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Research Article

Green Roofs, A Unique Habitat for Plants Conservation and Biodiversity in The Urban Matrix.

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Abstract

Loss of green spaces due to urban sprawl is one of the greatest current threats to biodiversity as it leads to habitat fragmentation and loss of native species. Given this scenario, green roofs have been positioned as an alternative technology that allows us to take advantage of the underutilized spaces in city buildings, such as roofs, to generate a habitat for the local flora while providing several environmental, social, and economical benefits. In Mexico City, where 80 % of its surface is covered by buildings and roads, this system was first tested more than twenty years ago. Given the ecosystem importance that has been recognized on this technology in various countries, this study sought to determine the species composition of flora that can be supported in extensive, semi-extensive and intensive green roofs in three sites in Mexico City, as well as evaluate seasonal changes in their communities and determine the causes of variations between sites. To accomplish this, we carried out seasonal censuses for vegetation during 2017 and 2018. As a result, we found 236 species of plants. We found out that the main factors of variation of the diversity between green roofs correspond to the plant taxonomic diversity and to the application of supplementary irrigation during the dry season. These results allow us to conclude that green roofs effectively fulfill the function of being a habitat for plant species in the urban matrix of Mexico City that compensate the loss of green areas.

Introduction

Our planet has experienced rapid urbanization during the last century leading to megacities by the migration of rural population to urban areas in search of better economic opportunities. Now about 50% of the global population lives in urban areas, and by 2050 it is estimated that this proportion will be over 65% [1,2]. It had been reported [3] that in Latin America and the Caribbean, an average of 80% of its inhabitants live in urban areas, and are also experiencing biodiversity loss within and beyond their physical limits, with consequences to the well-being of their citizens [4,5].This leads to the transformation of previously rural lands into urbanized [5] and industrialized areas leading to biodiversity loss [6-10] that alter the ecological balance [11] with negative implications in several order of human life. According to Preston [12] experience confirms the right, between others, to a clean, healthy and sustainable environment, ecosystems and biodiversity.The link between the presence of green spaces in terms of ecosystem services as health benefits (mental, clinical and physical), and spaces for physical activities has been recognized to improve health [13-16]. In this way the stability and health of ecosystems depend on biodiversity [17] which has its base on plant diversity, determining the structure and communities of the other living things associated with it [18]. Plants have unique functions like photosynthesis, which capture carbon dioxide and release oxygen and water to the atmosphere they are also the base of the trophic chain [19] Also, it is known that some species capture contaminants like heavy metals [20], polycyclic aromatics compounds [21] and carbon [22,23]. A solution is the greening of citie [24], and one is the establishment of green roofs. Urban centers have less than 50% of rich species of plants [25], not only due to the systematic removal of green areas but also to the homogenization of vegetation inherent to urbanization [26], since common species with high resistance are favored over native species [27]. Green spaces in the urban matrix are quickly becoming important refuges for native biodiversity [28].Since 1997, Sorensen et al. [28] mentioned that urban green spaces, or urban green areas, must not only serve the needs of all urban residents, but they must also participate fully in it, and other authors [30] added their contribution to people from physical and mental aspects, where recreational needs are met, the community identity is strengthened and which are developed and organized by being considered along with the structure masses. By now it is recognized that this is one of the solutions in the cities, particularly extremely necessary in developing countries [31-32], and essential to promote environmental sustainability as their acts as a natural buffers against pollution and supporting biodiversity [33], and retain rainwater [34].Urban vegetation [35], also known as urban greening systems, includes grasses, trees, forests, facades, and green roofs, [36] have been developed over the last few decades as part of the urban structure, seeking to mitigate the loss of green areas in cities and recover the ecosystemic functions of vegetation. They contribute significantly to maintaining the ecological balance, improve environmental quality, enhance the scenic beauty of the urban environment and provide important qualities of identity and legibility of the image of the city [37]. In particular, green roofs are recognized as refuges for biodiversity as they are spaces inaccessible to the general public, where the vegetation placed is mostly native [39-39] due that the amount of alien species displaces the native ones [40]. The environmental benefits provided derive from their functioning as ecosystems [41-43].Thanks to the various economic, ecological and social benefits they offer, their use has become popular in several countries to the point of even being mandatory to install (44). This technology is recognized as one of the most promising for increasing the green surface areas in cities (45).In general a green roof is defined as a vegetative roof system that contains live plants atop the roof membrane (46). They are made up of different layers and thicknesses that vary depending on the type of cover and/or climatic conditions; the basic layers of the roof upwards are generally: a waterproofing layer, a root barrier, a drainage, a filter, a substrate and a vegetation layer (47). Depending on their use there are extensive, semi-intensive and intensive green roofs, which vary in substrate depth, plant type and maintenance (42-43). Also, derived from their importance for biodiversity, have been known as biodiverse roofs, biodiversity roofs, or green roofs for biodiversity (48) and it is believed that green roofs can promote urban biodiversity (49).

