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Macro-invertebrate abundance on green roofs versus ground level sites in the city of Antwerp, Belgium

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Abstract. Here, the abundance of macro-invertebrates (Arthropoda and Gastropoda) of eight green roofs and their adjacent ground level habitats in the city of Antwerp, Belgium, is compared. All higher-level taxa found were present in both types of habitats without significant differences in their overall abundance between green roofs and ground level habitats. However, we found significant differences in abundances between the two types of habitats, when specific taxa were compared. Beetles (Coleoptera), isopods (Isopoda) and bees (Anthophila) were more abundant at ground level sites compared to green roofs, while for true bugs (Heteroptera) and cicadas (Auchenorrhyncha) the opposite was found. Our results support the idea that extensive green roofs in Belgium can provide a suitable habitat for different invertebrate taxa, but further research is needed to identify the true drivers behind differences in abundance between ground level and adjacent green roofs.

Keywords. Abundance, invertebrates, green roofs, urbanization.

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Introduction

Urbanization is one of the most significant anthropogenic alterations on the surface of the earth and poses one of the greatest threats to global biodiversity (FENOGLIO *et al.* 2020). The world's human population is constantly increasing with numbers expected to reach ten billion by 2050 (UNITED NATIONS 2019). Recent projections indicate that in the same timeframe the percentage of people living in urban areas will rise to 70% (UNITED NATIONS 2019). The trend towards urbanization causes an increase in habitat loss, more fragmentation and an overall change in habitat quality (SETO *et al.* 2012). Moreover, urbanization has several other negative effects such as the heat-island effect, an increased amount of pollutants, poor air and water quality, and changes in soil structure due to different types of land use (BYRNE 2007; PICKETT & CADENASSO 2009; PICKETT *et al.* 2011; FAETH *et al.* 2011; ELMQVIST *et al.* 2016). Green roofs are often promoted to counter these negative environmental effects of urbanization because they deliver ecosystem services normally provided by natural green (PATAKI *et al.* 2011). Recent studies show the benefits of green roofs on different levels. Green roofs improve water runoff and evapotranspiration (MENTENS *et al.* 2006), are an efficient solution to mitigate the heat-island effect (OBERNDORFER *et al.*

2007), create a reduction in the heat flux due to insulation (Kumar & Kaushik 2005; Jim & Tsang 2011), may lower carbon concentration in the nearby area (Li *et al.* 2010), and function as stepping stones and increase habitat connectivity for mobile arthropod species (Braaker *et al.* 2014).

Studies investigating the impact of urbanization on biodiversity have shown varying results including an increase in plant richness because of human introductions of non-native plant species (Walker *et al.* 2009), but also a general decrease in bird richness (Chace & Walsh 2006; McKinney 2008; Faeth *et al.* 2011; Batàry *et al.* 2017), and overall less diversity, species richness and abundance of terrestrial arthropods in more urbanized landscapes (Fenoglio *et al.* 2020; Piano *et al.* 2020).

Arthropods are the most diversified animals on Earth, with an estimated global richness of 6–8 million species (Ødegaard 2000). They encompass a wide range of functional groups that are important in providing different ecosystem services such as pollination, pest control and decomposition (Losey & Vaughan 2006). Moreover, they occupy a wide array of niches and microhabitats. The bewildering diversity of niche requirements within arthropods makes it hard to generalize the effect of urbanization on this taxon (Fenoglio *et al.* 2020). Some studies show no effect of urbanization on arthropod abundance (Faeth *et al.* 2011), while others demonstrate a decrease in abundance of ants (Korànyi *et al.* 2020), or – on the contrary – find an increase in arthropod abundance in more urbanized areas compared to rural areas (Lessard & Buddle 2005; Turrini & Knop 2015).

