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Bumblebees and butterflies in green structure elements in Malmö, Sweden

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Abstract

Within the BiodiverCity project in Malmö (Sweden), green structure elements were implemented aiming to support biodiversity and enhancing amenity in denser parts of the city. In this study, bumblebee and butterfly abundances and species richness were studied in 20 green structure elements in three areas in Malmö. The investigated green structure elements consisted of objects established within the BiodiverCity project and other green structure elements in their surroundings (e.g. road verges, lawns and flowerbeds). Observed bumblebee and butterfly abundances and species richness was generally low. In total, 528 bumblebees of eight species were recorded, with 97% of all bumblebees belonging to two species, *Bombus lapidarius* and *B. terrestris/lucorum*. A total of 154 butterflies from 10 species were detected, most commonly *Pieris* species. There were no significant differences in mean individual or species numbers (bumblebees and butterflies) between green structure elements designed to support biodiversity and conventional ones. Bumblebee species richness and abundance were positively correlated with mean cover of flowering vegetation and mean number of flowering plant species. Butterfly species richness and abundance were positively correlated with mean number of flowering plant species and size of the green structure. Observations of flower visits showed that the two groups of insects had different preferences. The results of this study show that enhancing bumblebee and butterfly diversity and abundances in densely built city areas can be challenging. To support bumblebees and butterflies more successfully, the habitat requirements of these insect groups need to be better considered from the beginning in the design of green structure elements.

Keywords Biodiversity · Densification · Ecological design · Flower visits · Insects · Urban green space

Introduction

There is increasing interest in urban ecology and urban biodiversity (Norton et al. 2016). This can be related to factors such as increasing urbanisation (UN 2018) and growing acknowledgement of the concept of ecosystem services, including those in urban areas, which are related to biodiversity (Norton et al. 2016). In addition, the dramatic decline in biodiversity has received broader attention in recent years, for example through a report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2019). Accelerating urbanisation means that urban green space is even more crucial for delivering a large range of urban ecosystem services, which are dependent on biodiversity. This includes the possibility to experience biodiversity in an urban context (Norton et al. 2016; Colléony et al. 2020). With growing awareness of biodiversity decline, urban biodiversity has attracted attention in the field of landscape architecture and planning (Parris et al. 2018). One result of this is the emergence of ecological design (ecological landscape design) (Rottle and Yocom 2011; Ito 2021). Ecological design, in the context of urban (landscape) design, aims to integrate ecological, and biodiversity aspects in the design of for example green space (Kirk et al. 2021), green roofs (Benvenuti 2014), green walls (Thorpert et al. 2022) or species rich lawns (Ignatieva 2018).

The interest in urban biodiversity now extends to species groups such as insects that were previously less considered in an urban context (see e.g. Hunter and Hunter 2008). Several factors may have contributed to this, including awareness of an alarming decline in insect numbers (e.g.

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Hallmann et al. 2017; Goulson 2019; Wagner et al. 2021), recognition of the important key functions insects perform in ecosystems, for example as pollinators (e.g. Noriega et al. 2018) and acknowledgement of the potential of urban areas for insect conservation (e.g. Baldock et al. 2015, New 2015; Hall et al. 2017; New 2018; Baldock et al. 2019). The increased interest in urban biodiversity including insect diversity has led for example to the establishment of urban meadows, which have shown to be beneficial for pollinators and other insects (Hicks et al. 2016; Mody et al. 2020).

Both bumblebee and butterfly abundances and species richness in urban green space are dependent on a range of different factors. Relevant in the context of this study are in particular flower resources, vegetation, patch size and degree of urbanisation. Flower resources are often identified as an important factor influencing bumblebee diversity and/or abundances (Ahrné et al. 2009; Gunnarsson and Federsel 2014; Foster et al. 2017). Hanley et al. (2014) found that bumblebees use both native and non-native garden plants as food resources, but that specialist species more often feed on plants from their own biogeographical range. They also mention the importance of non-garden plants (weeds) as a food resource. Sikora et al. (2020) observed that bumblebees prefer native plants as a food resource. Flower and nectar abundance affects also butterfly abundance and diversity (Soga and Koike 2012; Tsang and Bonebrake 2017; Majewska et al. 2018) and host plant abundance is crucial for butterflies (Koh and Sodhi 2004). Natural, semi-natural or less intensively managed green spaces are reported to be important for both butterflies and bumblebees (Öckinger et al. 2009; Chong et al. 2014; Sing et al. 2016; Aguilera et al. 2019; Dylewski et al. 2019; Zajdel et al. 2019).

The amount of green space is in general important for urban biodiversity (Beninde et al. 2015). Michołap et al. (2017) demonstrated the importance of large green spaces (> 30 ha) for bumblebee diversity in urban areas. Patch size has been found to increase butterfly species richness in some studies (Soga and Koike 2012; Sing et al. 2016).

Urbanisation can have different effects on pollinators depending on species group or study area (e.g. degree of urbanisation, Persson et al. 2020). Some studies have recorded higher species diversity or abundances in more urbanised areas (e.g. Martins et al. 2017) and some report a decline (Bates et al. 2011). In particular, butterflies are often negatively impacted by urbanisation (Ramírez-Restrepo and MacGregor-Fors 2017). The lowest numbers of butterfly species are usually found in urban centres (e.g. Blair and Launer 1997; Matsumoto 2015). Species richness of bees can be highest in areas with an intermediate level of urbanisation (Fortel et al. 2014). Despite negative impacts of urbanisation, many studies have concluded that urban sites have good potential as a habitat for pollinators (e.g. Bates et al. 2011; Fortel et al. 2014; Baldock et al. 2015; Fischer et al. 2016).

