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Original Article

Habitats Heterogeneity Affects Bee Species Assemblage in an Urban Green Space: A Case Study of Nairobi Museum Botanic Garden, Kenya

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ABSTRACT

The conversion of natural landscapes into human-dominated areas has been identified as one major threat to the existence of biodiversity. However, properly managed anthropogenic biomes can act as areas of biodiversity conservation with the potential to provide ecosystem services similar to those obtained in natural habitats. Classic examples are botanic gardens that have become popular in urban centres as examples of nature-based solutions to landscape loss and degradation. To assess the importance of botanic gardens as biodiversity habitats, a study was carried out in the Nairobi Museum Botanic Garden (NMBG). Bees were sampled using pan traps and sweep nets in four habitats classified as gardens, including the Herbal Garden (HG), Memorial Garden (MG), Succulent Garden (SG), and Quarry Garden (QG). A total of 286 individual bees were collected, with MG having 83 individuals, QG (75), SG (66), and HG (62). Though HG recorded the lowest abundance of bees, it recorded the highest number of bee species (14), MG (13), SG (12), and QG (5). The diversity of bees was highest in the HG (H'=1.89), SG (1.88), MG (1.67), and QG (1.15). Meanwhile, high bee abundances and richness were strongly correlated with diverse flowering plants per habitat, with HG having the highest number of flowering plants (23), MG (16), SG (13) and QG (7). The study found that different flowering plants provided habitats that supported unique assemblages of bee communities, a scenario attributed to enhanced habitat heterogeneity. The findings demonstrated that botanic gardens can act as important habitats and refugia for bees in human-dominated landscapes. Therefore, the establishment and conservation of botanic gardens in urban areas is one way to contribute to Sustainable Development Goal 11 of ensuring sustainable cities and human settlements.

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INTRODUCTION

Three of the seven major outcomes targets of the UN Sustainable Development Goal Number 11, 'Sustainable Cities and Communities' are to protect and safeguard the world's cultural and natural heritage, provide access to safe and inclusive green and public spaces, and reduce environmental impacts of cities (UN, 2019). In most urban areas, the green and public spaces include cultural or natural heritage sites, botanical gardens, arboretums, and parks that, apart from acting as recreational, aesthetic, and educational centres, are also important nature-based solutions for biodiversity conservation (Gitau et al., 2019; Aram et al., 2022; O'Hara et al., 2022). The urban green spaces and gardens are diverse and include spaces around single-family housing units, apartment complexes, row houses, and commercial or industrial normally vegetated with lawn grasses as well as large-lot single-family housing units, parks and golf courses characterized by large to medium trees, bushes, shrubs and herbs for recreation, erosion control or aesthetic purposes Aram et al. (2022).

The conversion of natural landscapes into urban areas is predicted to be one of the most destructive activities through the loss and degradation of habitats (Titeux et al., 2019; Molotoks et al., 2020). Land use changes are strongly linked to increasing carbon dioxide concentrations in the atmosphere and nitrogen enrichment, which constitute some of the well-documented major drivers of environmental change with serious direct effects on biota on all Earth's ecosystems (Vitousek, 1994; Sala et al., 2000; Molotoks et al., 2020). Urban areas represent a significant proportion of human-dominated ecosystems that are densely populated and cover approximately 7% of ice-free land or 0.48 million km^2 and support 3.12 billion people (Ellis & Ramankutty, 2008; Ellis, 2013; Jensen & Creinin, 2020). Notably, cities across the world occupy just 3% of the Earth's land yet account for 60-70% of energy consumption and 75% of carbon emissions (Kikstra et al., 2022), which underpins the need to restore and rehabilitate green urban spaces that support unappreciated attributes including ecological processes and functions as well as climate change mitigation (O'Hara et al., 2022).

Although more than three-quarters of the Earth's terrestrial biosphere has been converted into anthropogenic biomes, also known as anthromes, recent studies indicate that a significant percentage of native taxa may be conserved within anthromes if they are sustainably managed, thereby supporting biodiversity conservation and associated ecosystem services for the benefits of humans' well-being (Elmqvist et al., 2015; Sayre et al., 2017; Nicholson et al., 2020). It is predicted that sustainably managed urban environments can be refugia for biological species and perhaps act as their lifelines by providing connectivity between habitats, hence moderating threats relating to extinction due to the loss and degradation of habitats (Hutchinson et al., 2020; Šlachta et al., 2020). Meanwhile, studies on urban biodiversity and their associated ecological processes and functions, as well as the vital ecosystem services they support, remain poorly known and therefore underappreciated (Bolund & Hunhamma, 1999; Maddox, 2018; Martens et al., 2022). This knowledge can be used to change perceptions and guide their prudent governance

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(Dou et al., 2017; Ruckelshaus et al., 2020; Hame et al., 2021).

