Influences of landscape structure on butterfly diversity in urban private gardens using a citizen science approach

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Abstract

Although urbanization is increasing worldwide, private gardens may help mitigate the impact of urbanization on butterfly diversity. We investigated how local and landscape factors correspond with the observed butterfly species diversity and species composition in Viennese private gardens. The goal is to determine the importance of private gardens for butterfly conservation. Butterfly species were observed by skilled volunteers by applying a citizen science approach. We related butterfly species numbers in private gardens with local parameters and landscape composition in a radius of 1 km around each garden. Data were analyzed using a regression approach based on generalized linear models. The butterfly species richness in private gardens was positively correlated with butterfly species richness in the surrounding landscapes. Butterfly species richness in private gardens increased with higher proportions of area relevant for butterflies in the surrounding landscape and with increasing numbers of host and nectar plant species in the private gardens. A higher proportion of wooded areas in the surrounding landscape was related with a smaller proportion of the landscape butterfly species pool being observed in the private gardens. Overall, our results could be useful in land use planning, and for future studies of how to integrate citizen science and make urban gardens more beneficial for butterfly conservation.

Keywords Butterflies · Citizen science · Private gardens · Lepidoptera · Urban biodiversity · Landscape

Introduction

Urbanization is expanding worldwide (Carlucci et al. 2020), resulting in habitat modifications (Liu et al. 2016) which often alter the composition and distribution of species (Freitas et al. 2020), including insects (Corcos et al. 2019). Specifically, native invertebrate diversity mostly decreases with increasing urbanization, especially in central urban

core areas (Matteson and Langellotto 2010; Kuussaari et al. 2021). Furthermore, urbanization is a significant factor in both current and predicted species declines (Lee et al. 2015) and has been estimated to reduce butterfly diversity by 85% (Piano et al. 2020). Nonetheless, urban areas still accommodate species in semi-natural habitat remnants as well as in human-made habitats like private gardens. In recent years, ecologists have shown growing interest in the role and significance of private gardens for urban biodiversity (O’Connell et al. 2021).

Recent research has put urban biodiversity into the conservation focus, either by examining multi-city analyses at larger scales (Baldock et al. 2019; Cubino et al. 2020) or by focusing on patches within the urban landscape (Jain et al. 2020). The latter include semi-natural grassland (Öckinger et al. 2009), high-value urban green areas (Dylewski et al. 2019), green roofs (MacIvor and Lundholm 2011), community gardens (Matteson and Langellotto 2010), private gardens (Fontaine et al. 2016), and fallows or brownfields (Woodward et al. 2003). Most of the biodiversity monitoring studies have been undertaken at several scales of investigation, i.e. from a single garden to different land-uses and

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management practices, to predict the biodiversity response to urbanization (Lerman et al. 2018; Cubino et al. 2020). However, such biodiversity research, including studies on insects, has so far been conducted without conservation-based citizen science approaches.

Citizen science approaches are flourishing around the world, particularly as a means of biodiversity assessment at a large scale (Pocock et al. 2017). Much of the recent upsurge in citizen science has involved mass-participation projects, which seek to engage people with little or no previous experience in biodiversity monitoring (Loos et al. 2015). Such monitoring programs have the potential to play an even larger role in conservation by educating and encouraging participants to engage in conservation activities (Lewandowski and Oberhauser 2016). As urbanization increases (Pickett et al. 2011), there is growing recognition of the benefits of monitoring and conserving insect biodiversity in and around cities (Sanderson and Huron 2011). In light of butterfly biodiversity decline (Warren et al. 2021), citizen science will be an important approach to monitor butterfly biodiversity in urban landscapes (Baker and Potter 2019).

