Biodiversity and Conservation (2006) 15:817–827
DOI 10.1007/s10531-004-1461-x

Global diversity and conservation priorities in the Cactaceae

PABLO ORTEGA-BAES[1,*] and HÉCTOR GODÍNEZ-ALVAREZ[2]
[1]*Laboratorio de Investigaciones Botánicas (LABIBO), Facultad de Ciencias Naturales, Universidad Nacional de Salta, Buenos Aires 177, Salta 4400, Argentina and Instituto de Ecología, Universidad Nacional Autónoma de México, Apdo. Postal 70-275, México, D.F.04510, México;* [2]*UBIPRO, FES-Iztacala, UNAM. Av. de los Barrios 1, Los Reyes Iztacala, Tlalnepantla 54090, Edo. de México. Ap. Postal 314. México; *Author for correspondence (e-mail: portega@miranda.ecologia.unam.mx)*

Received 13 February 2004; accepted in revised form 7 July 2004

Key words: America, Complementarity analysis, Deserts, Endemic species, Species richness

Abstract. The purpose of this paper was to analyze the diversity patterns of Cactaceae at a global scale, to identify those countries where conservation actions should be performed. In order to do this, the species richness and the number of endemic species for 34 American countries were determined. With these data, the relationship between the total number of species or the number of endemic species and the area of the countries were analyzed. In addition, a complementarity analysis was conducted to determine the most important countries for cactus conservation. Results showed that Mexico had the highest number of total and endemic species followed by Argentina, Bolivia, Brazil, and Peru, among others. There was a significant positive relationship between both, the total and endemic species, and the area of the countries. Despite this fact, the cactus diversity in Mexico, Argentina, Peru, Bolivia, Chile, and Costa Rica was higher than expected according to their area. Further, these countries also presented the highest proportions of endemic species. The complementarity analysis indicated that 24 countries are necessary to preserve all cactus species. However, 94% of all species could be preserved with only 10 countries. Considering the diversity patterns and the complementarity analysis, three important groups for cactus conservation were identified: (1) Mexico, Argentina, Peru, Bolivia, Chile, and Costa Rica, (2) Paraguay and Cuba, and (3) Brazil and USA. Conservation efforts should be focused on these countries in order to preserve cactus diversity.

Introduction

Cactaceae is a family endemic to America where it distributes from Canada to Argentina (Bravo Hollis and Sánchez-Mejorada 1978; Gibson and Nobel 1986). The main diversity centers known are Mexico and SW of USA, the Central Andes (Peru, Bolivia, S of Ecuador, NE of Chile and NW of Argentina), E of Brazil, and W and S of Brazil, Paraguay, Uruguay and Argentina. Of all these regions, Mexico is the country with the highest species richness and endemism (Hernández and Godínez 1994; Oldfield 1997; Boyle and Anderson 2002).

These plants may grow in different ecosystems although the highest diversity is found in the arid and semiarid regions, located between 35°N and S latitudes as well as from sea level to altitudes over 5000 m (Bravo Hollis and Sánchez-Mejorada 1978; Gibson and Nobel 1986; Boyle and Anderson 2002). In these

ecosystems, cacti play important roles due to the numerous biological interactions established with other plants and animals. Additionally, some species of cacti represent important food resources to humans. These plants are also important because their ornamental value (Nobel 2002).

Cacti have some ecological traits that make them vulnerable to environmental perturbations such as restricted geographic distributions, long life cycles and low rates of individual growth (Hernández and Godínez 1994; Godínez-Alvarez et al. 2003). Moreover, the successful completion of some reproductive stages such as pollination and seed dispersal depend on the obligate participation of other organisms (Fleming and Valiente-Banuet 2002; Godínez-Alvarez et al. 2003). In addition to these ecological traits, cacti could also be negatively affected by human activities such as illegal collection, international trade, and habitat modification (Oldfield 1997; Hunt 1999; Boyle and Anderson 2002).