Bees are a classical group of organisms and are known as the greatest pollinators that humans and other biodiversity depend on for their survival (Ellis & Munn, 2005; Watson et al., 2019). Their nearly cosmopolitan distribution identifies them as a suitable group of organisms that can be used to improve our knowledge of the ecological importance of green and public spaces (Frankie, 2013; Hung et al., 2018; Onuferko et al., 2019). Bees' assemblages are a function of habitat diversity, though poorly documented in urban environment settings (Hernandez et al., 2009; Sardinas & Kremen, 2014; Landsman et al., 2019). Bees are known to nest in various habitats, with some dwelling on grounds, others nest in already existing cavities or crevices, while the social bees nest in man-made hives such as African honeybees (*Apis mellifera*) (Matteson et al., 2008). As pollinators, bees are known to be very specific about the flowers and habitats they visit in the search for resources, including nectar, pollen, water, resins, shade, mates, nesting, and resting sites (Klein et al., 2007). As such, bees have been categorized into two major groups of either generalists or specialists, with generalist bees foraging on different flowers of various plant species while specialists feed on the pollen of a single type of plant species (Michener, 2000). These bees' attributes form the basis for several researchers proposing bees as suitable candidates for assessing and monitoring the ecological health of urban environments (Gikungu, 2006; Watson et al., 2019; Lee et al., 2021).

To understand the effects of habitats on bee assemblages, a study was carried out in the Nairobi Museums Botanical Garden (NNBG) with the overall aim of assessing the importance of the gardens as a possible habitat for bees (Zanette et al., 2005; Hernandez et al., 2009). The specific objectives were to determine bee abundances and diversity in different habitats in NNBG and the relationship between bee species diversity and plant species richness. This study was guided by the hypothesis that bees are very sensitive to habitats' qualities and availabilities, and their abundance and richness were factors of plant diversities reflected by habitat heterogeneity. Higher bees' abundances and diversity were predicted in diverse habitats, expected to be rich in vital resources such as food and nesting sites. Additionally, these sites were viewed as supporting important ecological functions and processes, such as pollination, which are key to sustaining, regulating, and providing ecosystem services.

MATERIALS AND METHODS

Description of the Study Area and Study Sites

The study was conducted in Nairobi Museums Botanic Garden (NMBG), located at 1º 10'28.45' 'S, 36º 48'50.46"E and an elevation of 1674 meters above sea level. The area receives an annual rainfall of 900 mm that is experienced in two wet seasons between April and May and November and December. The garden is approximately 20 ha and occupies the south to the east part of the National Museums of Kenya (NMK) compound. It comprises woodlots along the Nairobi River (*Figure 1*). Portions of woodlots are remnants of initial mesic forests that covered Nairobi in the early to mid-1900s that are presently found in forests in Karura, City Park, Nairobi Arboretum and Ololua within the Nairobi City urban settings. Indeed, the NMBG woodlots serve as stop-over mini habitats for birds, mammals and insects moving between adjacent forests of Karura Forest, City Park and Nairobi Arboretum.

The NMBG was established in 1990 to preserve and exhibit plant species found in Kenya. It was designed and planned to act as recreational and educational for the rich country's natural heritage. Within the NMBG, four unique habitats /gardens have been established with unique assemblages of plants to preserve certain plants, act as an education centre, symbolize a memorial garden or be used to vegetate and rehabilitate disturbed areas such as quarries. These gardens are herein referred to as habitats and are approximately between 1000 m^2 and 2000 m^2 and consist of an