The objective of this study was to investigate abundances and species richness of bumblebees and butterflies in green structures established within the BiodiverCity project (BiodiverCity 2017; Malmö city 2017) in comparison to other conventional green structures in the vicinity. The BiodiverCity project in Malmö (Sweden) ran between the years 2012–2018. The projects objective was amongst others to develop and implement green structure that supports and enhances biodiversity and at the same time contributes to the vision of a green, attractive and healthy city (Malmö city 2017). It focused in particular on green solutions in the dense city (BiodiverCity 2017). The project was a collaboration between Malmö city, the Scandinavian green roof institute, researchers, architects and private companies (in housing and building business). This study here was carried out in the final phase of the BiodiverCity project. The aim was to study if the implemented green structures were beneficial for insect groups such as bumblebees and butterflies. Some other green structure elements that were established in order to enhance biodiversity were also included. Green structure elements designed to support biodiversity were compared with other conventional green structure (road verges, flowerbeds, lawns) in the surrounding concerning their bumblebee and butterfly abundances and species richness. Additionally, the aim was to investigate how factors as flower abundance, species richness of flowering plants and size affect bumblebee and butterfly abundances and species richness.

The main hypothesis was that green structure elements that were established to benefit biodiversity had higher abundances and species richness of bumblebees and butterflies than other conventional green structures.

The research questions were the following:

1. Do green structure elements that were designed to support biodiversity have higher abundances and higher species richness of bumblebees and butterflies than other conventional green structures nearby?
2. How do factors such as flowering vegetation and size of the green structure elements affect bumblebee and butterfly abundances and species richness?
3. What are the differences in flower visits between the two species groups?

Questions 2 and 3 were addressed to be able to give recommendations for the design of green structure elements that support bumblebees and butterflies.

Methods

Study area

The study was carried out in Malmö, Sweden's third largest city, which is located on the southern tip of the country. The city currently has a population of around 340,000, an increase of over 100,000 since 1990 (Statistics Sweden 2020). This rapid rate of rise in population, by around 5000 inhabitants per year, has led to increased construction of residential areas in the periphery, on former harbour sites and through densification of inner-city districts. Malmö is known for its large areas of green space, but green space provision has diminished in the city and declined from 154 m^2 per person in 2000 to 111 m^2 per person in 2015 (Statistics Sweden and Malmö city 2017).

In this study, green structure elements were investigated in three districts: Västra hamn (western harbour), Augustenborg and Hyllie (Fig. 1). Västra hamn is a former harbour site that has been converted to a new city district with residential housing, offices and other commercial buildings. Hyllie, located at the outer periphery, has also been built up during the past decade. Both Västra hamn and Hyllie are still under development, and are planned as dense city areas but still providing green space. Augustenborg, a district close to the city centre, was built in the 1940-1950s, although one densification project originates from around 2010. The three districts were chosen because they host green structure elements established within the BiodiverCity project.

Investigated green structure elements

The BiodiverCity green structure elements comprise a small part of a park, a green wall, inner yards and a biodiverse green roof (Table 1). They were established in the time when the project was running. Additionally, some other green structure elements that were in the vicinity and established in order to enhance biodiversity were also included. These were a '*wild corner*' on the roof of a shopping centre and areas sown with wildflower mixtures The other green structure elements investigated for comparison were located in the vicinity of the above objects and represented conventional green structure elements typical for the areas, such as road verges, lawns and flowerbeds. Thus, these were chosen because of their close distance and/or because they were typical for the neighbourhood. A few leftover green spaces,

Fig. 1 Study areas in Malmö, Sweden.
Source: Google Earth

Table 1 Green structure elements investigated in Malmö, Sweden ($n=20$)

District	Type	Biodiver-City object	Other objects designed to support biodiversity	Conventional green space	Left-over green space	Size of investigated transect area [m^2]	Total size of green structure object [m^2]
Västra hamnen	Grassland (unmanaged)				x	800	4050
	Varvs park, lawn			x		650	4075
	Varvs park, flowerbed 1			x		450	450
	Varvs park, flowerbed 2			x		300	300
	Varvs park, woodland	x				550	1250
	Koggen, inner yard	x				250	250
	Ohoj, green wall	x				50	50
	Road verge 1 Lilla varvsgatan			x		350	350
	Road verge 2 Lilla varvsgatan			x		375	375
	Road verge 3 Lilla varvsgatan			x		500	500
Hyllie	Klipporna, inner yard	x				175	175
	Grassland nearby Hyllie station				x	500	1375
	Road verge Hyllie stationsväg			x		700	700
	Edge with sown/planted wildflowers, Hyllie parking		x			250	750
	Emporia* green roof ('*wild corner*')		x			500	2000
	Emporia* green roof ("garden of senses")			x		75	75
Augustenborg	Lawn, residential area			x		400	1050
	Lawn, Augustenborg park			x		950	6300
	Green roof (SGRI)**	x, partly				350	480
	Sown meadow		x			375	500
Sum		5	3	10	2	8550	25,055

*Emporia is Malmö's largest shopping mall and has a well-known green roof, **SGRI = Scandinavian green roof institute

which remained from times prior to the development of the new city districts, were also included. Leftover green spaces in this context are informal green spaces, without or with low management and that have not been converted to a new land-use (infrastructure, buildings or formal green space) under the exploitation process.

Half the objects were conventional green space elements and half were biodiversity elements and left-over green space. The BiodiverCity project also established other objects, but these were too small to investigate with the methodology chosen for the study (transect method). The heterogeneity of the elements investigated is explained by the diversity of objects established within the BiodiverCity project and elements present in the surroundings.