At present, many species of cacti are considered threatened or endangered to extinction (Oldfield 1997; Hunt 1999) therefore some countries with high diversity such as Mexico and USA have performed conservation actions. Thus, several cacti have been included in red lists and the priority areas for the conservation of the family have been determined (Hernández and Bárcenas 1995, 1996; Gómez-Hinostrosa and Hernández 2000; Hernández et al. 2001, Hernández and Gómez-Hinostrosa 2002). Furthermore, the demographic data for some species and the legislation to regulate their conservation also exist in these countries (Oldfield 1997; Godínez-Alvarez et al. 2003). Unfortunately, the situation in other countries from Central and South America is different because there is no sufficient information on the areas where cactus diversity concentrates, the demography of the species, and the factors that threaten the maintenance of their populations. Consequently, conservation actions as the establishment of rules to insure the conservation of these plants are scarce or non-existent (Oldfield 1997; Boyle and Anderson 2002). Another factor affecting this situation is that most of the countries in America, excepting Canada and USA, have traditionally faced socio-economic crises which decrease the financial support provided to perform conservation actions. Furthermore, international cooperation institutions have focused their conservation efforts in the establishment of priority areas mainly in the tropical rain forests, instead of desert ecosystems where a high diversity of cactus exist (Myers 1988, 1990; Mares 1992; Mittermeier et al. 1998).

To preserve the diversity of Cactaceae in America, first it is necessary to identify those countries or political territories with an outstanding biological diversity. Based on these analyses, it is possible to define the priority countries for the conservation of this group of plants where financial support must be provided (Sisk et al. 1994; Ceballos and Brown 1995; Caldecott et al. 1996; Arita 1997; Mittermeier et al. 1997). These countries should perform actions through national and international projects to preserve their cactus diversity.

The main purpose of this paper was to analyze the diversity patterns of cactus at a global scale, to determine the countries with a high priority for

the conservation of this family. To accomplish this goal, species richness, endemism and species-area ratio were determined for 34 American countries. In addition, a complementarity analysis was conducted to determine the most important countries to preserve the majority of species. Specifically, the following questions were addressed: (1) what are the countries with the highest species richness and endemism? (2) is there a relationship between cactus diversity and the area of the countries? (3) are species richness and endemism related? and (4) what are the most important countries for the preservation of the majority of species?

Methods

Species richness and endemism

Based on species lists for each country taken from Hunt (1999), a species presence-absence matrix was constructed. This matrix was used to determine: (1) the total number of species or species richness, (2) the number of endemic species, and (3) the relative endemism, which was calculated as the number of endemic species divided by the total number of species for each country. It is important to mention that the number of species per country could vary depending on the taxonomically and provisionally accepted cactus species. However, we believe that Hunt (1999) represents a rather conservative approach and, at the same time, is one of the most complete datasets available until now. Therefore, we consider that its use is well justified in the study reported here.

Species–area ratio

Linear regression analyses between the species richness or the number of endemic species and the area of the countries were conducted to determine the species–area ratio. The area for each country was obtained from a geographic atlas (Oxford 1996). Both variables, number of species and area, were log-transformed to meet the regression analysis assumptions. Confidence intervals (95%) were calculated for the adjusted regression lines to determine those countries with the highest richness and/or endemism. The countries above the confidence intervals were considered as having higher diversity than expected according to their areas (Ceballos and Brown 1995; Arita 1997).

Species richness-endemism ratio

Linear regression analyses between the species richness and the number of endemic species were conducted to determine whether the countries with the

highest species richness were also those with the highest endemism. These regression analyses were conducted as previously described.

Complementarity analysis

A complementarity analysis was conducted to determine the importance of each country in the conservation of the cactus family. This analysis was carried out using an algorithm in which countries were selected according to their total number of species. The procedures followed were: (1) the country with the highest number of species was selected and their taxa were dropped from the analysis; (2) from the remaining countries, that with the highest number of species that had not yet been selected was chosen (i.e., the country with the highest complementarity). This procedure was repeated until all species of the family were selected.

Results

Species richness and endemism

Of all the countries analyzed, Mexico and Canada had the highest (660) and lowest (3) species richness, respectively. In other countries such as Argentina, Bolivia, Brazil, Peru, USA, and Chile, the total number of species ranged from 100 to 250. For the remaining countries, richness was less than 51 species. Similarly, Mexico had also the highest number of endemic species (576) followed by Brazil, Peru, Argentina, and Bolivia with 150–176. The number of endemic species in USA, Chile, Paraguay, and Cuba was relatively low (< 100). Twenty six percent of the countries did not have endemic species (Table 1).

In relation to the relative endemism, results showed that many countries presented high proportions of endemic species. Chile had the highest proportion of endemic species (80%) although there were other countries as Mexico, Peru, Brazil, Bolivia, Argentina, and Cuba where this proportion represented more than 50% of the total diversity (Table 1).