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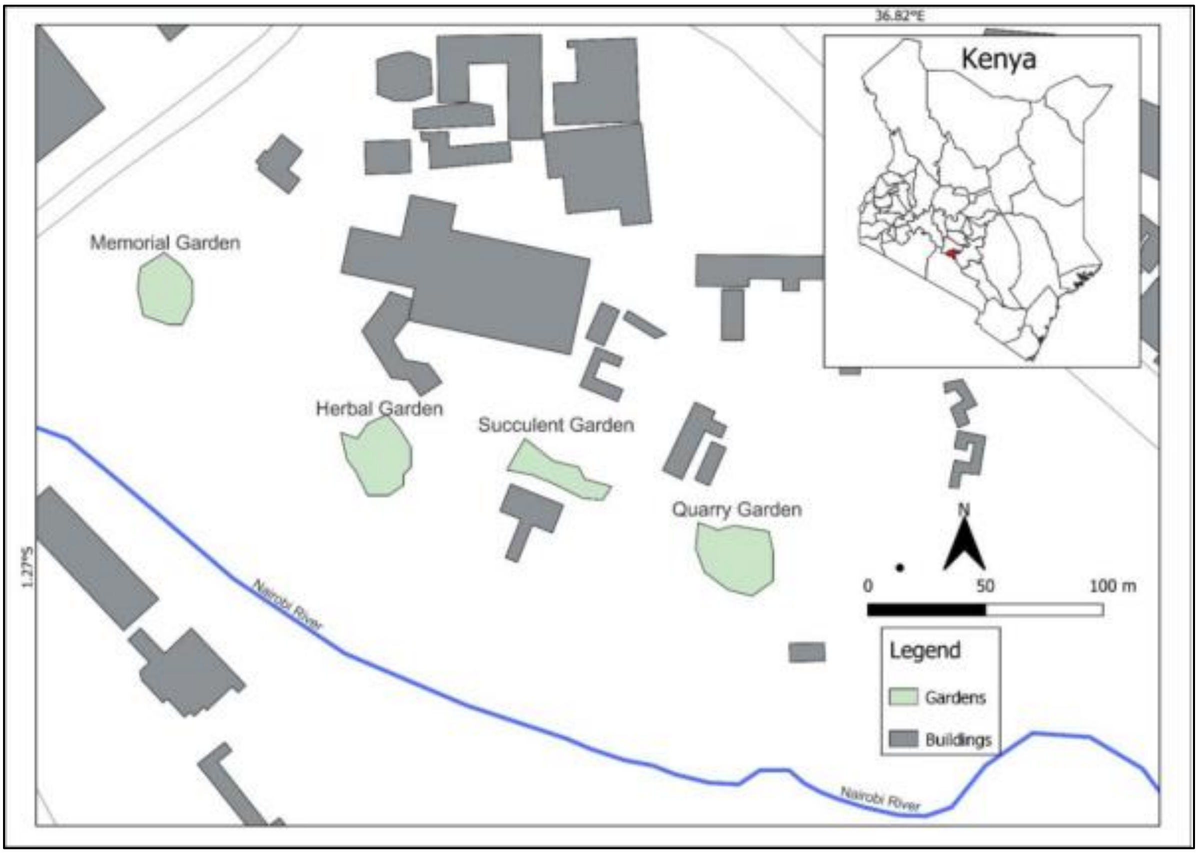
herbal garden (HG), memorial garden (MG), succulent garden (SG) and quarry garden (QG) (*Figure 2*). All four habitats were found in different locations, vegetated with different plants, and under intensive management regimes of irrigation during dry spells, manuring, pruning, and vegetation clearing. As used in this study, the term habitat refers to a limited portion of the total habitat delineated using similar vegetation formations. The herbal garden showcased Kenya's indigenous medicinal and food herbs and shrubs; memorial garden supported shrubs and trees, the succulent garden had more than 350 succulent plants and other plant species obtained from all over Kenya, whereas the quarry garden is a former quarry rehabilitated pond and supports an assortment of papyrus plants and water lilies.

Figure 1: A map of the National Museums of Kenya shows the locations of the four garden habitats



Source: Royal Botanic Garden-, KEW:

Study Design and Data Collection

Bees were sampled using pan traps and sweep netting method (Ausden & Drake 2013). Twelve pan traps of three different colours (Yellow, Blue, and White) were randomly placed in each of the four main habitats in the NMBG. The traps were left for eight hours, between 8 hr. and 16 hr. Each pan trap was half filled with water mixed with a few drops of detergent added to break the surface tension of the water. All the flower-visiting insects collected from the pan traps were transferred into vials and immediately fixed for preservation with 70% ethanol.