Bumblebee and butterfly recording

Bumblebees and butterflies (including *Zygaena* spp.) were recorded along transects on five occasions during summer 2016 (once in June, twice in July, twice in August). Both species groups were recorded at the same time. The methodology used for butterfly recording was based on Pollard and Yates (1993), with some modifications. Recording was performed between 10.00 and 17.00 h. Minimum temperature during recording was 16 °C, but wind speed was sometime above the recommended threshold. Sufficient recording would not have been possible otherwise, since Malmö's location near the sea results in many windy days. However, insect activity was not visibly impacted. Total standard transect width was 5 m, but half the green structures studied were not 5 m wide. In these cases, the green structure element was surveyed within its actual width, which was measured (tape measure). For the analysis, transect length (calculated in Google Earth Pro) was multiplied by transect width (measured in the field), resulting in transect area (m^2). Values were rounded to the nearest 25 m^2 before further statistical analysis (representing the accuracy in which measurements could be carried out). For some green structure elements, transect area and size of element were the same.

Bumblebees and butterflies were identified in the field. Butterflies were identified to species level, but *Pieris napi* and *P. rapae* were recorded together, since they often could not be distinguished in flight and or caught (but both species were observed during this study). Bumblebees were only recorded and identified when sitting on a flower, with very few exceptions, and *Bombus terrestris* and *B. lucorum* were not recorded separately. There are limitations to identifying bumblebees in the field, and thus species similar to

B. terrestris/lucorum, for example *B. magnus*, would not have been detected (these species would have been unlikely to be observed). In some cases, photos were taken and an expert was asked for help in species identification, but this approach also has limitations.

Flower visits

During transect recording, all flower visits by bumblebees and butterflies were noted, identifying the flowering plant species to species or genus level. The number of observed flower visits for bumblebees was almost identical to the total number of bumblebee observations, since bumblebees were only recorded when sitting on a flower. Butterflies were recorded when sitting or flying (and netted when needed/possible). Thus the number of observations of flower visits was much lower than the total number of butterfly observations.

Environmental factors

The following environmental factors were recorded in each transect area:

- Percentage cover of flowering vegetation (0-100% in 5% increments, but with 1% also used); four occasions (July-August).
- Percentage cover of bushes (0-100%, in 5% increments); one occasion (June).
- Percentage cover of trees (0-100%, in 5% increments); one occasion (June).
- Number of flowering plant species (identified to species or genus level); four occasions (July-August).
- Vegetation height of the herbaceous layer in three height classes (1: <10 cm, 2: 10–50 cm, 3: >50 cm); four occasions (July-August).

These factors were recorded on the same day(s) as the bumblebee and butterfly recordings. For further analysis, mean flowering vegetation cover and mean number of flowering plant species in each transect area were calculated. Vegetation height usually did not change between the four visits, so if one value was recorded at least three times it was applied in the statistical analysis, instead of using an average value. Where different height classes were found on a recording occasion, the highest was chosen.

Table 2 Bumblebee (*Bombus* spp.) abundances and frequencies observed in green structure elements in Malmö, Sweden

Species	Number of individuals	Percentage individuals	Frequency
B. lapidarius	270	51.1%	18
B. terrestris/lucorum	244	46.2%	15
B. hypnorum	7	1.3%	1
B. subterraneus	1	0.2%	1
B. vestalis	3	0.6%	1
B. bohemicus	1	0.2%	1
B. norvegicus	1	0.2%	1
B. rupestris	1	0.2%	1
Total	528	100%	

Analysis

For analysis of species richness and abundances, data from all five recording events were combined, and not analysed separately for each recording event. The total size of green structure elements was calculated in Google Earth Pro (width of certain elements was measured in the field, see above).

Tibco Statistica (Tibco 2018) was used in statistical analyses, which consisted of Spearman rank correlation analysis and multiple regression analysis (stepwise forward). Since the butterfly data were not normally distributed, multiple regression analysis was only performed for the bumblebee data.

Results

Green structure elements

Transect length studied in the 20 green structure elements was 2325 m and transect area covered in total 8550 m^2. Mean transect area investigated was 428 m^2 (min 50 m^2, max 950 m^2, STD 229 m^2). The green structure elements studied ($n=20$) comprised four road verges, three lawns, three green roofs, two grassland areas, two flowerbeds, two inner yards, two sown biotopes, one wooded part of a park and one green wall (Table 1).

Bumblebees

A total of 528 bumblebees from four bumblebee species (*B. terrestris* and *B. lucorum* were not separated) and four cuckoo bumblebee species were observed (Table 2). Two species, the red-tailed bumblebee (*B. lapidarius*) and the buff-tailed/white-tailed bumblebee (*B. terrestris/lucorum*), dominated, representing 51% and 46% of all observed individuals, respectively. These two species were also observed in most of the green structure elements studied. *Bombus lapidarius* occurred in all but the green wall and one inner yard, while *B. terrestris/lucorum* was observed in 75% of all green structure elements. All other species were only observed in a single green structure element, and often only once. Most observations were made in July (78.5%), while in June (9%) and August (12.5%) far fewer bumblebees were observed. However, in June the green structure elements were only investigated once, while in the other two months they were investigated twice. The mean number of bumblebees recorded in a green structure element (all five recording occasions) was 26.4 (min 0, max 148, STD 40.5). The mean number of bumblebee species observed (all five recording occasions) in a green structure element was 1.9 (min 0, max 4, STD 1.0). Two green structure elements contained 52% of all bumblebees recorded (277 individuals), while representing only 10% of the total transect area studied. One of these elements was a flowerbed in Västra hamn with high cover of *Salvia* spp. and *Lavendula* spp. (148 bumblebees, 4 species). The other was a sown meadow in Augustenborg (129 bumblebees, 3 species including *B. subterraneus*).

