

**Urbanization and urban habitat fragmentation do not compromise soil food web complexity
and conservation value**

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26 **Data accessibility**

27 Data supporting the results will be made available in Dryad Digital Repository, and the data DOI
28 will be included at the end of the article.

29

30 **Authorship**

31 BW conceived the idea and all authors substantially contributed to refine it. BW, SZ, ZQ, and
32 QY conducted the arthropod sampling and classification. BW, SZ, and ZQ conducted the literature
33 review and extracted $\delta^{15}\text{N}$ data. BW conducted the analysis and produced the figures, with support
34 from SS and XS. BW wrote the initial draft of the manuscript, and all authors contributed to the final
35 version of the manuscript.

36

37 **Abstract:** Urbanization-induced environmental changes such as habitat fragmentation impacts
38 arthropod assemblages and food web-related ecosystem functions. Yet, we lack insight into how
39 arthropod food webs are structured along urban fragmentation gradients. Here, we investigated the
40 community composition and food web structure of litter-dwelling arthropods along fragmentation
41 gradients. We found the density, biomass and taxa richness of litter-dwelling arthropods in small
42 urban fragments, i.e. parks, was relatively higher than in urban and natural forests, with 68% of the
43 individuals comprising primary consumers. Associated with the community composition, food webs
44 were more complex in small urban fragments, with abundant primary and secondary consumers
45 including decomposers. Supporting the dominance of bottom-up forces, the density of adjacent
46 trophic levels consistently correlated positively. Overall, our results suggest that small size urban
47 fragments maintain a diverse community of arthropods forming complex food webs and thereby may
48 contribute to conserving biodiversity and providing important ecosystem functions.

49

50 **Keywords:** urbanization, habitat fragmentation, litter-dwelling arthropods, trophic level, food web

51

1. Introduction

The global urban area rapidly expanded in the last 40 years and is expected to form home of 5 billion people by 2030, i.e. about 60% of the world's population will inhabit urban areas (Liu et al., 2020; United Nations, 2019). Rapid urbanization entails a corresponding increase in resource supplies from surrounding ecosystems, resulting in more green lands being merged during urban expansion and more natural habitats being transformed into smaller functional blocks for inhabitants of cities (Lin et al., 2019; Zhou et al., 2017). On the other hand, areas not suited for development, such as hills and wetlands, are increasingly transformed into urban forests, recreation parks or other types of green infrastructures, which is expected to alleviate environmental problems, conserving biodiversity and maintaining the ecological functions of urban ecosystems (Jia *et al.* 2018). Yet, the isolation of greenspaces due to constructions, roads and other paved urban areas is a global threat contributing to biodiversity loss and causing biotic homogenization (Joimel *et al.* 2019; Piano *et al.* 2020b). These changes likely also affect ecosystem functioning and services of urban greens (Liu *et al.* 2019; Hong *et al.* 2022), with a simplified food web structure (Buchholz et al., 2018; Piano, et al., 2020). However, the consequences of fragmentation and isolation of greenspaces on arthropod food webs and the energy they process remain poorly understood.

Soil and litter layer perform a wide range of ecosystem functions and services, for example providing refugia for wildlife, regulating microclimate, and nutrient cycling and sequestering carbon (Wang & Tong 2012; Malloch *et al.* 2020). Soils in urban areas often are artificially formed, e.g. by refilling with excavated deep soil and construction residues, and exposed to novel environmental conditions, such as increased temperature and input of pesticides (Nero & Anning 2018; Ulpiani 2021). Further, litter materials forming an important food resource for soil food webs often are removed in urban greenspaces (Milano *et al.* 2017; Kotze *et al.* 2022). These changes likely result in soil arthropod communities diverging from surrounding natural systems (Malloch *et al.* 2020).

