Vegetation attributes drive the taxonomic richness and functional composition of beetles and spiders in mountainous urban green spaces

Frederick Gyasi Damptey¹ · Bernard Fosu Frimpong² · Daniel Kwame Debrah³ · Prince Pascal Agro⁴ · Edward Debrah Wiafe⁵

¹ Department of Ecology, Brandenburg University of Technology, Cottbus-Senftenberg, Germany

² Department of Hydrology, Brandenburg University of Technology, Cottbus-Senftenberg, Germany

³ Forestry Research Institute of Ghana, Council for Scientific and Industrial Research, Kumasi, Ghana

⁴ Forest Services Division, Forestry Commission, Accra, Ghana

⁵ School of Natural and Environmental Sciences, University of Environment and Sustainable Development, Somanya, Ghana

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Abstract Urban green spaces (UGS) enhance the quality of life in urban environments and serve as habitat corridors or refuge for organisms, including beetles and spiders. The attributes of UGS allow them to harbour species that offer essential ecosystem services. However, the ability of UGS to provide services is limited by the extent to which they have been altered anthropogenically. We described the taxonomic richness and functional composition of arthropods in a mountainous urban ecosystem of Ghana by focussing on the activity of both beetles and spiders at the family level. Two main land-use types (woodlands and built-up areas) were identified and characterised based on the presence or absence of certain vegetation attributes. Sixteen plots in each land-use type with sizes 20 × 20 m were demarcated and fitted with four pitfall traps in each plot to sample continuously for eight weeks, the activity density of both beetles and spiders. Samples were sorted into families and functional groups (detritivores, fungivores, herbivores and predators). The taxonomic richness and activity density were both significantly higher in the woodlands than in the built-up areas. Similarly, all functional groups showed a higher affinity to the woodlands than the built-up areas. Habitat attributes defined by plant diversity and structural complexity were the underlying drivers explaining the differences in arthropod communities between the land-use types. Though the built-up areas seem degraded and open, the remaining small vegetation patches still support the activities of some taxa that should

merit the protection of such remnant vegetation in urban ecosystems.

Keywords Activity density · Arthropod community composition · Functional composition · Land-use change · Taxonomic richness · Mountainous urban ecosystem

1 Introduction

Urban green spaces (UGS) are ecosystems of significance, playing essential roles in biodiversity conservation as well as providing numerous ecosystem goods and services (Feltynowski and Kronenberg 2020; Kowarik et al. 2020; McPhearson et al. 2018). The characteristics of UGS (e.g., the degree of their naturalness, types of vegetation or diversity of plant species, types of fruits and flowers) allow them to harbour biodiversity (e.g., arthropods) that could offer essential services in the ecosystem and to society (Drillet et al. 2020; Duthie 2018). Such services include pollinating plants, decomposing organic materials, and regulating pest activities, amongst others (Damptey et al. 2021; Ramos et al. 2020). For instance, the predation activities of spiders regulate crop pests as a natural enemy, and the pollination role of bees and butterflies help plants to reproduce, while some beetles function as detritivorous, decomposing dead organic matter and contributing to nutrient cycling in ecosystems (Daniels et al. 2020; Nyfeler and Birkhofer 2017; Zanetti 2016).

The usefulness of UGS is hence seen by how they enhance the quality of life in urban environments, provide

✉ Frederick Gyasi Damptey
FrederickGyasi.Damptey@b-tu.de

biodiversity, and offer habitat corridors or refuge for numerous species (Cameron et al. 2020; Planchuelo et al. 2019; Wang et al. 2019; Mata et al. 2017; Mensah et al. 2016). However, despite these contributions of UGS, they are under threat due to population growth (Vargas-Hernández and Zdunek-Wielgońska 2021) coupled with other urban activities such as farming, and construction (Ives et al. 2016; Norton et al. 2016). Population growth hence has effects on land-use/land cover and biodiversity (Frimpong and Molkenhain 2021; Elmhagen et al. 2015). The conversion of land-use/land cover types (e.g. forest, agricultural lands, wetlands) to urban lands (e.g., built-up residential areas) is considered one of the major factors driving the changes in species diversity and subsequently affecting ecosystem productivity (Méndez-Rojas et al. 2021; Davis et al. 2019; Güneralp and Seto 2013; Seto et al. 2012). Hence, land-use/land cover change results in the reduction or extinction of native (and often endemic) species and sometimes an increase in non-native species (Mollet et al. 2017). It also impairs the habitats of some unique endemic species while creating alternative habitats for some unique species that can tolerate such urban conditions (Buczowski and Richmond 2012).

