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Evaluation of Sustainable Landscape Design: Presence of Native Pollinators in an Urban Park in Mexico City, Mexico

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Abstract: This study evaluated the habitat quality of pollinators in La Cantera Park, a recently renovated urban area in Mexico City. First, we analyzed the presence and preferences of three main pollinators (bees, butterflies, and hummingbirds) with respect to the vegetation composition of the park. Secondly, we assessed the theoretical habitat quality for the pollinators across the zones of the park. Through systematic sampling, we recorded the following species: four hummingbirds, 20 butterflies, and 21 bees, among which we observed a strong preference for native plants such as *Lantana camara* and *Salvia leucantha*. While some exotic plants also attracted pollinators, native plants played a central role in supporting diverse pollinator populations. Areas with greater floral diversity and a higher proportion of native species consistently exhibited better habitat quality scores, underscoring the critical link between native flora and pollinator activity. These findings highlight the importance of landscape management practices that strategically combine native and exotic plants to maximize resource availability, improving urban parks' capacity to sustain pollinator biodiversity. The study suggests that urban green space design strategies should incorporate both ecological infrastructure elements, such as water sources, and a careful selection of plant species to create suitable habitats for pollinators. This approach can contribute to the conservation of pollinators in densely populated urban environments, providing valuable ecosystem services and supporting urban resilience by promoting biodiversity.

Keywords: urban pollinators; ecological conservation; sustainable habitats; sustainable green areas; pollination services; green infrastructure

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1. Introduction

1.1. The Impact of Urbanization on Native Pollinators

The urbanization process has had a profound impact on biodiversity, particularly concerning pollinators. These organisms, which include a variety of insects, such as bees, butterflies, and some birds, are essential for pollinating approximately 75% of flowering plants and 35% of global food production [1–3]. In particular, native pollinators play a pivotal role in the sustenance of local ecosystems because they are adapted to indigenous plant species, which enhances the reproduction and stability of these species [4].

Urbanization affects pollinators by reducing their natural habitat and limiting their foraging and breeding areas [5]. However, creating vertical green spaces can provide suitable habitats for pollinators in densely populated urban areas, especially for native species that require specific habitats and local plants to survive [6]. In a previous study, Zeng, et al. [7] reported an increase in pollinator diversity in these areas, suggesting that green space restoration may be an effective strategy for supporting pollinators in highly urbanized cities. The authors highlighted the complexity of the relationship between urbanization and pollinators, underscoring the need for a multifaceted approach that encompasses habitat conservation, landscape planning, and green space creation in urban areas. As urban areas continue to expand, delineating and implementing strategies that promote the coexistence of biodiversity and urban development to ensure the long-term sustainability of ecosystems and food security are imperative.

1.2. Role of Landscape Design in Urban Biodiversity

Urban landscape design represents a principal instrument for the advancement of biodiversity and pollinator conservation in urban environments. The planning of green spaces, such as parks and gardens, can provide suitable habitats and contribute to the conservation of urban biodiversity [8]. The creation of green corridors and the incorporation of native plants in landscape design have been identified as effective strategies for increasing the diversity and abundance of pollinators [5,6]. These spaces not only provide shelter and food resources for pollinators but also enhance the quality of life for residents [9–11]. Furthermore, parks can serve as ecological corridors, facilitating the dispersal of pollinators and the propagation of seeds, which contributes to the regeneration of local flora. However, the impact of green areas on pollinators is not uniform, as the abundance and type of vegetation influence the composition of pollinator communities [12]. The diversity of pollinators is enhanced by the availability of nesting resources and the presence of flowering plants [13].

The conservation of native pollinators is crucial for the preservation of local ecosystems, as they play a pivotal role in the production of seeds and the perpetuation of native plants with which they have coevolved [14]. These pollinators are dependent on specific resources provided by local flora, necessitating a constant supply of flowers, suitable nesting sites, and protection against pesticides. Given that 87% of flowering plants rely on insects and animals for pollination, any alteration in pollinator populations, particularly those with specialized diets, can have a significant impact on biodiversity [15]. Furthermore, the introduction of invasive species has the potential to alter the dynamics between pollinators and native plants, affecting the availability of resources and interaction networks [16]. This highlights the necessity of urban management strategies that prioritize the conservation of native pollinators over urban expansion.

1.3. Pollinator Conservation in Latin America: Challenges and Opportunities in Mexico City

Latin America has the greatest diversity of bees in the world, with 26% of the species recorded. Furthermore, this region is the epicenter of biodiversity for vertebrate pollinators, including hummingbirds, birds, nectarivorous bats, and other pollinating mammals. However, the conservation of these pollinators and pollination services in the region is confronted with considerable challenges, such as large-scale agriculture, deforestation, and the excessive use of agrochemicals, which have played a substantial role in their decline [17].

Given the constant decrease in pollinator populations in Latin America, various strategies have been proposed to conserve them and improve pollination services. In

Mexico City, with a population of more than 9 million and the consequent constant pressure of urban expansion, the government has begun to implement urban park renovation initiatives that aim not only to beautify the city but also to restore ecosystems and promote biodiversity. Projects such as the "Green Corridor" and the revitalization of the "Parque de Chapultepec" are designed to increase vegetation cover and provide suitable habitats for pollinators. As these projects are implemented, evaluating their effectiveness and impact on native pollinator populations and the overall health of urban ecosystems is critical. Accordingly, there is a need to analyze the extent to which the renovations of these parks are achieving their goal of effectively supporting the presence of pollinators. The results of this analysis can provide a solid foundation that can facilitate decision-making to address ecological issues through green infrastructure design.

This study aims to evaluate the functionality of a recently renovated urban park in Mexico City in terms of its ability to provide favorable habitats for native pollinators. The objectives were as follows: (1) Assess the composition of native pollinator species (bees, butterflies, and hummingbirds) and identify their preferences concerning the plant species (native and exotic) that support their presence. (2) Determine theoretically the habitat quality across different park areas to assess and compare the benefits these zones provide for the pollinators.

2. Methodology

2.1. Study Area

Mexico City, one of the largest and densest urban areas in the world, is located 2240 m above sea level. For the case study, "La Cantera Park" was selected, a space renovated in the last 10 years that is accessible and close to residential areas and educational and health centers. Formerly an asphalt factory, the park was rehabilitated in 2017, providing an opportunity to study the impact of urban revitalization on pollinator habitats. The park has an extension of 51,236.1 m^2 and was divided into nine distinct zones, each characterized by unique plant compositions and infrastructures. This allowed a comprehensive analysis of the park's contribution to biodiversity and other ecological characteristics. The division was based on the distinct orography, the specific vegetation present, and the landscape elements that characterize each zone, such as fountains, playgrounds, sports courts, and other features. This approach yielded a more nuanced understanding of the ecological and infrastructural diversity within the park. To further support this analysis, Figure 1a provides a spatial representation of the park's composition according to the nine zones evaluated in this study, while Figure 1b shows representative images of each zone to illustrate their unique characteristics.

Table 1 summarizes the nine zones of La Cantera Park, which are differentiated by infrastructure and plant species. Each zone presents a unique combination of native and exotic plants, with different percentages. The results of this characterization, together with the existing infrastructure, will be analyzed in the habitat quality section to evaluate their influence on the presence of pollinators.

