Caldasia 47:e113461 | **2025**
http://www.revistas.unal.edu.co/index.php/cal

CALDASIA
Fundada en 1940

ISSN 0366-5232 (impreso)
ISSN 2357-3759 (en línea)

BIODIVERSITY

Cacti diversity in the xerophilous scrublands of the Valley of Mexico

Diversidad de cactáceas en los matorrales xerófilos del Valle de México

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- **Received:** 08/may/2024
- **Accepted:** 09/jun/2025
- **Online Publishing:** 04/nov/2025

Citación: Miguel-Talonia, C. 2025. Cacti diversity in the xerophilous scrublands of the Valley of Mexico. Caldasia. 47:e113461. doi: https://doi.org/10.15446/caldasia.v47.113461

ABSTRACT

In the middle of the densely populated Basin of Mexico, subsequently referred to as "Valley of Mexico", the xerophilous scrublands are the habitat of cacti, among many other species, which are threatened by intense human activities. Even though naturalists and botanists have studied the Cactaceae family of the Valley of Mexico, little is known about some aspects of its diversity, such as the beta diversity within this basin. The main objective of this study was to determine the diversity of the cacti established on igneous substrate in the Valley of Mexico. Based on a presence-absence matrix of taxa at 19 sites, cacti richness and beta diversity were calculated with the Chao 2 nonparametric estimator and the Jaccard index, respectively. A total of 27 species belonging to eight genera were observed and 65 species belonging to eight genera were estimated. A high beta diversity was found, which suggests that these insular ecosystems need protection to preserve the ecological communities which still exist in the Valley of Mexico.

Keywords: beta diversity, Cactaceae, igneous hills, similarity, urban ecology.

RESUMEN

En medio de la densamente poblada Cuenca de México, llamada de aquí en adelante "Valle de México", están los matorrales xerófilos que son el hábitat de cactáceas, entre otras especies, las cuales están amenazadas por las intensas actividades humanas. A pesar de que varios naturalistas y botánicos han estudiado la familia Cactaceae en el Valle de México, poco se sabe sobre algunos aspectos de su diversidad dentro de esta cuenca, como la diversidad beta. El principal objetivo de este estudio fue determinar la

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diversidad de cactáceas establecidas sobre el sustrato ígneo del Valle de México. A partir de una matriz de presencia-ausencia de taxones en 19 sitios, fueron calculadas la riqueza de cactáceas y la diversidad beta con el índice no paramétrico de Chao 2 y el índice de Jaccard, respectivamente. Se observaron 27 especies pertenecientes a ocho géneros y se estimaron 65 especies pertenecientes igualmente a ocho géneros. Se encontró una diversidad beta alta, la cual sugiere que estos ecosistemas insulares necesitan protección para conservar las comunidades ecológicas que aún existen en el Valle de México.

Palabras clave: Cactaceae, cerros ígneos, diversidad beta, ecología urbana, similitud.

INTRODUCTION

Mexico City is one of the most populated cities in the world (OECD 2015). The excessive growth of its metropolitan area endangers the remains of vegetation since they have been isolated within a fragmented landscape by urbanization and agriculture (Ibáñez 1983, Ezcurra *et al.* 2006). Particularly, cacti are vulnerable to land-use change due to their slow growth (Godínez *et al.* 2003, Valverde *et al.* 2004, Ortega *et al.* 2010). Throughout the 20th century, several authors have described species and published checklists of the Cactaceae family in the Valley of Mexico (e.g., Gold 1952, Scheinvar 1982). However, to the best of my knowledge, there is not a study that estimates the richness and beta diversity of cacti in this basin. In general, species diversity has three components: gamma, alpha, and beta diversity (Whittaker 1960, 1972). Gamma diversity refers to the total number of species (or species richness) within a given landscape, such as the Valley of Mexico. Alpha diversity represents the number of species at a specific site within that landscape, for example, a low hill in the Valley of Mexico. Beta diversity, on the other hand, measures the variation in species composition between two different sites (Halffter and Moreno 2005). Among these, beta diversity is particularly important for conservation planning, as it can help identify spatial networks of protected areas necessary to maintain species diversity in urban and suburban environments (Knapp *et al.* 2008, Hill *et al.* 2021). The diversity of cacti analysis, as a surrogate for xerophytic communities, is necessary in the face of a new reality such as the excessive urban growth, which inevitably causes land-use changes.