Butterflies

In total, 154 butterflies from 10 species were observed (*Pieris rapae/napi* were recorded together) (Table 3). The most abundant species were *Pieris rapae/napi* (38% of all individuals), the dayflying moth *Zygaena filipendulae* (six-spot burnet, 25%) and the common blue (*Polyommatus icarus*, 13%). *Zygaena filipendulae* is classified on the Red List in Sweden as near-threatened, but is commonly found in Malmö (Öckinger et al. 2009; Aguilera et al. 2019). An especially striking finding was the complete absence of some of the most common grassland species, for example the small heath butterfly (*Coenonympha pamphilus*). In six of the green structures (lawns, short-cut road verges and inner yards), no butterflies were recorded at all. Around 66% of all observations were made in July, 33% in August and only 1% in June (note that there was only one recording occasion in June, compared with two in the other months). Mean number of butterflies recorded in a green structure element was 7.7 (min 0, max 47, STD 13.5). Mean number of butterfly species per element was 1.9 (min 0, max 5, STD 1.8). Overall, 55% (85 individuals) of the recorded 154 butterflies were observed in two green structure elements.

Table 3 Butterfly abundances and frequencies observed in green structure elements in Malmö, Sweden

Species	Number of individuals	Percentage individuals	Frequency
Pieris rapae/napi	59	38%	12
Zygaena filipendulae	39	25%	3
Polyommatus icarus	20	13%	6
Maniola jurtina	15	10%	4
Inachis io	9	6%	4
Aglais urticae	5	3%	3
Cynthia cardui	5	3%	3
Pieris brassicae	1	1%	1
Lycaena phleas	1	1%	1
	154	100%	

These were an edge of a parking lot sown with a wild flower mixture in Hyllie and a leftover green space with unmanaged grass vegetation adjacent to Varvs park in Västra hamn. Together, these two green structures comprised 12% of the total transect area studied.

Comparison of green structure elements

Comparisons of bumblebee and butterfly abundances and species numbers revealed differences between the two species groups and between green structure elements (Fig. 2). Bumblebee abundances were considerably higher than butterfly abundances in most green structure elements, but not in grasslands (leftover green space) and the designed woodland patch (BiodiverCity object). Species numbers of both bumblebees and butterflies differed most between grasslands (in favour of butterflies) and green roofs and road verges (in favour of bumblebees). Differences between green structure elements were not statistically tested, due to small numbers in each category of the heterogeneous elements studied.

No significant differences in mean individual or species numbers were detected between conventional green structure elements and those designed to support biodiversity (t-test; all $p > 0.05$) (Fig. 3). Conventional green structure elements and those designed to support biodiversity also did not differ significantly in terms of percentage flowering plant cover (t-test; $p > 0.05$), but differed in flowering plant species richness (t-test; $p < 0.05$). The mean number of flowering plant species was on average twice as high in elements with a biodiversity aim (mean 12.3; STD 8.0) than in conventional green structures (mean 6.3; STD 1.6). The area of conventional green structure elements (mean 1418 m^2, STD 2071 m^2) was on average twice that of elements designed to support biodiversity (mean 682 m^2, STD 653 m^2), but this difference was not significant (t-test; $p > 0.05$).

Environmental factors influencing bumblebee and butterfly abundance and species richness

Bumblebee abundance was positively correlated with mean cover of flowering vegetation (Spearman rank correlation coefficient $(R) = 0.742$, $p < 0.001$) and mean number of flowering plant species ($R = 0.472$, $p < 0.05$) (Table 4). The same pattern was found for bumblebee species richness ($R = 0.530$ and $R = 0.486$ for mean cover of flowering vegetation and number of flowering plant species, respectively, both $p < 0.05$). Butterfly abundance and species richness were found to be positively correlated with mean number of flowering plant species (abundance $R = 0.672$, $p < 0.01$; species richness $R = 0.691$, $p < 0.001$) and size of green structure element (abundance $R = 0.497$, $p < 0.05$; species richness $R = 0.475$, $p < 0.05$) (Table 4). Spearman rank