76 However, not all urban greenspaces are strongly managed, e.g. urban forests may remain close to
77 natural systems.

78 Arthropods comprise the largest and most diverse phylum on Earth and account for
79 approximately 85% of the known species (Giribet & Edgecombe 2012). In terrestrial ecosystems,
80 arthropods colonize virtually any habitat from tropical forests to cold arctic regions (Stevens & Hogg
81 2002; Basset *et al.* 2012). They inhabit a wide array of ecological niches and provide a variety of
82 ecosystem services such as nutrient recycling and carbon sequestration, maintaining soil fertility,
83 pollination and pest control (Isaacs *et al.*, 2009; Wang *et al.*, 2021). Arthropod species can be
84 classified into different trophic groups according to their trophic position in the green and brown food
85 web, e.g. primary consumers/decomposers, secondary consumers/decomposers and predators
86 (Schneider *et al.* 2004; Maguire *et al.* 2016; Lagerlöf *et al.* 2017). While several studies documented
87 that environmental changes shape the composition of arthropod assemblages as well as their trophic
88 position (Geldenhuys *et al.* 2022; Zhou *et al.* 2022), the role of urbanization processes in shaping the
89 composition of arthropod communities received little attention.

90 Arthropod food webs are vertically structured with nodes (taxon groups), node positions as well
91 as edge features (predator-prey relationships). Stable isotope ratios of nitrogen ($^{15}\text{N}/^{14}\text{N}$) in consumer
92 tissue allow to identify the trophic position of consumers (Post 2002; Oelbermann & Scheu 2010;
93 Potapov *et al.* 2019b), but this has mainly been used for reconstructing aquatic food webs (Lin *et al.*
94 2020; Mérillet *et al.* 2022), whereas terrestrial arthropod food webs received little attention.

95 This study aimed at investigating how fragmentation of urban greenspaces affects the richness
96 and abundance of litter-dwelling arthropods, and their food web structure using Xiamen city, one of
97 most greening cities in China, as model area. We hypothesized that (i) soil and litter conditions are
98 harsher in urban areas compared to natural forest (poor in soil nutrients, low in litter quality, quantity
99 and diversity), resulting in lower abundance and biomass of litter-dwelling arthropods, (ii) compared
100 to natural forest (as a large continuous habit), the density, body mass, biomass and richness of litter-

dwelling arthropods is reduced in urban fragments and is lowest in the smallest fragments, (iii) arthropod taxonomic and trophic groups respond differently to fragmentation, and (iv) food web structure might be simplified in urban small fragments compared to forests and this is most pronounced in the smallest fragments.

2. Material and methods

2.1 Study area

The study was conducted in Xiamen city, which is located in south-eastern China (117°53'-118°26' E, 24°23'-24°54' N, Fig. 1). The region has a subtropical marine climate with an annual average air temperature of 22.8°C and annual average precipitation of 1078 mm; the rainy season spans from May to August. Textures of soils in Xiamen city are mostly silt loam and loamy sand, which are generally poor in soil organic matter and nutrients (Wang et al., 2017). Xiamen city is one of the most developed and most densely populated cities (9153 inhabitants km⁻²) in Fujian province and the urban area has rapidly expanded during the last 40 years. Nevertheless, the city is the highest urban green area (45%) compared to the other cities with at least 1 million inhabitants in China (Yearly Report of Urban Construction in China 2021 <https://www.mohurd.gov.cn/gongkai/fdzdgknr/sjfb/index.html>). Natural forests and urban forest remnants are dominated by *Acacia confusa*, *Schima superba* and *Pinus massoniana* in the canopy layer. The vegetation in urban green infrastructures mostly consists of exotic ornamental species, such as *Bauhinia variegata* and *Ceiba speciosa* and other foliage and flowering plants.

2.2 Experimental design and sampling

In June 2021, we selected four fragment types including three urban fragments, i.e. green median strips (MS), urban parks (UP) and urban forest surrounded by human constructions (UF), and continuous natural forest located outside of the city (NF; representing the least fragmented and most natural habitat) forming a gradient of increasing fragment size (Fig. 1). For each fragment type, we

125 set up four replicate sites spaced >2 km from each other. In each site we set up four plots of 20 m ×
126 20 m at least 100 m apart from each other, except for median strips, resulting in a total of 64 plots.
127 Tree and shrub species within plots were recorded. Within each plot, a subplot of 5 m × 5 m was set
128 up from which litter and soil samples were taken. Litter samples were taken using a frame (20 cm ×
129 20 cm, height 12 cm) which was randomly placed in the subplot. Soil samples were taken at the same
130 site where the litter samples were taken using a steel corer (5 cm diameter and 10 cm depth). The
131 physicochemical properties of soil and litter were analyzed (approaches and results were presented in
132 supporting information, Fig. S1).

