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Endangered Cacti in the Chihuahuan Desert: II. Biogeography and Conservation

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Abstract: *The distributions of the majority of the endangered cacti in the Chihuahuan Desert Region are concentrated in the southeastern and eastern segments of the area, where the predominance of narrow endemism is a remarkable phytogeographic phenomenon. We used three criteria—species richness, conservation value, and complementarity—to evaluate 37 cactus-rich area units in the Chihuahuan Desert. The evaluation of these three quantitative parameters together allowed us to determine that seven of these areas (Huizache, Tolimán, Ciudad Victoria, Metztitlán, Cuatro Ciénegas, Jaumave, and Xichú) should be considered conservation priorities because they hold the most significant assemblage of endangered species, in terms of their numbers and their rarity. Conservation actions in these seven areas would protect 52 (55.9%) of the 93 endangered species studied here, most of which have extremely narrow distributions. Geographically, these critical areas are located in the Queretaroan-Hidalgoan arid zone (in the States of Querétaro, Hidalgo, and Guanajuato), in the Jaumave Valley (Tamaulipas), and in two disjunct areas (San Luis Potosí and Coahuila) in the interior of the Chihuahuan Desert.*

Cactácuas Amenazadas en el Desierto Chihuahuense: II. Biogeografía y Conservación

Resumen: *Las áreas de distribución de la gran mayoría de las especies amenazadas en la Región del Desierto Chihuahuense se concentran hacia sus porciones sureste y este, en donde un fenómeno fitogeográfico notable es la predominancia de endemismos restringidos. En este estudio evaluamos 37 áreas ricas en especies dentro de la Región del Desierto Chihuahuense, a través del uso de tres criterios: riqueza de especies, valores de conservación y complementaridad. La evaluación de estos tres parámetros cuantitativos de manera combinada nos permitió establecer que siete de estas áreas son prioritarias en relacíon con sus necesidades de conservación (Huizache, Tolimán, Ciudad Victoria, Metztitlán, Cuatro Ciénegas, Jaumave y Xichú), debido a que, en términos del número de especies y de su rareza, éstas albergan la colección más significativa de especies. La implementación de acciones de conservación en estas siete áreas garantizarían la protección de 52 (55.9%) de las 93 especies amenazadas que se incluyeron en este estudio, la mayoría de las cuales tiene áreas de distribución extremadamente limitadas. Desde el punto de vista geográfico, estas áreas críticas se localizan dentro de la Zona Arida Queretano-Hidalguense (en los estados de Querétaro, Hidalgo y Guanajuato), en el Valle de Jaumave (Tamaulipas) y en dos áreas disjuntas (San Luis Potosí y Coahuila) dentro del cuerpo principal de la Región del Desierto Chihuahuense.*

Introduction

The Cactaceae family is one of the most endangered groups in the plant kingdom. More than one third (563) of the approximately 1500 species in the family are distributed in México, and 197 (35%) of the Mexican species are somewhat endangered (Hernández & Godínez 1994; Hernández & Bárcenas 1995). Most members of this family are distributed in arid and semiarid regions of this country, and the richest assemblage of species, including the endangered ones, is centered in the Chihuahuan Desert region (CDR).

In a previous paper (Hernández & Bárcenas 1995) we analyzed the distribution patterns of 93 species of endangered cacti from the CDR. The geographical distribu-

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tions of all the endangered species were integrated in a grid map with grid squares measuring 30 minutes latitude by 30 minutes longitude; species frequencies were calculated for each grid square. The great majority of the species-rich grid squares were aggregated toward the southeastern segment of the CDR, including several disjunct fragments located in isolated valleys in the Sierra Madre Oriental (e.g., Jaumave and Aramberri Valleys) and in the Queretaroan-Hidalgoan arid zone.

The identification of areas with a high concentration of endangered cacti in the CDR is a prerequisite for the implementation of actions toward their conservation. But species richness itself cannot be considered as the sole criterion for the selection of conservation areas. Several additional criteria, such as rarity, degree of threat, size, and naturalness, have been used to select conservation areas (Margules & Usher 1981; Usher 1986). Nevertheless, two of those easily quantifiable biological criteria—species richness and rarity—are among the most commonly used in site assessment (Margules & Usher 1981).

In the CDR endangered cacti differ in the extent of their geographical ranges. Some species are restricted to one or a few grid squares, whereas others occur in many (Hernández & Bárcenas 1995), and there is an inverse correlation between the geographical range of a species and its degree of vulnerability. Thus, a grid square with a high proportion of geographically restricted (stenoendemic) species is of has greater conservation priority than another with the same or even higher number of widespread species. We scored endangered species according to the number of grid squares in which they occurred; the stenoendemic species had the highest scores and the widespread ones the lowest scores. Consequently, the geographical information, expressed here as the number of grids occupied by each endangered

Table 1. Number of endangered species present, location, and conservation values of the grid squares having more than four species of endangered cacti in the Chihuahua Desert region.