One important menace to urban biodiversity is derived from the fragmentation and heterogeneity of the urban landscape caused by changes in land use (50) due to the aforementioned growth of migration of population to the cities, that increment the impervious surfaces and reduce urban plant diversity [18]. Therefore, considering the importance of the conservation of germplasm and biodiversity, this research we set out to determine the richness and diversity of vascular plants present in three green roofs of Mexico City, of different types and environments, and to analyze the variations between seasons and between study sites. The main purpose of this study was to determine the richness and diversity of flora (vascular plants) in three green roofs of MexicoCity of different types and environments, and to analyze the variations between seasons and between study sites to evaluate their importance as sites of plant biodiversity and conservation

Materials and Methods

Study sites

Three green roofs located in different parts of Mexico City with different configurations and green spaces in the surrounding areas were studied during the period between August 2017 and July 2018. The first (extensive) is located in the living plant collections building of the Botanical Garden (BG) at the southwest of National Autonomous University of Mexico (UNAM by its acronym in Spanish) and is the first one installed in Mexico City in 1999. The second (semi- intensive) is located in the central body of the Scientific Research Coordination east of UNAM (SRC) with six years old. The third (intensive) is located in the building that houses the Fine Arts Center of the private school The American School Foundation (ASF) located northwest of Mexico City with six years old. All sites have a lightweight substrate appropriate for green roofs, with light and porous volcanic material combined with compost (Table 1, Figure 1).

Table 1: Main characteristics of the studied green roofs.

Characteristics	Botanical Garden	Scientific Research Coordination	The American School Foundation
Type	**Extensive**	**Semi-intensive**	**Intensive**
Area (m^2)	260	400	760
Age (years)	21	6	6
Substrate depth (cm)	9	12	8
Building height (m)	3	8	13
Maintenance	Low	Medium	High

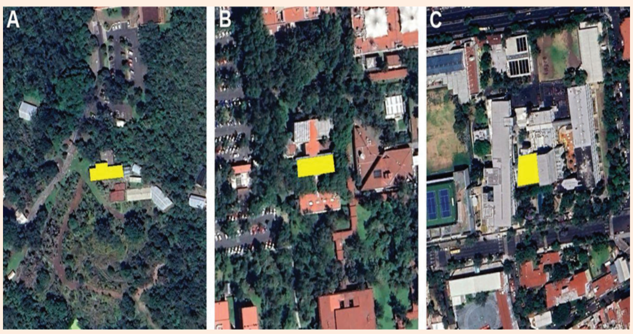

Figure 1: Surroundings of each green roof (marked in yellow). A: Extensive in the Botanical Garden; B: Semi-Intensive in the Scientific Research Coordination; C: Intensive in the American School Foundation.

Species richness and plant classification

It was determined through two exhaustive censuses on each entire green roof. The first was conducted during the rainy season, from August to September 2017, and the second during the dry season, from March to April 2018. The lists obtained were compared to determine the presence, absence, or species turnover between seasons.

Plants were classified in two categories according to their origin on the green roofs: planted and wild species.

Identification was carried out using botanical keys [51-52] and consultation with specialists, as well as with the help of lists published for the REPSA [53].

Statistics

Taxonomic diversity was analyzed using the Clarke-Warwick taxonomic distinctness index (Δ+) using Primer V7 software [54]. The similarity in category composition between sites was determined using the Jaccard Index (JI) and illustrated in a Venn-Euler diagram. Differences in richness between sites and categories were determined using a $\chi 2$ test. Significance was determined using a standardized residuals test.

Meteorological characteristics

In each study site maximum, average and minimum values of temperature and relative humidity, as well as precipitation values data were collected. For the BG and SRC data were obtained through the meteorological stations located within each site and were analyzed through the HOBOware software version 3.7.12. For the ASF the data were obtained from the meteorological station located 1.13 km northeast, at the National Preparatory School No. 4 (UNAM), through the electronic site of the University Network of Atmospheric Observatories

Results

Meteorological characteristics

The general climate in Mexico City is temperate subhumid [Cb(w1)(w)] [55]. According to this research, the rainy season was in May-October and the dry season from November to April with no differences among sites (X2= 256.65, fd= 2, P= 0.1 (Figure 2 A). The monthly average temperature records were very similar between sites; X2= 0.22, fd= 2, P= 0.1 (Figure 2 B); although a low annual average value is observed in the BG (4.72°C) and a high average in the ASF (9.10°C). This variation coincides with the recognized increase in temperature in paved or built-up areas (heat island effect), where absorbed solar radiation is greater, as well as with its decrease in urban green areas, where low absorption of solar radiation and evapotranspiration maintain a cooler environment [56]. Relative humidity is also similar (Figure 2 C) between sites within no differences (X2= 0.42, fd= 2, P= 0.1