Although seminal studies have confirmed that increasing land-use changes correlate strongly with a decline in biodiversity (Le Provost et al. 2020; Ahrne et al. 2009; Pauchard et al. 2006), there is also some evidence of some groups, especially certain insects or functional groups of arthropods peaking in terms of abundance in urban areas (Bang 2010; McIntyre 2000). Arthropod activity in urban areas primarily depends on vegetation and its attributes serving as habitat and food resources (Muller et al. 2014). These attributes (e.g., plant diversity, coarse wood debris, litter depth, etc.) offer food resources, serve as shelter, hibernation sites, and foraging sites for arthropods, as well as refuge from predation in urban ecosystems (Grodsky et al. 2018; Burks and Philpott 2017; Everett and Ruiz 1993).

Because of the synergetic relationship between arthropods and their environment, they have been used extensively as bio-indicators in assessing changes in the ecosystem induced by land-use/land cover change (Oliver et al. 2015; Hodkinson and Jackson 2005). For example, beetles and spiders are used as bio-indicators because of their short generation time, allowing them to respond quickly to changes in the urban environment (McIntyre 2000). Besides, they are abundant, occupy a broad range of niches and are present at many trophic levels (Borchard et al. 2014; McIntyre 2000). In addition, spiders play a role as predators reflecting changes in trophic structure in a human-altered ecosystem (Shochat et al. 2004), while beetles (e.g., Carabidae) echo ecological sustainability ecosystem health and reflect variations in natural

conditions (Koivula, 2011). Besides, these groups are also sensitive to human-induced habitat disturbance (Gómez-Cifuentes et al. 2017; Gardner et al. 2009).

An assemblage of communities depicts how species use resources or ecological components to perform their ecological functions (Choi et al. 2010; Blondel 2003). Some groups of species share similar morphological, physiological, and behavioural characteristics that allow them to be classified as functional groups because they perform similar functions in an ecosystem or process the same resources (Blondel 2003). These functional groups of arthropods often provide additional information on environmental changes because of their role in biological processes as predators, decomposers, pollinators, herbivores, etc. (Cardoso et al. 2013; Ulyshen and Hanula 2009).

We assessed how land-use changes affect the taxonomic richness and functional composition of spiders and beetles on a local scale in an urban setting characterised by green spaces (woodlands) and open habitat (built-up residential areas with little or no vegetation). We relied on ground-dwelling spiders and beetles and evaluated the responses of these taxa to changes in land-use types. These taxa relate to the environment and play the roles of predators, pollinators, herbivores, and decomposers with specialised functions in different ecosystems (Buczowski and Richmond 2012; Lee and Kwon 2015) as well as serving as an ideal system to assess the consequences of land-use change on a local scale (Christie et al. 2010).

2 Materials and methods

2.1 Study area

The impacts emanating from land-use changes on the taxonomic richness and functional composition of both spiders and beetles as well as their functional groups on a local scale were investigated in Akropong (latitude 5.955660° and longitude—0.096258°) on the Akuapim Hills of Ghana. Akropong is located in the Eastern Region of Ghana, about 58 km from Accra, the capital of Ghana (Fig. 1). The area is composed of a mixture of forest, shrub and other herbaceous vegetation and dominated by rocks of the Precambrian era, the Togo and Birimian series, with mountain and hilly terrain ranging between 381 and 488 m above sea level. Temperature ranges between 24 and 30 °C by the day, 13 and 24 °C by night with a bimodal annual rainfall pattern of 1270 mm (Owusu et al. 2015). The unique cold weather of the area and other geomorphological, edaphic and vegetation characteristics have created a micro-climatic range that serves as specific niches for diverse species (Wiawe 2014). Thus, the mountainous terrain of the area is characterised by a mosaic of different

