2008). Unfortunately, during the last decades, habitat deterioration and illicit collecting of individuals of particular species to become collectors' items have exacerbated the critical conservation status of rare cacti.

From the biogeographic and conservation perspective, the most important group of species (59 spp.) are the rarest ones occurring in areas smaller than 100 km^2 (41.6% of the sample), in particular the narrow endemics, restricted to areas smaller than 10 km^2 (Appendix 1 and Fig. 4). With a few exceptions, these microendemic species are well known and highly attractive to cactus collectors, most of them belonging to genera endemic to the CDR, such as the charismatic *Ariocarpus, Astrophytum, Aztekium, Geohintonia*, and *Turbinicarpus*, or to popular genera such as *Mammillaria* and *Echinocereus*. The extremely small area occupied by these species, in conjunction with the pressures exerted by illegal collectors, place these species in a critical conservation status. In fact, this group of microendemics is the rarest and most endangered species assemblage in Mexico.

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Appendix 1. General distribution, areas of occupancy, and conservation status of Chihuahuan Desert Cactaceae. L = Number of localities, S = Satellites, and C = Conglomerates. Taxonomic nomenclature follows Hunt (2006).

Species	*L*	*S*	*C*	*Confirmed distribution*	*Total area (km^2)*	*IUCN 2007*	*This paper*
Cylindropuntia kleiniae	145	7	11	Chih, Coah, Dgo, Hgo, NL, Pue, Qro, SLP, Son, Tamps, Zac; AZ, NM, OK, TX	132 702		LC
Peniocereus greggii	83	5	6	Chih, Coah, Dgo, Son, Zac; AZ, NM, TX	126 337		LC
Sclerocactus uncinatus	229	20	9	Chih, Coah, Dgo, NL, SLP, Son, Tamps, Zac; NM, TX	102 881		LC
Echinocactus texensis	56	5	4	Coah, Dgo, NL, Tamps, Zac; NM, OK, TX	87 276		LC
E. horizonthalonius	192	10	12	Ags, Chih, Coah, Dgo, Gto, NL, SLP, Son, Tamps, Zac; AZ, NM, TX	67 600		LC
Ferocactus hamatacanthus (e)	200	13	9	Chih, Coah, Dgo, NL, SLP, Tamps, Zac; NM, TX	65 566		LC
Myrtillocactus geometrizans	267	10	12	Ags, DF, Dgo, Gto, Hgo, Jal, Mex, Mich, NL, Oax, Pue, Qro, SLP, Tamps, Ver	51 367		LC
Sclerocactus scheeri[1]	48	4	3	Coah, NL, Tamps; TX	46 697		LC
Echinocereus poselgeri	39	4	2	Coah, NL, Tamps; TX	44 963		LC
Mammillaria crinita	216	15	11	Ags, Gto, Hgo, Jal, Mich, Qro, SLP, Zac	43 596		LC
*Grusonia grahamii** (e)	26	0	3	Chih, Coah, Dgo, Zac; TX	37 077		LC
Ferocactus histrix	91	4	4	Ags, Dgo, Gto, Hgo, Jal, Pue, Qro, SLP, Ver, Zac	30 713		LC
Opuntia rufida (e)	100	7	6	Chih, Coah, Dgo, Zac; TX	29 570		LC
Ferocactus latispinus	128	6	7	Ags, Coah, Gto, Hgo, Jal, Mex, Oax, Pue, Qro, SLP, Zac	29 125		LC
Epithelantha micromeris (e)	134	11	8	Chih, Coah, Dgo, NL, SLP, Zac; AZ, NM, TX	28 652		LC
Thelocactus bicolor (e)	120	7	7	Chih, Coah, Dgo, NL, SLP, Tamps, Zac; TX	28 631		LC
Mammillaria magnimamma	116	9	6	DF, Gto, Hgo, Jal, Mex, NL, Pue, Qro, SLP, Tamps, Tlax, Ver, Zac	23 868		LC
Ariocarpus fissuratus[2] (e)	75	9	4	Coah, Dgo, Zac; TX	19 576		LC
Echinocereus pentalophus	261	22	12	Coah, Gto, Hgo, Jal, NL, Qro, SLP, Tamps; TX	18 724		LC
Mammillaria pottsii (e)	86	8	5	Chih, Coah, Dgo, NL, SLP, Zac; TX	16 670		LC
Thelocactus hexaedrophorus (e)	100	7	4	Coah, NL, SLP, Tamps, Zac	15 420		LC
Echinocactus platyacanthus	242	13	10	Coah, Gto, Hgo, NL, Oax, Pue, Qro, SLP, Tamps, Zac	14 294		LC
Lophophora williamsii (e)	104	7	9	Chih, Coah, Dgo, NL, SLP, Tamps, Zac; TX	12 189		LC
Mammilloydia candida (e)	194	7	7	Coah, Gto, NL, SLP, Tamps, Zac	11 534		LC
Ariocarpus retusus[3] (e)	131	8	6	Coah, NL, SLP, Tamps, Zac	10 490		LC
Mammillaria formosa[4] (e)	208	18	12	Coah, NL, SLP, Tamps, Zac	9 456		LC
*Opuntia stenopetala** (e)	219	20	8	Coah, Gto, Hgo, NL, Qro, SLP, Tamps, Zac	8 795		LC
Ferocactus pilosus (e)	182	15	6	Coah, NL, SLP, Tamps, Zac	8 661		LC
Mammillaria compressa (e)	108	7	4	Gto, Hgo, NL, Qro, SLP, Tamps	8 363		LC
Turbinicarpus beguinii (e)	21	1	2	Coah, NL, SLP, Tamps, Zac	8 248		LC
Opuntia microdasys (e)	160	12	15	Coah, Hgo, Jal, NL, Qro, SLP, Tamps, Zac	7 953		LC
Mammillaria polythele (e)	15	1	1	Gto, Hgo, Qro	6 901		LC
Sclerocactus papyracanthus	23	1	4	AZ, NM, TX	6 859		LC
Coryphantha glanduligera (e)	50	4	3	NL, SLP, Tamps, Zac	6 690		LC
Sclerocactus warnockii (e)	21	1	2	Chih, Coah; TX	6 030		LC
Coryphantha poselgeriana (e)	41	2	4	Chih, Coah, Dgo, SLP, Zac	6 002		LC
C. clavata	34	2	3	Ags, Gto, Hgo, Jal, Qro, SLP, Zac	5 485		LC
Echinocereus palmeri[5] (e)	8	0	2	Chih, Dgo, Zac	5 169		LC
Astrophytum myriostigma (e)	112	3	6	Coah, Dgo, NL, SLP, Tamps	5 103		LC