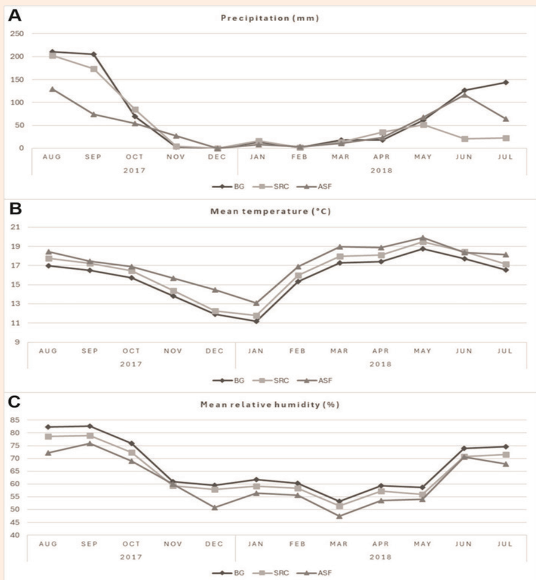

Figure 2: Climatic characteristics by study site. Precipitation (A), mean temperature (B) and mean relative humidity (C). Is notably the difference in precipitation between the rainy season (august, september,,- october 2017; may, june,,- july 2018) with the dry season (november and december 2017; january to june 2018). Same behavior is observed in mean temperature and mean relative humidity.

Plant classification

A total of 236 species were identified across the three sites and two seasons, belonging to 45 families and 22 orders (see the complete list in SI 1). The orders with the highest species richness were Asparagales with 37 species and Asterales with 35 species (Figure 3). 91 species were planted and 145 emerged wildly from the seed bank soil and from dispersion by the wind.

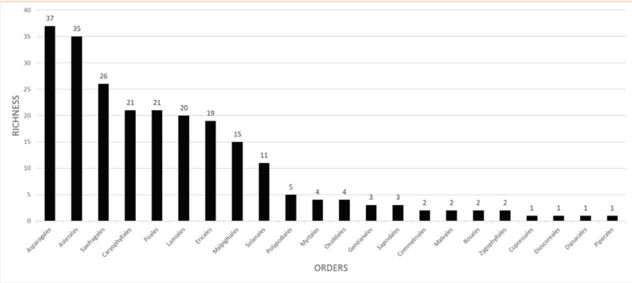

Figure 3: Number of plant orders named according APG IV [57] The number of species is indicated in each one. The orders with the highest number of species richness were Asparagales and Asterales.

Taxonomic diversity and species richness

The highest taxonomic diversity was recorded in BG followed by and ASF. In contrast, ASF recorded the highest species richness, followed by BG and SRC (Table 2).

Planted species were most abundant in the ASF, where total species abundance increased by 105% due to the development of wild species. In contrast, planted species abundance was lowest in the BG, while total species abundance increased by 185% thanks to the establishment of multiple wild species (Table 2).

Table 2: Taxonomic diversity (Δ+) and species richness (S) per category identified at each site: Botanical Garden (BG, extensive green roof), Scientific Research Coordination (SRC, semi-intensive green roof) and American School Foundation (ASF, intensive green roof). Planted species were more abundant in the ASF and lowest in the BG.

Site		Category		Total
		Planted	Wild	
BG	Δ+	65.69	76.03	77.04
	S	34	63	97
SRC	Δ+	74.25	74.40	76.51
	S	40	55	95
ASF	Δ+	65.53	73.70	75.20
	S	52	58	110

Of the total species recorded, 91 (38.56%) are planted and 145 (61.44%) were wild. Among the planted genera, those with the highest species richness were *Agave* (S=25), *Echeveria* (S=14), *Sedum* (S=8), and *Opuntia* (S=7). Among the wild genera the families with the highest species richness were Asteraceae (S=30), Poaceae (S=16), Fabaceae (S=14), Euphorbiaceae (S=12), and Convolvulaceae (S=9).

Composition of planted and wild species

Based on the analysis of site composition, it was found that all sites share the families Asteraceae, Asparagaceae, Cactaceae, and Crassulaceae. Similarly, twelve species were recorded across all sites, which are: *Agave mitis, Dahlia sorensenii, Echeveria agavoides, E. gibbiflora, Graptopetalum paraguayense, Opuntia robusta, O. joconostle, Pittocaulon praecox, Sedum dendroideum, S. moranense, S. pachyphyllum* and *S. rubrotinctum.*

According to Jaccard similarity for planted species the BG-ASF subset has the greatest similarity (IJ = 27.54%), while the subsets that include the SRC are less similar (SRC-ASF = 21.62%, BG-SRC = 21.31%). The Jaccard Index for wild species indicates that the greatest similarity was recorded in the SRC-ASF subset (IJ= 18.75%), while the subsets that include BG obtained lower values (BG-SRC= 9.35%, BG-ASF= 6.25%). The number of species shared between sites in this category is lower than in the previous one, amounting to only six (*Cosmos bipinnatus, Ipomoea* sp*., Mecardonia procumbens, Medicago polymorpha, Oxalis lunulata*, and Poaceae sp.). Based on the environment of each site, it is notable that ASF and SRC share more wild species. For both categories, the dissimilarity observed between sites is notable, with more than 70% of the primary species at each site being unique to them, while for wild species this proportion is greater than 80% across all sites.The first census, conducted during the rainy season, recorded greater species richness at all sites compared to the second one, conducted during the dry season. However, species richness by category varied significantly across sites. For planted species, their persistence at all sites was greater than 96%, with no significant differences between them ($\chi2 = 0.142$, d.f. = 2, $p = 0.932$). Species not observed during the dry season were *Manfreda scabra* in the BG, *Cestrum* sp. in the SRC, and *Agave weberii* and *Zea mays* in the ASF. In contrast, wild species showed a very significant difference ($\chi2$= 86,467, d.f.= 2, $p<0.001$), with 57.45% of the species remaining in SRC, 44.74% in ASF, and only 9.52% in BG. Species turnover during the dry season was only recorded at SRC and ASF sites, with the latter being more numerous (Figure 4).