At the same time, sweep netting was performed for one hour per habitat to capture flying bees. For each habitat, six 5 m transects were randomly sampled using a standard sweep. Captured insects were exterminated using ethyl acetate, preserved in vials, and later pinned in an entomological box. During sampling, a five-metre buffer from the edges was avoided to minimize edge effects on species data. For both pan traps and the sweeping methods, sampling was carried out three days per

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week for two months during the wet season in 2015. All specimens collected were morphologically identified using taxonomic keys (Michener 2000) and thereafter preserved in the Invertebrates Zoology laboratory of the National Museums of Kenya.

Meanwhile, all the plants visited by bees during sampling were identified from the site with the help of a botanist (Beentje et al., 1994; Agnew, 2013), and their relative abundance was characterized using DAFOR (dominant, abundant, frequent, occasional, or rare) method (Bullock 2013). The method is density or cover measure, and the researcher decides to score based on the relative cover or density of species. During this study, plant relative abundance per habitat was assigned a score using the density measure with dominant levels given a score of 5 for a density of 80-100%, abundance (4, 60-79%), frequent (3, 40-59%), occasional (2, 20-39%), and rare (1, 1-19%).

Figure 2: Images of the garden habitats with herbal (upper panel left), memorial (upper right), quarry (lower panel left) and succulent (lower panel right)

Data Analysis

A checklist of studied bees and plant taxa found in NMBG was compiled and enumerated. All data were analysed using both descriptive and univariate analyses as well as multivariate analyses. Means and standard errors (SE) were used to describe and compare species data between habitats. Data were checked for normality using the Shapiro-Wilk W- test with collected species distribution data found to be not normal. Therefore, the data was analysed using a non-parametric paired t-test of the Wilcoxon matched pair test and significance differences were accepted at $p < 0.05$. Species abundance and distribution (SAD) measures used to describe bees and plant assemblages were species diversity indices of Shannon Weiner diversity index (*H'*), Pielou evenness (*J'*), and richness (*N*), while taxa compositions between habitats were examined using Bray-Curtis Similarity. The relationship between bee assemblages and SAD's measures of vegetation (*H'*, *J'*, *N* and abundances) were examined using the multivariate analyses of Redundancy Analysis (RDA) that is suitable for data sets with monotonic distribution (ter Braak et

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al., 1995). The RDA is a constrained direct gradient analysis used to elucidate the relationships between bee assemblages and SAD's vegetation measures.

Limitations of this Study

Due to various reasons, this research has some limitations. The sampling regime was done during the wet season, implying some opportunistic bees and plants were missing. The study considered one study area, NMBG therefore discussions and conclusions should be treated with a degree of caution.

RESULTS

Bee Assemblages

A total of 286 individual bees were recovered and comprised 19 morphotaxa that belong to nine genera (*Table 1*). The genera were distributed within three families, namely Apidae with five genera, Halictidae and Megachilidae, each with two genera. The family Apidae had the highest number of bees (213 individuals), followed by Halictidae (65) and Megachilidae (8). Occurrences of bees in habitats showed that MG had 83 individuals, followed by QG (75), SG (66) and HG with 62. Meanwhile, species richness was found to be higher in HG with 14 taxa, followed by MG (13), SG (12) and QG with five. In contrast, SG had the highest species diversity of (H´=1.90), followed by HG (1.89), followed by MG (1.67), and QG had the lowest 1.15. Notably, four morphotaxa were well represented in the four habitats and included *Ceratina* sp. 1, *Ceratina* sp. 2, *Ceratina* sp. 5, and *Lasioglossum* sp. 1. Notably, *Ceratina* sp. 1 was the most abundant and widespread and accounted for 37% of all bee individuals sampled. Taxa assemblages displayed moderate similarities between gardens, with MG versus MG having 65%, MG v. SG (69%), MG v. QG (68%), HG v. SG (61%), HG v. QG (66%) and SG v. QG (60%). The Wilcoxon matched pair test analyses found insignificant differences between habitats at p = 0.05.