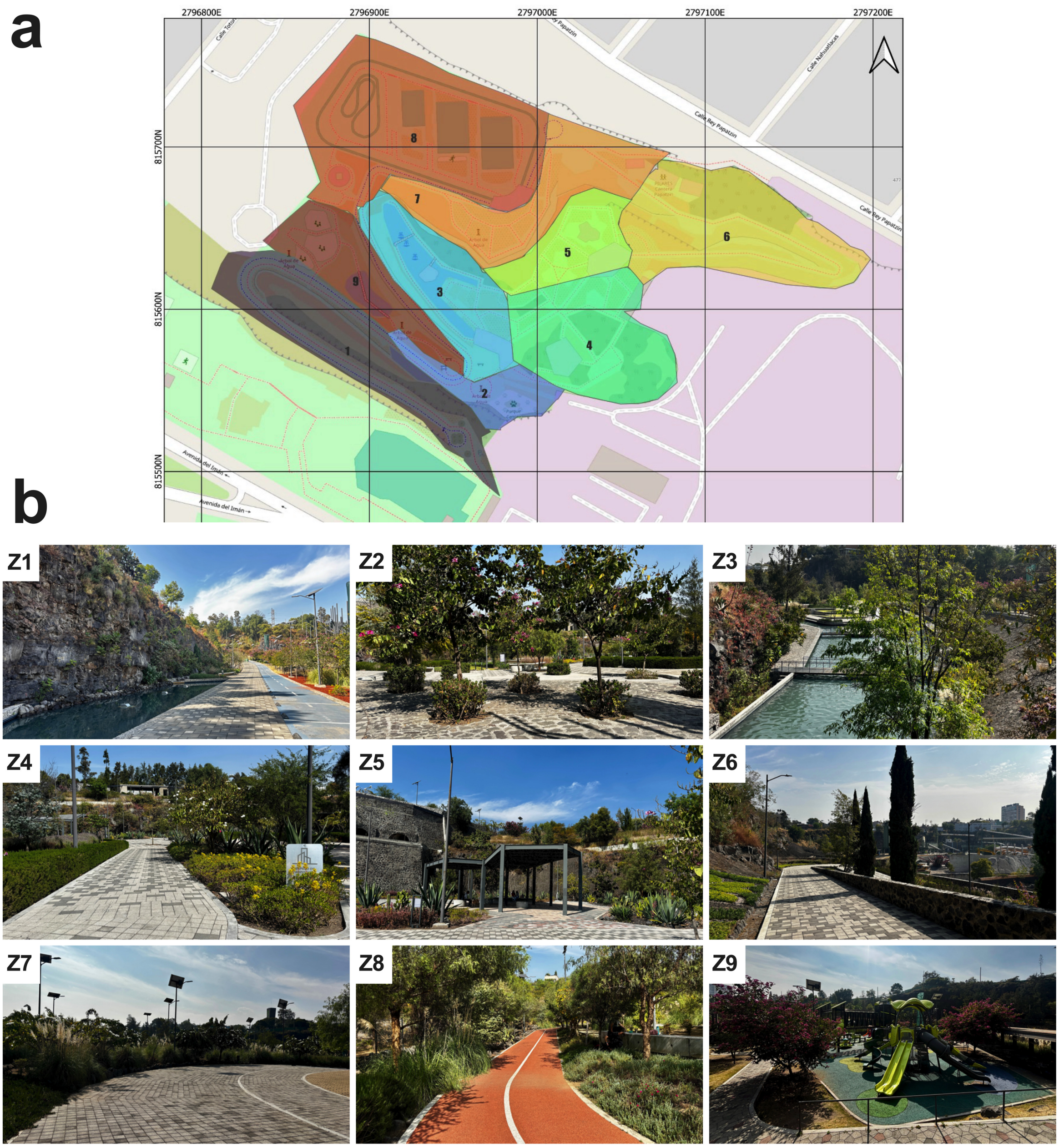

Figure 1. (**a**) Spatial division of La Cantera Park according to the nine zones that compose the urban park and (**b**) Representative images of each zone showing their distinctive characteristics.

Table 1. Characterization of the nine zones of La Cantera Park.

Zone	Area (m^2)	Infrastructure Present	Plant Species Present in the Zone	Percentage Covered Native/Exotic	Plants with Greater Surface Area (%, Origin)
1	6725.9	Land with two steep slopes and a stone wall that preserves much of the original ecosystem. It has a fountain.	*Acacia dealbata*, *Acacia neriifolia*, *Agapanthus africanus*, *Agave americana*, *Bauhinia variegata*, *Bougainvillea spectabilis*, *Cascabela thevetioides*, *Casuarina equisetifolia*, *Cortaderia communana*, *Cupressus sempervirens*, *Dahlia coccinea*, *Equisetum hyemale*, *Eucalyptus* spp., *Fraxinus uhdei*, *Jacaranda mimosifolia*, *Juniperus communis*, *Kalanchoe marmorata*, *Ligustrum lucidum*, *Nicotiana glauca*, *Opuntia* spp., *Passiflora caerulea*, *Salvia leucantha*, *Salvia rosmarinus*, *Sedum dendroideum*, *Schinus molle*, *Tecoma stans*, *Vachellia farnesiana*, *Wigandia urens*	80.1/19.8	*W. urens* (34.4, native) and *S. dendroideum* (19.5, native)

Table 1. *Cont.*

Zone	Area (m^2)	Infrastructure Present	Plant Species Present in the Zone	Percentage Covered Native/Exotic	Plants with Greater Surface Area (%, Origin)
2	2144.3	Flat ground covered with concrete. It has a rain catcher tree and a dog park.	*Acacia dealbata*, *Agapanthus africanus*, *Aloe arborescens*, *Bauhinia variegata*, *Buddleja davidii*, *Cestrum nocturnum*, *Equisetum hyemale*, *Fraxinus hudei*, *Lantana camara*, *Ligustrum lucidum*, *Salvia leucantha*, *Salvia rosmarinus*, *Searsia lancea*, *Tecoma stansi*	38.1/61.9	*S. rosmarinus* (43.3, Exotic) and *L. camara* (30.5, native)
3	5138.7	Land is dominated by a body of water that occupies almost the entire area. The access is given through corridors that surround it, and it is surrounded by scree remnants.	*Bahuinia variegata*, *Buddleja cordata*, *Buddleja davidii*, *Casuarina equisetifolia*, *Cortaderia sealana*, *Fraxinus uhdei*, *Lantana camara*, *Ligustrum lucidum*, *Quercus phellos*, *Salvia rosmarinus*, *Passiflora caerulea*, *Wigandia urens*	70.2/29.9	*W. urens* (45.3, native) and *S. rosmarinus* (20.2, exotic)
4	6070.5	Flat land covered with concrete, divided into four zones by corridors. It has an area for camping, whose terrain is dirt. It also has bathrooms and sandbox.	*Acacia dealbata*, *Acacia melanoxylon*, *Agapanthus africanus*, *Agave americana*, *Aloe arborescens*, *Bauhinia variegata*, *Bougainvillea spectabilis*, *Casuarina equisetifolia*, *Erythrina americana*, *Fraxinus uhdei*, *Ipomoea carnea*, *Jacaanda mimosifolia*, *Lavandula angustifolia*, *Kalanchoe marmorata*, *Quercus kelloggii*, *Nerium oleander*, *Salvia microphylla*, *Salvia rosmarinus*, *Schinus molle*, *Sedum dendreideum*, *Senna didymobotrya*, *Vachellia farnesiana*, *Yucca gigantea*	13.7/86.3	*S. rosmarinus* (58.5, exotic) and *Kalanchoe marmorata* (7.4, exotic)
5	3058.8	Flat ground covered with concrete. It includes a pergola that provides shade, where people practice yoga.	*Acacia dealbata*, *Agave americana*, *Bauhinia variegata*, *Bougainvillea spectabilis*, *Opuntia* spp, *Cascabela thevetioides*, *Fraxinus uhdei*, *Jacaranda mimosifolia*, *Lavandula angustifolia*, *Prosopis laevigata*, *Salvia rosmarinus*, *Schinus molle*, *Wigandia urens*, *Yucca gigantea*	85.3/14.7	*W. urens* (77.0, native) and *S. rosmarinus* (11.6, exotic)
6	7634.6	Land with two steep slopes. It has two rooms of the PILARES program, where dance and computer classes are taught, among others. It has a sandbox and signage that indicates a garden for pollinators.	*Acacia baileyana*, *Agapanthus africanus*, *Agave americana*, *Bauhinia variegata*, *Bougainvillea spectabilis*, *Buddleja cordata*, *Buddleja davidii*, *Opuntia* spp, *Carpobrotus edulis*, *Casuarina equisetifolia*, *Cupressus lusitanica*, *Cupressus sempervirens*, *Echeveria secunda*, *Lavandula angustifolia*, *Mesembryanthemum cordifolium*, *Prosopis laevigata*, *Salvia microphylla*, *Salvia rosmarinus*, *Schinus molle*, *Sedum dendroideum*, *Wigandia urens*	67.4/32.6	*W. urens* (51.4, native) and *S. rosmarinus* (19.2, exotic)
7	5433.6	Semisloping concrete land that connects the PILARES area with the courts and the children's play area.	*Acacia baileyana*, *Acacia neriifolia*, *Bauhinia variegata*, *Casuarina equisetifolia*, *Cortaderia sealana*, *Erythrina americana*, *Eysenhardtia polystachya*, *Fraxinus uhdei*, *Ipomoea arborescens*, *Lavandula angustifolia*, *Salvia leucantha*, *Salvia rosmarinus*, *Schhellia mollensiana*	62.2/37.7	*W. urens* (54.9, native) and *C. selloana* (29.5, exotic)
8	11,179.0	Semisloping terrain with two beach volleyball courts (with sand) and a basketball court.	*Acacia baileyana*, *Acacia neriifolia*, *Agave americana*, *Bauhinia variegata*, *Buddleja cordata*, *Cascabela thevetioides*, *Cortaderia selloana*, *Erythrina americana*, *Fraxinus uhdei*, *Jacaranda mimosifolia*, *Lampranthus spectabilis*, *Lavandula angustifolia*, *Ligustrum lucidum*, *Mesembryanthemum cordifolium*, *Salvia leucantha*, *Salvia rosmarinus*, *Schinus molle*, *Sedum dendroideum*, *Sedum versadense*, *Teigacoma stans*, *Vachelliandia farnesianans*	60.3/39.7	*W. urens* (14.2, native) and *S. dendroideum* (11.3, native)
9	3850.7	Flat land with a dirt floor. Play area for children, a tent, tables, a pergola that provides shade, and a small body of water.	*Acacia dealbata*, *Agapanthus africanus*, *Cascabela thevetioides*, *Cortaderia sealana*, *Crassula ovata*, *Casuarina equisetifolia*, *Fraxinus uhdei*, *Ficus benjamina*, *Ligustrum lucidum*, *Salvia leucantha*, *Salvia rosmarinus*, *Schinus molle*, *Searsia lancea*, *Tecoma stans*	10.3/89.7	*Agapanthus africanus* (28.5, exotic) and *C. selloana* (22.3, exotic)

2.2. Characterization of the Native Pollinator Community of La Cantera Park

This study focused exclusively on the identification and analysis of the native pollinators of La Cantera Park to better understand their role in the local ecosystem and their interaction with the park's flora. Data were collected by sampling methods adapted to capture the greatest diversity of native pollinators, including direct observation of flowers and the use of specific traps. These traps were placed in different areas of the park to account for habitat variability and vegetation distribution. In March, a 2-day pilot study was conducted to record the most important native pollinator communities, including bees, butterflies, and hummingbirds, selected for their importance in pollination.

2.2.1. Bees

The native bees in the park were sampled once a week via three capture methods. The main one consisted of tours of the study areas with entomological nets, which captured bees that visited or flew near flowers between 08:00 and 12:00. The other methods included colored traps (white, yellow, and blue) with soapy water placed in planters to attract and capture bees by chromatic attraction. In addition, special traps for "orchid bees" were used, which were made with perforated bottles and aromatic substances (methyl salicylate, cineole, and eugenol) that attract these bees and trap them in alcohol. The traps were placed at the beginning of the sampling and removed at the end. The collected samples were deposited at the National Insect Collection of the Institute of Biology at the National Autonomous University of Mexico where they were processed and identified.