In the Valley of Mexico, the Cactaceae family is common in xerophilous scrublands (Scheinvar 1982). These ecosystems are located mainly in the north of the valley, where precipitation is low (Ezcurra *et al.* 2006). Based on the lithological substrate, scrublands can be classified into those that developed on alluvial material, and those that were established on igneous rocks (Fig. 1a). On the one hand, the vegetation in the plain zone with alluvial (and colluvial) sediments have been affected by human activities since the middle-late Holocene due to Mesoamerican peoples' settlement in the area (McClung 2015). On the other hand, the scrublands established in low hills made up of igneous rocks (known locally as "cerros" and "pedregales") are relatively well preserved, forming an island system immersed into the land with intense human activity (Figs. 1b-c). The aims of this study were: (1) to determine the species richness and the beta diversity of cacti in an insular system originated by a fragmented landscape, and (2) to contribute with a species check-list of the Valley of Mexico, which includes new information of a species-rich site in the northwest.

MATERIALS AND METHODS

A literature review on floristic studies were carried out in the Valley of Mexico and some field observations were included, as well as herbaria data from the Herbario Nacional de México (MEXU) (Table S1). This information was compiled in a database with the following data fields: ID, genus, species, name site, latitude, longitude, altitude, author(s) and publication year. Three additional fields were obtained by consulting the accepted name of species in the online tool Taxonomic Name Resolution Service (Boyle *et al.* 2013) and the assessments of its conservation status from The Red List (IUCN c2012) and the Official Mexican Standard NOM-059-SEMARNAT-2010 (SEMARNAT c2010). Subsequently, a presence-absence matrix was built in which ''1'' indicated the presence of wild species (columns) in the sites (rows), while ''0'' indicated its absence. From this information, the cacti species richness of the Valley of Mexico was estimated with the Chao 2 non-parametric estimator:

$$S_{est} = S_{obs} + Q_1^2 / (2Q_2)$$

where $S_{es}t$ is the estimated richness, S_{obs} is the total number of observed species, Q_1 is the number of the species present at only one site, and Q_2 is the number of species present at two sites (Murguía and Villaseñor 2000). The sampling error (E_s) was estimate according to equation:

$$E_s = 1 - (S_{obs}/S_{est})$$

where Es takes values from 0 to 1. Lower values of E_s indicate a higher quality of the richness results (Murguía and Villaseñor 2000). Finally, beta diversity was calculated with the Jaccard index (β_j):

$$\beta_j = a / (a + b + c)$$

where a is the number of species present in two sites, b is the number of species present in the neighboring site but not in the focal one, and c is the number of species present in the focal site but not in the neighboring one (Koleff *et al.* 2003). $\beta_j = 0$ indicates the maximum species turnover and, $\beta_j = 1$ indicates that there is no species turnover. Similarly, richness, sampling error, and beta diversity were estimated at the genus level. All analyses were executed in the vegan package (Oksanen *et al.* 2022) using R v. 4.3.1 (R Core Team c2023).