Table 1: Bees' abundance and distribution in the four habitats

Family	Taxa	Acronyms	Habitats				All habitats
			MG	HG	SG	QG	
Apidae	*Xylocopa sp.1*	XYLsp1	1	2	0	1	4
	Xylocopa sp.2	XYLsp2	0	1	0	0	1
	Xylocopa flavorufa	XYLfla	0	1	0	0	1
	Apis mellifera	APImel	0	2	1	0	3
	Ceratina sp.1	CERsp1	31	27	10	39	107
	Ceratina sp. 2	CERsp2	29	7	17	20	73
	Ceratina sp. 3	CERsp3	2	0	2	0	4
	Ceratina sp. 4	CERsp4	0	0	2	0	2
	Ceratina sp. 5	CERsp5	1	4	3	2	10
	Ceratina sp. 6	CERsp6	1	0	1	0	2
	Ceratina sp. 7	CERsp7	1	0	0	0	1
	Braunsapis sp. 1	BRAsp1	1	1	2	0	4
	Amegilla sp. 1	AMEsp1	0	1	0	0	1
Halictidae	*Seladonia sp. 1*	SELsp1	6	1	1	0	8
	Lassioglossum sp. 1	LASsp1	6	11	22	13	52
	Lassioglossum sp. 2	LASsp2	1	0	4	0	5
Megachilidae	*Megachile sp. 1*	MEGsp1	1	1	1	0	3
	Megachile sp. 2	MEGsp2	2	1	0	0	3
	Heriades sp. 1	HERsp1	0	2	0	0	2
Bee population/ abundance			83	62	66	75	286
Species richness (N)			13	14	12	5	19
Species diversity (*H'*)			1.67	1.89	1.88	1.15	1.82
Species evenness (*J'*)			0.65	0.72	0.75	0.72	0.62

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Vegetation

Sixty-two plant taxa were recorded with the highest richness recorded in HG (26 taxa), MG (16), SG (13) and QG (7) (*Table 2*). The dominant to frequent taxa were *Biden pilosa*, *Commelina benghalensis*, *Oxalis corniculate*, *Rosmarinus* sp.1, *Euphorbia milii*, *Ocimum kilimandscharicum*, *Plumbago zeylanica*, *Aloe powysiorum*, *Aloe trancombei*, *Distictis buccinatoria*, *Euphorbia hirta*, *Justicia* sp. 2, *Plectranthus* sp. 1, *Rosmarinus officinalis*, *Salvia* sp. 1 and *Salvia* sp. 2. A significant number of the plant taxa were weedy flowering species that are very popular with pollinators. Similarly, HG had the highest vegetation species diversity (H´=3.06) followed by MG (2.68), SG (2.49) and QG the lowest 1.85. The Bray-Curtis similarities showed low overlaps of plant taxa assemblages between gardens with MG versus HG having 50%, MG v. SG (15%), MG v. QG (17%), HG v. SG (22%), HG v. QG (14%) and SG v. QG (20%). The Wilcoxon matched pair test analyses only found a significant difference at $p = 0.05$ between QG with MG ($Z = 2.13$) and HG ($t = 2.74$) .

Correlation between Bees and Vegetation

The four designated habitats according to vegetation characteristics were confirmed by multivariate analyses of RDA (*Figure 3*), and several observations were made. The rich plant taxa habitats were also rich in bee taxa. The vegetation endowed herbal garden (HG) with both the highest vegetation taxa abundance (score of 48) and richness (23 taxa) was positively correlated with bee richness (14 taxa) and the key indicator taxa found in this habitat were *A. mellifera*, *Heriades* sp. 1, *X. flavorufa*, and *Xylocopa* sp.2. Similarly, the memorial (MG) with remarkable vegetation abundance (score 41) and richness (16 taxa) was correlated with bee abundances (83) and richness (13 taxa) and associated bee taxa were *Ceratina* sp. 2, *Ceratina* sp. 3, *Ceratina* sp. 4, *Ceratina* sp. 6, *Ceratina* sp. 7, and *Seladonia* sp. 1. The succulent garden (SG) had moderate vegetation abundance (34) and richness (13 plant taxa) and had 12 bee taxa with moderate population (66) and the common bees were *Braunsapis* sp. 1, *Ceratina* sp. 4, *Lassioglossum* sp. 1, *Lassioglossum* sp. 2 and *Megachile* sp. 1. The poor vegetation quarry garden (QG) with abundance score of 13 and seven plant taxa was associated with impressive bees' abundance (75 individuals) but low richness of five bee taxa. There were no bee taxa indicative of QG; however, the few cosmopolitan species with remarkable individuals were *Ceratina* sp.1, *Ceratina* sp. 2, and *Lassioglossum* sp. 1. Meanwhile, there were weak associations between bees and the four measures of vegetation abundance and distribution, i.e., abundance, richness, diversity, and evenness. Similarly, all four measures were found to have an insignificant relationship with bee assemblages when RDA multiple linear regression was carried out, and these were unexpected results.