2.2.2. Butterflies

Butterflies were recorded through searches in defined periods, which revealed a greater diversity of microhabitats in the park [18]. Searches were conducted twice a week from April to August 2024, between 09:00 and 15:00, in blocks of 15 min, resulting in a total of 80 search hours. The species and their abundances were recorded via direct observation, photographs, and specimen collection with an entomological network. The collection was performed only to form a reference collection, avoiding the capture of more individuals if a species was already registered. The collected samples were identified with taxonomic guides and deposited in the National Insect Collection of the Institute of Biology, UNAM.

2.2.3. Hummingbirds

Hummingbirds were chosen as a focus group because they specialized in nectar consumption and their evolutionary relationships with more than 8000 plant species, of which they are the primary pollinators [19]. Although they are more efficient than insects at pollination in some systems [20], their effectiveness in urban environments may be lower because vegetation is influenced by human decisions rather than natural processes. However, hummingbirds in cities contribute to human well-being, improve quality of life, and enhance a sense of belonging. Because all hummingbird species have similar dietary needs, changes in their composition are associated with changes in habitat, making them useful indicators of environmental quality. To record their presence, systematic 15-min walks were conducted in the nine zones of the park, and binoculars and photographs were used for accurate identification. The walks, which were carried out three times a week beginning in April, made it possible to analyze plant-pollinator interactions and obtain detailed data on the distribution of hummingbirds in the park.

2.3. Theoretical Evaluation of the Quality of Habitat for the Pollinators of La Cantera Park

To theoretically evaluate the quality of the habitat and its benefits to the pollinators in La Cantera Park, the methodology of Zhu, et al. [21] was adapted and modified. These modifications enabled the analysis to a landscape level, considering the plant composition of each zone and the characteristics of the infrastructure present. The subsequent steps in the methodology are outlined below as follows: (1) identification of plant species; (2) determination of pollinator benefits of each plant species; (3) calculation of the pollination value index and pollinator benefit index per area; and (4) calculation of the adjusted habitat quality index for pollinators.

2.3.1. Identification and Registration of Plant Species

From April to May 2024, the park was visited to identify all the plants present, including ground cover, herbaceous, shrubbery, and trees. The identification of species was corroborated with specialized guides on local flora, ensuring accuracy in the classification of species as either native or exotic. Additionally, PictureThis (https://www.picturethisai.com/es/, accessed on 2 June 2024) and iNaturalist (https://mexico.inaturalist.org, accessed on 12 June 2024) applications were utilized, and the obtained information was validated by botanical experts through direct consultations.

During the visits, the polygons corresponding to each species were delimited using portable GPS devices, which recorded the precise coordinates of the areas occupied by each plant. For species with dense or continuous cover, such as ground cover and extensive shrubs, the total area occupied was measured using transect and quadrat methods. The percentage of cover within each quadrat was estimated, and the results were extrapolated to the total area. For isolated plants, such as scattered trees or shrubs, the area of cover was calculated considering the average diameter of their crowns. The collected data underwent a rigorous processing and validation procedure, which involved the use of georeferenced maps of the park. This approach ensured the accuracy of the values calculated for each species and their distribution by zone.

This meticulous approach culminated in the creation of an exhaustive database, which serves as a comprehensive repository of information concerning the vegetation composition of the park. Table 2 summarizes the 56 total plant species identified according to their origin and area covered by zone expressed in square meters.

Table 2. Plant community of La Cantera Park according to their origin and area (m^2) covered per zone.

Plant Species	**Origin**	**Z1**	**Z2**	**Z3**	**Z4**	**Z5**	**Z6**	**Z7**	**Z8**	**Z9**	**Area (m^2)**
Agave americana	Native	723.4	-	-	103.8	103.8	103.8	-	2.4	-	1037.3
Buddleja cordata	Native	-	-	5.3	-	-	5.3	-	4.0	-	14.6
Cascabela thevetioides	Native	25.0	-	-	-	3.7	-	-	28.8	12.0	69.5
Cestrum nocturnum	Native	-	2.0	-	-	-	-	-	-	-	2.0
Cupressus lusitanica	Native	-	-	-	-	-	3.0	-	-	-	3.0
Dahlia coccinea	Native	1.0	-	-	-	-	-	-	-	-	1.0
Echeveria secunda	Native	-	-	-	-	-	11.4	-	-	-	11.4
Equisetum hyemale	Native	25.8	25.8	-	-	-	-	-	-	-	51.5
Erythrina americana	Native	-	-	-	8.0	-	-	16.0	138.6	-	162.6
Eysenhardtia polystachya	Native	-	-	-	-	-	-	0.8	-	-	0.8
Fraxinus uhdei	Native	340.0	30.0	-	40.0	10.0	10.0	30.0	10.0	15.6	485.6
Ipomoea arborescens	Native	4.0	-	-	-	-	-	66.0	-	-	70.0
Ipomoea carnea	Native	-	-	-	3.8	-	-	-	-	-	3.8
Lantana camara	Native	-	456.7	33.8	-	-	-	41.8	-	-	532.2
Opuntia spp.	Native	6.0	-	-	-	121.1	121.1	-	-	-	248.3
Passiflora caerulea	Native	3.0	-	-	-	-	-	-	-	-	13.0
Prosopis laevigata	Native	-	-	-	-	7.0	2.0	-	-	-	9.0
Quercus kelloggii	Native	-	-	-	4.9	-	-	-	-	-	4.9
Salvia leucantha	Native	49.7	51.5	-	-	-	-	49.9	129.8	36.1	317.0
Salvia microphylla	Native	-	-	-	43.9	0.0	35.0	-	-	-	78.9
Sedum dendroideum	Native	882.1	-	-	49.4	0.0	50.3	-	195.7	-	1177.5
Sedum versadense	Native	-	-	-	-	-	-	-	1.0	-	1.0
Tecoma stans	Native	5.0	3.8	-	-	-	-	-	271.4	3.8	284.0
Vachellia farnesiana	Native	3.0	-	-	3.8	-	-	45.6	16.4	-	68.8
Wigandia urens	Native	1559.2	-	1657.1	0.0	2289.7	1102.8	1889.7	246.6	-	8745.2
Yucca gigantea	Native	-	-	-	2.7	2.5	-	-	-	-	5.2
Natives subtotal		3627.1	569.8	1706.2	260.3	2537.9	1444.8	2139.8	1044.7	67.5	13,398.1

Table 2. *Cont.*

Plant Species	Origin	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Area (m^2)
Acacia baileyana	Exotic	-	-	-	-	-	3.00	22.80	54.00	-	79.80
Acacia dealbata	Exotic	5.00	15.00	-	21.60	3.10	-	-	-	4.00	48.70
Acacia melanoxylon	Exotic	-	-	-	7.20	-	-	-	-	-	7.20
Acacia neriifolia	Exotic	15.00	-	-	-	-	-	45.10	20.80	-	80.90
Agapanthus africanus	Exotic	240.32	163.87	-	58.93	-	22.57	-	-	187.38	673.07
Aloe arborescens	Exotic	-	5.00	-	3.00	-	-	-	-	-	-
Bauhinia variegata	Exotic	160.00	60.00	20.00	5.00	10.00	40.00	25.00	95.00	-	415.00
Bougainvillea spectabilis	Exotic	5.00	-	-	17.69	17.69	50.27	-	-	-	90.65
Buddleja davidii	Exotic	-	2.00	6.00	-	-	4.00	-	-	-	12.00
Carpobrotus edulis	Exotic	-	-	0.00	-	-	45.44	-	-	-	45.44
Casuarina equisetifolia	Exotic	45.00	-	6.70	46.90	-	6.70	13.40	-	3.30	122.00
Cortaderia selloana	Exotic	5.81	-	146.59	-	-	-	1015.58	46.09	146.59	1360.66
Crassula ovata	Exotic	-	-	-	-	-	-	-	-	4.30	4.30
Cupressus sempervirens	Exotic	2.00	-	-	-	-	4.00	-	-	-	6.00
Eucalyptus spp.	Exotic	24.00	-	-	-	-	-	-	-	-	24.00
Ficus benjamina	Exotic	-	-	-	-	-	-	-	-	3.20	3.20
Jacaranda mimosifolia	Exotic	27.50	-	-	84.00	18.20	23.00	-	17.00	-	169.70
Juniperus communis	Exotic	8.00	-	-	-	-	-	-	-	-	8.00
Kalanchoe marmorata	Exotic	136.11	-	-	141.97	-	-	-	-	-	278.08
Lampranthus spectabilis	Exotic	-	-	-	-	-	-	-	129.38	-	129.38
Lavandula anguistifolia	Exotic	-	-	-	87.40	30.1	24.7	17.3	64.15	-	223.65
Ligustrum lucidum	Exotic	5.00	30.00	45.00	-	-	-	-	30.00	100.00	210.00
Mesembryanthemum cordifolium	Exotic	-	-	-	-	-	45.51	-	45.74	-	91.25
Nerium oleander	Exotic	-	-	-	3.98	-	-	-	-	-	3.98
Nicotiana glauca	Exotic	2.10	-	-	-	-	-	-	-	-	2.10
Quercus phellos	Exotic	-	-	7.00	-	-	-	-	-	-	7.00
Salvia rosmarinus	Exotic	209.98	647.98	491.86	1113.97	344.66	412.65	150.33	55.99	74.64	3502.06
Schinus molle	Exotic	7.00	-	-	49.00	12.00	17.00	8.10	129.00	64.00	286.10
Searsia lancea	Exotic	-	1.40	-	-	-	-	-	-	1.50	2.90
Senna didymobotrya	Exotic	-	-	-	4.10	-	-	-	-	-	4.10
Exotics subtotal		897.8	925.3	723.2	1644.7	435.8	698.8	1297.6	687.2	588.9	7899.2
Total by zone		4525.0	1495.0	2429.4	1905.0	2973.7	2143.6	3437.4	1731.9	656.4	21,297.3

2.3.2. Determination of the Benefits for Pollinators by Each Plant Species

To assess theoretically whether each plant attracts pollinators and provides benefits for pollinators, an exhaustive bibliographic search was conducted in sources such as the technical sheets of the National Commission for Biodiversity (CONABIO, https://www.biodiversidad.gob.mx/ecosistemas/procesose/polinizacion/jardin-de-polinizadores, accessed on 2 July 2024) and the Ministry of the Environment (SEDEMA). Furthermore, the information was supplemented with recommendations for the design of pollinator gardens in Mexico (https://www.biodiversidad.gob.mx/poliniza, accessed on 5 July 2024) and experts in the field. Key insights were provided by specialists in the production of plants for pollinators such as the "Paraiso colibrí" nursery (https://www.paraisocolibri.org, accessed on 28 June 2024). The specialists ensured the validity and relevance of the data in the Mexican context. Utilizing these data, the capacity of each species to attract pollinators and provide nectar, fruits, seeds, or nesting habitats for bees, butterflies, and hummingbirds was identified. As summarized in Table 3, 39 plant species were found to attract pollinators and exhibit habitat benefits.