Butterflies are among the most charismatic and popular insect groups, and many people associate positive feelings with them because of their spectacular, colorful wings and their image as indicators for natural habitats (Kühn et al. 2008; Han et al. 2021), however they are declining dramatically (Hallmann et al. 2017; Warren et al. 2021). The major cause of this decline is loss of appropriate habitats due to land-use changes such as agricultural intensification and urbanization. Nevertheless, urban landscapes can harbor diverse populations of butterflies, not just rare and endangered species (Strausz et al. 2012). Studies recommend considering landscape configuration for butterfly conservation and management because butterfly communities are composed of species with different habitat requirements (Liivamägi et al. 2014) and the quality of the environment (Lizée et al. 2011). In urban landscapes, high-quality grasslands (Dylewski et al. 2019) and flowering nectar plants (Han et al. 2021) can support rich and abundant butterfly populations.

The urban landscape is interspersed with fragmented and heavily managed gardens, woody areas, grassland, parks, greenways and other green spaces, which facilitate movement of butterflies and increase local species richness (Matteson and Langelotto 2010). Some publications encourage the public to make private gardens more butterfly-friendly by increasing the number of flowering nectar plants and host plants (e.g. Goddard et al. 2013; Fontaine et al. 2016). Restricted access to private gardens and the difficulty of biodiversity data collection in urban habitats probably accounts for the paucity of research on this topic but several studies have revealed that private garden characteristics are an important determinant

for butterfly diversity (Vickery 2007; Majewska et al. 2018), whereas others have concluded that the surrounding landscape plays the key role (Steffan-Dewenter and Tscharntke 2000; Dover and Settele 2009). Of the surrounding landscape types, semi-natural grassland and woodland are influential for butterfly dispersal (Bergerot et al. 2012; Bergman et al. 2018). Furthermore, understanding butterfly and plant distribution is a pre-requisite for developing conservation strategies, particularly for urban ecosystems (Mukherjee et al. 2018). Therefore, we tested whether species richness and relative species richness in private gardens in Vienna were correlated with parameters of landscape composition (proportion of woody areas, grassland, and gardens, respectively), with species richness in the landscape species pool, and/or with private garden characteristics (diversity of nectar and host plant species, respectively).

Materials and methods

Study sites

Vienna is situated in the northeast of Austria at the Danube River, between the foothills of the Alps and the Carpathians at altitudes between 151 and 543 m above sea level. To the west and to the north, the city is surrounded by an extensively managed cultivated landscape (Vienna Woods/Wienerwald) with many semi-natural, herb-rich meadows and deciduous forests. The landscape east and south of the city is characterized by intensive agriculture. To the southeast lies the Viennese part of the Donau-Auen National Park with a mosaic of alluvial forests, wet and dry grasslands. The climate is humid continental with an average temperature (30-year average) of 11.4 °C in the city center and 10.2 °C in suburban areas; mean annual precipitation ranges from more than 700 mm in the west to less than 550 mm in the east and southeast (Central Institute for Meteorology and Geodynamics 2016). Green areas (parks, agricultural areas, forests, gardens) make up around half of Vienna's surface area. The proportion of green areas within the individual municipal districts varies from two to 15 percent in the inner-city regions up to 70 percent in the Vienna outskirts (Municipal Department 22—Environmental Protection). We included 21 private gardens, distributed across Vienna, in our study design (Fig. 1). We built a network of volunteers with the help of targeted media (newspaper reports, TV and radio), talks and information booths at various (garden) events. The focus was on attracting many participants for the butterfly count and keeping the barrier to participation as low as possible. Subsequently, a central communication point comprising participants and experts was established for the monitoring and to train participants before butterfly observation.

Fig. 1 Map of the locations (black circles) of 21 urban private gardens in Vienna, Austria. The map was created in ArcGIS (source: Bivand et al. 2019; Land use of Vienna: Realnutzungskartierung 2018)