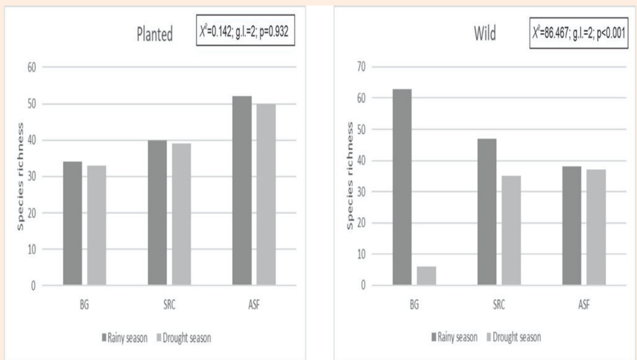

Figure 4: Species richness of planted and wild species during the rainy and drought seasons in each study site: BG (Botanical Garden), extensive green roof; SRC (Scientific Research Coordination), semi-intensive green roof. and ASF (American School Foundation), intensive green roof. For each group is indicated $\chi2$ value, freedom degree and significance level.

Discussion

In Mexico, this study is the first to determine the composition of the plant community in these incipient habitats.

The species richness present in the studied sites is high compared to other studies conducted in Europe [58-59] in six and 15 green roofs, respectively, even though the number of green roofs considered was greater, the richness is lower than that found in the present study. Similarly, in the work by Madre et al. [60], a greater richness is reported, although the number of sites studied was much higher (115 green roofs). Dunnett et al. [61] who report for Sheffield (United Kingdom) only 50 species in one green roof. The presence of lower richness in these studies may be due to the temperate climate typical of European cities, contrary to the warm climate predominant in Mexico, as well as to the high floral diversity that our country has.It is noteworthy that at least 65 of the species found in the present study are reported as native or naturalized within the conservation areas of Mexico City [62-63].Within the composition determined in the studied sites, three species were found (*Sedum moranense, S. reflexum* and *S. rubrotinctum*) and six genera (*Dalea, Manfreda, Muhlenbergia, Opuntia, Portulaca* and *Salvia*), which coincide with the lists of effective vegetation for green roofs by location [64]. At this point, it is possible to join the efforts of these authors and propose the use of the primary species recorded in this study (SI 1) as effective species on green roofs in Mexico City, thanks to their high survival between seasons and their ability to develop in arid environments and shallow substrates. In particular, those belonging to the Asparagaceae,Cactaceae and Crassulaceae families are recommended due to their ability to develop under extreme conditions of heat and aridity [65]. Their permanence has been confirmed in BG, where *Agave salmiana, A. difformis, A. horrida, Echeveria gibbiflora, Sedum agavoides, S. dendroideum, S. rubrotinctum, Opuntia ficus-indica* and *O. streptacantha* have lasted since the initial planting, more than 20 years ago. The richness of the site is determined by various factors. For planted species, their presence on green roofs is deliberate, so their composition depends on both the use of the site and the available space. Thus, the larger the roof, the greater the floral richness that can be accommodated. For wild species, the surrounding green areas and the dispersal capacity of the plant populations found there are likely to influence the plant composition, while the height of the buildings where the green roofs are located may represent a barrier to the arrival of these plants. Based on the comparison of richness and taxonomic diversity, the latter best explains the plant diversity at the studied sites. An example of this is the ASF where the highest species richness and lowest taxonomic diversity were simultaneously recorded. The analysis of taxonomic diversity by category (Table 2) shows that the index for primary species at the BG and ASF sites is very similar, as they primarily comprise Cactaceae, Crassulaceae and Asparagaceae families. In contrast, the index obtained at the SRC is higher thanks to the inclusion of a greater variety of plants, including grasses and shrubs. For wild species, diversity depends on several factors. At BG, for example, the absence of weeding activities may allow the arrival of a large number of wild plants, while increasing their competition for space. In contrast, at the SRC and ASF wedding activities prevent their establishment but favor the emergence of replacement species, thanks to the absence of competitors.It is important to highlight that the high species richness of the sites is not related to high taxonomic diversity, the latter being of greater importance as it allows for better use of the resources and niches available on the green roofs.The appropriate selection of plants for use on a green roof is essential for successful vegetation establishment. This depends largely on their ability to adapt to local conditions [43, 64]. Under this scenario, the use of succulent plants is a priority, since their survival on green roofs is directly related to the amount of water stored in their tissues [65-66]. In this regard, the results obtained in this research are consistent with this trend, as 70 primary species (76.92% of the richness) within the studied sites are succulents, belonging to the Asparagaceae, Cactaceae and Crassulaceae families. For wild plants, two succulents were recorded: *Kalanchoe delagoensis*, known as an aggressive weed with high invasive potential [62], and *Cylindropuntia tunicata*. It is noteworthy that the *Agave* genus recorded a much higher abundance than the *Sedum* genus, which is currently the most widely used and recommended in these systems. Therefore, its use on green roofs in Mexico City is highly recommended. Cactaceae and Crassulaceae families are recommended due to their ability to develop under extreme conditions of heat and aridity [65]. 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Although environmental and spatial restrictions on green roofs limit the number of species that can successfully establish on them, compositional similarity between sites was found to never exceed 30%. For primary species, this indicates that the richness found at the studied sites is broad enough to define very distinct compositions for each. The SRC had the lowest similarity compared to the other sites, due to itsgreater diversity, including herbaceous plants, shrubs, and even grasses. In contrast, the highest similarity was recorded between sites BGand ASF, as the composition of both sites is based primarily on Agavaceae, Cactaceae and Crassulaceae (Figure3). The three sites share a total of twelve species, of which ten are succulents and two belong to the Asteraceae family and are native to the region: *Dahlia sorensenii* and *Pittocaulon praecox* [62,67].