Table 3. Summary of the benefits for pollinators of the 39 plant species present in La Cantera Park that exhibited value for pollinators.

Plant Species	Attract Pollinators	Pollinator That Benefits	Benefits for Pollinators		
			Nectar	Nesting	Fruits and Seeds
Acacia baileyana	Yes	Bees	No	No	No
Acacia dealbata	Yes	Bees	No	No	No
Acacia melanoxylon	Yes	Bees	No	No	No
Agapanthus africanus	Yes	Bees, butterflies, hummingbirds	Yes	No	No
Agave americana	Yes	Bees, hummingbirds	Yes	Yes	No
Aloe arborescens	Yes	Bees, hummingbirds	Yes	No	No
Bauhinia variegata	Yes	Bees, hummingbirds	Yes	Yes	No
Bougainvillea spectabilis	Yes	Bees, butterflies, hummingbirds	Yes	Yes	No
Buddleja cordata	Yes	Bees, butterflies	Yes	Yes	Yes
Buddleja davidii	Yes	Butterflies	Yes	No	No
Cascabela thevetioides	Yes	Bees, hummingbirds	Yes	Yes	No
Cestrum nocturnum	Yes	Bees, butterflies	Yes	No	No
Dahlia coccinea	Yes	Bees	Yes	No	No
Echeveria secunda	Yes	Bees, hummingbirds	Yes	Yes	No
Equisetum hyemale	Yes	Bees	No	Yes	No
Erythrina americana	Yes	Bees, hummingbirds	Yes	No	No
Eysenhardtia polystachia polystachya	Yes	Bees, butterflies	Yes	No	No
Fraxinus uhdei	Yes	Hummingbirds	No	Yes	No
Ipomoea arborescens	Yes	Bees, hummingbirds	Yes	No	No
Ipomoea carnea	Yes	Bees, butterflies	Yes	No	No
Jacaranda mimosifolia	Yes	Bees, hummingbirds	Yes	No	No
Lampranthus spectabilis	Yes	Butterflies	Yes	No	No
Lantana camara	Yes	Bees, butterflies, hummingbirds	Yes	No	Yes
Lavanda angustifolia	Yes	Bees, butterflies	Yes	No	No
Ligustrum lucidum	Yes	Bees	Yes	No	No
Nicotiana glauca	Yes	Hummingbirds	Yes	No	No
Opuntia spp.	Yes	Bees, hummingbirds	Yes	Yes	No
Passiflora caerulea	Yes	Bees, butterflies, hummingbirds	Yes	Yes	No
Prosopis laevigata	Yes	Bees	Yes	Yes	Yes
Salvia leucantha	Yes	Bees, butterflies, hummingbirds	Yes	No	No
Salvia microphylla	Yes	Bees, butterflies, hummingbirds	Yes	No	No
Salvia rosmarinus	Yes	Bees, butterflies	Yes	No	No
Sedum dendroideum	Yes	Bees	Yes	Yes	No
Sedum versadense	Yes	Bees	No	Yes	No
Senna didymobotrya	Yes	Bees	Yes	Yes	No
Tecoma stans	Yes	Butterflies, hummingbirds	Yes	Yes	No
Vachellia farnesiana	Yes	Bees, butterflies	Yes	No	No
Wigandia urens	Yes	Bees, butterflies, hummingbirds	Yes	Yes	No
Yucca gigantea	Yes	Bees	Yes	Yes	No

2.3.3. Calculation of the Pollination Value Index and Pollinator Benefit Index per Area

As suggested by Zhu, Zheng and Newman [21], the pollination value and the three categories of the pollinator benefits (nectar, nesting, and fruits and seeds) constitute two primary components for assessing the habitat quality for pollinators. These metrics can be utilized to indicate the relative contribution of the plant community to support pollinators within an area as well as to provide habitat benefits [21]. Contrary to the approach proposed by the authors, who calculated the percentages of pollination value and pollinator benefits of the plant community for an entire area, in this study, we calculated these metrics for each zone of the park and expressed them per area in square meters. This approach was adopted to facilitate a more straightforward comparison of the relative contributions of the plant communities comprising the nine distinct zones of the park, with the results being adjusted by area. The calculations were performed as follows: (1) For each plant species that was determined to attract pollinators, the total area occupied by the plant in each zone of the park was considered as its pollination value. Similarly, for each of the pollinator benefits categories exhibited by a plant species, its total area was considered the pollinator benefit value. (2) For each of the four measures, the values of all plants within a zone were summed and divided by the total area of such zone. (3) The results were expressed as an index in m^2.

2.3.4. Calculation of the Adjusted Habitat Quality Index for Pollinators

The adjusted habitat quality index was subsequently calculated by incorporating all the features of a particular zone that supports pollinators. These features included pollination value, pollinator benefits, and data on infrastructure such as water sources, which have been demonstrated to positively influence the presence and activity of pollinators. The adjusted habitat quality index was calculated per square meter to ensure equitable comparisons between zones of varying dimensions and was adjusted by the presence of infrastructure and pollinator benefits according to the following formula:

$$\text{Adjusted habitat quality index} = \text{Pollination value index} \times [(\text{adjustment factor}) \times 0.8]$$

where adjustment factor = 1 + 0.1 or 0 (beneficial infrastructure present or not) + 0.05 or 0 (provides nectar or not) + 0.05 or 0 (provides nesting or not) + 0.05 or 0 (provides fruits and seeds or not).

Using this formula, we ensured that a zone exhibiting the greatest benefits and value for pollinators (highest pollination value index, presence of infrastructure, and all three pollinator benefits) would receive the maximum index of one, thus indicating the highest habitat quality per square meter:

$$\begin{aligned}\text{Adjusted habitat quality index} &= 1 \times [(1 + 0.1 + 0.05 + 0.05 + 0.05) \times 0.8] \\ &= 1 \times [(1.25) \times 0.8] \\ &= 1 \times [1] \\ &= 1\end{aligned}$$

Whereas a zone with the highest pollination value index but not providing extra pollinator benefits would receive a lower adjusted habitat quality:

$$\begin{aligned}\text{Adjusted habitat quality index} &= 1 \times [(1 + 0 + 0 + 0 + 0) \times 0.8] \\ &= 1 \times [(1) \times 0.8] \\ &= 1 \times [0.8] \\ &= 0.8\end{aligned}$$

In contrast, a zone with half the pollination value index but exhibiting all the pollinator benefits would receive half the maximum adjusted habitat quality index:

$$\begin{aligned}\text{Adjusted habitat quality index} &= 0.5 \times [(1 + 0.1 + 0.05 + 0.05 + 0.05) \times 0.8] \\ &= 0.5 \times [(1.25) \times 0.8] \\ &= 0.5 \times [1] \\ &= 0.5\end{aligned}$$

This adjustment facilitated the theoretical identification of the most effective areas for providing resources to pollinators, thereby enabling the prioritization of areas requiring improvement for conservation purposes. Table A1 summarizes a representative example of the calculations performed for Zone 1.

3. Results

3.1. Characterization of the Pollinator Community of La Cantera Park

3.1.1. Bees Present in the Park

A total of 21 native bee species were identified and are summarized in Table A2. Some of the genera, including *Bombus pensylvanicus* and *Euglossa viridissima*, were detected at the species level. Others could only be classified at the genus level, such as *Ceratina* spp. and *Thygater* spp., owing to the scarcity of taxonomic studies available for these groups in Mexico. While the presence of *Apis mellifera* was observed in nearly all the plants under study, its records were not included in the final analysis, as the objective of the study was to characterize the native pollinator community exclusively. However, future studies should evaluate the presence of this exotic species. As shown in Figure 2a, there was a heterogeneous distribution of the bee species across the zones of the park. With 120 sightings, Z4 was the area with both the highest visitation rate and the greatest number of bee species in the park, whereas Z7, Z5, and Z9 showed a reduced number of bee species and sightings recorded. According to the insert of Figure 2a, the genera *Lasioglossum* and *Ceratina* were particularly frequent because these accounted for 75.1% of the total 285 bee sightings recorded throughout the nine zones of the park.