Butterfly observation and data collection

We used data collected by trained volunteers in 21 private gardens in the “Vienna butterfly census”, a Citizen Science project which took place in 2005. We formulated criteria for private garden selection to ensure data quality: participation in the project for at least one year, species knowledge estimated by the proportion of unidentified species in participants’ recorded species lists, plausibility of recorded species, and personal impression during visits to participants’ private gardens. The average size of the private gardens was approx. 380 m², and the average private garden area examined by the participants was 124 m². On average, 25 species of flowering plants were recorded in the private gardens. All private gardens were managed by participants themselves. The private gardens selected for observation were mainly in the western

districts of Vienna, with nearby forests, meadows and vineyards along the eastern edge of the Alps. To guarantee data quality, regular communication and training was maintained with participants, and support in the form of identification sheets with species descriptions was provided. These regular communication and training improved participants skills and data reliability to identify butterflies. All gardeners were trained to count specimens using the line-transect method by Pollard and Yates (1993). However, gardeners who were classified as not capable in butterfly identification have been excluded for further analysis. Transect length was limited by recording time – five minutes per 90 m transect walk – and each butterfly within 5 m on either side and in front of the recorder was noted. Transect walks were restricted to sunny periods between 10 a.m. and 3 p.m. and were conducted nine times, randomly, from June to August. Species

counts of all nine transect walks were pooled for analyses. The “Whites” (e.g., *Pieris rapae*, *P. brassicae*, *P. napi* and *Leptidea sinapis/juvernica*) were not included in the analyses because of uncertainties in species identification. We combined the Small Heath (*Coenonympha pamphilus*) and Chestnut Heath (*C. glycerion*) under *Coenonympha* spp., because the typical wing spots become unclear at the end of their lifespan, making them more difficult to distinguish. They use similar host plants, and their habitats can overlap, but *C. pamphilus* is more widespread in Vienna (Höttinger et al. 2013). For the data evaluation, quality and plausibility checks, participants were told to provide photo evidence. Finally, Manfred Pendl as a butterfly expert verified the collected butterfly data.

As response variables, we calculated species richness and relative species richness for each private garden. The latter is the number of butterfly species in a private garden divided by the number of butterfly species in the surrounding landscape (i.e., the landscape species pool). Data for the landscape species pool were obtained from a database comprising all distributional data for butterflies in grid cells of 1250 m × 1000 m (Höttinger et al. 2006). The landscape species pool of each private garden was calculated as the total number of butterfly species in the grid cell containing the private garden and the eight adjacent grid cells. The species data in the database (Höttinger et al. 2006) were collected using the transect method at approximately the same time as the private garden observation. Species lists from these grid cells were compared with the species list from the respective private garden for plausibility. All species recorded in the private gardens also occurred in the respective landscape species pools.

Garden and landscape variables

The number of butterfly nectar plant species and number of host plant species per private garden (Settele et al. 2000) were used to describe private garden quality for butterflies (Table 1). Each plant species was recorded along the transect

walk by an expert at the same time when participants started butterfly observation. The minimum level of plant identification was genus, but most were determined to species level. Only nectar plants flowering during the survey period were considered. To calculate the landscape variables, the 43 land cover categories contained in a land cover map provided by the city of Vienna (City of Vienna 2016) were reclassified to wooded areas (WOOD: included areas with the categories forest and other tree dominated areas, incl. parks if appropriate), grassland dominated areas (GRASS: included the categories grassland/meadows and fallows), gardens (GARDEN: included the category garden with house gardens, allotments and suburban residential zone), nectar plants (NECTAR: plants with flower and nectar), host plant species (HOST: plants required for butterfly growth and larval development), and area relevant for butterflies as sum of Wood and Grass (ARB) (Table 1, A-1); land cover categories that were considered not relevant for butterflies were excluded (e.g., traffic areas or densely built-up urban residential and commercial zones). Subsequently, we calculated the proportions of these landscape categories within a radius of 1 km around each private garden.

Statistical analyses

We first analyzed differences in total butterfly species richness and abundance between private gardens and the surrounding landscape using ANOVA. Here, total species richness was calculated as the aggregated number of butterfly species observed per site. To examine the relative strength of confounding effects between private gardens and landscape variables, we used generalized linear models (*glm*) to analyze which variables contributed to explaining the observed butterfly species richness and relative species richness. Generalized linear models were calculated using the '*glm*'-function from the package 'rms' in R (www.r-project.org). We used the Poisson link function for species richness models, and the Gaussian link function for relative species richness models. Model selection and inference were based on