Figure 3 shows a Redundancy Analysis (RDA) trip-lot of the association between bee assemblages, habitats, and vegetation abundance measures (abundance, richness, diversity, and evenness, represented with green-coloured dotted arrows). The habitats are represented by abbreviations: HG, herbal garden; MG, memorial garden; SG, succulent garden; and QG, quarry garden. The blue solid arrow represents bee taxa with the first three italicized capital letters signifying Genus and the following three italicized lower case letters signifying species name. The bees' full names are provided in *Table 1*.

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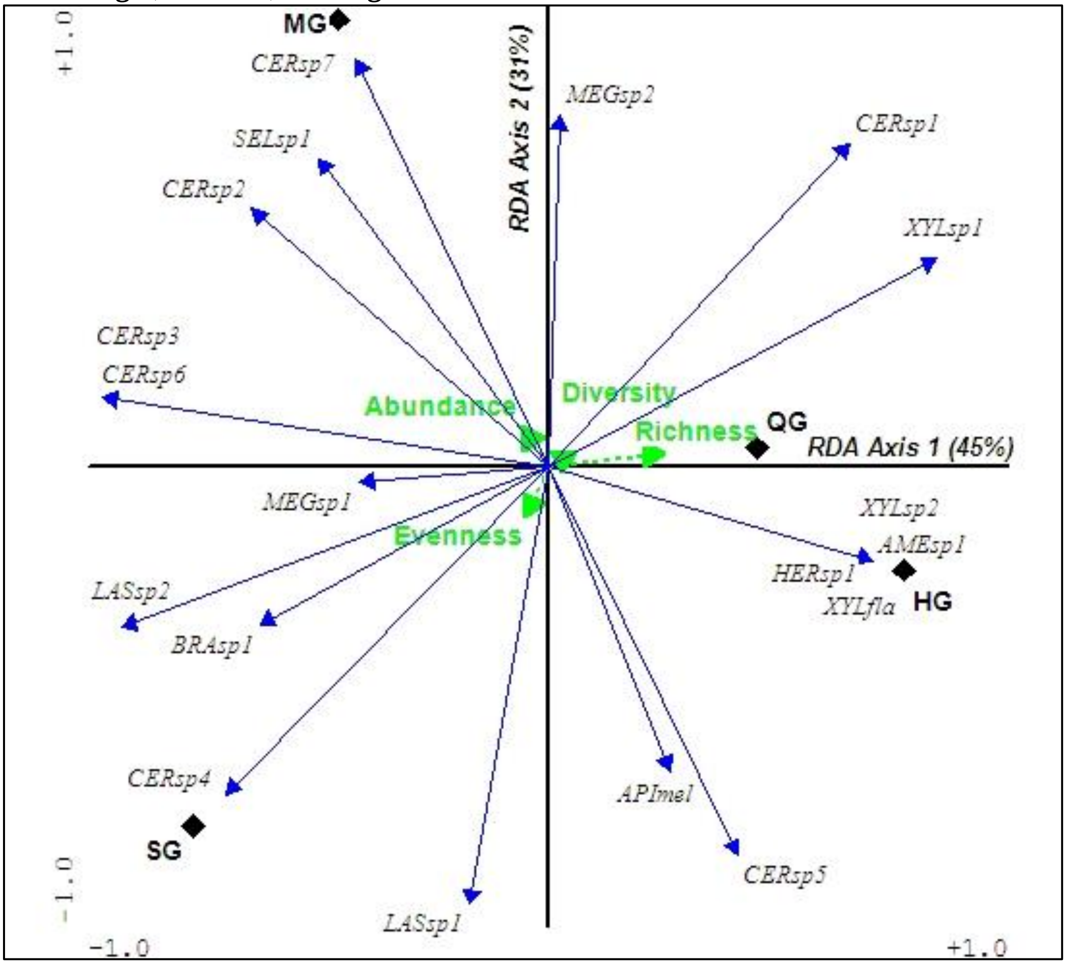
Table 2: Vegetation abundance and distribution in the four habitats