Green roofs can support species that are negatively impacted by habitat loss due to urbanization (Brenneisen 2006; Kadas 2006; Madre *et al.* 2013). Whether these green roofs can be as biodiverse, species rich and have a similar abundance as ground level habitats remains unclear due to a lack of ecological studies with adequate replication, controls and sufficient duration (Williams *et al.* 2014). Most green roofs in Belgium are extensive roofs, consisting of a 5–15 cm deep layer of homogenous, shallow substrate. Vegetation on these roofs consists of drought tolerant plants with minimal need for maintenance, such as species of *Sedum.* Overall, the vegetation height on these green roofs is low and there is a preference for plants with a shallower root system compared to ground level habitats. Green roofs are hard to access for less mobile species, have on average a smaller size than ground level habitats, have a more homogenous soil structure and constitute a drier and hotter environment to survive in (Holt 2016; Blank *et al.* 2017). Although not that much investigated, contrasting findings on diversity, abundance and richness of invertebrate communities on green roofs compared to ground level habitats have been published. Lower (Colla *et al.* 2009; Tonietto *et al.* 2011; Ksiazek *et al.* 2012; Braaker *et al.* 2017) to an equal or even greater number of species on green roofs compared to ground level sites (Kadas 2006) have been reported. Differences in plant structure, cover, diversity and different physical conditions between ground level habitats and green roofs could explain these differences in invertebrate diversity, richness and abundance (Madre *et al.* 2013; Braaker *et al.* 2017; Kratschmer *et al.* 2018; Ksiazek *et al.* 2018). Differences in abundance and diversity between ground-level habitats and green roofs could also be influenced by their size and by the degree of isolation of the green roof. The surface of contiguous green areas at ground level tends to be larger than the surface of green roofs, which could have an important impact on the abundance and diversity of species (Kyro *et al.* 2018). According to the island biogeography theory, larger fragments will contain a greater diversity of microhabitats and are more likely to be colonized (MacArthur & Wilson 1963, 1967). However, some studies that tested the island biogeography theory for arthropod communities on green roofs have not found a significant effect (MacIvor & Lundholm 2011; Braaker *et al.* 2017; Jacobs *et al.* 2022). Moreover, the level of isolation can have an influence on the abundance and diversity of arthropods, because of lower rates of immigration due to the vertical component (building height) and horizontal component (distance of building from open green areas) of green roofs (Blank *et al.* 2017).

The aim of our study was to examine macro-invertebrate abundance and taxon composition of public green spaces located in an urban environment and compare them with adjacent green roofs. Therefore, we studied eight green spaces and eight green roofs in the city of Antwerp, one of the most urbanized and industrialized areas of Belgium. We hypothesize that public green spaces have a higher abundance of invertebrates than green roofs. Furthermore, we assess the similarity of the macro-invertebrate communities between green roofs and adjacent ground level sites by comparing abundance for each individual taxon.

Materials and methods

Study Sites

Our study areas comprised eight public green spaces and eight adjacent green roofs in the city of Antwerp, Belgium. We sampled macro-invertebrates during the months of August and September in the years 2020 and 2021. The selection of the ground level sites was based on two parameters: the ground level sites were all located within a radius of 150 meters from the selected green roof sites and the ground level sites should be as similar as possible to the green roof's vegetation. The ground level sites were predominantly small parks and verges with grass, flower plants, shrubs and a few trees.

To test whether extensive green roofs support the same abundance as adjacent ground level sites, we sampled extensive green roofs with species of *Sedum* as the main vegetation cover (except green roof 'Boek' with a vegetation cover of species of *Sedum*, herbs and grasses). Most green roofs in Belgium belong to this type of green roof. See Table 1 for an overview of all the sampling sites (exact location of the sampling sites is shown in Figure 1).

The average temperature during the sampling period was 17.7°C (± 0.1) and the average precipitation was 92.6 mm. From 5 to 16 August 2020, a heatwave occurred (i.e., the temperature was at least 25 degrees on five consecutive days or more, with at least 30 degrees being reached for three days) (KMI 2021).