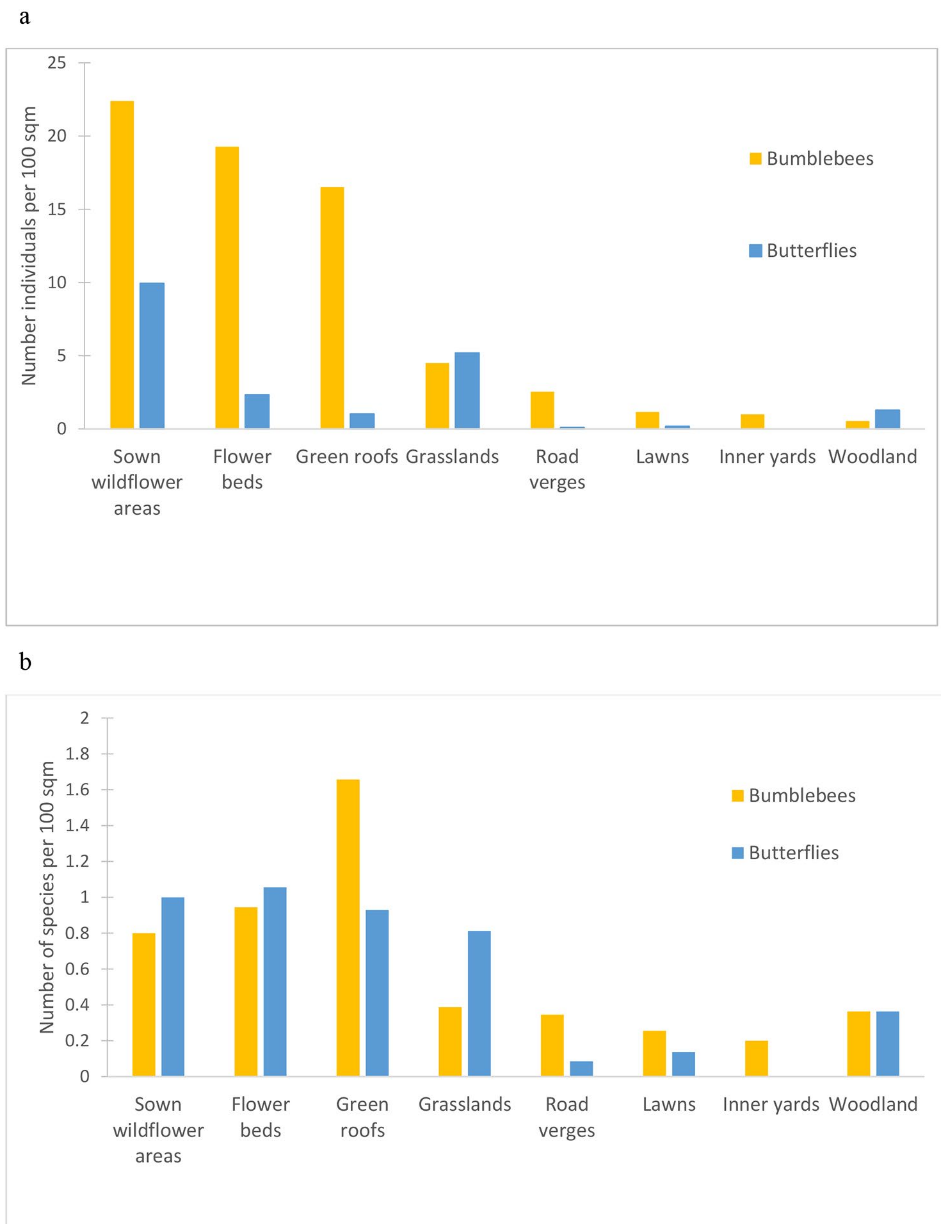

Fig. 2 Comparison of bumblebee and butterfly abundances **(a)** individuals per 100 m^2 investigated transect area and **(b)** species numbers per 100 m^2 transect area, in different green structure elements ($n = 19$) in Malmö, Sweden. Numbers are sum of five recording occasions. Number of green structure elements: Sown wildflower areas $n = 2$, flower beds $n = 2$, green roofs $n = 3$, grasslands $n = 2$, road verges $n = 4$, lawns $n = 3$, inner yards $n = 2$, woodland part of a park $n = 1$. No insects were observed at the green wall (up to 3 m height) so it is not included

correlation analysis also showed that mean cover of flowering vegetation was positively correlated with the mean number of flowering plant species ($R = 0.515$, $p < 0.05$; see Table S1 in Supplementary Material).

The results of multiple regression analysis (stepwise forward) also showed that mean cover of flowering vegetation best explained bumblebee abundances and species numbers (abundance $R^2 = 0.71$, $F = 44.2$, $p < 0.001$; species numbers $R^2 = 0.31$, $F = 7.9$, $p < 0.05$) (Table 5).

Flower visits

Altogether, 520 flower visits of bumblebees were observed and 68 flower visits of butterflies. Figure 4 shows the percentages of flower visits for bumblebees and butterflies, and the most common flowers visited. It can be seen that the two species groups had different preferences regarding flower visits. Bumblebees most often visited *Lavendula* spp., *Lotus corniculatus*, *Centaurea* spp., *Echium vulgare* and *Trifolium* spp. (*T. repens* and *T. pratense*). Visits to these flowering plants accounted for nearly two-thirds of all flower visits by bumblebees. Butterflies were most often observed on