Fig. 1 Map of the study area showing the two land-use/land cover types (the built-up is classified in pink and the woodland in green). The square white square polygons are the sampling points for the built-up areas, and the round green polygons are the sampling points for the woodlands

ecosystems with different vegetation dominated by woody-herbaceous plant species of different lifeforms. The changing terrain profile of the area with diverse forms of ecosystems is significant for maintaining biodiversity and enhancing people's quality of life and health. That notwithstanding, these mountainous ecosystems are under threat from anthropogenic activities (e.g. farming, building, other construction works, etc.) and other biophysical factors.

2.2 Sampling design

Thirty-two (32) sampling plots with sizes 20×20 m (16 in areas covered by woodlands, 16 in built-up areas) that capture variations in land-use types were demarcated and sampled for beetles and spiders as well as habitat characteristics. Akropong township is endowed with about 24 managed green spaces. We randomly selected 16 out of the 24 green spaces that were less anthropogenically impacted and had enough tree population and vegetation cover. To

obtain a standardised number of plots for comparison, we further selected 16 built-up areas with little or no vegetation cover at all. Plots were located at least 250 m apart to avoid spatial autocorrelation (Khanaposhtani et al. 2012). The study considered two main land-use/land cover types (woodland and residential-built-up areas). The woodland land-use/land cover type is defined by its heterogeneous tree cover on the Akuapim Hills. In contrast, the built-up areas are characterised by residential facilities, industrial, and commercial units.

2.3 Sampling and sorting arthropods

We relied on ground-dwelling spiders, beetles and their functional groups to investigate the effect of these anthropogenic changes on local biodiversity in a mountainous urban landscape of Ghana. We focussed on ground-dwelling spiders and beetles because they are sensitive bio-indicators reacting quickly to anthropogenically induced ecosystem changes (e.g., Beetles; Scarabaeinae), with their

taxonomy and ecology well known (Carrion-Paladines et al. 2021; Latha and Sabu 2019; Nichols et al. 2007) and their diversity and versatility (e.g., spiders) playing an important role in terrestrial food webs as predators which are a major ecosystem function affected by disturbance (Potapov et al. 2020; Nyffeler and Birkhofer 2017; Preito-Benitez and Mendez 2011). Besides, these groups are diverse and well represented in a disturbed environment, are simple to sample and have some families being conspicuous and easy to identify (Arganaraz et al. 2020; Braga et al. 2013; Gerlach et al. 2013).

Ground-dwelling arthropods (beetles and spiders) were trapped using four pitfall traps in each 32 plots. Traps were filled with 50% propylene glycol mixed with water and roofed with disposable white plates to prevent dilution of the solvent by rains during the sampling period (Underwood and Quinn 2010). Trapping was carried out continuously for eight weeks in the dry season (February to March 2020), being emptied weekly (sampling effort = 4 traps $\times$ 16 plots $\times$ 8 weeks $\times$ 2 land-use types). Trapped samples were first sorted into taxonomic groups. The orders Coleoptera (beetles) and Araneae (spiders) were then sorted into various families, which were classified into four main functional groups (detritivores, fungivores, herbivores and predators) following Choi et al. (2010); Susilo et al. (2009); Lassau et al. (2005). Samples were preserved in 70% ethanol and deposited at the Department of Environmental and Natural Resources Management Laboratory, Presbyterian University College, Ghana, for future projects.