Species–area ratio

The species–area regression was significantly positive ($F = 20.2$, d.f. = 1, 32, $p = 0.0001$, $R^2 = 0.39$), indicating that the number of species increases according to the area of the countries. However, some countries such as Mexico, Argentina, Peru, Bolivia, Chile, Paraguay, and Costa Rica presented a higher number of total species than expected (Figure 1).

Likewise, a significant relationship between the number of endemic species and the area was also found ($F = 22.8$, d.f. = 1, 32, $p < 0.00001$,

Table 1. Cactus diversity in 34 American countries.

	Total genera	Endemic genera (%)	Total species	Endemic species (%)
Argentina	26	3 (12)	258	158 (61)
Bahamas	5	0	9	2 (22)
Belize	6	0	10	0
Bolivia	30	4 (13)	240	153 (64)
Brazil	35	14 (40)	237	176 (74)
Caiman Islands	5	0	7	0
Canada	2	0	3	0
Colombia	17	0	35	6 (17)
Costa Rica	13	0	40	12 (30)
Cuba	15	0	48	25 (25)
Chile	13	1 (8)	104	83 (80)
Dominican Republic	11	0	27	3 (11)
Ecuador	18	2 (11)	43	15 (35)
El Salvador	9	0	11	1 (9)
French Guiana	6	0	6	0
Guatemala	18	0	42	4 (10)
Guyana	8	0	9	0
Haiti	12	0	23	5 (22)
Honduras	16	0	30	2 (7)
Jamaica	10	0	15	4 (27)
Lesser Antilles	9	0	18	1 (6)
Mexico	46	14 (30)	660	517 (78)
Netherland Antilles	10	0	15	1 (7)
Nicaragua	13	0	20	0
Panama	10	0	22	1 (5)
Paraguay	19	0	81	25 (31)
Peru	33	6 (18)	223	170 (76)
Puerto Rico	10	0	18	5 (28)
Suriname	7	0	9	0
Trinidad & Tobago	11	0	13	0
Uruguay	11	0	51	14 (27)
USA	26	1 (4)	202	86 (43)
Venezuela	16	0	39	6 (15)
Virgin Islands	7	0	10	0

Data taken from Hunt (1999).

$R^2 = 0.42$). Eight countries (Mexico, Argentina, Peru, Bolivia, Chile, Cuba, Costa Rica, and Peru) had more endemic species than expected according to their area (Figure 2).

Species richness-endemism ratio

The relationship between species richness and endemism was significantly positive ($F = 363.9$, d.f. $= 1, 32$, $p = 0.00001$, $R^2 = 0.92$). This implies that countries with the highest species richness also had the highest endemism. Six countries (Chile, Cuba, Costa Rica, Puerto Rico, Jamaica, and Honduras)

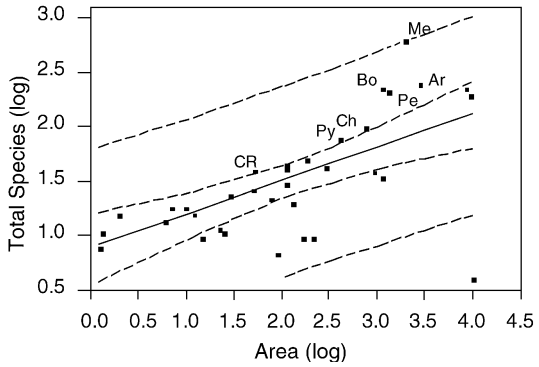

Figure 1. Relationship between total species and area for 34 American countries. Those countries with higher diversity than expected according to their area are: Me – Mexico, Ar – Argentina, Pe – Peru, Bo – Bolivia, Ch – Chile, Py – Paraguay, and CR – Costa Rica.

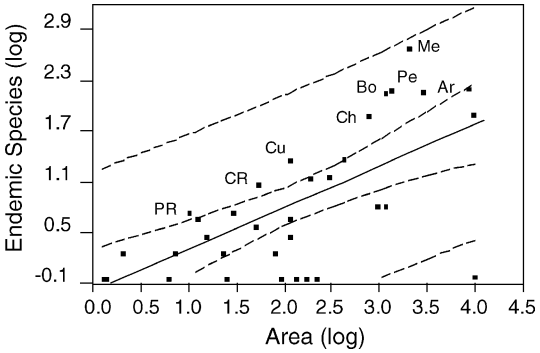

Figure 2. Relationship between endemic species and area for 34 American countries. Those countries with higher endemism than expected according to their area are: Me – Mexico, Ar – Argentina, Pe – Peru, Bo – Bolivia, Ch – Chile, Cu – Cuba, CR – Costa Rica, and PR – Puerto Rico.

presented more endemic species than expected according to their species richness (Figure 3).