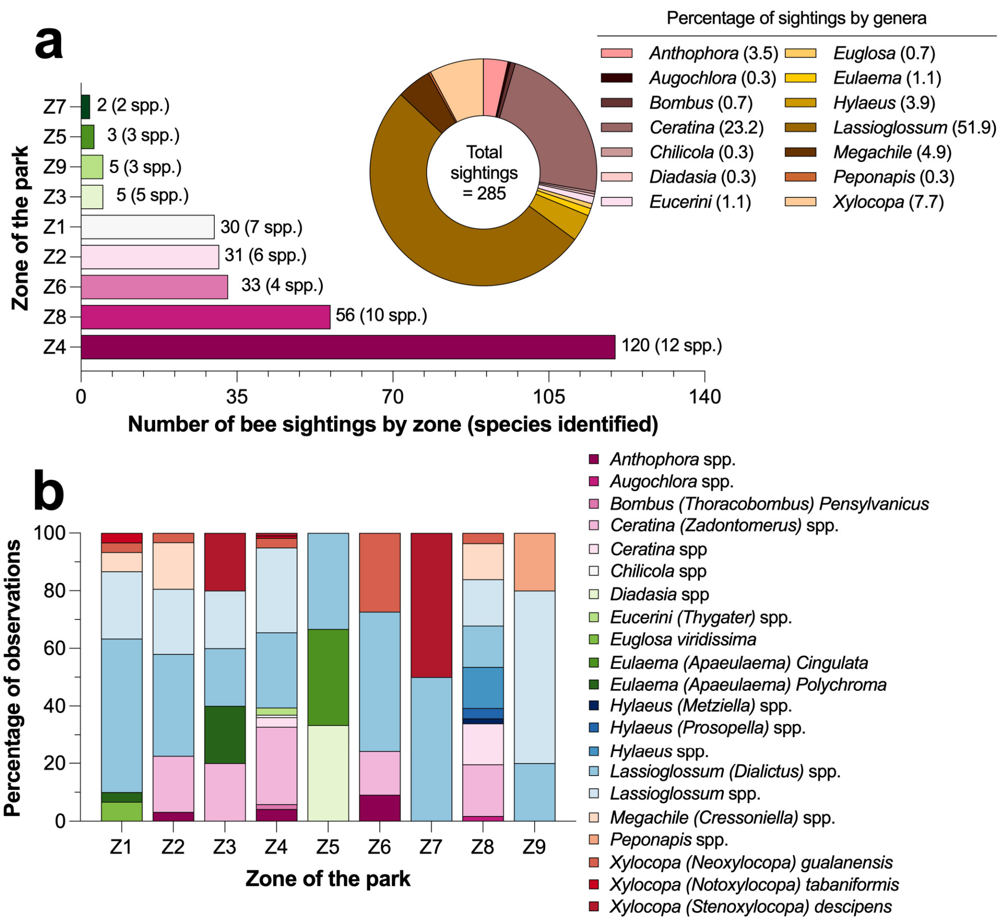

Figure 2. (**a**) Number of species and sightings of bees and (**b**) percentage distribution of bee species by zone of La Cantera Park.

According to Figure 2b, the results demonstrated a high degree of diversity in the bee species observed across the zones within the park. *Lassioglossum* (*Dialictus*) spp. was consistently identified in all the zones of the park, followed by *Lassioglossum* spp. as the second most frequent. These two species accounted for 51.92% (148 records) of the total sightings. Subsequently, *Ceratina* spp. 1 was observed on 54 occasions (18.94%), with other species of the genus *Xylocopa* that had 2–3 sightings in the park, thus constituting a smaller proportion of the total. Some species were recorded on a single occasion, which reflects the significant diversity in the presence of bees and the potential implications for the pollination of the urban ecosystem within the park.

3.1.2. Butterflies Present in the Park

Table A3 summarizes the distribution of the 20 species of butterflies recorded by zones of the park. In contrast to the sighting of bee species, there was an even distribution of species across eight out of nine zones of the park (Figure 3a). Except for Z9, between 9 to 11 butterfly species were recorded, though with a variable number of sightings among the zones, with Z2 being the one with the greatest number of records, followed by Z3 (96 and 68, respectively). As shown in the insert of Figure 3a, in total, there were 468 butterfly sightings in the park, with the genera *Agraulis* and *Leptophobia* contributing half the number of sightings (51.9% in conjunction). According to Figure 3b, with 163 sightings (38.8% of the total), *Agraulis vanilla* was the most frequently observed species in 8/9 zones. In contrast, in Z9, only the species *Papiro garamas* was recorded on one occasion. Species such as *A. vanillae*, *Leptophobia aripa*, *Cholosyne janais*, and *Papilio multicaudata* dominated the number of sightings across the park because they contributed 75.85% (355) of the total records. In contrast, other seven species were recorded on fewer than five occasions across the park. This disparity in the distribution of butterflies may reflect potential differences in the resources or microhabitats available throughout the park.

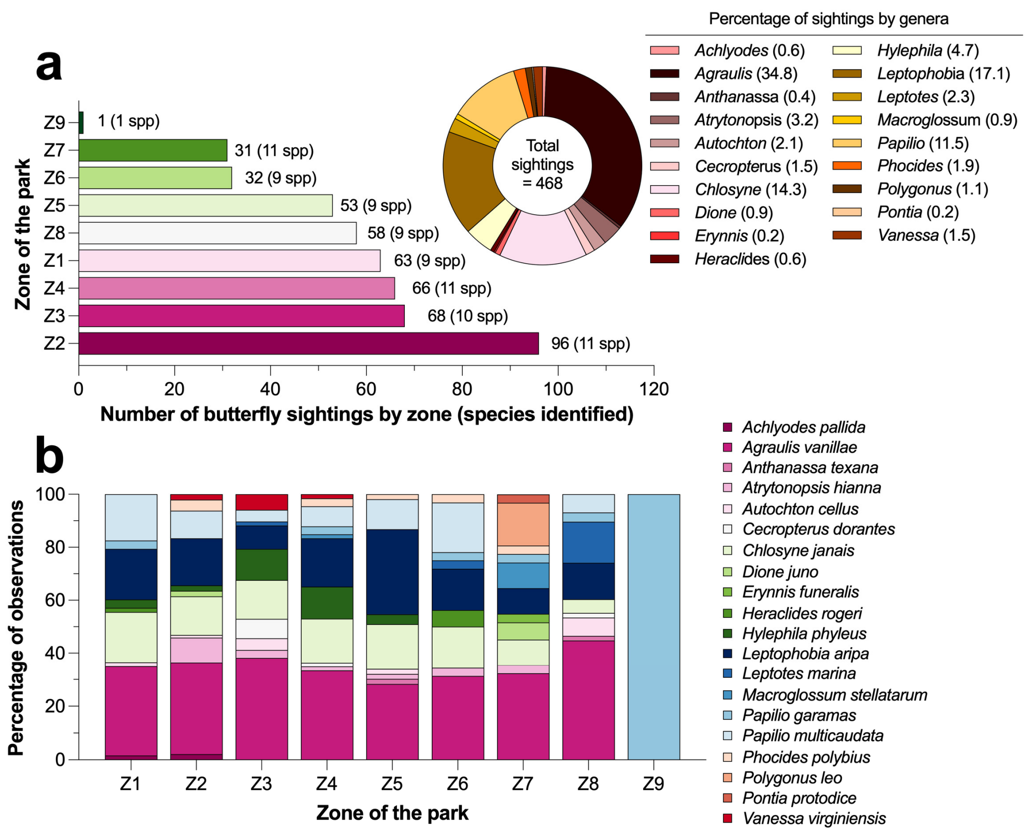

Figure 3. (**a**) Number of species and sightings of butterflies and (**b**) percentage distribution of species by zone of La Cantera Park.

3.1.3. Hummingbirds Present in the Park

A total of 96 hummingbird observations were recorded in the park, which corresponded to four species identified (Table 4). *Cynanthus latirostris* was the most frequently observed species, accounting for 53.1% of all sightings. *Saucerottia beryllina* was the second most common (38.5%), followed by *Tilmatura dupontii* and *Lampornis clemenciae*. Notably, Z1 and Z2 accounted for 54.2% of the total sightings in the park, whereas Z3 and Z5 had few observations each. Finally, no hummingbirds were registered at Z7, thus indicating a disparate and heterogeneous distribution of sightings.

Table 4. Number of sightings of each hummingbird species by zone of La Cantera Park.

Species	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Total by Species
Cynanthus latirostris	20	9	5	3	-	5	-	3	6	51
Saucerottia beryllina	13	7	-	5	2	6	-	3	1	37
Lampornis clemenciae	-	-	-	-	-	1	-	-	-	1
Tilmatura dupontii	-	3	-	4	-	-	-	-	-	7
Total by zone	33	19	5	12	2	12	-	6	7	96

3.2. Characterization of the Plant Community of La Cantera Park

Among the plant species recorded, 26 were native and 31 were exotic, representing 46.4% and 53.6% of the total 56 species, respectively. Despite the greater number of exotic species, native plants occupied a larger area, accounting for 62.9% of the total vegetated area (13,398 m^2), while exotic species covered 37.1% (7900 m^2). The species with the greatest coverage were the native *Wigandia urens*, covering 8745.2 m^2 (41.1%), and the exotic *Salvia rosmarinus*, covering 3502.1 m^2 (16.4%). Together, these two species accounted for more than half of the total vegetated area in the park (57.50%). *W. urens* was present in six out of nine zones, predominantly in Zones 1, 3, 5, 6, and 7, while *S. rosmarinus* had a broader distribution, being present in all park zones, with notable dominance in Zones 2 and 4 (Table 2).

3.3. Relationships Between the Pollinators of La Cantera Park and the Plant Community

According to Table A4, among the 56 plant species present in the park, 31 species (55.3%) exhibited pollinator–plant interaction with at least one of the three pollinator groups observed. The total number of interactions amounted to 576 interactions, of which 74.9% occurred in native plants (Figure 4a). Furthermore, 45.5% (262 interactions) of the total pollinator–plant interactions were performed by butterflies, followed by bees with 38.7% (221 interactions). In contrast, interactions involving hummingbirds were less frequent, representing 16.1% (93) of the total. As illustrated in Figure 4b, a discernible pattern of association emerged between the type of the plant and the pollinators. The analysis revealed that butterflies interacted more frequently with native plants compared to the other two pollinators, while bees showed the highest percentage of interactions with the exotic vegetation.