Data Collection

To assess ground dwelling macro-invertebrate abundance, we sampled the green roofs and adjacent ground level sites with pitfall traps (diameter = 8 cm, height = 6 cm). We randomly installed two pitfall traps per site. Pitfall trapping is a frequently used method for sampling ground-dwelling invertebrates. It has been successfully used to evaluate invertebrate diversity (Cooper & Whitmore 1990; Oberprieler *et al.* 2019). The pitfall traps were covered with a lid to protect the trap from flooding with rain, and propylene glycol was used to fill the traps to capture the invertebrates (Skvarla *et al.* 2014). Traps were emptied every three weeks, and invertebrates were stored in 70% ethanol. To assess flying invertebrate biodiversity, we sampled every three weeks with four randomly installed pan traps (diameter = 12 cm, height = 4 cm) of different colours (blue, yellow, red and white), the conventional way for assessing flying invertebrates (Shrestha *et al.* 2019). The pan traps were filled with propylene glycol and were emptied after 24 hours; invertebrates were stored in 70% ethanol. The macroinvertebrates were collected through a sieve, permeable to organisms smaller than 2 mm, this means that organisms smaller than 2 mm were not included in this study. For instance, most species of Collembola found on these green roofs have a body size smaller than 2 mm (Jacobs *et al.* 2022). Therefore, we did not include Collembola in the results. All adult specimens were identified to at least order level using a stereo microscope (Leica EZ4). For this preliminary study, we analysed higher level taxa, which have been used to compare green roofs and ground level habitats (Dromgold *et al.* 2020). We refer to Apocrita as wasps, which are distinct from bees (Anthophila) and ants (Formicidae) (see Appendix Table 2A). Nymphs and larvae were excluded because of uncertainty in identification.

Figure 1 – Locations of the different ground habitat sampling sites. **1**. RPDeu (G) (Recycling Park Deurne Ground). **2**. Iglo (G) (Linkeroever Ground). **3**. Beeld (G) (Beeldhouwersstraat Ground). **4**. Boek (G) (Boekenbergpark Ground). **5**. RPBer (G) (Recycling Park Berchem Ground). **6**. Mid (G) (Campus Middelheim Ground). **7**. Park (G) (Nachtegalenpark Ground). **8**. RPWil (G) (Recycling park Wilrijk Ground). All sampling sites are in proximity (max. 150 m) of a green roof sampling site.

TABLE 1

Overview of the sampling sites with the site code name, full name, location, habitat, vegetation cover of the green roof and remarks.

Green site code	**Green site full name**	**Location**	**Habitat**	**Remarks**
RPBer (G)	Recycling Park Berchem ground	Berchem (51.194° N, 4.437° E)	grasses, shrubs, a small creek	In between frequently used train tracks
Boek (G)	Boekenbergpark ground	Berchem (51.198° N, 4.462° E)	maple, birch, sweet chestnut, grassland	Park with a public ecological swimming pond
RPDeu (G)	Recycling Park Deurne ground	Deurne (51.237° N, 4.456° E)	grasses, shrubs	Proximity (< 100 m) to the river Schelde
RPWil (G)	Recycling Park Wilrijk ground	Wilrijk (51.158° N, 4.391° E)	grasses, shrubs, trees (oak)	
Park (G)	Nachetegalen Park	Wilrijk (51.181° N, 4.415° E)	grasslands, sandy plains and old trees	Park older than 150 years
Mid (G)	Campus Middelheim ground	Wilrijk (51.185° N, 4.419° E)	grasses, shrubs	University Campus
Iglo (G)	Linkeroever	Linkeroever (51.225° N, 4.383° E)	grasses, vines	
Beeld (G)	Beeldhouwersstraat	Antwerpen (51.207° N, 4.394° E)	trees, grasses, plants, ferns	City garden
Green roof code	**Green roof full name**	**Location**	**Vegetation cover**	**Remarks**
RPBer	Recycling Park Berchem	Berchem (51.194° N, 4.437° E)	*Sedum*	
Boek	Boekenberg	Berchem (51.198° N, 4.462° E)	*Sedum*/herbs/grasses	
RPDeu	Recycling Park Deurne	Deurne (51.237° N, 4.456° E)	*Sedum*	
RPWil	Recycling Park Wilrijk	Wilrijk (51.158° N, 4.391° E)	*Sedum*	
Park	Middelheim 2	Wilrijk (51.185° N, 4.419° E)	*Sedum*	
Mid	Middelheim 1	Wilrijk (51.183° N, 4.420° E)	*Sedum*	
Iglo	Stedelijke kinderopvang strandloper	Linkeroever (51.224° N, 4.383° E)	*Sedum*	
Beeld	Den Bell	Antwerpen (51.205° N, 4.397° E)	*Sedum*	