Complementarity analysis

The complementarity analysis showed that 24 countries are necessary to preserve all species of the cactus family (Figure 4). However, a high proportion (94%) of this total could be preserved with only 10 countries (i.e., Mexico, Argentina, Peru, Brazil, Bolivia, USA, Chile, Cuba, Costa Rica, and Paraguay).

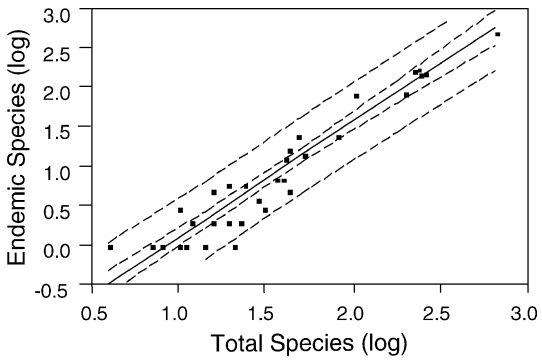

Figure 3. Relationship between endemic and total species for different American countries.

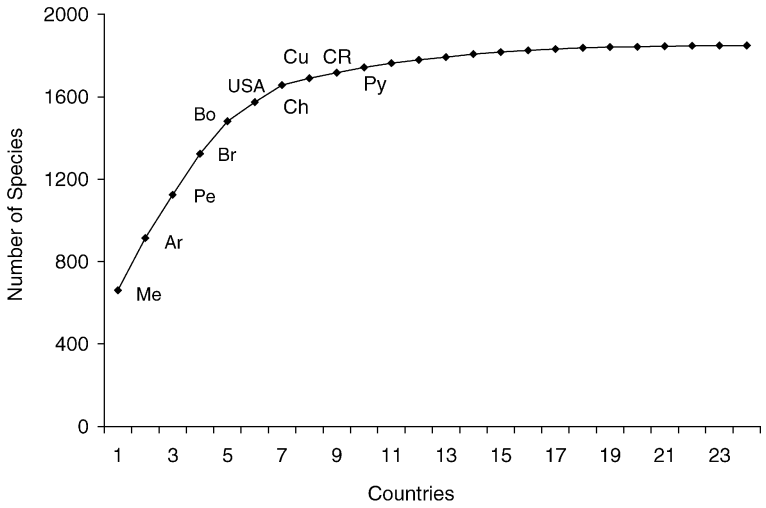

Figure 4. Complementarity analysis for 34 American countries. The first ten marked countries are: Me – Mexico, Ar – Argentina, Pe – Peru, Br – Brazil, Bo – Bolivia, USA – United States of America, Ch – Chile, Cu – Cuba, CR – Costa Rica, and Py – Paraguay.

Discussion

Because time and financial support are limited to preserve biodiversity, many studies have determined priority areas to perform conservation actions. These areas have been selected using the diversity and/or the existing threats for different groups of organisms such as butterflies, birds, mammals, and plants (Myers 1988; 1990; Sisk et al. 1994; Ceballos and Brown 1995; Hernández and Bárcenas 1995; Mittermeier et al. 1997; Ceballos et al. 1998; Mittermeier et al. 1998; Gómez-Hinostrosa and Hernández 2000; Hernández and

Gómez-Hinostrosa 2002). In this context, the results obtained in this work showed that Mexico is an important country for the conservation of the cactus family since 36% of all species occur in its territory (Hernández and Godínez 1994). However, there are other countries mainly in South America which are also important to preserve high proportions of cacti species. Thus, the proportion of species that could be preserved combining efforts in some countries such as Argentina, Bolivia, Brazil, and Peru is ca. 52%.

Some authors have indicated that Cactaceae is a group of plants characterized by high levels of endemism (Rzedowski 1992; Hernández and Godínez 1994; Hernández and Gómez-Hinostrosa 2002). The obtained results provide support to this idea because the seven countries with the highest diversity also presented high proportions ($> 50\%$) of endemic species. This endemism even increase to 80% in Chile. These high endemism in supraspecific taxa such as order and family are quite infrequent in mainland sites. On the other hand, this is a common situation in isolated geo-political units such as islands (Brown and Lomolino 1999). For example, Madagascar and Australia have high degrees of mammal endemism (Ceballos and Brown 1995; Caldecott et al. 1996; Mittermeier et al. 1997; Brown and Lomolino 1998), while Hawaii and Juan Fernandez archipelago are rich in endemic plants (Primack et al. 2001).