In the case of wild species, the green areas in the environment do not appear to be a determining factor in their composition, since the similarity between BG and SRC is only 15%, despite sharing a similar natural environment. In contrast, the ASF and SRC sites share more species, despite their very different environments (Figure 1). It should be noted that both sites receive routine maintenance, which could favor the dispersal of propagules through new plants, fertilizer, or even workers and visitors themselves. Hwang and Yue [68] point out that wind and fauna are important factors in the dispersal of seeds and propagules on green roofs; however, this was not analyzed during this research.

The seasonal variation (Figure 2) recorded for the planted species was less than 4% at all sites. This result was expected because their survival is a priority, so their selection is deliberate and their permanence is essential, particularly at the SRC and ASF sites, where they serve aesthetic and educational functions.

In quantitative terms, it is noteworthy that the persistence of primary species at the BG site is similar to that of the other sites, considering that no supplemental irrigation was applied during the dry season. Qualitatively, the plants always appeared vigorous and showed no apparent signs of pest damage.

The interseason persistence of secondary species at the SRC and ASF sites was close to 50% despite constant weeding. This indicates that maintenance efforts, particularly supplemental irrigation, promote their continued development at both sites. At the BG site, their persistence is subject to their particular physiology, such that, in the absence of irrigation, persistence decreases significantly, reaching only 9.52%. These results are consistent with various studies showing that species with C3 and C4 metabolisms, such as most of the identified wild species, require at least weekly irrigation to survive on a green roof, unlike succulents with CAM metabolism, which can survive up to four months without irrigation [65,69].The SRC had the highest percentage of persistence for primary (97.50%) and secondary (57.45%) species, likely because plant assemblages with greater taxonomic diversity perform better and make more efficient use of available resources [70-71].

Based on the results obtained in this study, it is clear that the diversity of vascular plants that can be used within green roofs in Mexico City is very broad. The inclusion of these new green areas is disruptive to the impoverished natural environment of the urban matrix (26). It is noteworthy that the primary species were able to develop in a substrate depth less than that recommended in conventional guidelines [72]. This opens the possibility of constructing a semi-intensive or intensive green roof with a saturated weight similar to that of an extensive one (Table 1), without detracting from the plant diversity installed. The dynamics of change that a green roof is subject to indicate that the development of wild species is inevitable [73]. This increase in species richness can be welcomed, as it does not involve competition with planted species. If a decrease in their establishment is preferable, it is advisable to establish a plant composition of high taxonomic diversity from the outset, which promotes niche occupation, thus maximizing site productivity and minimizing required maintenance.

Conclusion

In contrast to the traditional composition of green roofs, which is heavily based on the *Sedum* genus [42-43,74], the. Asparagaceae and Cactaceae families recorded the highest species richness, followed by Crassulaceae, together representing 35.17% of the primary species within the studied sites. This permanence, which was close to 100% between seasons and which, in the case of the extensive green roof (BG), has been maintained since the initial planting almost 20 years ago, allows us to assert that they can be successfully used in these systems within Mexico City. This opens the door to exploiting a greater variety of plants belonging to these families on green roofs, considering that in Mexico their combined species richness amounts to 1,494 species, many of which are native [75]. The ability of planted vegetation species to develop in a shallow substrate (8-12 cm), less than that recommended for extensive (≤15 cm) and intensive (>15 cm) green roofs [76], implies a decrease in the total weight of the naturalization system, since a smaller amount of substrate is required for the successful development of vegetation cover. Furthermore, since these species are adapted to arid and semi-arid environments, the maintenance work necessary for their survival, particularly supplementary irrigation, is minimal.