Grid square	*No. of endangered species*	*Location*	*Conservation value**
Tolimán	13	20°30′-21°00′ N, 99°30′-100°00′ W	793.7
Huizache	14	22°30′-23°00′ N, 100°00′-100°30′ W	618.5
Ciudad Victoria	8	23°30′-24°00′ N, 99°00′-99°30′ W	602.8
Jaumave	7	23°00′-23°30′ N, 99°00′-99°30′ W	441.7
Metztitlán	8	20°30′-21°00′ N, 98°30′-99°00′ W	431.5
Xichú	9	21°00′-21°30′ N, 100°00′-100°30′ W	318.6
Ramos Arizpe	7	25°30′-26°00′ N, 100°30′-101°00′ W	301.7
Querétaro	5	20°30′-21°00′ N, 100°00′-100°30′ W	294.2
Cinco de Mayo	6	25°00′-25°30′ N, 101°30′-102°00′ W	284.1
Cuatro Ciénegas	10	26°30′-27°00′ N, 102°00′-102°30′ W	278.0
San Miquel	5	20°30′-21°00′ N, 100°30′-101°00′ W	237.3
Rayones	4	25°00′-25°30′ N, 100°00′-100°30′ W	237.2
Matehuala	10	23°30′-24°00′ N, 100°30′-101°00′ W	236.4
Aramberri	8	24°00′-24°30′ N, 99°30′-100°00′ W	233.1
San Luís Potosí	7	22°00′-22°30′ N, 100°30′-101°00′ W	224.0
Miquihuana	7	23°30′-24°00′ N, 99°30′-100°00′ W	223.9
Peñamiller	4	21°00′-21°30′ N, 99°30′-100°00′ W	203.3
Tula	7	23°00′-23°30′ N, 99°30′-100°00′ W	181.4
Marte	8	25°30′-26°00′ N, 101°30′-102°00′ W	167.3
El Tepeyac	5	22°30′-23°00′ N, 99°30′-100°00′ W	165.2
Doctor Arroyo	10	23°30′-24°00′ N, 100°00′-100°30′ W	160.7
Mier y Noriega	10	23°00′-23°30′ N, 100°00′-100°30′ W	154.9
Landa	4	21°00′-21°30′ N, 99°00′-99°30′ W	142.3
Hipólito	6	25°30′-26°00′ N, 101°00′-101°30′ W	137.4
Viesca	6	25°00′-25°30′ N, 102°30′-103°00′ W	136.0
Saltillo	8	25°00′-25°30′ N, 100°30′-101°00′ W	135.5
General Cepeda	8	25°00′-25°30′ N, 101°00′-101°30′ W	132.8
Zimapán	4	20°30′-21°00′ N, 99°00′-99°30′ W	130.6
Pachuca	6	20°00′-20°30′ N, 98°30′-99°00′ W	129.2
Galeana	7	24°30′-25°00′ N, 100°00′-100°30′ W	116.4
San Pedro	6	25°30′-26°00′ N, 102°30′-103°00′ W	109.4
Parras	6	25°00′-25°30′ N, 102°00′-102°30′ W	99.0
Mexquitic	5	22°00′-22°30′ N, 101°00′-101°30′ W	73.2
Arista	6	22°30′-23°00′ N, 100°30′-101°00′ W	47.8
Villa de Guadalupe	5	23°00′-23°30′ N, 100°30′-101°00′ W	41.6
Gómez Palacio	4	25°30′-26°00′ N, 103°30′-104°00′ W	34.3
Big Bend	4	29°00′-29°30′ N, 103°30′-104°00′ W	32.1

**Sum of index of rarity values for resident species.*

species, provides a quantitative index of rarity (IR) that reflects the conservation values of the analyzed area units.

In addition, we used the principle of complementarity to prioritize the conservation importance of the grid squares. As outlined by Williams et al. (1991), Humphries et al. (1991), and Pressey et al. (1993), this principle, when applied to specific areas, allows us to recognize and set priorities for the selection of area networks within particular regions in order to optimize the protection of biodiversity. Thus, our analysis of the principal centers of concentration of endangered cacti in the CDR was based on species richness, geographic range size, and complementarity.