2.4 Sampling plant attributes

All trees were counted within each demarcated plot, and their diameter at breast height (dbh) was measured with a diameter tape. Tree heights were measured using a Nikon Forestry pro II Laser Rangefinder (Nikon, USA). Vegetation height or layer and litter depth were measured with a graduated pole. For each plot, three measurements were taken and averaged to represent the vegetation height per plot. We measured deadwood diameter at the longitudinal midpoint with a diameter tape and length with a measuring tape. In addition, deadwood volume was calculated using Huber's formula (Husch et al. 2003). Finally, the percentage canopy openness, and vegetation cover of each plot were estimated (in percentages) based on images taken with a digital camera (brand: Sony Alpha a6000 Mirrorless Digital Camera with 16-500 mm lens) on mid-sunny days.

2.5 Data analysis

We estimated the taxonomic richness (based on family level) and activity density (active number of individuals

caught per trap in a period of 8 weeks; Castro et al. 2014) of sampled arthropods per land-use type. We log-transformed ($\log(X + 1)$) our dataset for further analysis due to its non-normal discrete distribution (Sokal and Rohlf 1987). Based on the log-transformed data, diversity indices (Pielou's evenness, Shannon, and Simpson; Pielou 1975; Simpson 1949; Shannon 1948) were estimated using the "Diverse" function in Primer vs 7. Statistically significant differences between the land-use types for diversity indices, taxonomic richness and activity density were evaluated with a one-factorial permutational analysis of variance (PERMANOVA) using Bray–Curtis similarity and an unrestricted permutation ($N = 9999$) of raw data with a type III (Partial) sum of squares (Clarke et al. 2014; Bray and Curtis 1957). Land-use type was used as a fixed factor with plot nested in land-use as a random factor.

To evaluate the magnitude of the differences in taxonomic composition between groups (woodlands and built-up areas), we estimated their effect sizes based on Hedges'd with bias-corrected 95% bootstrap confidence intervals together with the resampling distribution from 5000 resamples (Ho et al. 2019).

A similarity percentage analysis (SIMPER) was used to estimate taxonomic contributions to the observed dissimilarities between land-use types based on a 70% cut-off for lower taxonomic contribution (Clarke 1993). Finally, to determine the relative importance of predictor plant variables on arthropod community composition, the Linear Model (LM) and Variance partitioning based on Canonical correspondence analysis (CCA) were performed (Oksanen et al. 2011). All statistical analyses and visualisation were carried out with the Plymouth Routines in Multivariate Ecological Research (PRIMER vs 7, and the PERMANOVA add-on; Clarke and Gorley 2015), and the R statistical computing software version 2.15.3 (R Core Team 2019).

3 Results

A total of 5401 individual arthropods (beetles: 4019, spiders: 1382) were recorded across the two land-use types. The taxonomic richness and activity density were significantly higher in the woodlands than in the built-up areas. Except for Pielou's evenness which was not statistically significant between the two land-use types, both the Shannon and Simpson diversity indices were significantly higher in the woodlands than in the built-up areas (Table 1).

The number of individual beetles was significantly higher in the woodlands (3267) than in the built-up areas (752), with the same trend recorded for taxonomic richness (Woodlands = 17; Built-up = 14; Table 2). Scarabaeidae

Table 1 Diversity indices across the two land-use types. (Means and standard errors are given; N per habitat = 16)

Indices	Woodlands		Built-up		p -value
Taxonomic richness (S)	32		26		0.001
No. of individuals (N)	4074		1327		0.001
Activity density (A_D)	34.605		18.467		0.001
	Mean	SE	Mean	SE	
Pielou's evenness (J)	0.939	0.00	0.943	0.00	0.438
Shannon (H'log _e)	2.699	0.05	2.220	0.06	0.001
Simpson (1-Lambda)	0.950	0.00	0.929	0.01	0.002

Differences in indices for the land-use types were tested by applying One-Way ANOVA ($p < 0.05$). Significant pairs are in bold

was the most abundant family in both land-use types (Woodlands = 975; Built-up = 322). Beetle family composition differed significantly between the two land-use types ($F_{1,30} = 43.12$; $p = 0.001$; Table 3). Hydrophilidae, Scaphidiidae, Staphylinidae, and Trogossilidae were utterly absent in built-up areas, while only Trogidae was absent in the Woodlands.