RESULTS

The cacti richness in the Valley of Mexico was described with the observed and estimated richness in both species and genus taxonomic levels. Thus, a total of 27 species were found in the reviewed literature and field observations (Table 1); these species belong to eight genera: *Coryphantha* (four species), *Cylindropuntia* (three species), *Echinocereus* (one species), *Ferocactus* (one species), *Mammillaria* (six species), *Myrtillocactus* (one species), *Opuntia* (eight species), and *Stenocactus* (three

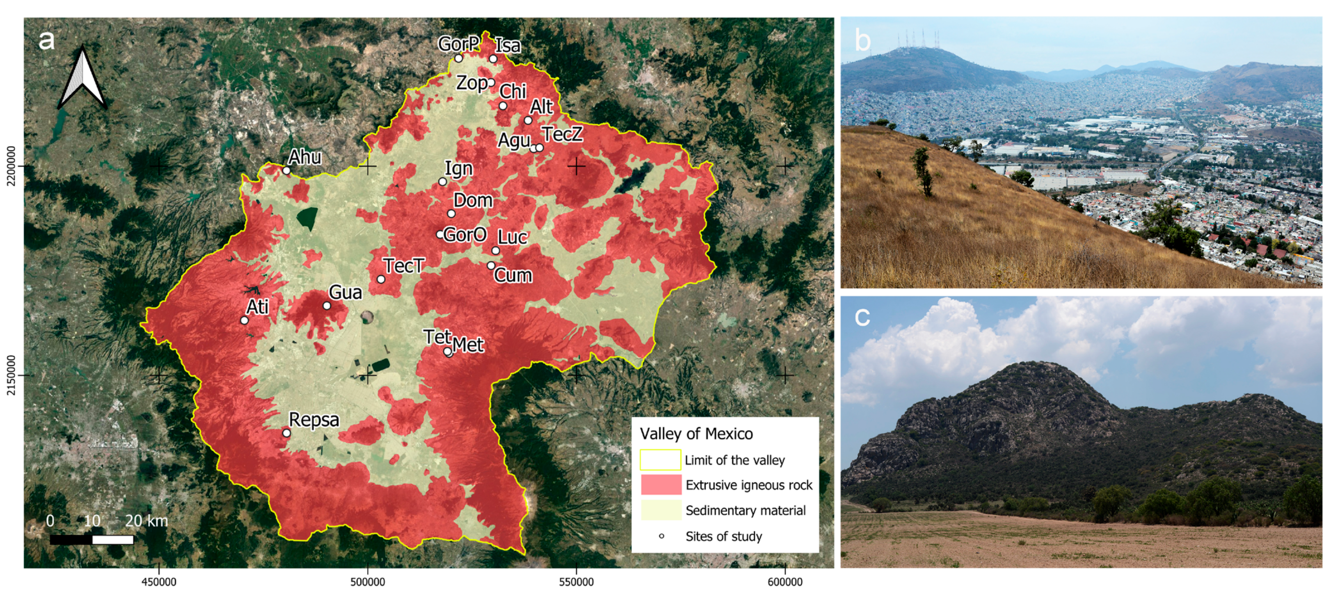

Figure 1. Study area in the Valley of Mexico. a. the 19 sites on igneous substrate for present study; b. Sierra de Guadalupe, an urban landscape on the limits of Mexico City and State of Mexico; c. El Chilelete, a low igneous hill with xerophilous scrubland surrounded by agricultural land. Map made with a Google Earth image (background) and information from the Mexican Geological Service. Map coordinates: UTM zone 14Q. See Table S1 for the abbreviations of the sites name.

Table 1. Cacti species in the xerophilous scrublands of the Valley of Mexico. A: threatened; DD: Data Deficient; EN: Endangered; LC: Least Concern; ND: undetermined category; Pr: Subject to Special Protection.