Species	*L*	*S*	*C*	*Confirmed distribution*	*Total area (km²)*	*IUCN 2007*	*This paper*
Leuchtenbergia principis (e)	42	5	3	Coah, Dgo, NL, SLP, Tamps, Zac	4 345		LC
Thelocactus tulensis (e)	124	3	7	NL, SLP, Tamps	4 319		LC
Th. conothelos (e)	73	4	4	NL, SLP, Tamps	3 964		LC
Sclerocactus mariposensis (e)	25	1	3	Coah; TX	3 865		LC
*Grusonia bradtiana** (e)	20	1	2	Coah, Dgo	3 354		LC
Stenocactus coptonogonus (e)	19	1	2	Gto, Hgo, SLP, Zac	3 291		LC
Mammillaria picta (e)	56	7	2	Coah, NL, SLP, Tamps	2 840		LC
Echinocereus parkeri (e)	43	3	3	NL, SLP, Tamps, Zac	2 567		LC
Mammillaria pilispina (e)	48	2	1	Coah, NL, SLP, Tamps	2 492		LC
Turbinicarpus pseudopectinatus (e)	25	2	2	NL, SLP, Tamps	2 336	VU	LC
Coryphantha octacantha (e)	12	1	1	Gto, Hgo, Qro	2 282		LC
Ferocactus macrodiscus	16	0	2	Gto, Oax	2 200		LC
Mammillaria bocasana (e)	59	1	3	SLP, Zac	1 982		LC
Ferocactus glaucescens (e)	15	1	1	Gto, Hgo, Qro	1 912		LC
Astrophytum capricorne (e)	31	2	3	Coah, NL	1 901		LC
Mammillaria muehlenpfordtii (e)	16	1	1	Gto, Qro, SLP	1 746		LC
Coryphantha erecta (e)	57	2	6	Gto, Hgo, Qro, SLP	1 111		LC
*Opuntia pachyrrhiza** (e)	20	3	1	NL, Qro, SLP	988	VU	LC
Pelecyphora strobiliformis (e)	9	1	1	NL, SLP, Tamps	919		VU
Mammillaria elongata (e)	28	1	2	Gto, Hgo, Qro	889		LC
Thelocactus rinconensis (e)	14	1	2	Coah, NL	879		LC
Mammillaria gigantea (e)	15	1	2	Gto, Qro, SLP	856		LC
M. decipiens (e)	9	0	2	Gto, SLP	817		VU
Turbinicarpus schmiedickeanus[6] (e)	41	1	4	NL, SLP, Tamps	589	NT	LC
Thelocactus leucacanthus (e)	22	2	2	Gto, Hgo, Qro	498		LC
Astrophytum ornatum (e)	34	0	4	Gto, Hgo, Qro, SLP	479		LC
Mammillaria longimamma (e)	20	0	4	Gto, Hgo, Qro, Ver	451		LC
Coryphantha jalpanensis (e)	10	0	2	Gto, Qro, SLP	407		VU
C. werdermannii (e)	10	2	1	Coah	372		VU
*Cylindropuntia anteojoensis** (e)	6	1	1	Coah	304		VU
*Opuntia xandersonii** (e)	17	1	2	SLP, Tamps	284		LC
Cephalocereus senilis (e)	8	0	1	Hgo, Ver	251		VU
Turbinicarpus viereckii (e)	13	0	2	NL, SLP, Tamps	244	NT	LC
Neobuxbaumia polylopha (e)	8	0	2	Gto, Hgo, Qro	213		VU
Turbinicarpus knuthianus (e)	15	0	1	SLP	187	NT	LC
Mammillaria rettigiana (e)	10	1	1	Gto	185	VU	VU
M. moelleriana (e)	7	0	2	Dgo, Zac	175		VU
M. lenta (e)	7	0	2	Coah	174		VU
M. perbella (e)	10	0	2	Gto, Hgo, Qro	167		VU
Turbinicarpus valdezianus (e)	8	1	2	Coah, NL, SLP	158	VU	VU
Mammillaria parkinsonii (e)	14	0	2	Hgo, Qro	151		LC
Pelecyphora aselliformis (e)	18	0	3	SLP	141		LC