Our results indicated that the species richness and the number of endemic species in all the analyzed countries may be explained in some degree by their area. This increase in the number of species with the area is a well-documented pattern that has been used to explain the existence of megadiverse countries (Ceballos and Brown 1995; Arita 1997). In this work, the cactus diversity of certain countries as Brazil and USA was explained by their area. However, diversity in other countries such as Mexico, Argentina, Peru, Bolivia, Chile, Paraguay, Costa Rica, Cuba, and Puerto Rico was higher than expected according to their areas. Therefore, these countries have an outstanding diversity of cactus and should be considered important for the conservation of these plants. This importance is enhanced considering the positive relationship between species richness and endemism. This implies that conservation actions performed in these countries insure the preservation of both, species richness and endemic species.

Based on the complementarity analysis, 24 countries are needed to preserve all cactus species. This large number of countries results from the high levels of endemism found in this family. Despite this fact, in practical terms, it is difficult to perform conservation actions in such a high number of countries; therefore, it is necessary to establish priority areas to optimize the use of the available financial support. In this regard, Mexico, Argentina, Peru, Brazil, Bolivia, USA, Chile, Cuba, Costa Rica, and Paraguay could be considered priority areas because they concentrate ca. 94% of all cactus species. Therefore, financial support to preserve cactus diversity should be focused to these countries. Some of them have already been considered as megadiverse for other groups of organisms, being supported by the international cooperation institutions (Mittermeier 1988; Caldecott et al. 1996; Mittermeier et al. 1997).

However, it is important to mention that such financial support is mainly focused to tropical ecosystems, instead of arid and semiarid regions (Redford et al. 1990; Mares 1992).

Of all the countries selected in the complementarity analysis, Mexico, Argentina, Peru, Bolivia, Chile, and Costa Rica constitute the most important group for cactus conservation because they have higher species richness and endemism than expected according to their areas. Particularly, Mexico, Argentina, and Peru are specially important since they have 49 and 47% of the total and endemic species, respectively. Likewise, Paraguay and Cuba represent a second important group since they present higher species richness or endemism than expected to their area. The third group is conformed by Brazil and USA which have wide areas and high proportions of species, some of them endemic to these countries. Finally, the remaining countries (14) constitute the fourth important group for the conservation of cactus species.

According to the IUCN Cactus and Succulent Specialist Group, financial support to perform cactus conservation actions should ideally focus on: (1) taxonomic studies, (2) evaluation of the conservation status of species, (3) *in situ* protection, (4) *ex situ* protection, (5) development of efficient national regulations, (6) control of national and international trade, and (7) educational programs (Oldfield 1997). Some of these actions have already been proposed and enforced in some of the countries regarded as important in this work. Thus, USA and Mexico have achieved significant advances in cactus conservation (Oldfield 1997; Boyle and Anderson 2002; Hernández and Gómez-Hinostrosa 2002). However, it is necessary to conduct these conservation actions in other priority countries, mainly those located in South America. These actions should be performed immediately since in some countries such as Argentina and Peru currently there are no national red lists of species as well as demographic studies of threatened or endangered cacti. At the same time, it is unknown the conservation status of those species affected by human activities and there is no legislation to regulate their national and international trade.

Acknowledgements

We are grateful to Silvia Sühring, Rurik List, Leticia Ríos, Heliot Zarza, and two anonymous referees for reviewing the manuscript. POB thanks Latin American Plant Sciences Network (RLB) for supporting a research stay at UNAM, Mexico.

References

Arita H. 1997. The non-volant mammal fauna of México: species richness in a megadiverse country. Biodiver. Conserv. 6: 787–795.