133 **2.3 Extraction and classification of arthropods**

134 Arthropods were extracted in the laboratory using Berlese (Macfadyen 1961). See more detail
135 in Qiao *et al.* (2022). A total of 35 taxonomic groups were distinguished and ascribed to four trophic
136 groups according to the $\delta^{15}\text{N}$ values (Fig. S2). Adult arthropods were measured for body length and
137 maximum body width using the software S-gauge (Nikon SMZ745T, Tokyo, Japan). Length and
138 width were used to estimate individual fresh body mass (Jochum *et al.*, 2017; Potapov, *et al.*, 2019).
139 Total biomass of arthropods in each plot was calculated as the sum of individual body masses. A
140 network binary adjacency matrix was built based on predator-prey relationships, searched on GloBI
141 (<https://www.globalbioticinteractions.org>). In cases where the description of prey was overly vague
142 the link was removed, this was also done for cannibalistic loops.

143 **2.4 Trophic level of arthropods**

144 We searched for published data on nitrogen stable isotope ($\delta^{15}\text{N}$) values of arthropods using
145 “nitrogen stable isotope*” and “arthropod*” as search terms in ISI Web of Science. The search
146 resulted in 2,904 hits from which we filtered 94 studies that matched the following eligibility criteria:
147 the study reported at least one species included in our arthropod groups and the $\delta^{15}\text{N}$ values given
148 were calibrated to the local litter material ($\delta^{15}\text{N}$ values). A maximum of ten references were used for

each arthropod group. In total, 3065 data were retrieved and compiled (Fig. S2). Based on Minagawa & Wada(1984), Scheu and Falca (2000), and Potapov *et al.* (2019b) the assumption of an enrichment of 3.4‰ per trophic level, the taxonomic groups in our study were ascribed to four trophic levels: (I) Phycophages/plant sucking insects (-3.4-0‰) feeding mainly on lichens and algae, (II) primary decomposers/herbivores (0-3.4‰) feeding on plant litter/detritus but also on living plant tissue, (III) secondary decomposers and first order predators (3.4-6.8‰) predominantly feeding on microorganisms, in particular fungi, but also living as predators and omnivores, and (IV) second order predators (6.8-10.2‰) feeding on other arthropods.

2.5 Statistical analysis

The statistical analysis of community structure followed the approach used by Potapov *et al.* (2019a) and Yin *et al.* (2022). All of the analysis were performed in R version 4.2.1 (R Core Team 2022), and results were visualized using the *ggplot2* package (v3.3.6).

To characterize the trophic structure of arthropod communities and their habitat conditions (composition of the litter layer), we used the *vegan* package (v2.6-2) to calculate taxa density and taxa richness. Mean differences in density and taxa richness of all arthropods between fragment types were tested via mixed-effects linear model with ‘Site code’ as a random factor. For each taxonomic group, the mean differences in arthropod density, biomass and body mass were analyzed using general liner models. We then employed non-metric multidimensional scaling (NMDS) based on Bray-Curtis dissimilarity to analyze the species composition of litter and community structure of arthropod, respectively. Significant differences in connectivity and multivariate homogeneity of group dispersion of arthropod structure between fragment types were determined using permutational multivariate analysis of variance and a multivariate analogue of Levene's test *betadisper* models, with 999 permutations, (Anderson 2005).

To structure the food web of litter-dwelling arthropods, the *fluxing* function in the *fluxweb* package was used (v0.2.0; (Gauzens *et al.* 2017, 2019). *A priori* conceptual food webs were

constructed based on published $\delta^{15}\text{N}$ values and predator-prey relationships (Fig. S3). First, arthropod groups were ordered according to published mean $\delta^{15}\text{N}$ values. The vertical position of arthropod taxa in the food web (V_v) was calculated as $V_v = \delta^{15}\text{N} * l + \kappa$ where l is the classified trophic level (range 1-4), κ is a constant that generally equals to the enrichment of ^{15}N per trophic level (3.4‰). The horizontal position of arthropod taxa in the food web (H_v) was calculated as difference between the focal arthropod taxon and its front-neighboring arthropod taxon as $H_v = \sqrt{(\delta^{15}\text{N}_i - \delta^{15}\text{N}_{i-1})}$, where $\delta^{15}\text{N}_i$ and $\delta^{15}\text{N}_{i-1}$ are the mean $\delta^{15}\text{N}$ values of the i^{th} and the $i-1^{\text{th}}$ arthropod taxon.