As depicted in the heatmap of Figure 4c, the ranking of the 12 top plants with the highest number of interactions indicated that 7 out of 12 plants were native, with three ranking in the top three. While both native and exotic species attract pollinators, native species such as *L. camara* and *S. leucantha* are particularly significant, accounting for 53.1% of the total interactions observed in the park. These findings underscore the importance of preserving and promoting the use of native plants to support pollinator biodiversity in urban parks. While exotic species may be less dominant in interactions, they fulfill a complementary role in providing resources (Table A4).

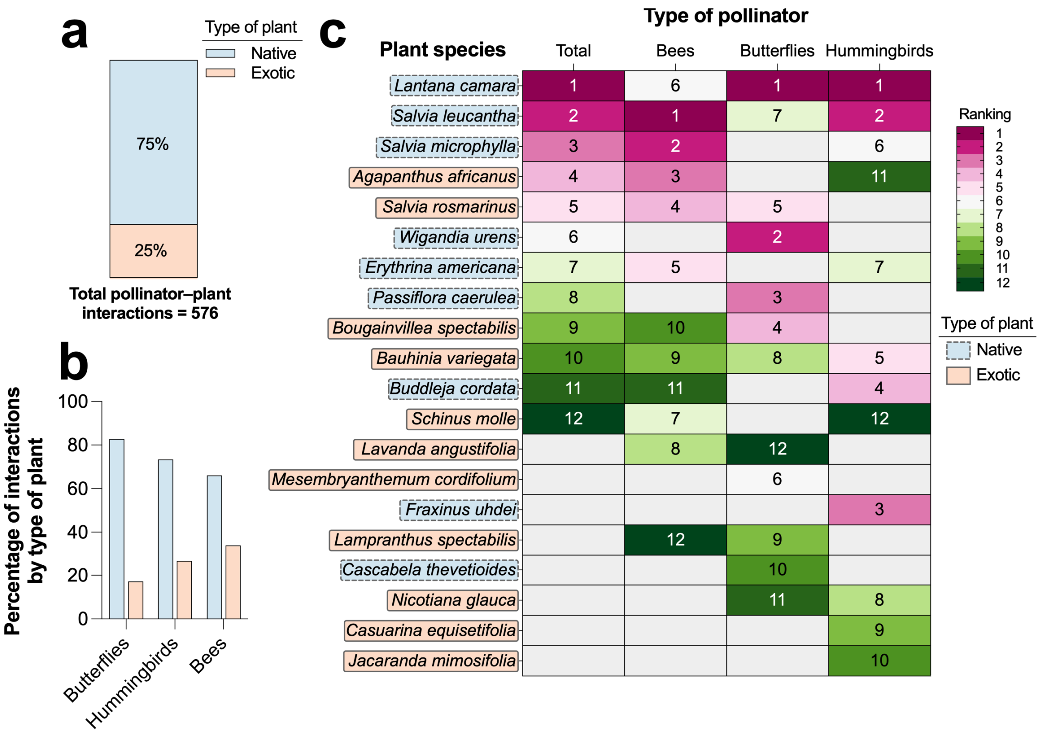

Figure 4. (**a**) Percentage of pollinator–plant interaction according to the origin of the plant, (**b**) distribution of interactions according to the pollinator group, and (**c**) heatmap of the ranking of 12 plants with the greater number of interactions according to the pollinator group.

Notably, all three pollinator groups exhibited a distinctive pattern of association with the plants, though in all the cases the top-ranked plant was native (Figure 4c). The bees showed a marked preference for *S. leucantha*, which accounted for 35.3% of all their interactions with plants. This was followed by *S. microphylla* and *Agapanthus africanus* (16.3% and 15.8%, respectively). In contrast, butterflies interacted primarily with *L. camara*, which accounted for 63.3% of their interactions, followed in a distant second place by *W. urens* with 10.3% of all the butterfly–plant interactions, and *Passiflora caerulea* with 4.9%. Finally, for the plants visited by hummingbirds, 74.2% of the visits were to native species (69/93), with *L. camara* being the most common (36.6%). Among the exotic plants, *Bauhinia variegata* was the most frequently visited, representing 25% of the visits to exotic plants (Table A4).

3.4. Theoretical Evaluation of the Habitat Quality of the Pollinators of La Cantera Park

The analysis of the plant species found in La Cantera Park revealed significant variability in their theoretical contributions to pollinator habitat and the benefits they provide (Table A5). Among the species evaluated, *W. urens* exhibited the highest pollination value, providing bees, butterflies, and hummingbirds with both nectar and nesting habitats. Other notable contributors included *S. rosmarinus*, *Sedum dendroideum*, and *A. americana*, which primarily provide nectar for all three pollinator groups. Conversely, species such as *Dahlia coccinea*, *S. versadense*, and *Eysenhardtia polystachia* exhibited a negligible impact due to their limited coverage, which constrained their influence on the park's ecosystem. Nevertheless, the biodiversity of plant species contributes significantly to pollinators, thereby enhancing the habitat quality, particularly regarding their capacity to produce nectar.

The theoretical evaluation of the habitat quality revealed clear differences between the different areas of the park (Table 5). Z5 emerged as the most efficient zone, exhibiting an adjusted habitat quality index of 0.852 per m^2, a notable accomplishment despite the absence of water. This outcome may be attributed to the high concentration of beneficial plants, underscoring its significance for pollinator conservation. Z2, despite being the smallest area of the park (2144.3 m^2), achieved an adjusted habitat quality index of 0.640, ranking it second among the zones examined. This indicates that Z2 can provide significant resources for pollinators, even though it is much smaller than other zones of the park. Z1, which includes a water source, presented a habitat quality value of 0.611 m^2 and thus stood out as the third highest index. It may be therefore considered one of the most important areas for supporting pollinators. In stark contrast, Z8 and Z9 exhibited the lowest values of habitat quality (0.127 and 0.108) despite both zones possessing water bodies and thus receiving an adjustment for infrastructure. This observation suggests that, while infrastructure may offer benefits, it alone is insufficient to significantly enhance efficiency, particularly when the diversity and quantity of beneficial species are limited. In comparison, areas lacking water but with a high concentration of beneficial species exhibited the highest levels of efficiency, underscoring the importance of biodiversity in supporting pollinator populations.

Table 5. Adjusted habitat quality per square meter for each of the La Cantera Park areas.

Zone	Area (m^2)	Pollination Value Index	Provides Benefit (Adjustment Factor)				Adjusted Habitat Quality Index
			Nectar	Nesting	Fruits and Seeds	Infrastructure	
1	6725.9	0.637	Yes (0.05)	Yes (0.05)	No (0)	Yes (0.1)	0.611
2	2144.3	0.697	Yes (0.005)	Yes (0.05)	Yes (0.05)	No (0)	0.640
3	5138.7	0.442	Yes (0.05)	Yes (0.05)	Yes (0.05)	Yes (0.1)	0.441
4	6070.5	0.273	Yes (0.05)	Yes (0.05)	No (0)	No (0)	0.240
5	3058.8	0.968	Yes (0.05)	Yes (0.05)	No (0)	No (0)	0.852
6	7634.7	0.265	Yes (0.05)	Yes (0.05)	No (0)	No (0)	0.233
7	5433.6	0.433	Yes (0.05)	Yes (0.05)	Yes (0.05)	No (0)	0.398
8	11,179.0	0.133	Yes (0.05)	Yes (0.05)	No (0)	Yes (0.1)	0.127
9	3850.7	0.113	Yes (0.05)	Yes (0.05)	No (0)	Yes (0.1)	0.108

4. Discussion

The results of this study show that La Cantera Park harbors a moderate diversity of native pollinators, with a clear preference pattern for native plants. Areas with higher coverage of native plants, such as *L. camara* and *S. leucantha*, were frequented by bees, butterflies, and hummingbirds, suggesting that habitat quality is closely related to the proportion of native flora. Although exotic plants were present, they played a secondary role in supporting pollinators, underscoring the importance of prioritizing native plants in the design and management of urban parks.

Concerning the 23 species, the diversity of native bees documented in La Cantera Park may be considered moderate compared to other urban areas within Mexico City. In the Pedregal de San Angel Ecological Reserve (REPSA), which is just 1 km away, 74 species of hummingbirds were documented in a year [22]. Furthermore, in the REPSA during the same period when this study was conducted (April–August), 50 active species of hummingbirds were recorded. These findings indicate that the richness of La Cantera Park is less than half that of the REPSA. The discrepancy in diversity may be attributed to the greater degree of urbanization and the paucity of diverse habitats at La Cantera Park, despite the geographic proximity and similar environmental conditions. A recent study in the Bosque de Chapultepec reported 22 species of bees, 20 of which were found in urbanized areas [23]. This indicates that La Cantera Park has a bee diversity comparable to the environment found in a larger park in Mexico City. Although more species are anticipated in parks of this size, it is probable that with more comprehensive annual sampling, the current numbers will be surpassed.

Across the different zones of La Cantera Park, Z4 was the most frequently visited by bees, with 121 documented sightings, primarily *Lasioglossum* (*Dialictus*) spp. and *Ceratina* spp. Such a result may be associated with the presence of plants that are rich in nectar, including *S. leucantha* and *L. camara*, which are plants known for attracting bees in urban environments [24–26]. These findings align with those of previous studies that have underscored the importance of native flora in providing essential resources, such as food and nesting sites, for bees [27]. The presence of native plants not only attracts a greater diversity of native pollinators but also ensures their survival and reproduction, which is of particular importance in urban environments where natural habitats are scarce. In contrast, Z3, Z5, and Z9 presented low levels of bee activity, which is likely attributable to a combination of factors, including lower floral diversity and a paucity of nesting sites. These findings lend support to the notion that an increased diversity of indigenous flora can markedly increase the prevalence of bees in urban parks [28]. The findings in Z4 indicate that, with appropriate planning, urban parks can serve as vital habitats for pollinators.