Statistical analysis

All samples were combined to compare the overall macro-invertebrate abundance of green roof sites with ground level sites. To determine whether sufficient samples had been taken for both types of habitat, we calculated rarefaction curves (ROCCHINI *et al.* 2009). Assumptions of normality were checked with a Shapiro-Wilk test (SHAPIRO & WILK 1965). The data followed a normal distribution and the difference in overall abundance between green roofs and ground level habitats was checked performing a sample paired t test. Furthermore, differences in abundances between green roof and ground level sites for each individual taxon of macro-invertebrates were analysed with paired sample t tests. All data were analysed using R version 3.6.3 (R CORE TEAM 2020), and the packages: "dplyr" (WICKHAM *et al.* 2022), "matrixStats" (BENGTSONN 2017) and "lme4" (BATES *et al.* 2015).

Results

We collected a total of 10602 specimens during the two sampling years 2020 and 2021 on the green roofs and adjacent ground level sites (see Appendix Table 1A). In total, we identified specimens belonging to thirteen different taxa: Coleoptera (beetles), Arachnida (spiders), Isopoda (isopods), Formicidae (ants), Brachycera (flies), Nematocera (mosquitoes), Anthophila (bees), Apocrita (wasps), Heteroptera (true bugs), Auchenorrhyncha (cicadas), Sternorrhyncha (aphids), Gastropoda (snails), and Myriapoda (myriapods). The rarefaction curves suggest that we have sampled a sufficient number of specimens to investigate taxon composition, as the rarefaction curves both reach a plateau suggesting that we have a good representation of the community of the green roofs and ground level sites (Figure 2).

To test our hypothesis whether public green spaces (mean = 789.5, sd = 275.4) have higher overall abundance than green roofs (mean = 535.7, sd = 173.8), we performed a dependent sample t-test. The null hypothesis was not rejected ($t(14) = 2.061$, $p(0.058)$), meaning there was no significant difference in overall abundance between green roofs and adjacent ground level habitats. In contrast, differences in individual taxa abundances between green roof sites and ground level sites were significant (Table 2).