Study Area and Methods

Data on the localization, limits, flora, climate, and other characteristics of the CDR are summarized in Hernández and Bárcenas (1995), which was based on published reports (Henrickson & Straw 1976; Schmidt 1979; Medellín-Leal 1982; Van Devender 1986, 1990). The 93 species included in this study are part of a larger list of Mexican endangered cacti compiled by Hernández and Godínez (1994). To obtain an index of rarity for each of the endangered species of cacti from the CDR, the species were scored by dividing the total number of grid squares containing endangered species in the CDR (122) by the number of grid squares occupied by the species. Thus, the more geographically restricted species (e.g., *Ariocarpus agavoides* and *A. bravoanus*) that occur only in one grid square had the highest score, 122. On the other side of the spectrum, endangered species such as *Echinocactus platyacanthus*, which is distributed in 27 grid squares of the CDR, had a score of 4.5. Appendix 1 lists the IR values of the 93 endangered species studied by Hernández and Bárcenas (1995). The locality data for the calculation of the IR were taken exclusively from a database of herbarium collections from North and Central America (Hernández et al. 1993; Hernández and Bárcenas 1995); this database contains over 9000 records from 32 Mexican, U.S. and European herbaria. To provide a reasonable measure of the conservation value of each grid square, we added the IR values of all the endangered species found in a grid square. The conservation values of the grid squares with at least four endangered species are reported in Table 1. Information regarding species richness per grid square is that of Hernández and Bárcenas (1995), but the species richness figure in the Xichú square is slightly modified in Table 1 to reflect recent findings in that part of the CDR (Bárcenas, personal communication).

The principle of complementarity (Humphries et al. 1991) was used as the third criterion to assess the conservation priorities of each of the grid squares. The principle requires the subdivision of a region into smaller area units (grid squares in the present study). From these, the first-priority area—that containing the highest number of endangered species—is determined. The remaining areas are ordered according to their contribution of additional species not found in the first-priority area.

Based on floristic similarity indexes (Jaccard index of floristic similarity) among the grid squares (Hernández & Ruokolainen, personal communication), the CDR was divided into three subregions that we called Cuatro Ciénegas, Huizache, and Tolimán (Fig. 1). For each of the subregions the complementarity values were calculated individually according to the following steps: (1) The grid square with the highest number of endangered species in each subregion was selected as first priority. Thus, the Cuatro Ciénegas, Huizache, and Tolimán grid squares were considered first-priority areas in their respective subregions. (2) The complement, that is, the total number of endangered species in each subregion was calculated. (3) The residual complement was calculated as the difference between the complement and the

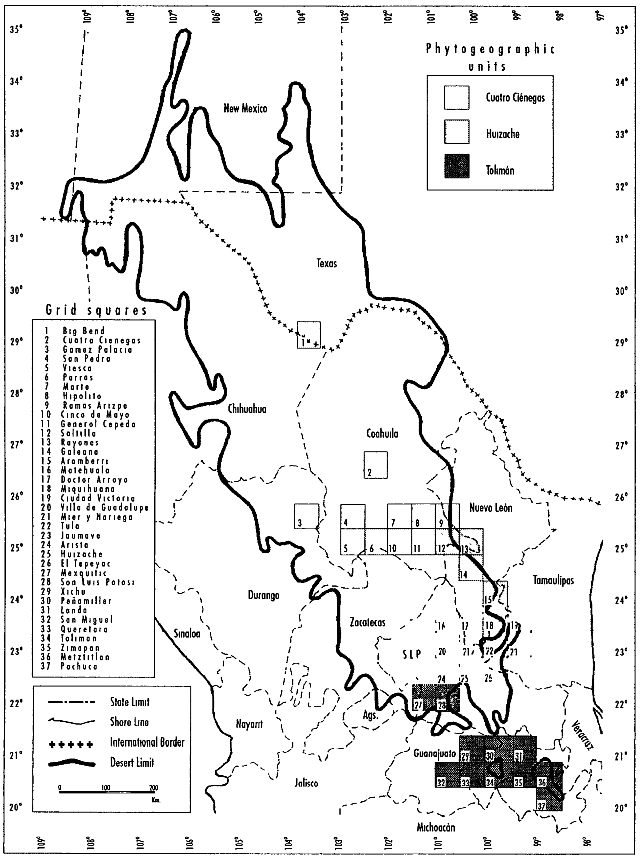

Figure 1. Approximate phytogeographic units within the Chihuahuan Desert region as suggested by similarity indexes of cactus distributions. Only those 37 grid squares containing four or more species are included.

Table 2. Complementarity values of grid squares in the Chihuahuan Desert region.

Subregion *Grid square*	*Complement*	*Residual complement*	*Complementarity value*
Cuatro Cienegas	28	18	
Cuatro Ciénegas			—
Ramos Arizpe			33.3
General Cepeda			27.8
Viesca			22.2
Cinco de Mayo			22.2
Hipólito			16.7
Parras			16.7
Marte			16.7
Gómez Palacio			11.1
San Pedro			5.6
Big Bend			0.0
Huizache	38	24	
Huizache			—
Jaumave			25.0
Ciudad Victoria			25.0
Miquihuana			12.5
Saltillo			12.5
Aramberri			12.5
Matehuala			12.5
Doctor Arroyo			12.5
Rayones			8.3
Galeana			8.3
Tula			8.3
Mier y Noriega			8.3
Villa de Guadalupe			4.2
El Tepeyac			4.2
Arista			0.0
Tolimán	32	19	
Tolimán			—
San Luís Potosí			26.3
Metztitlán			26.3
Xichú			26.3
Mexquitic			21.1
San Miguel			21.1
Querétaro			15.8
Pachuca			15.8
Landa			10.5
Zimapán			10.5
Peñamiller			5.3

number of endangered species found in the first-priority grid square. (4) The complementarity value for each of the grid squares within their particular subregion was calculated by multiplying the number of unique endangered species (those not found in the first-priority square) by 100 and dividing the product by the residual complement. For instance, the Gómez Palacio grid square, which belongs to the Cuatro Ciénegas subregion, had a residual complement of 18 species and two unique species; thus, $(2 \times 100) / 18 = 11.1\%$. The resulting percentage indicates the additional contribution from the residual complement to biodiversity in the first-priority square. The complementarity values of those 34 grid squares containing four or more endangered species are shown in Table 2.