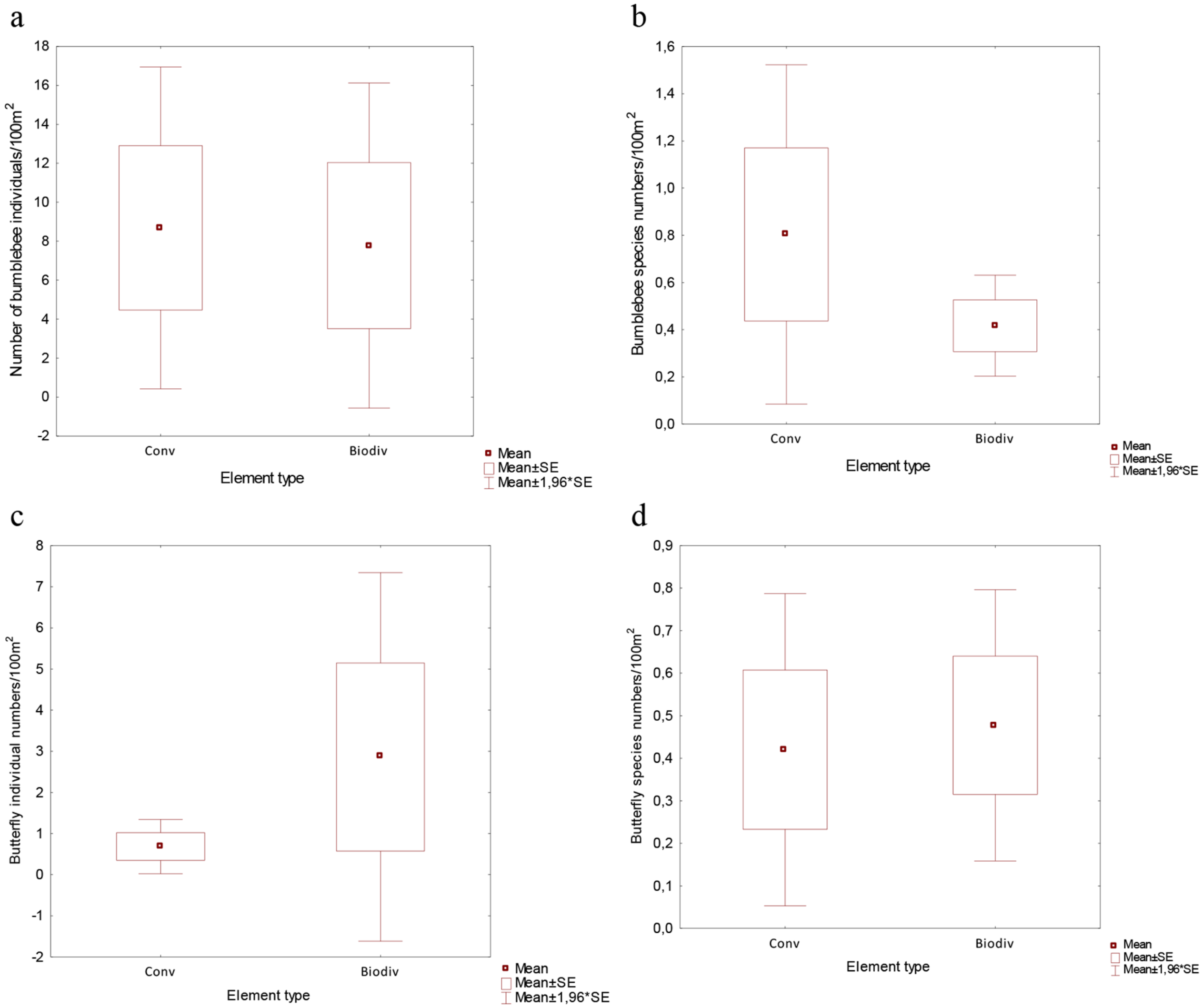

Fig. 3 Mean number of **(a)** bumblebee individuals and **(b)** species numbers; and **(c)** mean number of butterfly individuals and **(d)** species numbers, in green structure elements in Malmö, Sweden (per 100 m^2 transect area). Conv = conventional green structure elements (road verges, lawns, flowerbeds), $n = 10$; Biodiv = green structure elements designed to support biodiversity (BiodiverCity objects, sown objects and green roof –'wild corner'), $n = 8$. Left-over green space was excluded ($n = 2$). None of the differences was significant (t-test; $p > 0.05$)

Table 4 Spearman rank correlation coefficient (R) for environmental variables and bumblebee and butterfly abundances and species numbers in green structure elements ($n = 20$) in Malmö, Sweden. Mean cover flowering vegetation and mean number of flowering plant species from four recording occasions July-August, vegetation height in classes (1–3, see methods)

	Bumblebees abundances	Bumblebee species numbers	Butterfly abundances	Butterfly species numbers
Mean cover of flowering vegetation [%]	0.742***	0.530*	0.332	0.304
Cover of bush vegetation [%]	0.019	0.241	0.272	0.167
Cover of tree vegetation [%]	-0.112	-0.059	-0.279	-0.396
Vegetation height	0.363	0.290	0.440	0.372
Mean number of flowering plant species	0.472*	0.486*	0.672**	0.691***
Transect size [m^2]	0.009	0.212	0.340	0.329
Size of green structure element [m^2]	0.064	0.206	0.497*	0.475*

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5 Results of multiple regression analysis (stepwise forward). Variables included were mean cover of flowering vegetation [%], cover bush vegetation [%], cover tree vegetation [%], vegetation height, mean number of flowering plant species, transect size [m^2], size of green structure element [m^2]

		multiple R	multiple R^2	multiple R^2 change	F to entr/rem	p-value
Bumblebee abundances	Mean cover of flowering vegetation [%]	0.84	0.71	0.71	44.18	0.000003
Bumblebee species numbers	Mean cover of flowering vegetation [%]	0.55	0.31	0.31	7.94	0.0113

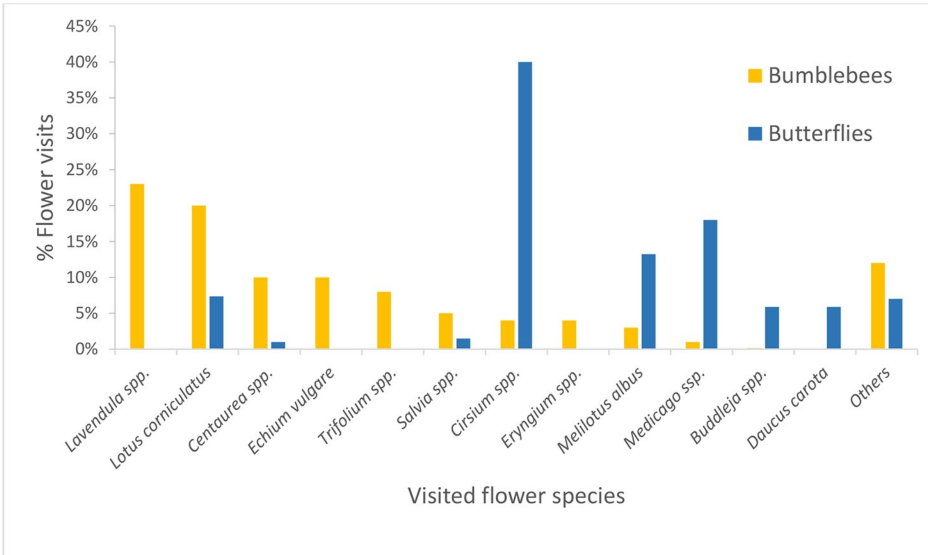

Fig. 4 Flower visits by bumblebees and butterflies in green infrastructure elements in Malmö, Sweden, bumblebees $n=520$, butterflies $n=68$

Cirsium spp., *Medicago* spp. (mostly *Medicago sativa*) and *Melilotus albus*.