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Author Contributions

All authors contributed to the study conception and design. Material preparation and data collection, was performed by Julyo Espinoza, analysis were performed by Julyo Espinoza and Margarita Collazo-Ortega. The first draft of the manuscript was written by Julyo Espinoza and Margarita Collazo-Ortega, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Consent for publication

All authors give their consent.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose, or conflict of interest.

References

1. UN (United Nations) Department of Economic and Social Affairs (2015) Population Division World Urbanization Prospects: The 2014 Revision (ST/ESA/SER. A/366).
2. USAID (United States Agency for International Development) (2017) Sustainable Urbanization for Global Progress and Security W,ashington DC USA
3. Dobbs C, Escobedo FJ, Clerici N, de la Barrera F, Eleuterio AA, et al. (2019) Urban ecosystem services in Latin America: Mismatch between global concepts and regional realities? Urban Ecosyst 22(1): 173-187.
4. Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J et al. (2008) Global change and the ecology of cities. Science 319(5864): 756-760.
5. Montambault JR, Dormer M, Campbell J, Rana N, Gottlieb S, Legge J et al. (2018) Social equity and urban nature conservation. Conserv Lett 11(3): 1-13.
6. Legorreta J (1994) Efectos ambientales de la expansión de la Ciudad de México 1970-1993. 1ra Ed. Centro de Ecología y Desarrollo, México 182.
7. Vitousek PM, Mooney HA, Lubchenco J, Melillo JM (1997) Human domination of Earth's ecosystems. Science 277(5325): 494-499
8. Niemelä J, Saarela S, Söderman, Kopperoinem L, Yli-Pelkonen V, et al. (2010) Using the ecosystem services approach for better planning and conservation of urban green spaces: A Finland case study. Biodiversity Conserv 19: 3225-3243.
9. Rojas C, Sepúlveda E, Barbosa O, Rojas O, Martínez C (2015) Patrones de urbanización en la biodiversidad de humedales urbanos en Concepción metropolitano. Revista de Geografía Norte Grande 61: 181-204.
10. Johnson CN, Balmford A, Brook BW, Buettel JC, Galetti M, Guangchun L, Wilmshurst JM (2017) Biodiversity losses and conservation responses in the Anthropocene. Science 356(6335): 270-275.
11. Zubicaray G, Brito M, Ramírez Reyes L, García N, Macías J (2021) Las ciudades mexicanas: Tendencias de expansión y sus impactos. Coalition for Urban Transitions London and Washington DC.
12. Preston BJ (2024) The nature content and realisation of the right to a clean healthy and sustainable environment. J Environ Law 36(2): 159-186.
13. Markevych I, Schoierer J, Hartig T, Chudnovsky A, Hystad P, et al. (2017) Exploring pathways linking greenspace to health: Theoretical and methodological guidance. Environ Res 158: 301-317.
14. Rojas-Rueda D, Nieuwenhuijsen MJ, Gascon M, Perez-Leon D, Mudu P (2019) Green spaces and mortality: A systematic review and meta-analysis of cohort studies. Lancet Planet Health 3(11): E469-E477.
15. Femke B, Davies Z, de Vries S, Glanville J, Keune H, et al (EKLIPSE EWG) (2021) Blue space in urban and peri-urban areas and mental health: Which blue space types and characteristics are most beneficial? In: WHO (ed) Green and New Evidence and Perspectives for Action Green and blue spaces and mental health: new evidence and perspectives for action 24-27.
16. Egorov AI, Griffin SM, Styles JN, Kobylanski J, Klein J, et al. (2024) Time outdoors and residential greenness are associated with reduced systemic inflammation and allostatic load. Environ Pollut 344: 123408.
17. Brondízio ES, Settele J, Diaz S, Ngo HT (2019) Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat 1148.
18. Yan Z, Teng M, He W, Liu A, Li Y (2019) Impervious surface area is a key predictor for urban plant diversity in a city undergone rapid urbanization. Sci Total Environ 650(1): 335-342.
19. Rodes R, Collazo-Ortega M (2013) Metabolismo energético de las plantas. In: Márquez-Guzmán J, Collazo-Ortega M, Martínez-Gordillo M, Orozco-Segovia A, Vázquez-Santana S (eds) Biología de angiospermas. Facultad de Ciencias, UNAM, Coordinación de la Investigación Científica.
20. Ríos GG (2021) Captación de metales potencialmente tóxicos por tres especies de Opuntia (Cactaceae) y Agave celsii (Asparagaceae) en una azotea verde extensiva. Dissertation Universidad Nacional Autónoma de México.
21. Arellano-Leyva E, Hernández-Quiróz M, Huerta-Guzmán RG, Collazo-Ortega M (2017) Extensive green roofs as a means to capture polycyclic aromatic hydrocarbons. Polyciclic Aromat Com 37(4): 280-291.
22. Collazo-Ortega M, Rosas U, Reyes-Santiago J (2017) Towards providing solutions to the air quality crisis in the Mexico city metropolitan area: Carbon sequestration by succulent species in green roofs. PLoS Curr 9 ecurrents-dis.
23. Camacho MS (2023) Evaluation of CO_2 capture by Sedum stahlii and Sedum griseum under rainy and dry conditions on green roofs. Dissertation, National Autonomous University of Mexico
24. Farkas JZ, Hoyk E, de Morais MB, Csomós G (2023) A systematic review of urban green space research over the last 30 years: A bibliometric analysis. Heliyon 9(2): e13406.
25. McKinney ML (2002) Urbanization biodiversity and conservation: The impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. BioScience 52(10): 883-890.
26. McKinney ML (2006) Urbanization as a major cause of biotic homogenization. Biol Conserv 127(3): 247-260.
27. Sæbø A, Benedikz T, Randrup TB (2003) Selection of trees for urban forestry in the Nordic countries. Urban For Urban Greening 2(2): 101-114.