Results and Discussion

Geographic Ranges

The 93 species of endangered cacti from the CDR included in this study are listed in Appendix 1, together with the number of grid squares in which each one has been found and their calculated IRs. The range size of the endangered species varies enormously. Figure 2 is a graphic representation of the frequency distribution of the number of grid squares occupied by the species; it illustrates the pronounced stenoendemism among endangered cacti in Mexico. For instance, 35 endangered species, representing 37.6% of the total number of analyzed species, are restricted to a single grid square. In addi-

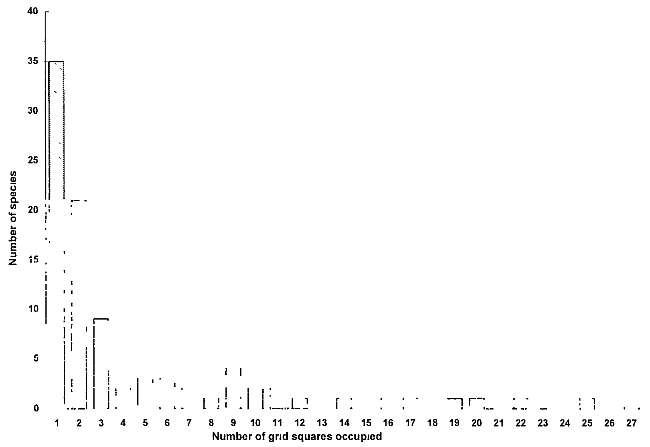

Figure 2. Frequency distribution of the number of endangered species of cactus per grid square in the Chihuahuan Desert region.

tion, 21 species (22.6%) are found in only two, and nine (9.7%) are found in only three grid squares. This means that 69.9% of the endangered species we studied are restricted to three or fewer grid squares. In contrast, only 13 of the species are distributed in 10 or more grid squares. This supports previous suggestions (Hernández & Godínez 1994) that stenoendemism is a common phenomenon among Mexican Cactaceae. It is likely that the profusion of narrowly endemic species in the Cactaceae, as well as in several other plant families in the CDR, arose as a consequence of area contractions during the last Pleistocene glacial period (Van Devender & Burgess 1985; Van Devender 1986, 1990; Betancourt et al. 1990). It has been hypothesized (Van Devender & Burgess 1985; Van Devender 1986; Hernández & Bárcenas 1995) that several areas within the CDR acted as refugia of desert floristic elements during these climatic changes.

Species Richness and Conservation Values

Table 1 shows the conservation values of 37 grid squares, that contain more than four endangered species. The high degree of variation in the conservation values among the grid squares (range = 793.7-32.1) is only partially explained by differences in species richness. In fact, as a result of differences in species composition (IR differences), in a number of instances some grid squares have significantly higher conservation values than others with the same or even higher number of endangered species. For example, the conservation value of the Ciudad Victoria grid square with eight endangered species is more than four times higher than that of the Saltillo and General Cepeda grid squares, which have the same number of endangered species (Table 1).

In the first contribution of this series (Hernández & Bárcenas 1995), we determined that the endangered cacti of the CDR tend to be aggregated toward the southeastern and eastern segments of this desert. Two areas were outstanding for their particularly high concentration of endangered cacti. The most important is located in central and northern San Luis Potosí, southern Nuevo León, and southwestern Tamaulipas, particularly around the localities of Huizache, Matehuala, Doctor Arroyo, and Mier y Noriega. The second in importance corresponds to a smaller area found within the Queretaroan-Hidalgoan arid zone, specifically in the southern portion of the Estórax River basin in Querétaro (see Fig. 3 in Hernández & Bárcenas 1995).