With respect to butterflies, a total of 20 species were recorded at La Cantera Park, with *A. vanillae* being the most common. This species richness may be considered moderate in comparison to that of the REPSA, where more than 40 species of diurnal butterflies have been documented [29]. Butterflies are sensitive to environmental changes and are therefore considered reliable indicators of habitat quality in urban areas [30]. Therefore, despite the proximity between the two areas, which could have contributed to the greater diversity in La Cantera, factors such as habitat fragmentation and urban landscape management may have limited the migration and establishment of butterflies, thereby explaining the observed difference in species richness.

The butterflies found in La Cantera Park were observed with greater frequency in areas dominated by native plants, with *L. camara* being the most frequently sighted species. This highlights the importance of native plants in maintaining butterfly populations in urban environments [25]. While visits to exotic plants such as *Bougainvillea spectabilis* and *S. rosmarinus* were also documented, the preference for native plants was evident. In addition to the dominance of native plants, other characteristics of the areas in which more butterflies were recorded included the presence of microenvironments provided by bodies of water, slopes, and especially remnants of rocky vegetation original to the site, as observed in Z2, Z3, and Z8. The presence of butterflies is contingent upon not only the availability of floral resources but also the accessibility of their host plants and the microenvironments that shelter them, as is the case in these areas. Therefore, the results demonstrate that urban parks managed with a landscape approach based on the use of native plants and the microenvironments created with them, as well as the connectivity generated between urban parks, can maximize their ecological value for the conservation of plants and butterflies. This is achieved by providing them with food, places of refuge, and reproduction. Accordingly, La Cantera Park can enhance its structural integrity by incorporating more native species identified in the REPSA to facilitate year-round connectivity with this reserve and expand the diversity of floral resources to pollinators.

A previous study documented the interaction between 17 species of hummingbirds and 84 species of plants in Mexico City [31]. Other studies have shown that natural protected areas exhibit the greatest diversity of hummingbirds, with 14 species, followed by urban parks, with 11 species. This suggests a relatively low richness of hummingbirds in La Cantera, with only four species. *C. latirostris* and *S. beryllina* are the two most common species recognized for their ability to adapt to urban resources and their increasing abundance in cities [32]. Although *T. duponti* was found to be less common, it is characteristic of urban parks and natural protected areas [31]. Therefore, our study indicates that La

Cantera Park has the potential to attract species of hummingbirds commonly found in urban green areas.

The presence of native plants in La Cantera Park constituted a significant factor for the preference of hummingbirds for these locations. These plants are known to provide essential resources for the hummingbird population, including nectar and nesting structures. This finding aligns with previous studies that highlighted the high frequency of visits to *S. leucantha* in urban environments [31]. While some exotic plants were observed to be visited, their relatively low presence in the park may limit the diversity of hummingbirds, as exotic species such as *Melaleuca citrina* and *Nicotiana glauca* are known to attract these pollinators in urban environments. The introduction of additional exotic plants may increase the diversity of hummingbirds, as in urban environments. The selection of plants is primarily based on their functional characteristics rather than their origin [31].

Although the introduction of exotic plants may be an incongruous proposition, they can provide crucial resources, such as an increased nectar supply and extended flowering periods, which would benefit hummingbirds when native plants are not in bloom [31,32]. An illustrative example is *W. urens*, a native plant that, although it is commonly visited in natural areas, has demonstrated limited utilization in urban settings such as La Cantera. This finding indicates that urban environments modify plant–pollinator interactions such that the integration of exotic and native plants would optimize the resources available to hummingbirds in these settings.

The different species of bees, hummingbirds, and butterflies found in La Cantera Park preferred native plant species. This observation underscores the vital role these plants play in providing essential resources for pollinators in urban ecosystems. Despite its limited extent within the park, *L. camara* was a preferred habitat for both butterflies and hummingbirds, thereby demonstrating its high ecological value. This finding indicates that the quantity of vegetation is not the sole determining factor; the quality of the species present is also crucial. Certain native plants can have disproportionate impacts on the attraction and sustainability of pollinators. This finding is consistent with the results of previous studies that have indicated that native plants, owing to their evolutionary history with local pollinators, are particularly effective in providing nectar and habitat [33,34]. Similarly, *S. leucantha* attracted 35.3% of the bees observed, thereby demonstrating its importance as a nectar source and nesting site for bees in urban settings [24,26].

With respect to the park's infrastructure, the findings indicate that the mere presence of bodies of water or advantageous infrastructure does not necessarily ensure optimal efficiency in terms of providing resources for pollinators. Zones lacking bodies of water but exhibiting a high concentration of beneficial plants, such as Z5, demonstrated the greatest efficacy in terms of pollination value per square meter. These findings indicate that the diversity and quality of vegetation are critical determinants of pollinator success in urban ecosystems [27,28]. Conversely, despite having favorable infrastructure, Z6, Z8, and Z9 presented diminished pollination values per unit of area, indicating that such areas may benefit from targeted interventions. The increase in the diversity and quantity of native and exotic plants with high pollination values has the potential to markedly increase their capacity to sustain pollinator populations. This is because the provision of infrastructure alone does not appear to be a sufficient means of attracting and maintaining a high diversity of species [30,35]. This highlights the need for a comprehensive approach to landscape management that integrates the provision of suitable infrastructure with the strategic introduction of diverse vegetation, to optimize the resources available to pollinators across the entire park.

The findings of this study contribute to broader sustainability efforts by supporting the objectives outlined in Sustainable Development Goals (SDGs) 13 (Climate Action) and

15 (Life on Land). The prioritization of native plants in urban parks, as demonstrated by the preferences of pollinators in La Cantera Park, highlights a practical strategy for conserving biodiversity in urban areas, directly addressing SDG 15. Native flora plays a critical role in maintaining ecological processes and supporting pollinator populations, which are essential for the stability of urban ecosystems and the services they provide. Additionally, well-managed green spaces that incorporate diverse vegetation, as discussed in this study, contribute to SDG 13 by enhancing urban resilience to climate change. Native plants, with their adaptation to local conditions, require fewer resources for maintenance, while their ability to support biodiversity increases the ecological functionality of urban parks. This dual role of urban green spaces—as hubs for biodiversity and as tools for climate adaptation—illustrates their importance in meeting global sustainability goals. By integrating native and exotic plants strategically, urban parks can provide both ecological and social benefits, reinforcing their value as essential components of sustainable cities.

5. Conclusions

The findings of this study met the proposed objectives by identifying the most important plant species for pollinators in La Cantera Park and characterizing the preferences of each pollinator group. This study highlights the critical role of native flora in supporting pollinator biodiversity in urban environments. The three groups of native pollinators (bees, hummingbirds, and butterflies) clearly showed a preference for the native plant species of La Cantera Park, underscoring the vital importance of conserving native flora to ensure the continued availability of essential resources such as nectar and nesting sites. Specifically, *Lantana camara* was the most frequently visited by butterflies and hummingbirds, whereas *S. leucantha* was the most frequently visited by bees. Areas with the greatest floral diversity, especially those dominated by native species, consistently presented the highest habitat quality values. These findings underscore the necessity of prioritizing the use of native plants in urban park design and management to maximize pollinator biodiversity. Native species, due to their evolutionary history with local pollinators, provide essential resources more effectively than exotic species. While exotic plants can play a complementary role by extending flowering periods and providing additional resources, they should be integrated strategically and only to supplement the resources provided by native flora. The results demonstrate that a landscape management strategy focused on native species, supported by targeted inclusion of exotic plants and effective green infrastructure, can significantly enhance urban resilience and pollinator conservation. Future research should explore the long-term dynamics of pollinator populations in urban parks, assess the impacts of varying proportions of native and exotic species, and develop actionable guidelines for urban planners and policymakers. By prioritizing biodiversity through the conservation and promotion of native plants, urban green spaces can provide critical ecological services and contribute to the sustainability of urban ecosystems.

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Appendix A

Table A1. Representative example of the calculation for the theoretical adjusted habitat quality index in Zone 1 based on the plant species in the zone.

Species	Nectar	Nesting	Fruits and Seeds	Area Covered in Zone 1 by Plant (m^2)	Pollination Value	Nectar	Nesting	Fruits and Seeds
Acacia dealbata	No	No	No	5	5	-	-	-
Agapanthus africanus	Yes	No	No	240.3	240.3	240.3	-	-
Agave americana	Yes	Yes	No	723.4	723.4	723.4	723.4	-
Bauhinia variegata	Yes	Yes	No	160	160	160	160	-
Bougainvillea spectabilis	Yes	Yes	No	5	5	5	5	-
Cascabela thevetioides	Yes	Yes	No	25	25	25	25	-
Dahlia coccinea	Yes	No	No	1	1	1	-	-
Equisetum hyemale	No	Yes	No	25.8	25.8	-	25.8	-
Fraxinus uhdei	No	Yes	No	340	340	-	340	-
Ipomoea arborescens	Yes	No	No	4	4	4	-	-
Jacaranda mimosifolia	Yes	No	No	27.5	27.5	27.5	-	-
Ligustrum lucidum	Yes	No	No	5	5	5	-	-
Nicotiana glauca	Yes	No	No	2.1	2.1	2.1	-	-
Opuntia spp.	Yes	Yes	No	6	6	6	6	-
Passiflora caerulea	Yes	Yes	No	3	3	3	3	-
Salvia leucantha	Yes	No	No	49.7	49.7	49.7	-	-
Salvia rosmarinus	Yes	No	No	210	210	210	-	-
Sedum dendroideum	Yes	Yes	No	882.1	882.1	882.1	882.1	-
Tecoma stans	Yes	Yes	No	5	5	5	5	-
Vachellia farnesiana	Yes	No	No	3	3	3	-	-
Wigandia urens	Yes	Yes	No	1559.2	1559.2	1559.2	1559.2	-
Total area of Zone 1 (m^2) = 6725.9								
Sum of the plant species by zone in m^2				4282.1	4282.1	3911.3	3734.5	0
Index (sum area covered by measure/total area of the zone)					0.637	0.582	0.555	0.0
Values for calculation of adjusted habitat quality index			Pollination value index		0.637			
			Infrastructure		0.1			
			Nectar		0.05			
			Nesting		0.05			
			Fruits and seeds		0			

Table A2. Number of sightings of each bee species by zone of La Cantera Park.