To assess differences in food web structure among fragment types, we structured network analyses with taxonomic groups as nodes (N) and predator-prey relationships as edges (E). The food web structure was assessed based on the number of potential edges ($E_p = C_N^2$), linkage density ($d = \frac{E}{E_p}$), directed connectance ($C = \frac{E}{N^2}$) and mean path length and sum of weight (Anderson & Sukhdeo 2011; Tamaris-Turizo *et al.* 2018). The longest food chain in fragments was found out using ‘*longest.chain*’ function in *loop* package (version 1.1, Chen, 2013).

To identify potential drivers of the abundance of each trophic group across fragment types, we inspected correlations between soil and litter physicochemical properties, and the abundance of arthropod trophic groups (I-IV) using Mantel test (*mantel_test* function in the *ggcor* package with 999 permutations, v0.9.7). Further, Pearson's correlations were used to evaluate the relationships between trophic levels I, II, III and IV.

3. Results

3.1 Arthropod communities

A total of 13,842 arthropod individuals, representing 35 taxonomic groups (32 genera and 3 larval groups), were recorded. Entomobryomorpha, Poronoticae, Holosomata and Mesostigmata were the most abundant groups accounting for 34%, 15%, 12%, and 10% of the total individuals,

197 respectively. Average densities of arthropods in the litter layer ranged from 2000 (urban forest) to
198 9344 ind. m⁻² (urban park) and taxonomic richness ranged from 10 (urban forest) to 16 (urban park
199 and natural forest). Arthropod density varied significantly with fragment type ($F_{3,12} = 4.46$, $P = 0.025$);
200 it was highest in urban park and lowest in urban forest with that in median strip and natural forest
201 being intermediate (Fig. 2A). Taxonomic richness also varied significantly with fragment type ($F_{3,12}$
202 $= 8.10$, $P = 0.003$); it was high in urban park and natural forest and lower in median strip and urban
203 forest (Fig. 2D). Further, arthropod community composition in urban forest differed from that in the
204 other three fragment types (Fig. 2E, PERMANOVA: $F_{3,59} = 4.35$, $P < 0.001$).

205 Compared to natural forest, the density of 63% and 71% of the taxonomic groups was lower in
206 median strip and urban forest, respectively (Fig. S4 A-C). By contrast, the density of 68% of
207 taxonomic groups was higher in urban park than in natural forest. Specifically, the density of
208 Euptyctima, Poduromorpha, Symphypleona and Thysanoptera were significantly decreased in green
209 median strip and urban forest, whereas the density of Entomobryomorpha and the body mass of
210 Isopoda was increased compared to natural forest (Fig. S4 A, B, H and I). Moreover, the density of
211 Araneae, Coleoptera larva, Cucujiformia, Dermaptera, Isopoda and Poronoticae were significantly
212 higher in urban park than in natural forest. Further, Pseudoscorpionida was absent in all urban
213 fragments, whereas Dermaptera were only found in urban fragments.

214 3.2 Trophic groups of arthropods

215 The average density of arthropods of trophic level I, II, III and IV was 3653±562, 652±106,
216 964±165 and 244±34 ind. m⁻² across fragment types, respectively. By contrast, arthropod biomass
217 was highest in trophic level II (232±103 mg dry mass m⁻²) and arthropod body mass was highest in
218 trophic level IV (256±106 µg dry mass individual⁻¹). Each density, taxonomic richness, biomass and
219 body mass of arthropod differed significantly between trophic levels (Table S2, $P < 0.001$). Trophic
220 level I contributed most to total arthropod density (Fig. 3A), but their density varied with fragments
221 and was lowest in urban forest ($F_{3,60} = 4.55$, $P = 0.006$). By contrast, the body mass of trophic level I

was generally lowest across fragment types (Fig. 3C). The biomass of trophic level II also varied significantly with fragment type ($F_{3,60} = 4.53$, $P = 0.006$); it was particularly high in median strip and urban park (Fig. 3B).