Based on species richness values alone, it is easy to assign priority among the grid squares. But when the conservation values of these area units are taken into consideration, based on specific geographic range sizes, the number of endangered species per grid square and their conservation values are not always correlated. Thus, combining these two criteria (Fig. 3) provides a more realistic approach to the evaluation of these areas. Five grid squares that have both high species numbers and conservation values have the highest conservation priority (Fig. 3). The most important of these are the Huizache (14 spp.) and the Tolimán (13 spp.), which have conservation values of 618.5 and 793.7 respectively (Table 1 and Fig. 3). Located in northcentral San Luis Potosí, the Huizache grid square is well known for its diversity of cactus species, and it is the area with the highest concentration of endangered cacti in the entire CDR. The high conservation value in this area is determined by the abundance of stenoendemic species, such as *Ariocarpus*

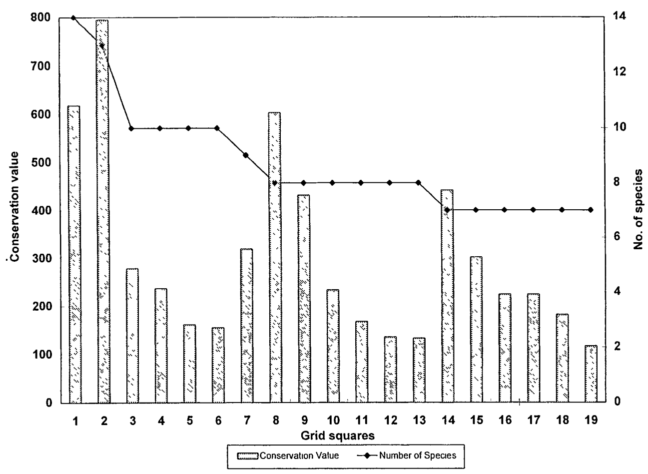

Figure 3. Species richness and conservation value of the grid squares with seven or more endangered cactus species within the Chihuahuan Desert region. Data taken from Table 1: 1, Huizache; 2, Tolimán; 3, Cuatro Ciénegas; 4, Matehuala; 5, Doctor Arroyo; 6, Mier y Noriega; 7, Xichú; 8, Ciudad Victoria; 9, Metztitlán; 10, Aramberri; 11, Marte; 12, Saltillo; 13, General Cepeda; 14, Jaumave; 15, Ramos Arizpe; 16, San Luis Potosí; 17, Miquihuana; 18, Tula; 19, Galeana.

Table 3. Transformed (%) values of number of species, conservation value, and complementarity of grid squares in the Chihuahuan Desert region.

Grid square	*No. of species*	*Conservation value*	*Complementarity*	*Cumulative value*
Tolimán	0.9	1.0	1.0	2.9
Huizache	1.0	0.8	1.0	2.8
Ciudad Victoria	0.6	0.8	1.0	2.4
Metztitlán	0.6	0.5	1.0	2.1
Cuatro Ciénegas	0.7	0.4	1.0	2.1
Jaumave	0.5	0.6	1.0	2.1
Xichú	0.6	0.4	1.0	2.0
Ramos Arizpe	0.5	0.4	1.0	1.9
San Luís Potosí	0.5	0.3	1.0	1.8
General Cepeda	0.6	0.2	0.8	1.6
Matehuala	0.7	0.3	0.5	1.5
San Miguel	0.4	0.3	0.8	1.5
Cinco de Mayo	0.4	0.4	0.7	1.5
Doctor Arroyo	0.7	0.2	0.5	1.4
Aramberri	0.6	0.3	0.5	1.4
Querétaro	0.4	0.4	0.6	1.4
Miquihuana	0.5	0.3	0.5	1.3
Marte	0.6	0.2	0.5	1.3
Viesca	0.4	0.2	0.7	1.3
Mexquitic	0.4	0.1	0.8	1.3
Saltillo	0.6	0.2	0.5	1.3
Mier y Noriega	0.7	0.2	0.3	1.2
Pachuca	0.4	0.2	0.6	1.2
Hipólito	0.4	0.2	0.5	1.1
Tula	0.5	0.2	0.3	1.0
Parras	0.4	0.1	0.5	1.0
Galeana	0.5	0.2	0.3	1.0
Rayones	0.3	0.3	0.3	0.9
Landa	0.3	0.2	0.4	0.9
Zimapán	0.3	0.2	0.4	0.9
Peñamiller	0.3	0.3	0.2	0.8
El Tepeyac	0.4	0.2	0.2	0.8
San Pedro	0.4	0.1	0.2	0.7
Villa de Guadalupe	0.4	0.1	0.2	0.7
Gómez Palacio	0.3	0.0	0.3	0.6
Arista	0.4	0.1	0.0	0.5
Big Bend	0.3	0.0	0.0	0.3

bravoanus, Coryphantha odorata, Mammillaria surculosa, and *Turbinicarpus knuthianus* all of which are restricted to the area. The Tolimán grid square, on the other hand, is part of a disjunct portion of the CDR known as the Queretaroan-Hidalgoan arid zone, and it is the area possessing the highest conservation value based on range sizes. Four species of endangered cacti are restricted to this grid square: *Echinocactus grusonii, Echinocereus schmollii, Thelocactus hastifer*, and *Turbinicarpus pseudomacrochele*. Four more species (*Lophophora diffusa, Mammillaria herrerae, M. parkinsonii, Strombocactus disciformis*) are found in this and one additional grid square.