Table 1 List of explanatory variables including abbreviation, mean and range. Wooded areas ('WOOD'; included areas with the category forest and tree dominated areas), grasslands ('GRASS'; included the category grassland/meadows and fallows), gardens ('GARDEN';

included the category garden with house gardens, allotments and suburban residential zone), area relevant for butterflies ('ARB'; sum of the three other landscape variables)

Explanatory Variable	Abbreviation	Mean	Range
Proportion wooded areas at radius 1000 m (%)	WOOD	10.6	0.5–47.2
Proportion gardens at radius 1000 m (%)	GARDEN	26.5	7.9–40.7
Proportion grassland at radius 1000 m (%)	GRASS	6.7	0.2–20.1
Proportion area relevant for butterflies (%)	ARB	43.8	25.1–83.3
Species richness landscape species pool	POOL	31.1	11–80
Number of nectar plant species	NECTAR	21.6	6–46
Number of host plant species	HOST	4.7	1–15

Akaike's Information Criterion (AIC) and Akaike weights (w_i). We used the AIC in its corrected form AICc because sample size was small (21 private gardens) relative to the number of variables. The presence of overdispersion was checked for by adding observation level as a random factor in the model (Harrison 2014; Hussain et al. 2021). We verified model assumptions (i.e. normality of model residuals and variance homogeneity) by visually inspecting residual plots. Pearson rank correlation was computed to assess the relationship between different landscape variables and species richness and abundance. To determine the abundance-based species richness estimates in each of the 21 sampled private gardens, we used the *iNEXT* package in R that uses counts (numbers of individuals) of species at a single site.

Results

In total, 624 butterfly individuals comprising 12 species were recorded (Table 2). The most frequently observed species were *Maniola jurtina* (16 private gardens), *Vanessa atalanta* (14 private gardens) and *Iphiclides podalirius* (13 private gardens); no species was observed in all private gardens. Butterfly species richness ranged from 4 to 10 species per private garden. The landscape species pool comprised between 11 and 80 species. Relative species richness ranged from 11.3% to 53.8%.

The number of observed butterfly species in private gardens increased with higher proportions of area relevant for butterflies in the surrounding landscape ($F_{1,19} = 8.78$, $p = 0.007$; Fig. 2A), and with increasing numbers of host

plant ($F_{1,19} = 2.46$, $p < 0.05$; Fig. 2B) and nectar plant species in the private gardens ($F_{1,19} = 1.74$, $p < 0.05$; Fig. 2C). The relation with proportion of wooded habitats was negative, i.e., the higher the proportion of wooded areas in the surrounding landscape, the smaller the proportion of the landscape species pool that was observed in the private gardens ($F_{1,19} = 2.40$, $p < 0.05$; Fig. 2D). In contrast, the relation with the number of nectar plant species in the surrounding landscape was positive ($F_{1,19} = 0.32$, $p < 0.05$; Fig. 2E). Species richness in the private gardens was positively correlated with species richness in the surrounding landscapes ($r = 0.50$, $p = 0.01$, Fig. 3). We did not find any significant effect of landscape variables on butterfly abundance in the private gardens. *Maniola jurtina* was more frequently recorded where the landscape species pool was more diverse and the proportion of woody habitats in the surrounding landscape was lower. *Aglaia urticae* was positively correlated with several explanatory variables (Table 1; GRASS, GARDEN, NECTAR, HOST) but also negatively correlated with WOOD. In contrast, two other species, *Issoria lathonia* and *Neptis rivularis*, were positively related to the proportion of woody habitats in the surrounding landscape.