Species	*L*	*S*	*C*	*Confirmed distribution*	*Total area (km^2)*	*IUCN 2007*	*This paper*
Mammillaria plumosa (e)	5	0	1	Coah, NL	130		EN
Lophophora diffusa (e)	13	1	1	Qro	110	VU	LC
Mammillaria surculosa (e)	8	0	1	SLP, Tamps	92		VU
Echinocactus parryi (e)	9	1	2	Chih	82		VU
Mammillaria glassii (e)	17	2	4	Coah, NL	80		LC
M. microthele (e)	10	1	1	SLP, Tamps	73	EN	VU
*Ariocarpus kotschoubeyanus**[†] (e)	35	35	-	Coah, NL, Qro, SLP, Tamps, Zac	68	NT	LC
Neobuxbaumia euphorbioides	8	0	2	Tamps, Ver	65		VU
Mammillaria albicoma (e)	7	0	2	NL, SLP, Tamps	49	EN	VU
Ariocarpus agavoides (e)	6	0	2	SLP, Tamps	38	VU	VU
Strombocactus disciformis[†] (e)	19	19	-	Gto, Hgo, Qro	37		LC
Coryphantha odorata[†] (e)	15	15	-	NL, SLP, Tamps	30	VU	LC
*Opuntia megarrhiza** (e)	8	2	1	SLP	24	EN	VU
Coryphantha pulleineana (e)	6	1	1	SLP, Tamps	20		VU
Mammillaria erythrosperma (e)	7	1	1	SLP	20		VU
Astrophytum asterias[†]	9	9	-	Tamps; TX	18	VU	VU
Echinocactus grusonii	11	0	2	Hgo?, Qro, Zac	17	CR	LC
Obregonia denegrii (e)	9	0	2	Tamps	11	VU	VU
Turbinicarpus saueri (e)	5	1	1	Tamps	11	CR	EN
Ariocarpus hintonii[†] (e)	5	5	-	SLP	10		EN
Hamatocactus crassihamatus (e)	8	1	1	Gto	10		VU
Turbinicarpus pseudomacrochele[†](e)	5	5	-	Hgo, Qro	10	VU	EN
Ariocarpus scaphirostris (e)	3	0	1	NL	8.3	VU	EN
Mammillaria aureilanata (e)	7	0	2	SLP	7	VU	VU
*Opuntia chaffeyi**[†] (e)	3	3	-	Zac	6	CR	EN
Aztekium ritteri (e)	6	0	1	NL	4.8		VU
Acharagma aguirreanum[†] (e)	2	2	-	Coah	4	CR	EN
Mammillaria albiflora (e)	4	1	1	Gto	3.7	CR	EN
Turbinicarpus subterraneus (e)	5	0	2	NL	3.5	VU	EN
T. laui (e)	2	0	1	SLP	3.1	VU	EN
Thelocactus hastifer (e)	5	0	1	Qro	3.1	VU	EN
Mammillaria baumii (e)	7	0	3	Tamps	2.8		VU
Astrophytum caput-medusae[†] (e)	1	1	-	NL	2		CR
Echinocereus mapimiensis[†] (e)	1	1	-	Coah	2		CR
E. nivosus[†] (e)	1	1	-	Coah	2		CR
Mammillaria anniana[†]	1	1	-	Tamps	2	CR	CR
M. herrerae[†] (e)	1	1	-	Qro	2	CR	CR
M. humboldtii[†] (e)	1	1	-	Hgo	2		CR
M. laui[†] (e)	1	1	-	Tamps	2		CR
M. luethyi[†] (e)	1	1	-	Coah	2	EN	CR
M. marcosii[†] (e)	1	1	-	Gto	2	CR	CR
M. sanchez-mejoradae[†] (e)	1	1	-	NL	2	CR	CR