Arthropods of medium size, such as Holosomata, Poronoticae and Entomobryomorpha, ranged between 15% (in urban park) and 57% (in urban park and median strip) of the total population of trophic level I arthropods. While, the biomass mostly comprised by Entomobryomorpha, which ranged between 77% (in urban forest) and 99% (in median strip and urban park) of the total biomass of the trophic level I arthropods. Diplopoda and Isopoda comprised 76% and 95% of the total biomass of trophic level II in urban park and median strip, respectively. Trophic level IV arthropods had the highest body mass in each of the fragment types except urban park (Table S2, $F_{3,902} = 11.18$, $P < 0.001$), but both density and biomass were considerably lower than in arthropods of trophic level I and II. Across fragment types Araneae on average contributed 48% of total density and 98% of the total biomass of trophic level IV arthropods.

3.3 Food web structure of litter-dwelling arthropods

There were 126, 169, and 111 and 143 edges for the arthropod food web in median strip, urban park, urban forest and natural forest (Table 1, Fig. 4). The food web structure in urban forest was the simplest, whereas that in urban park was the most complex among the four fragment types (Fig. 4B C). Total energy flux in median strip, urban park, urban forest and natural forest was 26.64, 59.19, 18.52 and 30.58 J m⁻² year⁻¹, respectively (Fig. S5). Urban forest and natural forest had similar food web structure as indicated by similar edge density, directed connectance, sum of weight, and node degree (Table 1 and Fig. S6). The food webs in median strip and urban park had similar structure and the longest food chains, but lower mean path length compared to natural forest (Table 1, S4). Araneae formed the apex predator in median strip, urban forest and natural forest, whereas in urban park Chilopoda formed the apex predator receiving 85% of the energy from Araneae (Fig. 4B).

246 3.4 Correlation between trophic groups and properties of soil and litter

247 Of the studied soil and litter properties only litter moisture and TP content and biomass of
248 decomposed litter significantly correlated with the density of arthropods of at least one trophic level
249 (Fig. 5). The biomass of decomposed litter correlated with each the density of arthropods of trophic
250 level I ($r = 0.24$, $P = 0.02$), III ($r = 0.40$, $P < 0.001$) and IV ($r = 0.19$, $P = 0.05$). Further, the density
251 of arthropods of trophic level III arthropods significantly correlated with litter TP ($r = 0.26$, $P = 0.04$),
252 and trophic level IV was significantly correlated with litter moisture content ($r = 0.21$, $P = 0.05$).

253 In addition to environmental factors, Pearson's correlations indicated that arthropods in urban
254 fragments were significantly influenced by trophic interactions; correlations between the density of
255 trophic levels were consistently positive (Fig. 5). Correlations were strongest between trophic level I
256 and II ($r = 0.67$, $P < 0.001$), and gradually weakened between higher levels ($r = 0.53$, $P < 0.001$ and
257 $r = 0.35$, $P = 0.002$ between trophic levels II and III, and III and IV, respectively).

258 4. Discussion

259 4.1 Density and biomass of litter-dwelling arthropods in fragments

260 In contrast to our first hypothesis, the edaphic conditions and litter quality in small urban
261 fragments (median strip and urban park) were favorable for arthropods and resulted in higher density
262 and biomass of arthropods than in natural and urban forests. Edaphic conditions, such as soil moisture
263 content and pH, were important environmental factors driving arthropods communities (Qiao *et al.*
264 2022). Previous research showed that the abundance of arthropods is generally higher in humid and
265 alkaline soils, as soil moisture reduces desiccation risk of arthropods and most soil arthropods have a
266 high tolerance for alkaline soils (Stenchly *et al.* 2017; Manu *et al.* 2021). In the current study, due to
267 the greenspace management practices, the soils in green median strip and urban park received more
268 irrigation water than urban forest resulting in a humid soil environment for arthropods. The soil pH
269 was significantly higher in median strip and urban park than in forests also contributing to favorable

270 soil conditions for soil invertebrates. These favorable edaphic conditions contributed to the potential
271 of small urban green spaces serving as refuges for vital soil food webs.