Discussion

Several studies have identified nectar plants as a determining factor for enhanced attractiveness of gardens for butterflies (Schneider et al. 2003; Straka 2004; Fontaine et al. 2016). Different nectar resources are attractive for adult butterfly individuals (e.g., *Phengaris* spp.), and promote their

Table 2 Butterfly species list from the three-month recording period in 2005 in Viennese gardens. Whites were excluded because of uncertainty in identification. The Heaths are pooled to *Coenonympha* spp. Raster frequency in Vienna (Höttinger et al. 2013); Mobility/dispersion ability: 1 (extremely low mobility) to 9 (migrant butterfly); Host

plant specialization (Settele et al. 2000 with own additions); Red list status: VU – vulnerable, LC – least concern, "–" not threatened in Vienna (Höttinger et al. 2013). VCR – Vienna Conservation Regulation 2000 (Wiener Naturschutzverordnung 2000)

Scientific name	Abbreviation	Frequency in gardens (%)	Raster frequency in Vienna (%)	Mobility/dispersion ability	Host plant specialization	Red list status	VCR
<i>Maniola jurtina</i>	MANJUR	76.2	59.4	4–6	polyphagous	–	
<i>Vanessa atalanta</i>	VANATA	66.7	46.9	9	monophagous	–	
<i>Iphiclides podalirius</i>	IPHPD	61.9	47.4	4–6	monophagous	VU	priority protected
<i>Inachis io</i>	INAIO	57.1	55.9	6	polyphagous	–	
<i>Gonepteryx rhamni</i>	GONRHA	47.6	40.1	6	oligophagous	–	
<i>Argynnis paphia</i>	ARGPAP	47.6	43.1	4	monophagous	–	
<i>Melanargia galathea</i>	MELGAL	42.9	47.9	3	oligophagous	–	
<i>Aglaia urticae</i>	AGLURT	38.1	35.3	6	monophagous	–	
<i>Neptis rivularis</i>	NEPRIV	33.3	22.7	3	oligophagous	LC	priority protected
<i>Issoria lathonia</i>	ISSLAT	23.8	30.5	5	monophagous	–	
<i>Polyommatus icarus</i>	POLICA	23.8	62.0	4	oligophagous	–	
<i>Coenonympha</i> spp.	COESPP	19.0	17.9	3	polyphagous	–

Fig. 2 Linear regression showing the relationship between the number of butterfly species and (A) Proportion area relevant for butterflies in the garden (%), (B) the number of host plant species in the garden,

(C) number of nectar plant species in the garden; (D) relative species richness compared to woodland and (E) number of host plant species in the garden

populations. Butterflies spend a substantial part of their time feeding and searching for nectar sources (Dennis et al. 2006; Thomas et al. 2011). Thus, a private garden designated for butterfly promotion should host a high diversity of nectar plant species (Curtis et al. 2015). In fact, in urban landscapes, where even the natural or semi-natural habitats have poor nectar resources (Hicks et al. 2016), private gardens represent the main patches of suitable habitat for flower-dependent arthropods, especially pollinators like butterflies (Muratet and Fontaine 2015). In this context, private gardens with enhanced nectar plant communities in highly urbanized areas are likely to be beneficial for butterflies.

Literature for the broader public that aims at promoting gardening for butterflies focuses strongly on the flower needs and only marginally considers relations with the surrounding landscape (Witt 2001). Although gardeners clearly cannot influence the latter, butterfly promotion should not be limited to planting *Buddleja* bushes; other plants are equivalent or even better. In a detailed survey (Straka 2010), 12 of the 24 recorded butterfly species were observed on *Buddleja*, but only 10.4% of the individuals fed on *Buddleja*. In total, butterflies utilized 114 nectar plant species. In a private garden near Vienna, Straka (2010) recorded 9 out of 30 butterfly species and 53 of the 627 individuals (8.5%) on *Buddleja*. This suggests that *Buddleja* can help to increase species

numbers in Viennese private gardens, however based on our results, increasing numbers of host plant and a broader representation of different nectar plants species must be recommended in the private gardens.