Two additional grid squares, the Ciudad Victoria and Jaumave, include together all of the Jaumave Valley and are also recognized individually for their high conservation values (Fig. 3). The Jaumave Valley is a semiarid, geographically isolated fragment of the CDR in which several species, including the monotypic genus *Obregonia*, have been reported as restricted to its limits. Despite the fact that the species richness in these two grid squares is comparatively low (eight and seven endangered species respectively), their conservation value is high because of the high frequency of stenoendemic species. Likewise, the Metztitlán square, with eight endangered species, which is also part of the Queretaroan-Hidalgoan arid zone, has a relatively high conservation value (C.V. = 431.5) because of the occurrence of three stenoendemic species: *Cephalocereus senilis, Mammillaria humboldtii*, and *Turbinicarpus horripilus*. It is likely that the high frequency of stenoendemic cacti in the Queretaroan-Hidalgoan arid zone (Tolimán and Metztitlán grid squares) and in the Jaumave Valley (Jaumave and Ciudad Victoria grid squares) is a consequence of geographic and climatic isolation, which has stimulated speciation in these disjunct pockets of the CDR.

A contrasting situation is illustrated by the Cuatro Ciénegas (C.V. = 278), Matehuala (C.V. = 236.4), Doctor Arroyo (C.V. = 160.7), and Mier y Noriega (C.V. = 154.9) grid squares, all of which are relatively rich in cactus species (10 endangered species each), but their conservation values are very low (Fig. 3). A possible explanation for this pattern is that all of these grid squares are located within the main body of the CDR and the species included in them have low IRs, as they extend into adjacent grid squares. This situation is also true for all the grid squares with low conservation values within the CDR (Fig. 3).

The Principle of Complementarity

Figure 1 is a graphic representation of the phytogeographic units within the CDR, based on similarity-index data of endangered cactus distributions. Three primary phytogeographic areas (subregions) were established according to a preliminary analysis (Hernández & Ruokolainen, personal communication): Cuatro Ciénegas, Huizache, and Tolimán. To assess the conservation importance of the grid squares, their complementarity values were calculated individually by subregion. Data on total number of endangered species per subregion (complement), residual complement, and complementarity values are presented in Table 2.

In the Cuatro Ciénegas subregion (complement = 28 spp.), the Ramos Arizpe grid square was the second-priority choice, with a complementarity value (COV) of 33.3%. This square is followed by the General Cepeda (COV = 27.8%), the Viesca, Cinco de Mayo (COV = 22.2%), the Hipólito, Parras, and Marte grid squares (COV = 16.7%) (Table 2). In the Huizache subregion (complement = 38 spp.), the Jaumave and Ciudad Victoria grid squares, both within the Jaumave Valley, are the obvious second choice (COV = 25%). These are followed by five grid squares (third choice) with an equal number of unique species (COV = 12.5%): Miquihuana, Saltillo, Aramberri, Matehuala, and Doctor Arroyo. In the Tolimán subregion (complement = 32 spp.), three grid squares are second-priority choices (Table 2): San Luis Potosí, Metztitlán, and Xichú (COV = 26.3%). The third- and fourth-priority grid squares in this subregion were Mexquitic, San Miguel (COV = 21%), Querétaro, and Pachuca (COV = 15.8%). These grid squares, those with the highest complementarity values within each subregion, add the greatest biodiversity to the first-priority grid squares (Cuatro Ciénegas, Huizache, and Tolimán); thus, they are of highest conservation priority. There are several areas with few additional species (those not found in the first-priority area) that are of low conservation priority. Two grid squares, Big Bend and Arista, have zero complementarity value.

Conclusion

We used three criteria to evaluate the conservation priorities of 37 cactus-rich area units within the CDR. Each criterion provides insight for the selection of conservation areas. When all three are combined, however, a more realistic picture emerges. With the purpose of making them comparable, the data presented in Tables 1 and 2 (species richness, conservation value, and complementarity) are given as percentages in Table 3, and these results are shown graphically in Fig. 4.

There are seven grid squares that have cumulative values above 2 (Fig. 4), and these should be considered as top priority for conservation of endangered cacti in the CDR. These seven grid squares hold 52 endangered species, representing 55.9% of the endangered species included in this study; the remaining 41 endangered species are distributed among the other 30 grid squares. The most important of the seven grid squares are the Tolimán and Huizache, both of which have cumulative values approaching the maximum of 3; conservation actions in these two areas are extremely urgent. Geograph-