Plant species	MG	HG	SG	QG	All	Plant species	MG	HG	SG	QG	All
Adenia globosa	0	0	3	0	3	*Nymphaea nouchali*	0	0	0	2	2
Ageratum conyzoides	0	2	0	0	2	*Ocimum gratissimum*	2	1	0	0	3
Aloe dessertii	0	0	3	0	3	*Ocimum kilimandscharicum*	2	3	0	0	5
Aloe powysiorum	0	0	4	0	4	*Oxalis corniculate*	1	3	1	1	6
Aloe trancombei	0	0	4	0	4	*Plectranthus barbatus*	0	3	0	0	3
Biden pilosa	2	3	2	1	8	*Plectranthus sp. 1*	1	3	0	0	4
Cassia occidentalis	0	3	0	0	3	*Plumbago zeylanica*	5	0	0	0	5
Commelina africana	0	2	0	0	2	*Pontederia cordata*	0	0	0	2	2
Commelina benghalensis	2	3	1	1	7	*Rosmarinus officinalis*	3	1	0	0	4
Cyperus involucratus	0	0	0	3	3	*Rosmarinus sp. 1*	3	3	0	0	6
Cyphostemma jiguu	0	0	2	0	2	*Rumex bequetiaae*	0	0	0	3	3
Distictis buccinatoria	4	0	0	0	4	*Salvia sp. 1*	4	0	0	0	4
Euphorbia hirta	0	2	2	0	4	*Salvia sp. 2*	4	0	0	0	4
Euphorbia bussei	0	0	3	0	3	*Scadoxus multiflorus*	0	0	2	0	2
Euphorbia milii	0	1	4	0	5	*Sida cunnelfolia*	0	2	0	0	2
Gigasiphon macrosiphon	0	0	3	0	3	*Triumfetta rhomboidei*	0	2	0	0	2
Justicia betonica	0	2	0	0	2	*Zehneria scabra*	0	2	0	0	2
Justicia sp. 1	2	1	0	0	3	*Abundances score*	41	48	34	13	136
Justicia sp. 2	2	2	0	0	4	*Species richness (N)*	16	23	13	7	39
Lantana sp. 2	2	1	0	0	3	*Species diversity (H')*	2.68	3.06	2.49	1.85	3.59
Lantana sp. camara	2	1	0	0	3	*Species evenness (J')*	0.97	0.98	0.97	0.95	0.98
Mirabilis jalapa	0	2	0	0	2						

Figure 3: A Redundancy Analysis (RDA) trip-lot showing the association between bee assemblages, habitats, and vegetation abundance measures



DISCUSSION

This study revealed that different habitats in NMBG supported unique assemblages of bee communities, a scenario attributed to the presence of different habitats supporting varied flowering plants. These were interesting findings and supported considerations of increasing habitat heterogeneity or diversities of both macro and micro habitats during the establishment of botanic gardens. It demonstrated the potential of botanic gardens and green spaces in the rehabilitation and restoration of degraded landscapes in human-dominated biomes, which is consistent with the UN Sustainable Development Goal Number 11 as well as the mission of the UN Decade on Ecosystem Restoration that both aims to prevent, halt, and reverse the degradation of ecosystems (UN 2019, UNEP 2021). Generally, the rehabilitated areas are vegetated with diverse plants that comprise one of the major types of nature-based solution initiates that improve these landscapes' ecological processes and functions, thereby supporting diverse ecosystem services (Aram et al., 2022; O'Hara et al., 2022).

The correlation found between bee assemblages and flowering vegetation across habitats stressed the importance of restoring degraded landscapes with diverse flowering plants. The unique nature of each plant species is predicted to provide a unique habitat that is available to specific groups of bees as predicted, habitats with diverse plants were rich in bees. For instance, bees are grouped as either generalists (i.e. Polylectic) or specialists (Oligolectic), with generalist bees foraging on different flower plants, whereas specialists feed on a few types of plants (Michener 2000). Bees have been reported to be specific to plant flowers and habitats they visit in search of resources such as nectar, pollen, water, resins, shade, mates, nesting, and resting sites (Klein et al., 2007).

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During restoration initiatives, one of the major outcomes is to enhance habitat heterogeneity by growing as many types of plants as possible, particularly the indigenous ones, to increase the diversities of habitats and facilitate bees' co-existence and diversities.