272 Plant residues play an essential role in soil processes, vegetation regeneration and biodiversity
273 conservation by providing favorable microhabitat conditions and nutrient resources (Berg *et al.* 2010;
274 Trentini *et al.* 2018). Compared to the natural forest, the litter layer in median strip and urban park
275 provided sufficient and high-quality material needs for arthropod density and biomass increases, as
276 high-quality litter matches the feeding preference of these fresh or withered leaf feeders (Sauvadet *et*
277 *al.* 2017; Reis *et al.* 2018). Among the soil and litter physicochemical properties studied, the biomass
278 of decomposed litter was significantly correlated with the density of trophic level I, III and IV
279 arthropods. The highly porous structure and humid environment (Wang *et al.*, 2016), and carbon
280 resources in decomposed litter provide favorable habitat conditions for fungi and detritivore
281 arthropods (Joseph *et al.* 2015; Wang *et al.* 2021). In our study, the amount of decomposed litter in
282 particular favoured the density and biomass increases of decomposer taxa such as
283 Entomobryomorpha, Poronoticae, Isopoda and Diplopoda.

284 In addition to decomposing litter as a major resource of the soil animal food web the density of
285 trophic groups of arthropods consistently correlated positively underlining the dominance of bottom-
286 up forces in the studied urban fragments (Vidal & Murphy 2018). Arthropods of trophic levels I and
287 II reached very high densities in median strip and urban park and provided ample prey for predators
288 of trophic levels III and IV in a walkable patrol area, thus leading to population increase of predators.
289 However, the very high density of trophic level I and II arthropods also indicates that top-down
290 regulation is limited, which is consistent with the assumption that fragmentation more strongly affects
291 high trophic level taxa typically being of larger body size and foraging at larger scales than low
292 trophic level taxa. Wide prey spectrum and generalist feeding including omnivory and intra-guild
293 predation may also explain the general decline in the strength of correlations between the abundance
294 of adjacent trophic level arthropods with increasing trophic level. Assuming that body size increases

295 along trophic chains top level arthropods may prey in particular on preys with subduable body size,
296 such as larvae of Diptera and Coleoptera as well as mesopredators of trophic level III such as
297 Dermaptera and Apocrita. The consistent positive correlation among arthropods of each of the trophic
298 levels points to indirect effects of low trophic level arthropods on higher trophic level taxa including
299 top predators presumably reflecting the prevalence of generalist feeding and omnivory in
300 belowground food webs (Scheu & Setälä 2002; Walton *et al.* 2006; Digel *et al.* 2014; Yin *et al.* 2022).
301 High abundance of trophic level II arthropods in small urban fragments also may have resulted from
302 the control of mesopredators by top predators, i.e. trophic level omnivory and intra-guild predation
303 (Ritchie & Johnson 2009; Bonato *et al.* 2021).

304 **4.2 Richness and community structure of soil arthropods in fragments**

305 Soil biodiversity in urban ecosystem is declining because of environmental changes and habitat
306 fragmentation during urbanization processes (Piano *et al.* 2020a, b; Szabó *et al.* 2023). Contrary to
307 these studies and our hypothesis, density and biomass of soil arthropods was relatively higher in urban
308 fragments compared to natural forest, and was lowest in the smallest fragments. However, taxa
309 richness of arthropods in urban park was similar to that in natural forest, whereas, taxa richness in
310 median strip was low. Most of the urban parks in urban areas had been established on historical areas
311 little disturbed by humans or in wet coastal areas next to lakes characterized by high biodiversity
312 (Kowarik, 2011). Therefore, from a biodiversity perspective urban park have high conservation
313 potential for arthropods (Kostrakiewicz-Gierałt *et al.* 2022).

314 We found that these isolated green fragments in the meddle of roads are a valuable component
315 of urban habitats, the density and biomass of arthropods in median strip were second only to urban
316 park, while the taxa richness in median strip was relatively lower than in urban park. The median
317 strips are highly isolated from the other systems by road lanes and traffic, resulting in a low success
318 rate for wingless arthropods to immigrate into this system (Martin *et al.* 2019), such as Diplopoda in
319 our study. Despite the winged arthropods, such as Coleoptera, Homoptera and Lepidoptera, can

320 successfully moving to the median strip, the airflow created by running cars may disturb them and
321 could not easily settle down in the median strip, consequently, the winged arthropods (including their
322 larva) in median strip were two times less than in urban park. The microclimate conditions in median
323 strip were uninhabitable for most of the arthropods, the road lanes heat and dry the median strip soil
324 too much by absorbing solar radiation during daytime (Richards & Edwards 2017; Luo *et al.* 2022).
325 Moreover, due to the extensive planting of ornamental plants, the diversity and palatability of litter
326 to arthropods decreased in the median strips (Donoso *et al.* 2010; Sánchez-Galindo *et al.* 2021).