Species	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Total by Species
Anthophora (*Anthophoroides*) spp.	-	-	-	1	-	-	-	-	-	1
Anthophora spp.	-	1		5	-	3	-	-	-	9
Augochlora spp.	-	-	-	-	-	-	-	1	-	1
Bombus (*Thoracobombus*) *Pensylvanicus*	-	-	-	2	-	-	-	-	-	2
Ceratina (*Zadontomerus*) spp.	-	6	1	32	-	5	-	10	-	54
Ceratina spp.	-	-	-	4	-	-	-	8	-	12
Chilicola spp.	-	-	-	1	-	-	-	-	-	1
Diadasia spp.	-	-	-	-	1	-	-	-	-	1
Eucerini (*Thygater*) spp.	-	-	-	3	-	-	-	-	-	3
Euglosa viridissima	2	-	-	-	-	-	-	-	-	2
Eulaema (*Apaeulaema*) *Cingulata*	-	-	-	-	1	-	-	-	-	1
Eulaema (*Apaeulaema*) *Polychroma*	1	-	1		-	-	-	-	-	2
Hylaeus (*Metziella*) spp.	-	-	-	-	-	-	-	1	-	1
Hylaeus (*Prosopella*) spp.	-	-	-	-	-	-	-	2	-	2
Hylaeus spp.	-	-	-	-	-	-	-	8	-	8
Lassioglossum (*Dialictus*) spp.	16	11	1	31	1	16	1	8	1	86
Lassioglossum spp.	7	7	1	35	-	-	-	9	3	62
Megachile (*Cressoniella*) spp.	2	5	-	-	-	-	-	7	-	14
Peponapis spp.	-	-	-	-	-	-	-	-	1	1
Xylocopa (*Neoxylocopa*) *gualanensis*	1	1	-	4	-	9	-	2	-	17
Xylocopa (*Notoxylocopa*) *tabaniformis*	1	-	-	1	-	-	-	-	-	2
Xylocopa (*Stenoxylocopa*) *descipens*	-	-	1	1	-	-	1	-	-	3
Total by zone	30	31	5	120	3	33	2	56	5	285

Table A3. Number of sightings of each butterfly species by zone of La Cantera Park.

Species	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Total by Species
Achlyodes pallida	1	2	-	-	-	-	-	-	-	3
Agraulis vanillae	21	33	26	22	15	10	10	26	-	163
Anthanassa texana	-	-	-	-	1	-	-	1	-	2
Atrytonopsis hianna	-	9	2	1	1	1	1	-	-	15
Autochton cellus	1	1	3	-	1	-	-	4	-	10
Cecropterus dorantes	-	-	5	1	-	-	-	1	-	7
Chlosyne janais	12	14	10	11	9	5	3	3	-	67
Dione juno	-	2	-	-	-	-	2	-	-	4
Erynnis funeralis	-	-	-	-	-	-	1	-	-	1
Heraclides rogeri	1	-	-	-	-	2	-	-	-	3
Hylephila phyleus	2	2	8	8	2	-	-	-	-	22
Leptophobia aripa	12	17	6	12	17	5	3	8	-	80
Leptotes marina	-	-	1	-	-	1	-	9	-	11
Macroglossum stellatarum	-	-	-	1	-	-	3	-	-	4
Papilio garamas	2	-	-	2	-	1	1	2	1	9
Papilio multicaudata	11	10	3	5	6	6	-	4	-	45
Phocides polybius	-	4	-	2	1	1	1	-	-	9
Polygonus leo	-	-	-	-	-	-	5	-	-	5
Pontia protodice	-	-	-	-	-	-	1	-	-	1
Vanessa virginiensis	-	2	4	1	-	-	-	-	-	7
Total by zone	63	96	68	66	53	32	31	58	1	468

Table A4. Number of sightings of bees, butterflies, and hummingbirds by plant species.

Species	Origin	Bees	Butterflies	Hummingbirds	Total by Plant
Lantana camara	Native	13	166	34	213
Salvia leucantha	Native	78	6	9	93
Salvia microphylla	Native	36	-	5	41
Agapanthus africanus	Exotic	35	-	2	37
Salvia rosmarinus	Exotic	27	10	-	37
Wigandia urens	Native	-	27	1	28
Erythrina americana	Native	14	-	4	18
Bougainvillea spectabilis	Exotic	1	11	1	13
Passiflora caerulea	Native	-	13	-	13
Bauhinia variegata	Exotic	2	4	6	12
Buddleja cordata	Native	1	1	7	9
Fraxinus uhdei	Native	-	-	7	7
Mesembryanthemum cordifolium	Exotic	-	7	-	7
Nicotiana glauca	Exotic	-	3	4	7
Schinus molle	Exotic	5	-	2	7
Lavandula angustifolia	Exotic	3	3	-	6
Lampranthus spectabilis	Exotic	1	4	-	5
Casuarina equisetifolia	Exotic	-	-	4	4
Jacaranda mimosifolia	Exotic	-	-	4	4
Cascabela thevetioides	Native	-	3	-	3
Cortaderia Sealana	Exotic	-	2	-	2
Cupressus lusitanica	Native	-	-	1	1
Echeveria secunda	Native	1	-	-	1
Ipomoea arborescens	Native	1	-	-	1
Ligustrum lucidum	Exotic	-	-	1	1
Opuntia spp.	Native	1	-	-	1
Portulaca oleracea	Exotic	1	-	-	1
Prosopis juliflora	Native	1	-	-	1
Agave americana	Native	-	1	-	1
Senna spp.	Exotic	-	1	-	1
Tecoma stans	Native	-	-	1	1
Total by pollinator		221	262	93	576

Table A5. Pollination value and pollinator benefits by plant species in the park.

Species	Origin	Total Area Covered in the Park (m^2)	Pollination Value	Nectar	Nesting	Fruits and Seeds
Agave americana	Native	1037.2	1037.2	1037.2	1037.2	–
Buddleja cordata	Native	14.6	14.6	14.6	14.6	14.6
Cascabela thevetioides	Native	69.5	69.5	69.5	69.5	–
Cestrum nocturnum	Native	2	2	2	-	–
Dahlia coccinea	Native	1	1	1	-	–
Echeveria secunda	Native	11.4	11.4	11.4	11.4	–
Equisetum hyemale	Native	51.6	51.6	-	51.6	–
Erythrina americana	Native	162.6	162.6	162.6	-	–
Eysenhardtia polystachia	Native	0.8	0.8	0.8	-	–
Fraxinus uhdei	Native	485.6	485.6	-	485.6	–
Ipomoea arborescens	Native	70	70	70	-	–
Ipomoea carnea	Native	3.8	3.8	3.8	-	–
Lantana camara	Native	532.3	532.3	532.3	-	532.3
Opuntia spp.	Native	248.2	248.2	248.2	248.2	–
Passiflora caerulea	Native	13	13	13	13	–
Prosopis laevigata	Native	9	9	9	9	9
Salvia leucantha	Native	317	317	317	-	–
Salvia microphylla	Native	78.9	78.9	78.9	-	–
Sedum dendroideum	Native	1177.5	1177.5	1177.5	1177.5	–

Table A5. *Cont.*

Species	Origin	Total Area Covered in the Park (m^2)	Pollination Value	Nectar	Nesting	Fruits and Seeds
Sedum versadense	Native	1	1	-	1	–
Tecoma stans	Native	284	284	284	284	–
Vachellia farnesiana	Native	68.8	68.8	68.8	-	–
Wigandia urens	Native	8745.1	8745.1	8745.1	8745.1	–
Yucca gigantea	Native	5.2	5.2	5.2	5.2	–
Acacia baileyana	Exotic	79.8	79.8	-	-	-
Acacia dealbata	Exotic	48.7	48.7	-	-	-
Acacia melanoxylon	Exotic	7.2	7.2	-	-	–
Agapanthus africanus	Exotic	673.1	673.1	673.1	-	–
Aloe arborescens	Exotic	8	8	8	-	–
Bauhinia variegata	Exotic	415	415	415	415	–
Bougainvillea spectabilis	Exotic	90.7	90.7	90.7	90.7	–
Buddleja davidii	Exotic	12	12	12	-	–
Jacaranda mimosifolia	Exotic	169.7	169.7	169.7	-	–
Lampranthus spectabilis	Exotic	129.4	129.4	129.4	-	–
Lavanda angustifolia	Exotic	223.65	223.65	223.65	-	–
Ligustrum lucidum	Exotic	210	210	210	-	–
Nicotiana glauca	Exotic	2.1	2.1	2.1	-	–
Salvia rosmarinus	Exotic	3502.2	3502.2	3502.2	-	–
Senna didymobotrya	Exotic	4.1	4.1	4.1	4.1	–
Sum of the plant species in the park in m^2		18,965.75	18,965.75	18,291.85	12,662.7	555.9

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