Boyle T.H. and Anderson E. 2002. Biodiversity and Conservation. In: Nobel P.S. (ed.), Cacti. Biology and Uses. University of California Press, Los Angeles, pp. 125–141.
Bravo-Hollis H. and Sánchez Mejorada H. 1978. Las Cactáceas de México, Vol. I. Universidad Nacional Autónoma de México, México D.F.
Brown J.H. and Lomolino M.V. 1998. Biogeography. Sinauer Associates, Inc. Publishers.
Caldecott J.O., Jenkins M.D., Johnson T.H. and Groombridge B. 1996. Priorities for conserving global species richness and endemism. Biodiver. Conserv. 5: 699–727.
Ceballos G. and Brown J.H. 1995. Global patterns of mammalian diversity, endemism, and endangerment. Conserv. Biol. 9: 559–568.
Ceballos G., Rodríguez P. and Medellín R. 1998. Assesing conservation priorities in megadiverse Mexico: mammalian diversity, endemicity, and endangerment. Ecol. Appl. 8: 8–17.
Fleming T.H. and Valiente-Banuet A. (eds) 2002. Columnar cacti and their mutualists. Evolution, ecology and conservation. The University of Arizona Press, Tucson.
Gibson A.C. and Nobel P.S. 1986. The cactus primer. Harvard University Press, Cambridge, Massachusetts.
Godínez-Alvarez H.Valverde T. and Ortega-Baes P. 2003. Demographic trends in the cactaceae. Bot. Rev. 69: 173–203.
Gómez-Hinostrosa C. and Hernández H.M. 2000. Diversity, geographical distribution and conservation of Cactaceae in the Mier y Noriega region, Mexico. Biodiver. Conserv. 9: 403–418.
Hernández H.M. and Godínez H. 1994. Contribución al conocimiento de las cactáceas mexicanas amenazadas. Acta Botánica Mexicana 26: 33–52.
Hernández H.M. and Bárcenas R.T. 1995. Endangered cacti in the Chihuahuan Desert. I. Distribution patterns. Conserv. Biol. 9: 1176–1188.
Hernández H.M. and Bárcenas R.T. 1996. Endangered cacti in the Chihuahuan Desert. II. Biogeography and conservation. Conserv. Biol. 10: 1200–1209.
Hernández H.M., Gómez-Hinostrosa C. and Bárcenas R.T. 2001. Diversity, spatial arrangement, and endemism of Cactaceae in the Huizache area, a hot-spot in the Chihuahuan Desert. Biodiver. Conserv. 10: 1097–1112.
Hernández H.M. and Gómez-Hinostrosa C. 2002. An integrated approach to the conservation of cacti in Mexico. In: Maunder M., Clubbe C., Hankamer C. and Groves M. (eds), Plant Conservation in the Neotropics. Royal Botanical Gardens Kew, Great Britain, pp. 350–367.
Hunt D. 1999. CITES. Cactaceae checklist. Royal Botanic Gardens Kew and International Organization for Succulent Plant Study, U.K.
Mares M.A. 1992. Neotropical mammals and the myth of Amazonian biodiversity. Science 255: 976–979.
Mittermeier R.A. 1988. Primate diversity and the tropical forest: case studies from Brazil and Madagascar and the importance of the megadiversitu countries. In: Wilson E.O. (ed.), Biodiversity. National Academic Press, Washington, pp. 145–153.
Mittermeier R.A., Gil P.R. and Mittermeier C.G. 1997. Megadiversidad. Los países biológicamente más ricos del mundo. CEMEX, México.
Mittermeier R.A., Myers N. and Thomsen J.B. 1998. Biodiversity hotspot and major tropical wilderness areas: approaches to setting conservation priorities. Conserv. Biol. 12: 516–520.
Myers N. 1988. Threatened biotas: hotspots in tropical forests. Environmentalist 8: 178–208.
Myers N. 1990. The biodiversity challenge: expanded hot-spots analysis. Environmentalist 10: 243–256.
Nobel P.S. (ed.) 2002. Cacti. Biology and uses. University of California Press, Los Angeles, USA.
Oldfield S. (compiler). 1997. Cactus and succulent plants: status survey and conservation action plan. IUCN/SSC cactus and succulent specialist group. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland, and Cambridge, United Kingdom.
Oxford. 1996. Atlas of the world. Oxford University Press.
Primack R., Rozzi R., Feinsinger P., Dirzo R. and Massardo F. 2001. Fundamentos de la conservación biológica: Perspectivas Latinoamericanas. Fondo de Cultura Económica, México.

Redford K.H., Taber A. and Simonetti J.A. 1990. There is more to biodiversity than the tropical rain forests. Conserv. Biol. 4: 328–330.

Rzedowski J. 1992. El endemismo en la flora fanerogámica mexicana: una apreciación analítica preliminar. In: Halffter G. (ed.), La diversidad biológica de Iberoamérica Acta Zoológica Mexicana. vol. especial, pp. 337–359.

Sisk T.D., Launer A.E., Switky K.R. and Ehrlich P.R. 1994. Identifying extinction threats. Bioscience 44: 592–604.