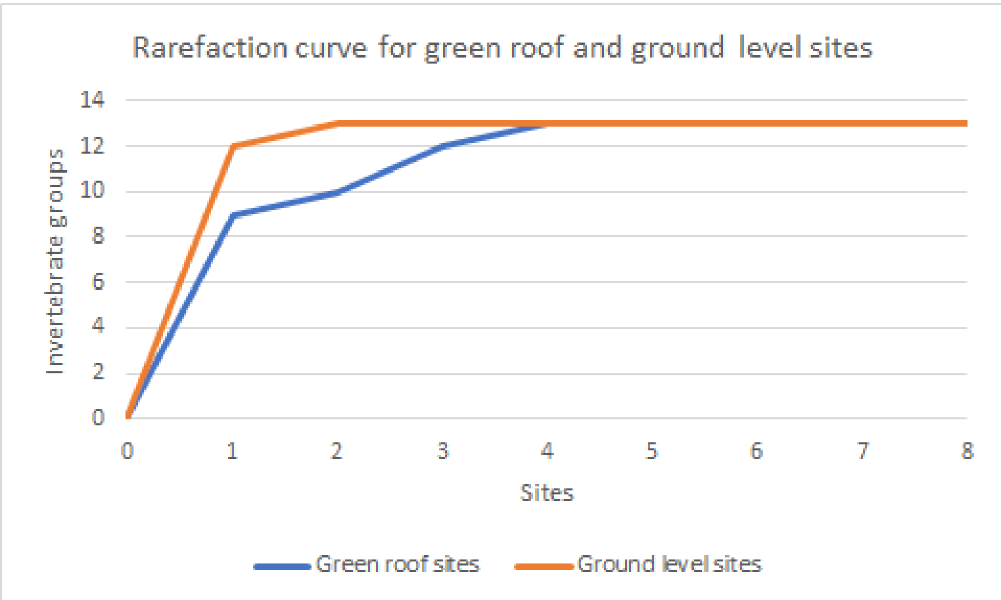

Figure 2 – Rarefaction curves for the two site types (Green roofs and Ground level sites). Total number of individuals are n = 4286 and n = 6316 for green roofs and ground level sites, respectively.

TABLE 2

Results of the paired sample t test comparing abundances between green roofs and ground level sites for individual taxa. Table shows the t value, degrees of freedom (df) and significance of the paired sample t test (sig). * indicates significant p values ≤ 0.05)

Group	t value	df	sig (two-tailed)
Coleoptera (beetles)	4.777	14	0.0002*
Arachnida (spiders)	-0.385	14	0.705
Isopoda (isopods)	2.915	14	0.011*
Formicidae (ants)	1.049	14	0.312
Brachycera (flies)	0.081	14	0.936
Nematocera (mosquitoes)	0.526	14	0.607
Anthophila (bees)	2.507	14	0.025*
Apocrita (wasps)	-0.472	14	0.644
Heteroptera (true bugs)	-3.112	14	0.008*
Auchenorrhyncha (cicadas)	-2.390	14	0.031*
Sternorrhyncha (aphids)	1.478	14	0.161
Gastropoda (snails)	0.274	14	0.788
Myriapoda (myriapods)	-0.902	14	0.382

For Coleoptera, Isopoda and Anthophila abundances were significantly higher on ground level sites compared to green roofs. In contrast, for Heteroptera and Auchenorrhyncha abundances were significantly higher on green roofs compared to ground level sites (Table 2).

Discussion

We investigated macro-invertebrate (Arthropoda and Gastropoda) abundance on eight green roofs and eight adjacent ground level sites in an urban environment. Our results do not support the hypothesis that public green spaces have a higher invertebrate abundance at a higher taxonomic level than green roofs. However, a comparison between individual taxa revealed several significant differences in abundance, between green roofs and ground level sites (Table 2). Beetles, isopods and bees were more abundant at ground level sites compared to green roofs while for true bugs and cicadas, we show the opposite result.

The lower number of beetles on green roofs is not surprising as mostly winged individuals seem to actively colonise green roofs, while other life-stages such as eggs can only be brought in by the planting material during the construction of the roof (Pétremand *et al.* 2018; Kyro *et al.* 2018). Nonetheless, it is possible for common species of beetles to reproduce and maintain populations on green roofs, indicated by the fact that we found different developmental stages of these species, which confirms the results of a study by Kaupp *et al*. (2004). We observed the highest beetle abundance on the only green roof that is covered with vegetation of species of *Sedum*, herbs and grasses ('Boek'). A previous study has shown that abundances of beetles on green roofs are mainly influenced by the local roof characteristics in case green infrastructures are common, whereas in case green infrastructures are scarce the specific location of the roof may be the main determinant (Kyro *et al.* 2018). As roof 'Boek' is located in a park (i.e., where green infrastructures are common), we presume that the roof characteristics (e.g., vegetation cover of *Sedum*, herbs and grasses) explain the higher abundance of beetles compared to other green roofs with a more homogenous vegetation cover of almost exclusively species of *Sedum*. Ideally, an experimental set-up where all factors are controlled and with only the vegetation cover as an explanatory variable should be set-up to test the true drivers behind these higher beetle abundances, but practical difficulties (e.g., need for high number of 'similar' roofs) often hamper such efforts.