327 Compared to the small fragments in urban areas, urban forests are generally less fragmented and
328 play a pivotal role in biodiversity conservation (Ferreira *et al.* 2018; Koricho *et al.* 2022). However,
329 we found that the taxa richness of arthropods in urban forest was more simple than in the other
330 fragments studied including natural forests. As stressed earlier Liu *et al.*, (2019b) and Kantsa *et al.*,
331 (2013), the soil conditions, coupled to environmental changes in urban areas were unfavourable for
332 the arthropods in urban forests (Long *et al.* 2019). These poor habitat conditions resulted in a low
333 richness of arthropods. On the other hand, due to the habitat loss in urban areas, larger urban animals,
334 such as birds, are mostly inhabiting in these less human disturbance fragments (Gunnarsson *et al.*
335 2009). Therefore, macrofauna in urban forests, including the apex predators i.e. Araneae and
336 Chilopoda are likely to be consumed by birds (Braschler *et al.* 2021; Szabó *et al.* 2023).

337 Consistent with our third hypothesis that arthropod taxonomic and trophic groups may respond
338 differentially to fragment size. Due to the adverse environmental conditions in bigger fragments, most
339 of the arthropods in urban and natural forests were considerably lower than in urban park.
340 Nevertheless, it was colonized by more arthropod groups including some primary consumers, such
341 as Archaeognatha and Isoptera who rely on cellulose in plant detritus (Pothula *et al.* 2019; Marchin
342 *et al.* 2022), they would be benefiting from the massive accumulation of woody debris on the urban
343 forest. In addition to these decomposers, Astigmata, most of which involve parasitic or commensal
344 relationships with other organisms, such as feather mites and ear mange mites (Domes *et al.* 2007),

345 were significantly higher in urban forest than in small urban fragments. This could be due to the
346 intensive activities (foraging and nesting) of the host animals, such as urban birds and bats (Dietz *et*
347 *al.* 2020). In contrast to Pseudoscorpionida, the apex predators in median strip and urban park
348 preformatted better than in natural forest. Probably due to these macropredators *per se* having a width
349 range of environmental adaptability (Meineke *et al.* 2017; de Tranaltes *et al.* 2022), and a width range
350 of feeding resources in their prey spectrum, not only mesofauna but also some macrofauna, which
351 may be a prohibitive prey to Pseudoscorpionida.

352 **4.3 Food web structure of arthropod**

353 We reconstructed food webs of litter-dwelling arthropods of urban fragments by using published
354 $\delta^{15}\text{N}$ values. Unexpectedly, in contrast to our fourth hypothesis food webs in urban and natural forests
355 were simpler than in urban park and median strips, with a higher number of edges, edge density,
356 connectance and total energy fluxes, and lower mean path length. Further these complex food webs
357 were characterized by being bottom-heavy, i.e., high biomass in trophic levels I and II, but low in
358 trophic level IV. Nevertheless, the total energy flux in natural forest was slightly higher than in
359 median strip, but 50% less than in urban park. The complex food webs in urban park might, on the
360 one hand, relate to the taxa composition of predators, especially the marcoarthropod predators such
361 as Chilopoda, which is not only rich in abundance and body size, but also have a wide prey spectrum
362 (Bonato *et al.* 2021; Li *et al.* 2023). For example, we found only a few links between Araneae and
363 trophic level I arthropods, whereas Chilopoda was intensively linked to the trophic level I arthropods,
364 despite most of them had low body mass, all these direct linkages between the apex predator and its
365 preys decreased the value of mean path length, implying a faster energy flow in urban park, despite
366 the total amount of energy fluxes from the trophic level I and II was low. On the other hand, the
367 increase in richness of predator guilds resulted in more and longer longest food chains in urban park
368 compared to median strip, indicating a diversification of energy fluxes in urban fragments.