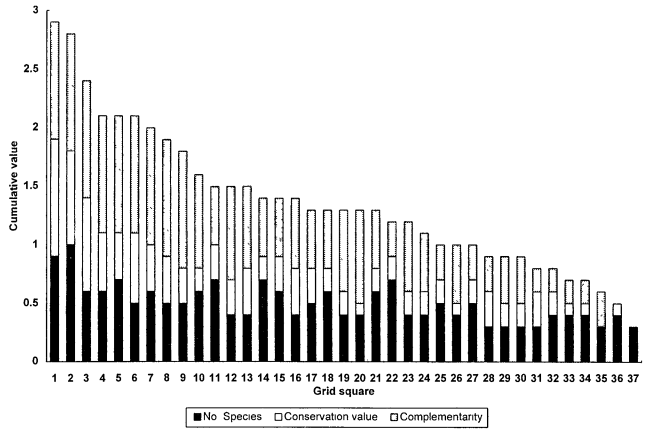

Figure 4. Cumulative values of number of endangered cactus species, conservation value, and complementarity of the 37 cactus-rich grid squares in the Chihuahuan Desert region. The size of the bars reflect conservation priority. Data taken from Table 3: 1, Tolimán; 2, Huizache; 3, Ciudad Victoria; 4, Metztitlán; 5, Cuatro Ciénegas; 6, Jaumave; 7, Xichú; 8, Ramos Arizpe; 9, San Luis Potosí; 10, General Cepeda; 11, Matehuala; 12, San Miguel; 13, Cinco de Mayo; 14, Doctor Arroyo; 15, Aramberri; 16, Querétaro; 17, Miquihuana; 18, Marte; 19, Viesca; 20, Mexquitic; 21, Saltillo; 22, Mier y Noriega; 23, Pachuca; 24, Hipólito; 25, Tula; 26, Parras; 27, Galeana; 28, Rayones; 29, Landa; 30, Zimapán; 31, Peñamiller; 32, El Tepeyac; 33, San Pedro; 34, Villa de Guadalupe; 35, Gómez Palacio; 36, Arista; and 37, Big Bend.

ically, three of the most important grid squares (Tolimán, Metztitlán, and Xichú) belong to the Queretaroan-Hidalgoan arid zone, whereas the Ciudad Victoria and Jaumave correspond to the isolated Valley of Jaumave, and the Huizache and Cuatro Ciénegas are located within the main body of the CDR. The majority (20 out of 37) of the grid squares (grid squares 8–27; Fig. 4) have moderate cumulative values ranging from 1 to 1.9, and 10 have values below 1 (range = 0.3–0.9). The information in Fig. 4 sets the basis for the selection of an area network for the conservation of endangered cacti in the CDR. It must be emphasized that the grid squares with relatively low cumulative values should not automatically be excluded from the network. Most of the grid squares with very low cumulative values hold stenoendemic cactus species, giving some conservation and complementarity values to the areas.

The information provided here, together with that in the first contribution (Hernández & Bárcenas 1995), is a starting point for understanding the geographic relations of the endangered cacti in the Chihuahuan Desert region. However, we need to bring our knowledge of the distribution patterns of these plants to a higher level of resolution. We hope that these data and ideas will stimulate further studies that will test the biogeographic congruence of endangered cacti with other plant groups (e.g., Agavaceae, Nyctaginaceae) and animal groups (e.g., Reptilia) that are reputed to have high degrees of endemism in the area. Unfortunately, basic information on endangered cacti at the population level are still lacking. It is particularly important to direct scientific research toward an understanding of their demography, genetic structure, and reproductive biology, including pollination biology, breeding systems, and seed-dispersal mechanisms.

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Appendix 1

Index of rarity of endangered species of cacti from the Chihuahuan Desert region and marginal areas.