Discussion

Green structure elements designed to support biodiversity versus conventional green structure

The hypothesis that green structure elements that were designed to support biodiversity have higher abundances and a higher species richness of bumblebees and butterflies was not confirmed. There are serval reason that can explain this fact. The objects established within the BiodiverCity project had often a more species rich design, but this design was not oriented towards supporting pollinator diversity. The chosen plant material was in some cases (e.g. inner yards) not in particular attractive for pollinators. There was also no specific focus on native species, which are important for the urban fauna (Berthon et al. 2021). It can be concluded that a general approach to create more species rich green structure elements does not necessarily support bumblebees and butterflies, if the design is not directed towards these species groups. Kirk et al. (2021) emphasises the need to consider biodiversity aspects at the start of a project for being successful. This applies also for projects aimed to support pollinators. Besides a lack of consideration or knowledge about habitat requirements of bumblebees and butterflies, other factors influenced this outcome. Butterflies occur in low abundances in many green structure elements, but are more abundant in more semi-natural habitat types (grasslands, sown wildflower meadows or verges; more below). Still, certain conventional green infrastructure types can be very attractive for bumblebees as flowerbeds with flowering plants attractive for this species group (for example lavender). Thus, there were both attractive (e.g. flowerbeds) and unattractive (e.g. road verges, lawns) conventional green structure elements and attractive (e.g. sown wildflower areas) and unattractive (e.g. inner yards) green structure elements designed for biodiversity. These outweighed each other to a certain degree. Finally, the number of green structure elements designed for biodiversity was limited and heterogeneous, which influenced the results of this study.

Species richness and abundances

The species numbers recorded for bumblebees and butterflies in this study were low. The species observed represented a sub-set of mostly very common species or species found in an urban context in other comparable studies in Sweden (e.g. Ahrné et al. 2009; Öckinger et al. 2009; Gunnarsson and Federsel 2014, Johansson et al. 2018; Aguilera et al. 2019; Persson et al. 2020). Regarding bumblebees, it was striking in particular that otherwise comparatively common species, such as *B. hortorum*, *B. pasquorum* and *B. pratorum*, were not found. One reason for this low bumblebee species richness was the type of green structure investigated in this study, where the focus was on a variety of typical green structure elements in city areas with a higher density of buildings and population. This excluded certain habitats not present in the target areas, such as larger parks, many urban semi-natural habitat types known to be species-rich (such as ruderal areas) and certain types of gardens (allotment gardens, private gardens of detached houses). Most other studies in Sweden investigating bumblebees, or more broadly pollinators, in urban areas have either included gardens/allotment gardens (Gunnarsson and Federsel 2014) or focused in particular on these (Ahrné et al. 2009; Persson et al. 2020). Gardens have been shown to support higher species numbers of bumblebees than green structure elements other than flowerbeds (Gunnarsson and Federsel 2014). However, Persson et al. (2020), who studied 14 rural and 39 urban gardens in and around Malmö (Sweden), did not observe B. *pasquorum* in any of the urban gardens, and observed *B. pratorum* in only one and *B. hortorum* in only three of the 39 urban gardens. In general, bumblebee diversity in that study was lower in urban gardens than in rural gardens (Persson et al. 2020).

Another reason for the low bumblebee species numbers observed in the present study was the comparatively high degree of urbanisation in the study areas. Areas with a high degree of urbanisation have been shown to support fewer bumblebee species (e.g. Bates et al. 2011; Persson et al. 2020). Comparisons with studies carried out in rural areas in the Malmö region (Scania) indicated that the species pool of the region as regards bumblebees is much larger. Söderman et al. (2016) observed 17 different bumblebee species and Carrié et al. (2018) 21 different species. The bumblebees species found in the present study thus represent around one-third of the regional species pool in Scania (Carrié et al. 2018).

Despite the rather low bumblebee diversity observed, a species not expected in urban settings was recorded. The presence of *B. subterraneous* indicates that even bumblebee species which are less common in an urban context can be attracted when offering suitable habitats. In this case, the species was found in a sown and flower-rich urban meadow.

While bumblebee species numbers were low, abundances in certain habitats were high. Abundance of nectar resources was the most important factor affecting individual numbers of bumblebees, followed by the diversity of flowering plant species available. This confirms previous findings in similar studies (e.g. Ahrné et al. 2009; Gunnarsson and Federsel 2014; Foster et al. 2017). That means that flowerbeds with few, but attractive nectar sources, such as lavender and sage, and sown habitats rich in several flowering species can both attract a number of bumblebees, even in very urban areas. This was also seen for the biodiverse green roofs included in this study, which offered abundant nectar sources at least during parts of the season. Even road verges in inner-city parts were used for foraging by bumblebees, when the sward height allowed clover species to flower.

Butterfly species numbers observed in this study were very low. Ten species were found (*Pieris napi* and P. *rapae* were both present, but could not always be separated in the field and were therefore considered together). The species observed represented a sub-set of the most common species found by Öckinger et al. (2009) and Aguilera et al. (2019), who investigated parks, ruderal sites and other green spaces in Malmö. The most notable finding was the absence of common grassland species such as *Coenonympha pamphilus*. While bumblebees were attracted by a high cover of flowering vegetation, even if this was provided by few plants species, this was not the case for butterflies in this study. Butterfly species numbers and abundances were positively affected by flowering species diversity, as previous studies have shown (e.g. Nagase et al. 2019) and by the size of the green structure element (Soga and Koike 2012; Sing et al. 2016). The size effect was not identified for bumblebees. This means that is more difficult to attract butterflies to small areas, even if attractive nectar resources are provided by a limited number of plant species. The low species richness for butterflies in the urban areas studied was expected (see e.g. Blair and Launer 1997; Matsumoto 2015; Ramírez-Restrepo and MacGregor-Fors 2017), but an unexpected finding was that even very common species were absent. The reason for the extreme low diversity of butterflies, as for bumblebees, was the high degree of urbanisation, which resulted in a limited number of urban habitat types in urban green structures of comparable small size. The high intensity of management of certain habitats studied, for example most road verges, further reduced the availability of crucial resources. High management intensity has been shown to reduce butterfly diversity in urban areas (Aguilera et al. 2019). Two other factors probably also affected butterfly species numbers negatively. One was the almost total lack of areas with high grass vegetation, which is important for several common grassland butterflies. The other was lack or low availability of larval host plants or larval habitat. One butterfly species found, *Zygaena filipendulae*, is classified as nearly threatened in Sweden (SLU 2020), although the species is commonly found in Malmö (Öckinger et al. 2009; Aguilera et al. 2019). The butterfly species found in this study represented about one fifth (Hammarstedt 1996) to on eighth (County Administration Board in Scania 2015) of the regional (Scania) species pool.