Spider family composition also differed significantly between the two land-use types ($F_{1,30} = 6.50$; $p = 0.001$; Table 3), with Lycosidae being the most dominant family

Table 3 Taxonomic composition across the two land-use types

Taxa	Factor	df	Pseudo-F	P (perm)	Unique perms
Beetles	Site	1	58.468	0.001	9948
Spiders	Site	1	6.503	0.001	9955
<i>Functional groups</i>					
Detritivores	Site	1	97.010	0.001	9918
Fungivores	Site	1	94.918	0.001	9803
Herbivores	Site	1	36.630	0.001	9926
Predators	Site	1	55.914	0.001	9897

Differences in taxa for the land-use types were tested by applying One-Way ANOVA ($p < 0.05$)

across the two land-use types (Woodland = 477; Built-up = 355; Table 2). Individual spiders were higher in woodland plots (807) than in built-up areas (573). The same holds for their taxonomic family richness (Woodland = 16; Built-up = 13). Members from the spider families Idiopidae, Migidae, and Theraphosidae were completely absent in the built-up areas, while only Palpimanidae was absent in the woodland plots.

The activity of Trogidae and Curculionidae characterised the built-up areas, while the woodland plots were shaped by Carabidae, Endomychidae, Cetoniidae,

Table 2 Number of individual families across land-use types. Differences in land-use types for each group (spiders, beetles) were tested by applying One-Way ANOVA ($p < 0.05$)

Beetles	Wood-lands	Built-up	ANOVA	Spiders	Wood-lands	Built-up	ANOVA
Bruchidae	1	1	1.000	Barychelidae	10	2	0.289
Carabidae	555	270	0.001	Corinnidae	31	52	0.138
Cetoniidae	51	3	0.001	Ctenidae	82	11	0.001
Curculionidae	29	8	0.004	Cyrtoucheniidae	25	9	0.062
Endomychidae	1	4	0.243	Gnaphosidae	5	6	0.817
Elateridae	8	9	0.850	Idiopidae	4	0	0.033
Erotylidae	198	9	0.001	Liocranidae	1	3	0.532
Histeridae	29	87	0.009	Lycosidae	477	355	0.069
Hydrophilidae	209	25	0.001	Migidae	33	0	0.008
Nitidulidae	894	7	0.001	Oxyopidae	3	5	0.431
Pselaphidae	23	2	0.001	Palpimanidae	0	4	0.034
Scarabaeidae	975	322	0.001	Salticidae	61	23	0.077
Scaphidiidae	3	0	0.073	Tetragnathidae	2	1	0.559
Scydmaenidae	8	1	0.005	Theraphosidae	2	0	0.154
Staphylinidae	41	0	0.001	Thomisidae	4	2	0.381
Tenebrionidae	196	4	0.001	Zodariidae	67	122	0.073
Trogossilidae	5	0	0.014				
No. of individuals	3226	752		No. of individuals	807	575	
Taxonomic richness	17	14		Taxonomic richness	16	13	

Significant pairs are in bold

Hydrophilidae, Elateridae, Erotylidae, Curculionidae etc. There was no effect of land-use type on either Bruchidae or Elateridae (Fig. 2a).

The distinction between the two land-use types in terms of beetle family composition was confirmed by a One-Way ANOSIM ($R = 0.975$, $p = 0.01$). An average dissimilarity (based on SIMPER) of about 70% is confirmed between the two land-use types, with 4 out of 18 families contributing approximately 75% to the above dissimilarity. Nitidulidae

is the most discriminating beetle family, contributing about 29% to the average dissimilarity between land-use types. Higher activities of Nitidulidae, Scarabaeidae, Carabidae and Hydrophilidae, were observed in the woodland plots than in the built-up areas. Hydrophilidae was utterly absent in the built-up areas (Table 4).