Taxon	*No. of grids*	*Index of rarity*
Ariocarpus agavoides (Castañeda) Anderson	1	122.0
A. bravoanus Hernández et Anderson	1	122.0
A. fissuratus (Engelmann) Schumann	20	6.1
var. *fissuratus*		
var. *hintonii* Stuppy et Taylor		
var. *lloydii* (Rose) Marshall		
A. kotschoubeyanus (Lemaire) Schumann	11	11.1
A. retusus Scheidweiler	19	6.4
A. scaphirostris Bödeker	1	122.0
A. trigonus Schumann	4	30.5
Astrophytum asterias (Zuccarini) Lemaire	2	61.0
A. capricorne (Dietrich) Britton et Rose	9	13.6
A. myriostigma Lemaire	10	12.2
A. ornatum (De Candolle) Weber ex Britton et Rose	6	20.3
Aztekium hintonii Glass et Fitz	1	122.0
A. ritteri (Bödeker) Bödeker ex Berger	2	61.0
Cephalocereus senilis Haworth	2	61.0
Coryphantha odorata Bödeker	1	122.0
C. poselgeriana (Dietrich) Britton et Rose	12	10.2
C. pseudoechinus Bödeker	3	40.7
C. werdermanii Bödeker	4	30.5
Echinocactus grusonii Hildmann	1	122.0
E. parryi Engelmann	3	40.7
E. platyacanthus Link et Otto	27	4.5
Echinocereus delaetii (Guerke) Guerke	2	61.0
E. knippelianus Liebner	3	40.7
E. longisetus (Engelmann) Ruempler	2	61.0
E. nivosus Glass et Foster	1	122.0
E. palmeri Britton et Rose	1	122.0
E. pulchellus (Martius) Schumann	5	24.4
E. schmollii (Weingart) Taylor	1	122.0
Escobaria aguirreana (Glass et Foster)?	1	122.0
E. laredoi (Glass et Foster) Taylor	1	122.0
E. roseana (Bödeker) Marshall	2	61.0
Ferocactus latispinus (Haworth) Britton et Rose		
var. *latispinus*	22	5.5
F. macrodiscus (Martius) Britton et Rose		
var. *septentrionalis* Meyrán	2	61.0
F. pilosus (Galeotti) Werdermann	14	8.7
Geohintonia mexicana Glass et Fitz	1	122.0
Hamatocactus crassihamatus (Weber) Buxbaum	2	61.0
Leuchtenbergia principis Hooker	11	11.1
Lophophora diffusa (Croizat) Bravo	2	61.0
Mammillaria albicoma Bödeker	1	122.0
M. aureilanata Backeberg	1	122.0
M. aurihamata Bödeker	1	122.0
M. baumii Bödeker	1	122.0
M. carmenae Castañeda	1	122.0
M. grusonii Ruenge	2	61.0
M. hahniana Werdermann	2	61.0
M. herrerae Werdermann	2	61.0
M. humboldtii Ehrenberg	1	122.0
M. klissingiana Bödeker	1	122.0
M. lenta K. Brandegee	2	61.0
M. longimamma De Candolle	6	20.3
M. mathildae Kraehenbuehl et krainz	1	122.0
M. melaleuca Karwinsky ex Salm-Dyck	1	122.0
M. moelleriana Bödeker	2	61.0
M. nana Backeberg	5	24.4

Appendix 1. Continued

Taxon	*No. of grids*	*Index of rarity*
M. painteri Rose	1	122.0
M. parkinsonii Ehrenberg	2	61.0
M. pennispinosa Krainz	2	61.0
var. *nazarensis* Glass et Foster		
var. *pennispinosa*		
M. pilispina Purpus	3	40.7
M. plumosa Weber	2	61.0
M. rettigiana Bödeker	1	122.0
M. schiedeana Ehrenberg	3	40.7
M. surculosa Bödeker	1	122.0
M. theresae Cutak	1	122.0
M. weingartiana Bödeker	1	122.0
M. zephyranthoides Scheidweiler	5	24.4
Neobuxbaumia euphorbioides (Haworth) Buxbaum	3	40.7
N. polylopha (De Candolle) Backeberg	3	40.7
Obregonia denegrii Fric	2	61.0
Opuntia rufida Engelmann	16	7.6
Pelecyphora aselliformis Ehrenberg	2	61.0
P. strobiliformis (Werdermann) Fric et Scheelle	3	40.7
Peniocereus greggii (Engelmann) Briton et Rose		
var. *greggii*	17	7.2
Sclerocactus intertextus (Engelmann) Taylor	6	20.3
S. mariposensis (Hester) Taylor	9	13.5
S. uncinatus (Galeotti) Taylor	25	4.9
S. unguispinus (Engelmann) Taylor	10	12.2
Stenocactus coptonogonus (Lemaire) Berger	9	13.5
Strombocactus disciformis (De Candolle) Britton et Rose	2	61.0
Thelocactus hastifer (Werdermann et Bödeker) Knut	1	122.0
T. macdowellii (Reb. ex Quehl) Britton et Rose	1	122.0
T. tulensis (Poselger) Britton et Rose	9	13.5
var. *tulensis*		
var. *buekii*		
var. *matudae*		
Turbinicarpus gautii Benson	7	17.4
T. gielsdorfianus (Werdermann) John et Riha	1	122.0
T. horripilus (Lemaire) John et Riha	1	122.0
T. knuthianus (Bödeker) John et Riha	1	122.0
T. laui Glass et Foster	1	122.0
T. pseudomacrochele (Backeberg) Buxbaum et Backeberg	1	122.0
T. pseudopectinatus (Backeberg) Glass et Foster	8	15.2
T. saueri (Bödeker) John et Riha	1	122.0
T. schmiedickeanus (Bödeker) Buxbaum et Backeberg	7	17.4
var. *dickisoniae* Glass et Foster		
var. *flaviflorus* (Frank et Lau) Glass et Foster		
var. *gracilis* (Glass et Foster) Glass et Foster		
var. *klinkerianus* (Backeberg et Jacobsen) Glass et Foster		
var. *macrochele* (Werdermann) Glass et Foster		
var. *schmiedickeanus*		
var. *schwarzii* (Schurly) Glass et Foster		
T. subterraneus	1	122.0
var. *subterraneus*		
var. *zaragozae*		
T. valdezianus (Moeller) Glass et Foster	3	40.7
T. viereckii (Werdermann) John et Riha	2	61.0
var. *major* (Glass et Foster) John et Riha		
var. *viereckii*		