Abundance of butterflies was considerably lower (by around 33%) than that of bumblebees. This is not always the case, since Haaland and Gyllin (2010) found more butterflies than bumblebees in peri-urban and rural green structures using the same survey methodology for both species groups in the same areas. Thus, abundances of these two groups in relation to each other are context-dependent. Bumblebees appeared to be more often able to use resources in parts of the city where butterflies were mostly absent, for example intensively managed road verges, lawns and inner yards, but butterflies also used green roofs and flowerbeds to a lower degree.

Flower visits

Planted flowers and shrubs and wild flowers (self-seeded, sown or planted, e.g. on green roofs) were used as a food resource by both butterflies and bumblebees, but to differing degrees. Bumblebees visited planted herbs such as lavender, sage and sea holly more often than butterflies. A notable observation was high use of thistles by butterflies. Previous studies have shown use of both non-native and native plants by butterflies and bumblebees (e.g. Garbuzow and Ratnieks 2013; Rollings and Goulson 2019). Some have even found higher use or higher abundances of butterflies in relation to exotic plants (Shapiro 2002; Bergerot et al. 2010; Majewska et al. 2018). The latter was not confirmed in the present study.

Implications for measures to support bumblebee and butterfly fauna in green structure elements in dense urban areas

The results obtained in this study show that the scope to support rich bumblebee and butterfly fauna in inner city areas may be limited, even when providing habitats with higher plant diversity than usual. The vision of a dense green city, which offers high liveability and at the same time supports biodiversity and related ecosystem services may be an ideal formulated in the context of densification, but might be difficult to achieve regarding biodiversity. Dense city areas are often characterised by a lack of habitats that can potentially support biodiversity, such as grasslands, ruderal areas, large parks, private gardens and allotment gardens (see e.g. Tappert et al. 2018). This was also the case in the areas investigated here. Potential for green space is particularly limited in compact city areas, but '*biodiversity in cities needs space*' according to Beninde et al. (2015). Urban green spaces, especially less formal spaces, are subject to constant changes in size and/or management, which can reduce insect diversity (see e.g. New 2018). In this context, it should be mentioned that the sown wildflower patch where *B. subterraneous* was observed has since been partly converted to a bicycle parking area. The left-over grassland in Västra hamn, one of the sites with most butterfly species, will soon be incorporated into an adjacent park, with a more formal design and partly planted with trees (though high grassland vegetation will be kept in some parts).

While common bumblebee species were seen to be attracted by favourable habitat patches, sometimes even in large numbers, in the very urbanised areas studied, these were more difficult for butterflies to access. Thus, there seems to be a limit to how far quantity of green space can be replaced by quality with regard to biodiversity. Green space in very urbanised areas also tends to receive more intensive management, which has been shown to reduce biodiversity (e.g. Aguilera et al. 2019). Providing attractive green space for urban residents and biodiversity is challenging (Aronson et al. 2017), especially in highly urbanised areas where green space is scarce. Finally, the focus on adult nectar resources when enhancement of insect habitats is considered in an urban context might lead to too little attention being paid to other resources needed to complete the insect life cycle, as host plants or overwintering habitats.

This does not mean conditions for bumblebees and butterflies cannot be improved in densely built-up areas. Even if the number of species that can survive in these areas is limited, the aim should be to create conditions so that these species can survive in the city. Measures known to be beneficial, such as providing flowerbeds with attractive nectar sources for these insect groups, should continue to be offered or enhanced. Sowing wildflowers has been shown to increase insect numbers in urban settings (e.g. Blackmore and Goulson 2014; Mody et al. 2020) and this measure could be applied to a much greater extent. Green roofs can be a habitat for particular life cycle stages of certain insect species (Benvenuti 2014), especially for generalists (Williams et al. 2014; Hofmann and Renner 2018). Since arthropod diversity on green roofs has been shown to increase with higher connectivity (Braaker et al. 2017), biodiversity can probably be enhanced by a greater number of green roofs designed for this purpose. A reduction in management intensity for some existing green space elements (e.g. road verges, lawns) would benefit biodiversity (Aguilera et al. 2019). Left-over green space or informal urban green space (Rupprecht et al. 2015) is scarce in dense city areas, but could support higher biodiversity when present (Rupprecht et al. 2015). Finally, to enhance insect diversity in urban areas, it is important to base green structure design partly on expert knowledge in the field of urban insect ecology. Some approaches may fail to fulfil their potential because of lack of knowledge (e.g. regarding choice of plant material, lack of consideration of host plants or generally other life-cycle stages). Thus, better collaboration between landscape architects and ecologists might enable greater success in supporting and enhancing insect diversity in cities.

Conclusions

The results of this study could not show that green structure elements designed for supporting biodiversity had higher abundances or species richness of bumblebees and butterflies than the conventional green structures investigated. One reason for this is that the design of these green structure elements was not oriented towards supporting pollinator biodiversity from the beginning. Observed bumblebee and butterfly abundance and diversity was rather poor in the green structure elements studied, including green spaces designed to increase biodiversity. This suggests that the scope to support richer insect fauna in densely built-up urban areas might be limited, even when efforts are made to improve the quality of green space, if green areas are scarce. Wildflowers were seen to be an important nectar resource, especially for butterflies. This underlines the need for semi-natural habitats or at least similar elements to sown wildflower areas. Efforts to enhance insect diversity even in dense city areas are recommended, even if efforts here to date have not achieved the expected success. A crucial increase in green space areas with less intensive management and conversion of conventional green space such as short-cut road verges into wildflower areas might lead to an increase in insect diversity. Consultation with experts in the field of urban insect ecology could optimise the positive effects regarding biodiversity in urban green space.

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