Corinnidae, Liocranidae, Oxyopidae, Palpimanidae and Zodariidae characterised the built-up areas for spider family composition, while Ctenidae, Cyrtacheniidae,

Fig. 2 Mean effect size (Hedges' d) and bias-corrected 95%- bootstrap confidence intervals for differences in the land-use types for each **a** beetle, **b** spider family

Table 4 Comparative contribution of the individual beetle and spider families (based on SIMPER) to the distinctions between the land-use types

Beetles family	Wood-land Av. Ab	Built-up Av. Ab	Contrib%	Cum. %	Spiders family	Wood-land Av. Ab	Built-up Av. Ab	Contrib%	Cum.%
Nitidulidae	55.88	0.44	28.62	28.62	Lycosidae	29.81	20.94	42.59	42.59
Scarabaeidae	60.94	20.13	25.37	54.00	Zodariidae	4.19	7.63	17.94	60.53
Carabidae	34.69	16.88	12.86	66.86	Ctenidae	5.13	0.69	10.39	70.92
Hydrophilidae	13.06	0.00	7.99	74.85					

The resemblance is based on Bray–Curtis similarity and 70% cut-off for low contribution. (Av. Ab. = Average abundance, Contrib % = contribution percentage, Cum % = Cumulative percentage)

Barychelidae, Idiopidae, Ctenidae, Salticidae, amongst others, shaped the woodland plots (Fig. 2b). The distinction between the two land-use types in terms of spider family composition was confirmed by a One-Way ANO-SIM ($R = 0.325$, $p = 0.04$). An average dissimilarity (based on SIMPER) of about 48% was confirmed between the two land-use types, with 3 out of 17 families contributing approximately 71% to the above dissimilarity. Lycosidae contributed about 43% to the above dissimilarity. A higher abundance of Lycosidae and Ctenidae was recorded in the woodland plots than in the built-up areas (Table 4).

The habitat attribute variations defined by plants and vegetation properties in each land-use type (Table 5) could explain the differences in arthropod taxa composition between the two land-use types. Except for tree canopy openness which was significantly higher in the built-up areas, all other habitat attributes were significantly higher in the woodland plots (Table 5).

A significant relationship was observed between arthropod taxa (beetles and spider) and habitat variables ($p = 0.008$). The first principal axis explained 67% of the variation ($p = 0.005$), while the second axis also explained 16% of the total variation ($p = 0.197$). The CCA triplot showed that Palpimalidae, Liocrinidae and Trogossilidae

were closely associated with canopy openness in the built-up areas. Erotylidae, Nitidulidae and Idiidae were also closely associated with tree height, and Staphylinidae was also influenced by tree size (*dbh*). Theraphosidae, Scarabaeidae, Hydrophilidae and Trogossilidae were also associated with tree abundance, litter depth, and deadwood volume (Fig. 3). Families such as Scarabaeidae, Ctoniidae, Histeridae, Curculionidae, Lycosidae, Hydrophilidae, and Ctenidae concentrated at the centre of the triplot suggest that their abundance may be associated with a combination of habitat attributes instead of just a single habitat attribute.

All four functional groups differed significantly between the two land-use types, with all groups exhibiting significantly higher activity density in the woodland plots than built-up areas (Fig. 4).

4 Discussion

4.1 Differences in taxonomic richness and activity density of beetles and spiders across land-use types

The taxonomic richness and activity density were significantly higher in the woodlands than in the residential land-

Table 5 Habitat attributes (mean values and SE) of the two land-use types

Habitat attributes	Built-up		Woodland		<i>p</i> Value
	Mean	SE	Mean	SE	
Tree abundance	2	0.44	17	1.99	0.001
Tree diameter (cm)	7.721	1.38	16.590	1.34	0.001
Tree height (m)	5.875	1.05	9.250	0.41	0.005
Tree canopy openness (%)	89.563	2.42	20.250	1.36	0.001
Vegetation cover (%)	18.688	3.62	75.813	1.80	0.001
Vegetation height (m)	0.481	0.10	1.425	0.05	0.001
Litter depth (m)	0.023	0.01	0.304	0.03	0.001
Deadwood volume (Mg/ha)	1.259	0.31	8.633	0.54	0.001