The common occurrence of bees on green roofs compared to ground level habitats (Table 2) demonstrates that green roofs can be a suitable habitat for bee species (Colla *et al.* 2009; Tonietto *et al.* 2011), although green roofs have overall lower abundances of this taxon than adjacent ground level habitats. The abundance of bees on green roofs is known to be affected by a number of factors such as floral resources and substrate type (Kratschmer *et al.* 2018). Indeed, also in our study we found the highest abundance of bees on green roofs on the one that has not only *Sedum*, but also herbs and grasses ('Boek'; see Appendix Table 1A). Future studies could design a multi-factorial experimental set-up in which only one roof characteristic would be altered between different roofs, e.g., *Sedum* roofs vs more diverse roofs, to study the effect of vegetation cover of green roofs on bee abundances.

The very low number of isopods on the green roofs (see Appendix Table 1A) compared to ground level sites was to be expected. Limiting factors for colonisation by isopods might be height of the green roof (Jones 2002; Rumble 2013) and the preference of isopods for a more humid environment (Csonka *et al.* 2018). A low number of earthworms (Lumbricidae) was captured in the pitfall traps as by-catch. We only found this taxon on the ground level sites (eight individuals found at four different sites). Earthworms prefer a humid environment, with an optimal soil moisture content of around 30% (Hindell *et al.* 1997; Berry & Jordan 2001), and have limited mobility, i.e., earthworms are unable to move rapidly to places with abundant resources when limiting resources drop below a crucial level (Barot *et al.* 2007). The soil moisture in green roofs is below 20% during extended periods throughout the year (Shafique *et al.* 2018), which in combination with the shallow substrate makes it a very inhospitable habitat for earthworms. The low number of isopods and the absence of earthworms on green roofs suggests that organisms with low (vertical) mobility and with a preference for a humid environment have difficulties in colonising these higher urban habitats.

True bugs and cicadas show higher abundances on green roofs than on ground level sites in our study. MacIvor & Lundholm (2011) also found higher abundances of true bugs on intensive green roofs compared to ground level habitats while overall abundance did not significantly differ between the two types of habitat. They investigated the heteropterans as one large group, whereas we divided them into true bugs (Heteroptera) and cicadas (Auchenorrhyncha). They attributed the higher number of heteropterans on green roofs to a higher number of leafhoppers (Cicadellidae). In our study, leafhoppers are grouped within Auchenorrhyncha, yet still we find a statistically higher number of true bugs on green roofs (Table 2), contradicting the conclusion by MacIvor & Lundholm (2011). True bugs are known to use a wide array of habitats, including green roofs, in a very successful way, although they are one of the less species-rich insect groups of (Schuh & Slater 1995). Their overall success possibly lies in the fact that they have a wide array of feeding types from phytophagous to predatory (Schuh & Slater 1995). Cicadas are known to be long distance migrants that can reach high altitudes and are able to colonise different habitats in a fast way (Reynolds *et al.* 2017). This possibly is true for heteropterans in general, as they are very mobile. Nonetheless, other factors influencing the higher number of true bugs and cicadas on green roofs cannot be excluded (e.g., less predators), and future studies should try and determine the true drivers behind these higher abundances.

Butterflies were often seen on the sampling sites, both on green roofs as well as on ground level habitats, but we failed to catch any specimens in our traps, probably due to biases in the sampling methods. Pan traps are statistically less efficient to capture butterflies than net sampling (Popic *et al.* 2013). The butterflies seem to avoid them in an active behavioural way (Popic *et al.* 2013). If this would be a target group in future studies, other sampling methods, such as swipe netting, should be applied.

The causes of variation in abundance between green roofs are often difficult to identify because the characteristics of green roofs vary tremendously, such as the difference compared to their surrounding environment, the habitat diversity within a single green roof, soil substrate, height, age and many others.