28. Goddard MA, Dougill A, Benton TG (2010) Scaling up from gardens: Biodiversity conservation in urban environments. Trends Ecol Evol 25(2): 90-98.
29. Sorensen M, Smit J, Barzetti V (1997) Good practices for urban greening. Washington DC May CENV-109: 80
30. Yılmaz S, Mumcu S (2016) Urban Green Areas and Design Principles. In Efe R, Cürebal İ, Gad A, Tóth B, Kliment ST (eds) Environmental Sustainability and Landscape Management. ST Kliment Ohridski University Press Sofia: Sofia Bulgaria 100-118p.
31. Rahman SR, Ahmad H, Mohammad S, Rosley MSF (2015) Perception of green roof as a tool for urban regeneration in a commercial environment: The secret garden Malaysia Procedia-Social and Behavioral Sciences 170: 128-136.
32. Ramaiah M, Avtar R (2019) Urban green spaces and their need in cities of rapidly urbanizing India: A review. U Sci 3(3): 94.
33. Diluiso F, Guastella G, Pareglio S (2021) Changes in urban green spaces value perception: A meta-analytic benefit transfer function for European cities. Land Use Policy 101: 105116.
34. Arellano-Leyva EA, López-Portillo M, Muñoz-Villers LE, Prado-Pano, BL (2021) Rainfall retention and runoff generation processes in tropical mature green roof ecosystems. Hydrol Process 35(11): e14382.
35. Dige G, Eales R, Baker J, Sheate W, Zamparutti T, et al. (2011) Green infrastructure and territorial cohesion. The concept of green infrastructure and its integration into policies using monitoring systems. Technical Report 18, European Environment Agency Copenhagen.
36. Boukita H, Elwahab F, El Ammari M, Chemchaoui A, Benchahid B, et al. (2024) A Systematic Review of Urban Vegetation Research during 2000-2023: A Bibliometric Analysis. Int J For Res 2024(1): 4313232.
37. Capitanachi C, Amante HS (1995) Las áreas verdes urbanas en Xalapa, Veracruz. Catálogo de flora urbana. Universidad Veracruzana-Instituto de Ecología AC Xalapa Veracruz México 524.
38. Brenneisen S (2006) Space for urban wildlife: Designing green roofs as habitats in Switzerland. Urban Habitats 4(1): 27-36.
39. Schindler B, Griffith AB, Jones KN (2011) Factors influencing arthropod diversity on green roofs. Cities and the Environment (CATE) 4(1): 1-20.
40. Wania A, Kühn I, Klotz S (2006) Plant richness patterns in agricultural and urban landscapes in Central Germany-spatial gradients of species richness. Landscape Urban Plann 75(1-2): 97-110.
41. Berndtsson JC, Emilsson T, Bengtsson L (2006) The influence of extensive vegetated roofs on runoff water quality. Sci Total Environ 355(1-3): 48-63.
42. Getter KL, Rowe DB (2006) The role of extensive green roofs in sustainable development. HortScience 41(5): 1276-1285.
43. Oberndorfer EJ, Lundholm B, Bass RR, Coffman H, Doshi N, (2007) Green roofs as urban ecosystems: Ecological structures functions and services. BioScience 57(10): 823-833.
44. MacIvor JS, Margolis L, Perotto M, Drake JAP (2016) Air temperature cooling by extensive green roofs in Toronto Canada. Ecol Eng 95: 36-42.
45. Madre F, Vergnes A, Machon N, Clergeau P (2013) A comparison of 3 types of green roof as habitats for arthropods. Ecol Eng 57:109-117.
46. Cavanaugh LM (2008) Redefining the green roof. J Archit Eng 14(1): 4-6.
47. Bianchini F, Hewage K (2012) How green are the green roofs? Lifecycle analysis of green roof materials. Build Environ 48: 57-65.
48. Gedge D, Kadas G (2005) Green roofs and biodiversity. Biologist 52(3):161-169.
49. Wang L, Wang, H, Wang Y, Che Y, Ge Z (2022) The relationship between green roofs and urban biodiversity: A systematic review. Biodiversity Conserv 31(7): 1771-1796.
50. Wang C, Wang Y, Wang R, Zheng P (2018) Modeling and evaluating land-use/land-cover change for urban planning and sustainability: A case study of Dongying city China. J Clean Prod 172: 1529-1534.
51. Rzedowski GC, Rzedowski J (2005) Flora fanerogámica del Valle de México. 2ª ed. Instituto de Ecología, A.C. y Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. Michoacán, México 1406 p.
52. Espinosa-García FJ, Sarukhán J (1997) Manual de malezas del Valle de México Ed. Universidad Nacional Autónoma de México y Fondo de Cultura Económica. México DF México.