Similarity of species richness between private gardens and the surrounding landscape indicates that the private garden assemblages depend on an exchange with butterfly populations from the surroundings. This finding may not be surprising because many of the species recorded in the studied private gardens were generalists and very mobile (Matteson and Langellotto 2010). Consequently, the more species-rich the landscape species pool, the more species can potentially appear in a private garden. The relationship between butterfly species diversity in private gardens and surrounding habitat types indicates that habitat diversity in the surroundings could increase butterfly diversity in the private gardens (Mukherjee et al. 2018). Surprisingly, the proportion of grassland and other open habitats in the surroundings was not an important variable, although species of these habitats made up a high share of the observed species set. One explanation is that the land-use data were too coarse and failed to cover many very small patches of open landscape that still serve as butterfly habitats (Lizée et al. 2012), or that the plant species composition in the grassland could not provide enough food resources to butterflies due

Fig. 3 Correlation matrix showing co-occurrences of species abundance, richness and landscape characteristics. Negative correlations are shown in red color and positive correlations are presented in blue. The size of the circle and color intensity is relative to the correlation coefficients. In the right side of the matrix, the legend color shows the corresponding colors and the correlation coefficients

to intensive mowing (Aguilera et al. 2019). Accordingly, a lower percentage of species from the landscape species pool was observed in private gardens with a higher proportion of wooded habitats in their surroundings. Our interpretation is that landscape species pools in more heavily wooded areas comprised woodland species that are unlikely to migrate into private garden areas.

By necessity, simpler observation designs are used for citizen science approaches than in professional monitoring schemes (Engel and Voshell 2002), requiring careful handling of data. Nonetheless, butterfly citizen science approaches can make a valuable contribution to long-term biodiversity monitoring. Furthermore, involving the local public in butterfly monitoring schemes may enhance civic engagement and activity (Leach et al. 2005), especially in programs like “Assessing Butterflies in Europe” (Roy et al. 2020), thus bearing the potential to raise public awareness (Silvertown 2009), e.g. for the loss of biodiversity. Such awareness can, for example, influence gardening practices – such as increased provision of nectar resources for insects – and stimulate an interest in host plant or butterfly observation, which can directly benefit butterfly biodiversity in urban landscapes. Given the increasing popularity of citizen science in the field of biodiversity conservation, this

approach has the capacity to strengthen nature-public connectivity in the urban landscape.

Private gardens contribute to conservation efforts for butterflies in Vienna mainly by providing nectar and host plant species. The close association of the introduced bush *Spiraea* sp. with the populations of *Neptis rivularis* in the suburban and urban area of Vienna (Räuschl 2002) demonstrates that protected species can profit even from ornamental plants in private gardens and parks. Such associations should be considered in any private and public planning process. To encourage people to take up wildlife gardening, particularly butterfly gardening, we suggest generating and implementing a Garden Habitat Action Plan (Ryall and Hatherell 2003). This would help establish private gardens as important stepping stones and habitats for butterflies and many other species in urban landscapes (Garbuzov and Ratnieks 2014). Furthermore, citizen-science based research is an important way to help foster the human-nature-relationship, one place to do this kind of research is private gardens, it helps raise awareness about urban gardens as refuges while allowing the study of nature in private gardens.

Citizen science-based observation of butterflies and gardening with the aim to support butterflies are important keystones in the human-nature-relationship (Sneep et al. 2011).

Gardeners consider their private gardens as a place of reunion with nature (Goddard et al. 2013). Private gardens could provide an ideal link between biological and social sciences, between biodiversity and urban citizens. This in turn would raise awareness for the role of private gardens as biodiversity refuges for butterflies in urban areas. Last but not least, a citizen science approach could provide a great way to study private gardens, which are difficult to sample otherwise at a large scale because of access restrictions.

Conclusions

This study showed that the diversity of butterflies observed in private gardens was influenced by the composition of the surrounding landscape, the butterfly diversity in the surrounding landscape, and the diversity of nectar and host plants in the private gardens. Private gardens in Vienna support common butterfly species mostly by providing nectar and host plants. Although private gardens are currently not crucial for conserving rare and endangered species, their role for species that are still common is important because even those species can show negative population trends (Dennis et al. 2017). A citizen science approach – like the one presented here – can be useful to monitor population trends of common butterfly species and to promote public awareness of butterfly conservation issues.

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Availability of data Data will be available on request.

Declarations

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Consent to participate Not applicable.

Consent for publication All authors consent to the publication of this work.

Conflicts of interest/competing interests All authors have agreed with the manuscript contents, declare no conflict of interest and approved the final version.

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