Species	Sites	Red List Category	NOM-059 Category
Coryphantha cornifera (DC.) Lem.	5	LC	ND
Coryphantha elephantidens (Lem.) Lem.	1	LC	A
Coryphantha octacantha (DC.) Britton & Rose	3	LC	ND
Coryphantha pycnacantha (Mart.) Lem.*	3	EN	ND
Cylindropuntia imbricata (Haw.) F.M.Knuth*	6	LC	ND
Cylindropuntia pallida (Rose) F.M.Knuth	3	ND	ND
Cylindropuntia tunicata (Lehm.) F.M.Knuth*	3	LC	ND
Echinocereus cinerascens (DC.) Lem.	5	LC	ND
Ferocactus latispinus (Haw.) Britton & Rose*	5	LC	ND
Mammillaria discolor Haw.	1	ND	ND
Mammillaria haageana Pfeiff.	1	LC	ND
Mammillaria magnimamma Haw.*	6	LC	ND
Mammillaria rhodantha Link & Otto*	10	LC	ND
Mammillaria uncinata Zucc. ex Pfeiff.	1	LC	ND
Mammillaria zephyranthoides Scheidw.*	1	LC	A
Myrtillocactus geometrizans (Mart. ex Pfeiff.) Console	1	LC	ND
Opuntia hyptiacantha F.A.C.Weber*	9	LC	ND
Opuntia lasiacantha Pfeiff.	5	LC	ND
Opuntia leucotricha DC.	1	LC	ND
Opuntia rastrera F.A.C.Weber	1	ND	ND
Opuntia robusta H.L.Wendl. ex Pfeiff.*	6	LC	ND
Opuntia spinulifera Salm-Dyck	3	ND	ND
Opuntia streptacantha Lem.*	5	ND	ND
Opuntia tomentosa Salm-Dyck*	4	LC	ND
Stenocactus crispatus (DC.) A.Berger*	9	DD	ND
Stenocactus dichroacanthus (Mart. ex Pfeiff.) A.Berger ex Backeb. & F.M.Knuth	1	ND	ND
Stenocactus phyllacanthus (Mart) A.Berger	2	DD	ND

*Observed species in Cerro de la Ahumada, Tequixquiac, Mexico State.

species) (Fig. 2). However, 65 species were estimated for the study area with the Chao 2 estimator, i.e., more than two-fold of the observed species. This contrasts with the case of genera, where the estimated number is equal to the observed one. The differences between observed and estimated taxa are reflected in the sampling error values, where the sampling error of the genus level was lower (E_s = 0) than that of the species level (E_s = 0.6). Regarding beta diversity, low values of β_j (β_j < 0.5; Table S2) at species level were mainly obtained indicating high beta diversity and low similarity between sites (Koleff *et al*. 2003). The most common species in the Valley of Mexico were *Mammillaria rodhantha* Link & Otto (ten out of 19 sites), *Opuntia hyptiacantha* F.A.C.Weber (nine out of 19 sites), and *S. tenocactus crispatus* (DC.) A. Berger (nine out of 19 sites), while there were nine uncommon species (one out of 19 sites) (Table 1). This uneven and specific distribution of cacti species resulted in a high turnover of species across the Valley of Mexico. Nonetheless, values of β_j increased in the analysis at genus level, obtaining values between 0 and 1 (Table S3).