53. Castillo-Argüero S, Martínez-Orea Y, Meave JA, Hernández-Apolinar M, Nuñez-Castillo O (2009) Flora: Susceptibilidad de la comunidad a la invasión de malezas nativas y exóticas. In: Lot A, Cano-Santana Z (eds) Biodiversidad del ecosistema del Pedregal de San Ángel UNAM México 107-117.
54. Clarke KR, Gorley RN (2015) PRIMER v7: User manual/tutorial 296. Plymouth UK: PRIMER-E.
55. García E (2004) Modificaciones al sistema de Clasificación Climática de Köppen (para adaptarlo a las condiciones de la República Mexicana). 5ta Ed. Instituto de Geografía. Universidad Nacional Autónoma de México, México.
56. Norton BA, Coutts AM, Livesley SJ, Harris RJ, Hunter AM et al. (2015) Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landscape Urban Plann 134: 127-138.
57. APG IV (2016) An Update of the Angiosperm Phylogeny Group Classification for the Orders and Families of Flowering Plants. Bot J Linn Soc 181(1): 1-20.
58. Landolt E (2001) Orchideen-Wiesen in Wollishofen (Zürich)- ein erstaunliches Relikt aus dem Anfang des 20. Jahrhunderts. Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich 146(2-3): 41-51.
59. Catalano C, Marcenò C, Laudicina VA, Guarino R (2016) Thirty years unmanaged green roofs: Ecological research and design implications. Landscape Urban Plann 149: 11-19
60. Madre F, Vergnes A, Machon N, Clergeau P (2014) Green roofs as habitats for wild plant species in urban landscapes: First insights from a large-scale sampling. Landsc Urban Plan 122:100-107.
61. Dunnett N, Nagase A, Hallam A (2008) The dynamics of planted and colonizing species on a green roof over six growing seasons 2001-2006: Influence of substrate depth. Urban Ecosyst 11(4): 373-384.
62. Rivera HJE, Espinosa HA (2007) Flora y Vegetación del Distrito Federal. In: Luna-Vega I, Morrone JJ, Espinosa-Organista E (eds.) Biodiversidad de la Faja Volcánica Transmexicana. Universidad Nacional Autónoma de México (UNAM)-Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México DF México.
63. Rivera-Hernández JE, y Espinosa-Henze A (2011) Nueva información sobre registros recientes de las familias Meliaceae, Poaceae y Viscaceae en la flora fanerogámica del Distrito Federal, México Revista Científica UDO Agrícola 11(1): 83-88.
64. Dvorak B, Volder A (2010) Green roof vegetation for north american ecoregions: A literature review. Landscape Urban Plann 96(4): 197-213.
65. Rayner JP, Farrell C, Raynor KJ, Murphy SM, Williams NS (2016) Plant establishment on a green roof under extreme hot and dry conditions: The importance of leaf succulence in plant selection. Urban For Urban Greening 15: 6-14.
66. Razzaghmanesh M, Beecham S, Kazemi F (2014) The growth and survival of plants in urban green roofs in a dry climate. Sci Total Environ 476-477: 288-297.
67. Carrasco-Ortiz M, Munguía-Lino G, Castro-Castro A, Vargas-Amado G, Harker M, Rodríguez A (2019) Richness, geographical distribution and conservation status of the genus Dahlia (Asteraceae) in Mexico Acta Bot Mex 126.
68. Hwang YH, Yue Z EJ (2015) Observation of biodiversity on minimally managed green roofs in a tropical city. J Living Archt 2(2): 9-26.
69. Durhman AK, Rowe DB, Rugh CL (2006) Effect of watering regimen on chlorophyll fluorescence and growth of selected green roof plant taxa. HortScience 41(7): 1623-1628.
70. Cadotte MW (2013) Experimental evidence that evolutionarily diverse assemblages result in higher productivity. PNAS 110(22): 8996-9000.
71. Burns JH, Strauss SY (2011) More closely related species are more ecologically similar in an experimental test. Proc Natl Acad Sci USA 29(108): 5302-5307.
72. Landschaftsbau FL (2002) Guidelines for the planning, execution and upkeep of green-roof sites. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau Bonn Germany.

73. Köhler M (2006) Long-term vegetation research on two extensive green roofs in Berlin. Urban habitats 4(1): 3-13.

74. Dvorak B Byerley B Volder A (2013) Plant species survival on three water conserving green roofs in a hot humid subtropical climate. J Living Archt 1(1): 39-53.

75. Villaseñor JL (2016) Checklist of the native vascular plants of Mexico. Revista Mexicana de Biodiversidad 87: 559-902.

76. Snodgrass EC, McIntyre L (2010) The Green Roof Manual. A Professional Guide to Design Installation and Maintenance Timber Press. United States of America ISBN 978-1-60469-049-1