369 In median strip and urban park arthropods of trophic level I and II dominated. For example,
370 Entomobryomorpha reached high density in urban park and median strip of 4000 and 2000 ind. m⁻²,
371 respectively. However, the energy fluxes from these decomposers to higher trophic levels were low
372 and did not differ much between fragment types. On the contrary, arthropods of trophic levels III and
373 IV were the important energy supplier to the apex predators, for example, the trophic levels III and
374 IV together contributed 72% and 93% of energy fluxes to Araneae in median strip and Chilopoda in
375 urban park, respectively. While, as the most important food supplier to the apex predators, 55% of
376 the energy of Apocrita in median strip and 70% of the energy of Araneae in urban park were supported
377 by the arthropods in trophic level III, but not by the most abundant taxa groups in the trophic level I
378 and II. This pattern is likely related to the feeding preference of the predators, which are likely to
379 prefer hunting for prey of suitable body size to increase prey capture (Potapov 2022). The preferential
380 consumption of mesopredators by apex predators in median strip and urban park likely contributed
381 to the high population density of Entomobryomorpha in these habitats.

382 5. Conclusions

383 Our findings provide new insight into biodiversity conservation of litter arthropods in urban
384 greens. Decomposing litter on the soil surface of urban greens rather than litter quality and species
385 richness shapes litter-dwelling arthropod density and food web structure, particularly favoring
386 arthropods in trophic levels I, III and IV. The density, body mass, biomass and richness of arthropods
387 in small urban fragments were unexpectedly high and exceeded that in urban forest. Arthropods of
388 trophic levels I and II dominated in density and biomass in median strip and urban park, whereas in
389 urban and natural forest arthropods of trophic levels III and IV were (relatively) more important. The
390 smaller fragments (median strips and parks) had a more complex food web structure with higher
391 linkage density and length of the longest chain but lower mean path length, on the contrary, the food
392 web structure in the urban forest was the simplest. Overall, our results indicate that fragmentation of
393 urban habitats may be less detrimental than commonly assumed and may even increase the

394 complexity of community composition and food web structure of litter-dwelling arthropods,
395 contributing substantially to energy fluxes. If managed the litter layer appropriately, these urban
396 fragments therefore may sustain diverse arthropod communities and contribute to biodiversity
397 conservation, and thereby to major ecosystem functions and services such as nutrient cycling and
398 energy fluxes.

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407

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628 **Captions and Tables**

629

630 **Fig. 1** Map of sampling plots in Xiamen city, China. Median strip (MS, orange), urban park (UP,
631 blue), urban forest (UF, red), and natural forest (NF, green). The map of China was downloaded from
632 <http://bzdt.ch.mnr.gov.cn/index.html>, the satellitic map of Xiamen city is a screen capture from
633 Google Earth Pro (version 7.3.4.8248).

634

635 **Fig. 2** Variations in arthropod density (A), body mass (B), biomass (C), species richness (D) and
636 community composition (E) with urban fragment type (green median strip, urban park, urban forest,
637 natural forest). Lowercase letters and represent significant differences between fragment types as
638 indicated by Tukey's HSD tests at $P < 0.05$. Variations in arthropod community composition are
639 based on Bray-Curtis distance. Ellipses represent 95% confidence ranges.

640

641 **Fig. 3** Density (A), body mass (B), biomass (C) and richness (D) of arthropods of four trophic levels
642 in median strip (MS), urban park (UP), urban forest (UF) and natural forest (NF). Trophic levels were
643 classified based on published $\delta^{15}\text{N}$ values (see Fig. S1). Different lowercase letters denote significant
644 differences among fragment types within the same trophic level; different capital letters denote
645 significant differences among trophic levels in the same fragment type (Tukey's HSD pairwise
646 comparisons at $P < 0.05$).

647

648 **Fig. 4** Food web structure in median strip (A), urban park (B), urban forest (C) and natural forest (D).
649 Food webs were constructed based on predator-prey relationships. The position of nodes was based
650 on published $\delta^{15}\text{N}$ data (for more details see Methods and Fig. S1). Width of links scaled with the
651 \log_{10} of energy fluxes (calculated using biomass, metabolic rates and feeding efficiencies; see
652 Methods). The size of nodes corresponds to the total biomass of arthropod groups.

Fig. 5 Correlation matrix between trophic levels I and IV and physicochemical properties of soil (S.) and litter (L.). Non-significant correlations were omitted from the graph. Blue and deeppink lines indicate significance levels $0.01 < P < 0.05$ and $P < 0.001$, respectively. Asterisks indicate significance levels: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

659 **Table 1** Indicators of arthropod food web structure (number of species and links, linkage density,
660 connectance, mean path length, longest food chain and sum of weight) in the four types of urban
661 fragments studied.

662