Differences in attributes for the land-use types were tested by applying One-Way ANOVA ($p < 0.05$)

Fig. 3 CCA of 35 arthropod taxa across the two land-use types (Woodland in green, Built-up areas in red). Abbreviations: Ba- Barychelidae, Co- Corinnidae, Ct- Ctenidae, Cy- Cyrtoucheniidae, Gn- Gnaphosidae, Id- Idiopidae, Li- Liocranidae, Ly- Lycosidae, Mi- Migidae, Ox- Oxyopidae, Pa- Palpimanidae, Pi- Pisauridae, Sa- Salticidae, Te- Tetragnathidae, Th- Theraphosidae, Tho- Thomisidae,

Zo- Zodariidae, Br- Bruchidae, Ca- Carabidae, Ce- Cetonidae, Cu- Curculionidae, En- Endomychidae, El- Elateridae, Er- Erotylidae, Hi- Histeridae, Hy- Hydrophilidae, Ni- Nitidulidae, Ps- Pselaphidae, Sc- Scarabaeidae, Sca- Scaphidiidae, Scy- Scydmaenidae, St- Staphylinidae, Ten- Tenebrionidae, Tr- Trogossidae

use type. Different groups reacted differently based on the magnitude of changes in land-use types (Fenoglio et al. 2020). These differences could be due to the influential roles of plant attributes favouring the activity of both beetles and spiders in the woodlands. For example, a more abundant tree species, greater vegetation cover, higher deadwood volume, and the different strata defined by vegetation and tree height might have created a wider potential diversity of available ecological niches (Keroumi et al. 2012). These ecological niches might have created an appropriate habitat and offered possible food resources (e.g., leaves, fruits and seeds) for most taxa's existence, survival, and activity in the woodland plots compared to the built-up areas. Hence, diverse trees serve as “keystone structures”, providing habitats for beetles and spiders (Schuldt et al. 2019; Schowalter 2017; Sebek et al. 2016). Our results confirm that arthropod taxonomic richness and

activity increase with vegetation complexity defined by its diversity and structure (Mata et al. 2020; Wenninger and Inouye 2008; Lassau et al. 2005). In a similar study, beetle activity increased with vegetation diversity (Jouveau et al. 2020), while vegetation structure complexity enhanced spider activity (Štokmane and Spungis 2016).

Moreover, the activity of beetles correlated positively with all measured habitat characteristics, in agreement with previous studies highlighting the positive roles of habitat attributes on beetle diversity. For instance, deadwood volume has been discussed extensively to increase beetle (saproxylic) activity (Ekström et al. 2021; Haeler et al. 2021; Schiegg 2000), offer important microhabitat (Dufour-Pelletier et al. 2020; Bače et al. 2019; Seibold and Thorn 2018), provide refuge from predation (Seibold 2015) and offer food resources (Parisi et al. 2018).

Fig. 4 Activity density of arthropod functional groups in woodlands and built-up areas (**a**: Detritivores, **b**: Fungivores, **c**: Herbivores and **d**: Predators)

4.2 Characteristic taxa of the different land-use types

Most beetle taxa showed a stronger affinity for woodlands, which could be related to the availability of food and habitat resources offered by such woodlands. Most species of Carabidae are usually polyphagous and predacious on other arthropods, which prefer habitats characterised by diverse tree species (Bergmann et al. 2012). Such habitats usually harbour other arthropods, which are preyed on by Carabidae (Ebeling et al. 2018). The higher activity of Endomychidae in the woodlands also confirms their positive association with habitat attributes such as deadwood volume because they prefer decaying wood or fungal spores (Leschen 1993). Most species within Endomychidae exploit diverse fungi and the microhabitats they provide (Majka 2007). Histeridae were also dominant in the woodlands because they are generalist predators with a wide range of habitats but reduce activity in open and degraded ecosystems (Cajaiba 2017). Lassau et al. (2005) affirmed the role of habitat complexity in shaping beetle families such as Staphylinidae and Carabidae. Complex habitats usually provide diverse conditions for organisms because of the variety of microhabitats and trees that characterise such habitats (Khanaposhtani et al. 2012).