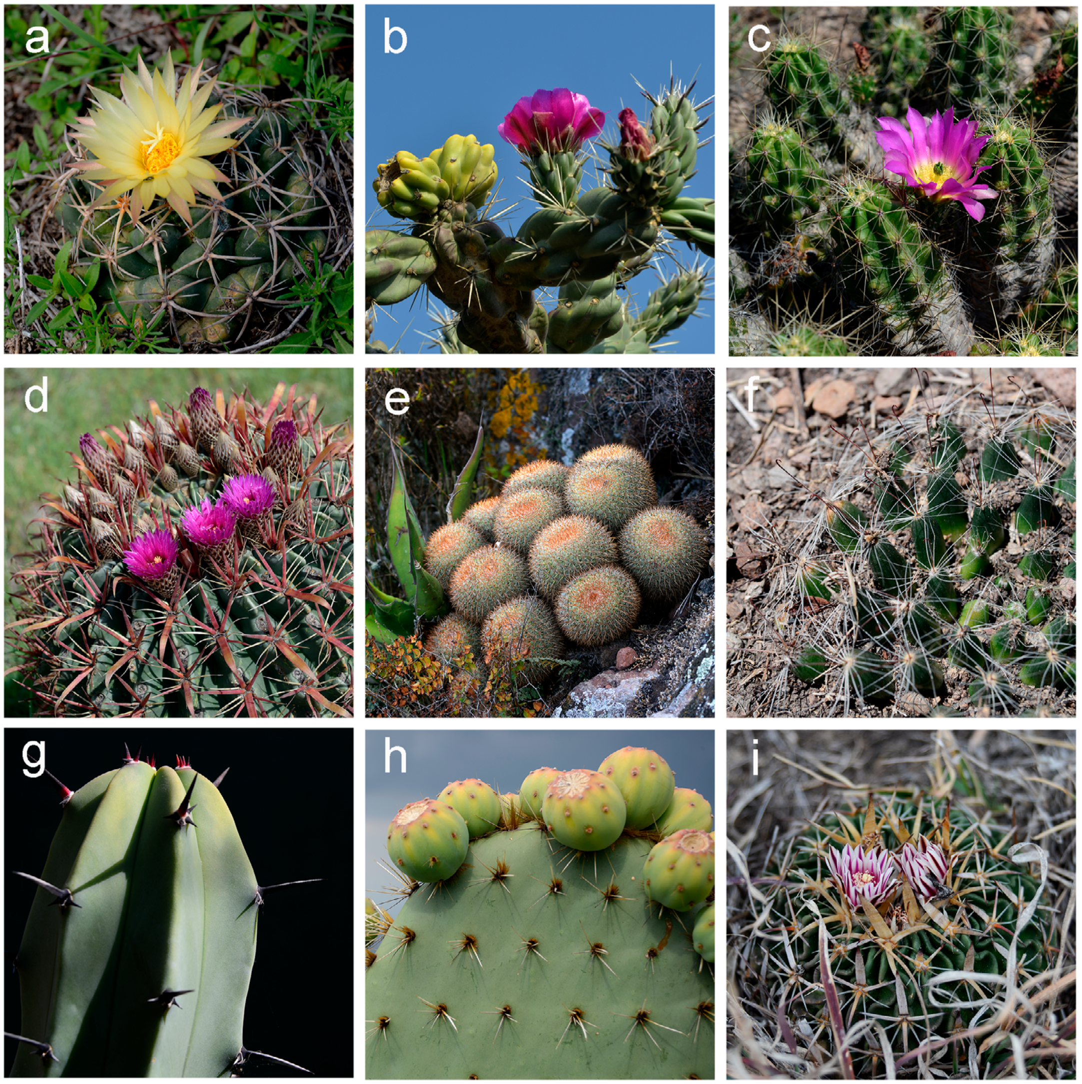

Figure 2. Species that represent the cacti genera in the Valley of Mexico. a. *Coryphantha pycnacantha*; b. *Cylindropuntia imbricata* (Haw.) F.M.Knuth; c. *Echinocereus cinerascens* (DC.) Haage; d. *Ferocactus latispinus* (Haw.) Britton & Rose; e. *Mammillaria rhodantha*; f. *Mammillaria zephyranthoides*; g. *Myrtillocactus geometrizans* (Mart. ex Pfeiff.) Console; h. *Opuntia robusta* H.L.Wendl. ex Pfeiff; i. *Stenoctatus crispatus* (DC.) A. Berger.

DISCUSSION

The main objective of this study was to determine the species richness and beta diversity of cacti in the Valley of Mexico, a fragmented landscape. I found a notable difference between the observed and estimated species richness, as well as a high level of beta diversity.

First, the difference between the observed and estimated species richness has been interpreted as the number of species that theoretically remain to be recorded (e.g., Arenas *et al.* 2020). However, considering the changes in land use, it is reasonable to think that this difference may reflect the number of species that have already disappeared. Future studies and/or botanical expeditions are necessary to shed light on these questions.