Species	*L*	*S*	*C*	*Confirmed distribution*	*Total area* (*km*²)	*IUCN 2007*	*This paper*
M. schwarzii† (e)	1	1	-	Gto	2	CR	CR
M. tezontle† (e)	1	1	-	SLP	2		CR
M. wiesingeri† (e)	1	1	-	Hgo	2		CR
M. zeilmanniana† (e)	1	1	-	Gto	2	EN	CR
Thelocactus macdowellii† (e)	1	1	-	Coah	2		CR
Turbinicarpus alonsoi† (e)	1	1	-	Gto	2	CR	CR
T. gielsdorfianus† (e)	1	1	-	SLP	2	CR	CR
T. horripilus† (e)	1	1	-	Hgo	2	VU	CR
T. mandragora† (e)	1	1	-	Coah	2	CR	CR
T. ysabelae† (e)	1	1	-	Tamps	2	CR	CR
T. zaragozae† (e)	1	1	-	NL	2	VU	CR
Aztekium hintonii (e)	3	0	1	NL	1.8		CR
Mammillaria melaleuca (e)	2	0	1	Tamps	1.5		CR
M. theresae (e)	2	0	1	Dgo	1.3		CR
Geohintonia mexicana (e)	2	0	1	NL	1.2		CR
Mammillaria mathildae (e)	3	0	1	Qro	1.2	VU	CR
M. microhelia (e)	2	0	1	Qro	0.98	VU	CR
Ariocarpus bravoanus (e)	3	0	1	SLP	0.13	VU	CR
Mammillaria carmenae (e)	2	0	1	Tamps	0.13		CR

(e) Chihuahuan Desert endemic (Hernández et al. 2004).
* AOO data taken from Hernández and Navarro (2007).
† Indicates that each locality was considered as a satellite.
[1]. Includes *Sclerocactus brevihamatus.*
[2]. Excludes *Ariocarpus hintonii.*
[3]. Includes *Ariocarpus trigonus.*
[4]. Includes *M. chionocephala.*
[5]. Includes subsp. *palmeri* and subsp. *mazapil.*
[6]. Includes subsp. *dickisoniae*, subsp. *flaviflorus*, subsp. *gracilis*, subsp. *klinkerianus*, subsp. *macrochele*, subsp. *schmiedickeanus*, and subsp. *schwarzii.*