The activities of Bruchidae and Elateridae was neutral and showed no preference for any of the two land-use types. Trogidae and Curculionidae were the only two beetle families that showed a higher affinity to the built-up areas. We could, in this case, not assign any tangible explanation to this trend; however, we could only speculate that other factors aside from vegetation attributes (e.g. exposure to the sun leading to the dryness of the area or bare ground providing exceptional support) contributed to the dominance of these two families of beetles in the built-up areas.

A comparison between the spider and beetle groups revealed that they both reacted differently to habitat complexity. A more significant proportion of their taxa showed a preference for either the woodland or the built-up areas, confirming their strong association with habitat characteristics (Entling et al. 2007). The variation in land-use types driven by environmental conditions associated with vegetation attributes could explain the differences in spider and beetle communities between the two land-use types (Delgado de la flor et al. 2020; Štokmane and Spungis 2016).

4.3 Effect of habitat characteristics on arthropod functional groups

All four functional groups (detritivores, fungivores, herbivores and predators) were significantly higher in the

woodlands than in the built-up areas. This trend may have been mediated by the habitat characteristics of the two land-use types. Our results affirmed that functional group activity becomes more pronounced when plant diversity increases with structural complexity (Sattler et al. 2010). Accordingly, a complex habitat structure may have modified the niche space and offered resources for the activity of the various functional group's (Staab and Schuldt 2020).

The built-up of ground litter and deadwood volume within the woodland areas might have benefited the detritivores. This perhaps could be attributed to their saproxylic nature, thus living and feeding on decayed wood and other decomposing plant parts (Mestre et al. 2018; Parisi et al. 2018; Wende et al. 2017). Higher predator activity in woodlands could be a response of these groups to more diverse vegetation, often coupled with higher prey availability (Diehl et al. 2013). In a similar study, a diverse and complex vegetation structure of woodlands (forests) offered alternative habitats and prey, subsequently increasing predatory organism numbers (Dampney et al. 2021). In addition, this diverse vegetation might have also provided refuge for predators (Barnes et al. 2020). Herbivores activity correlated significantly with plant attributes in the woodlands. For instance, herbivores activity increased with increasing tree diversity of the woodlands. Hence, diverse tree habitats support a greater range of feeding demands by herbivores (O'Brien et al. 2017). In addition, these diverse trees offer a variety of diets, which subsequently improve herbivores fitness, leading to their higher activity (Coley and Barone 1996).

5 Conclusion

Our results revealed that the built-up areas were open and degraded with little capacity to support most beetle and spider activities. However, their small remnant vegetation provided the necessary habitat and feeding resources for some specialised groups, including Trogidae, Curculionidae, Zodariidae, Palpimanidae, Oxyopidae and Corrinidae. Habitat characteristics played an important role in explaining the variations in arthropod community composition between the two land-use types. Plant diversity and vegetation complexity offered the strongest explanatory power to the observed arthropod community differences. This then points to the need to continuously conserve such remnant vegetation in urban ecosystems to support some taxonomic groups of ecological value.

The results of this study are relevant for urban planners and managers in incorporating green spaces in urban landscape designs to save the few urban arthropod communities that are useful in ecosystem service provision.

We only had a small sampling size and did not consider the seasonal effects on arthropods across multiple land-use types other than woodland and built-up areas. Therefore, we recommend that future studies focus on unraveling seasonal factors and their interactions with different land-use types to shape the arthropod community in an urban setting. We also recommend that urban planners and managers consider planting multipurpose tree species in built-up areas to provide shade, habitat, and food resources for arthropods, birds, and other small mammals. Finally, urban planners could enhance the habitat quality of remnant vegetation by collaboratively engaging community members and other relevant stakeholders in urban greening projects.

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Author's contributions All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by FGD, BFF, DKD, PPA and EDW. FGD wrote the first draft of the manuscript and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declaration

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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