The complex interplay between all these factors makes it difficult to pinpoint the true drivers behind differences in abundance between roofs and ground level habitats. Nonetheless, overall, our results indicate that green roofs can be a habitat for a variety of invertebrates in an urban environment (see also WILLIAMS *et al.* 2014). However, they do not completely compensate for the loss of ground level habitats. The abundances of some individual taxa, such as Coleoptera is higher on ground level habitats. In contrast, for some taxa, such as Heteroptera, green roofs in Belgium seem to provide a more suitable habitat than adjacent ground level habitats, at least as far as abundance is concerned.

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Appendix

TABLE 1A

Overview of the total number of specimen sampled from each site per taxon over the entire study period (Col = Coleoptera; Ara = Arachnida; Iso = Isopoda; For = Formicidae; Bra = Brachycera; Nem = Nematocera; Ant = Anthophila; Apo = Apocrita ; Het = Heteroptera; Auc = Auchenorrhyncha; Ste = Sternorryncha; Gas = Gastropoda and Myr = Myriapoda) (G = ground level site).

Group	Col	Ara	Iso	For	Bra	Nem	Ant	Ste	Het	Auc	Ste	Gas	Myr
Site													
Beeld	3	86	0	306	40	46	0	10	18	15	1	11	2
Boek	27	85	1	84	241	104	7	51	89	85	3	38	11
Iglo	9	9	0	7	31	79	1	17	10	5	0	0	1
Mid	8	52	3	20	104	39	4	29	102	226	8	1	0
Park	6	72	0	151	31	51	1	21	47	78	1	2	0
RPBer	11	27	0	5	83	159	3	81	57	48	0	21	0
RPDeu	8	19	0	3	114	153	1	19	124	115	2	0	0
RPWil	8	59	1	74	144	75	5	114	35	82	4	42	0
Beeld (G)	88	13	700	10	28	13	19	82	0	2	1	34	0
Boek (G)	22	3	9	10	71	133	7	24	2	1	1	23	0
Iglo (G)	60	63	8	119	68	95	1	9	13	18	6	22	0
Mid (G)	117	23	279	148	82	147	4	43	25	41	10	19	0
Park (G)	78	78	346	255	115	53	7	18	3	25	2	19	0
RPBer (G)	37	28	36	94	193	106	4	15	26	48	6	0	2
RPDeu (G)	109	54	274	103	125	53	12	52	28	26	8	10	2
RPWil (G)	44	98	261	420	126	117	15	40	10	12	3	4	0

TABLE 2A

Overview of the taxonomical groups with their respective reference name as used in our paper, and remarks on how we defined each group.

Taxonomical group	Reference name	Remarks
Coleoptera	beetles	considering the suborders Archostemata, Myxophaga, Adephaga and Polyphaga
Arachnida	spiders	concerning Araneae, Opoliones, Scorpiones and other adult animals with eight legs
Isopoda	isopods	all terrestrial isopods often referred to as woodlice (Oniscidae)
Formicidae	ants	all belonging to the family Formicidae
Brachycera	flies	includes the most evolved flies such as houseflies and fruit flies
Nematocera	mosquitoes	consists of four families: mosquitoes (Culicidae), blackflies (Simullidae), biting midges (Ceratopogonidae), and sandflies (Phlebotominae)
Anthophila	bees	considered as a clade (Antophila) with 16000 species of bees
Apocrita	wasps	Apocrita in our paper is referring to the wasps, which are neither a bee nor an ant
Heteroptera	true bugs	suborder Heteroptera, referred to as true bugs in our paper
Auchenorrhyncha	cicades	including cicades, spittlebugs, leafhoppers, and planthoppers
Sternorrhyncha	aphids	including aphids and white flies
Gastropoda	snails	commonly known as snails and slugs, belonging to the phylum Mollusca
Myriapoda	myriapods	centipedes (Chilopoda), millipedes (Diplopoda), pauropods (Pauropoda) and pseudocentipedes (Symphyla)