The widespread occurrences and distribution of some bees, including *Ceratina* sp.1, *Ceratina* sp. 2 and *Lassioglossum* sp. 1 showed degraded landscapes can be rehabilitated to have biodiversity capable of supporting important ecological processes such as pollination. Bees are an invaluable part of the ecosystems by aiding in the pollination of plants that are responsible for one-third of the food that the world's population eats (Klein et al., 2007). Also, they offer hope for the survival of bees, especially from the many threats they face presently, ranging from habitat loss, climate change, invasive species, pesticide use, pests, and pathogens (Goulson et al., 2015; Šlachta et al., 2020). These restored areas in urban set-ups assist in increasing connectivities among suitable habitats available to bees, thereby enhancing movements and interactions between populations and communities, halting inbreeding. Species inhabiting different areas in a landscape are capable of interacting through dispersal and migration processes and ultimately maintain high biological diversity through a process known as 'source-sink' dynamics (Hanski, 1998; Kratschmer et al., 2018).

The multivariate analyses uniquely grouped habitats distinctively according to bee assemblages and measures of vegetation abundance and distribution. This implied that the four studied habitats had different ecological conditions and with levels of greening interventions being mirrored by bees' assemblages. Bees have been reported to be influenced by factors such as foraging resources, nesting sites, and habitat connectivity (Hernandez et al., 2009; Wenzel et al., 2020). Leslie et al. (2022) observed that during greening rehabilitation programmes, the purposeful introduction of a diverse array of vegetation known to support should include plants that offer resources to floral specialist pollinators. Additionally, the success levels of such conservation initiatives can be assessed by determining the representation of specialists' and generalists' bee assemblages in varying urban landscape settings. These bees' attributes have made several researchers propose bees as suitable bio-indicators of ecological conditions of landscapes (Gikungu, 2006; Watson et al., 2019; Lee et al., 2021).

CONCLUSION AND RECOMMENDATIONS

The findings of this study reiterated the importance of science-supported, natural-based solutions during the restoration and rehabilitation of urban-impacted landscapes. The four habitats (succulent, herbal, memorial, and quarry) were purposely vegetated with suitable vegetation to promote the conservation of threatened and ecologically important species of succulent plants, medicinal plants in the herbal garden and educational and recreation ones in memorial and quarry areas. Several lessons were learnt from this study.

The rehabilitation of disturbed urban green spaces should be primarily vegetated with bee-friendly vegetation. Some of these are native floral species that are known to be friendly to bees and landscapes (Burghardt et al., 2009; Hernandez et al., 2009).

The greening exercise should include diverse plant species to increase habitat heterogeneity as well as habitats to promote co-existence among different functional groups of bees, i.e. specialists and generalists. For instance, Landsman et al. (2019); Gardiner & Fargeaud (2020) found bees are linked with habitat quality and the characteristics of macro habitats from local to landscape scale. Thus, efforts should be made to enhance urban biodiversity interactions by creating connectivities and corridors between all green spaces in Nairobi City, including remnants of forests of Karura, City Park, and Nairobi Arboretum.

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The greening of urban spaces can achieve several benefits that are core to minimizing impacts of drivers of environmental degradation such as increasing CO_2, land use change and invasive species (Vitousek 1994; Bolund & Hunhammar 1999). Supporting the conservation of bees and vegetation not only achieves biodiversity conservation but also urban sustainability and food security (Hoehn et al., 2008; Leslie et al., 2022).

Botanical gardens, arboretums and green spaces are centres of recreation and tourism. This great asset can be explored to educate and create awareness about the role of bees in sustaining biodiversity among urban communities that visit these areas for leisure and recreational purposes (Gitau et al., 2019). Despite their critical roles in the environment, bees' knowledge, especially in their ecology in urban environments, remains scanty (McIntyre, 2000; Leslie et al., 2022).

Efforts to support the sustainable management of urban green spaces can be realized if supported by policies and legislation at the levels of county and national governments. Weak governance and opaque ownership expose these areas to grabbing and conversion to other land use types. More resources, including financial, should be allocated to support research, education, and initiatives towards sustainable management of urban environments and their intertwined biodiversity.

CONFLICTS OF INTERESTS

The authors declare that they have no conflicts of interest.

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Consent

The research and findings presented in this manuscript were obtained under the auspices of the National Museums of Kenya. Which is governed by its collection and research policy framework that abides by national and international research standards and is mandated by an Act of Parliament, The National Museums and Heritage Act of 2006 (https://www.museums.or.ke/biodiversitydatabase/). Thus, NMK is a Kenyan government institution, and its core mandate is to undertake biodiversity research and manage all biological collections in Kenya.

Authors' Contributions

Both authors contributed equally to the study design, data collection, analyses, and compilation and have read and approved the final manuscript for submission to the journal for publication.

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