Secondly, beta diversity could serve as a useful criterion for designing a network of local protected areas aimed at conserving xerophilous scrubland (e.g., Saraiva *et al.* 2015). Nonetheless, Rocha *et al.* (2023) argue that prioritizing sites with higher alpha diversity (i.e., species richness) may better support overall gamma diversity.

It is important to highlight that the number of cacti species reported in the Valley of Mexico has been changing according to the updates in the nomenclature systems (e.g., Hunt 1989), and therefore, with the time in which the study was carried out. For instance, Gold (1952) reported ten genera and 20 species in the entire valley; conversely, Rzedowski and Rzedowski (2005) reported 59 taxa into eleven genera; specifically, in basaltic rocks and hillsides with other igneous material, like the scrublands studied here. Scheinvar (1982) found fewer species: *Senecio praecox* (Cav.) DC. scrubland reported nine species, *Eysenhardtia* scrubland reported eleven species, and *Hechtia* scrubland reported six species.

In Mexican scrublands, legumes (e.g., *Acacia* and *Eysenhardtia*) and "nopales" (*Opuntia*) are typical plants that play an important role in the vegetation structure (Yeaton and Manzanares 1986, Domínguez *et al*. 2013). When *Opuntia* dominates the plant community, the vegetation type is known as a "nopalera" (Miranda and Hernández-X 2014). In the Valley of Mexico, "nopaleras" are common, with *Opuntia* being the genus with the highest number of species and the widest distribution in scrublands developed on igneous substrates (Ezcurra *et al*. 2006, Table 1). In addition to *Opuntia*, species of *Mammillaria* are also common cacti in Mexican scrublands (e.g., Goettsch and Hernández 2006). In the present study, *Mammillaria* ranked second in number of recorded species (Table 1).

Most species are distributed beyond the limits of the Valley of Mexico and they have a Least Concern (LC) conservation status (Table 1). However, it is important to note that these species represent jeopardized xerophytic communities due to local land-use changes. Only the Reserva Ecológica del Pedregal de San Ángel (six species), Sierra de Guadalupe (ten species), Parque Estatal Atizapan-Valle Escondido (six species) and Cerro Tecajete (four species) are protected sites with a program of conservation but not homes to *Coryphantha pycnacantha* (Mart.) Lem. (Fig. 2a), the unique endangered species in the valley (Table 1). In the northwest limit of the Valley of Mexico, the Cerro de la Ahumada (in Tequixquiac, Mexico State) is the richest site (Table S1). This site houses the endangered *C. p ycnacantha* and *Mammillaria zephyranthoides* Scheidw. (Table 1), but it is not protected. The latter species was declared locally extinct by Rzedowski and Rzedowski (2005); thus, this study contributes with the rediscovery of *M. zephyranthoides* in the Valley of Mexico (Fig. 2f). Even though only the southern slope of Cerro de la Ahumada strictly belongs to the Valley of Mexico, it is important to consider the entire hill when it comes to biological conservation purposes. The conservation of vegetation remnants distributed in several sites may not only contribute to the conservation of biodiversity but also to social well-being in urban and suburban landscapes (de la Barrera *et al*. 2016).

In conclusion, beta diversity reveals that the species and genera of cacti is unequally distributed in the island system of the Valley of Mexico. In other words, each scrubland studied has a particular species (and genera) composition, and it is thus necessary to establish environmental protection measures for these low hills in order to ensure the survival of the cacti and the ecological communities (to which they pertain). Future botanical expeditions and studies are necessary to update cacti records and explain the patterns of diversity in the complex and dynamic Valley of Mexico.

ACKNOWLEDGEMENTS

I thank Ulises Guzmán for his valuable comments on the species check-list. Likewise, I am grateful to Alan Aristizábal for his proof reading of the final English draft, and to Alejandro Rangel for his help to visit and explore El Chilelete hill. I would also like to thank the Anonymous Reviewers for their constructive feedback.

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