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RESEARCH ARTICLE

Neglected puzzle pieces of urban green infrastructure: richness, cover, and composition of insect-pollinated plants in traffic-related green spaces

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Abstract
Context In cities, insect-pollinated vascular plants enhance environmental quality, support pollinators, and provide essential ecosystem services for citizens. However, floral communities associated with traffic-related green spaces are rarely considered valuable elements of urban green infrastructure (UGI).
Objectives The main objective of this work was to assess if traffic-related green spaces in Finland possess species-rich floral communities and can assist urban ecological restoration—converting degraded areas into functionally diverse ecosystems. Thus, we evaluated richness, cover, and community composition of insect-pollinated plants (emphasizing flowering ones) on traffic islands, parking lots, and road verges.
Methods The assessment was performed during the mean flowering phenophase of insect-pollinated plants in the European boreal zone (July and August) using a standard quadrat (1 m^2) placement method. We studied plants in urban and suburban locations of three highly populated (> 170 000 inhabitants) Finnish cities—Helsinki, Tampere, and Turku. There were 90 sampling sites with 15 replicates per location type in each city and five measurement replicates per green space (habitat) type. The species richness, cover, and composition were assessed in relation to location, habitat type, city, the average daily traffic (ADT), and distance to the road.
Results Urban locations had lower total plant species richness and fewer indicator species (characterized only by a single indicator species) compared to suburban locations (characterized by five indicator species). Species richness of plants flowering during the time of the survey did not differ among locations. Traffic islands were richer habitats for flowering plants than road verges but did not differ from parking lots. Total vegetation cover and cover of insect-pollinated flowering plants increased with an increasing distance from the road. Vegetation cover differed among habitats being higher on road verges than on traffic islands irrespective of ADT. In all habitat types, the two most common flowering species were yarrow *Achillea millefolium* and autumn hawkbit *Leontodon autumnalis* which occurred at 70.2% and

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67.8% of the sampling sites, respectively. However, the mean cover of the ten most common flowering species (when present) was low and varied between 1.5 and 9.5% per m^2.
Conclusions Similar richness of flowering plants (but not total plant species) in urban and suburban locations might indicate equal importance of ecosystem services provided by flowering plants in cities irrespective of location. Because traffic islands and parking lots contain rich plant communities, they should be better integrated into UGI and valued by city planners. Management intensity in terms of grass cuts should be ecologically justified. An increase in the number of insect-pollinated plant species in urban traffic-related green spaces might help to improve environmental quality in cities in terms of increasing pollinator biodiversity and reducing pollution.

Keywords Flowering plants · Road verges · Parking lots · Plant communities · Traffic islands · Traffic volumes · Urban ecological restoration

Introduction

The sustainable development of cities requires efficient biodiversity conservation strategies. When such strategies are considered and implemented, urban landscapes offer resources for aquatic and terrestrial flora and fauna (Hassel et al. 2021; Rega-Brodsky et al. 2022; Xu et al. 2022), including rare and endangered species (Koperski 2010). Also, urban biodiversity provides resilient ecosystem services for citizens (Andersson et al. 2014). Plant biodiversity in urban green spaces, such as urban forests, cultivated lands, lakes, wetlands, lawns, parks, and meadows, affects climate regulation, as biodiversity decline reduces carbon input to soil and decreases long-term soil carbon stocks (Bolund and Hunhammar 1999; Hungate et al. 2017). Biodiversity enables the self-sustainable development of urban green areas (Lepczyk et al. 2017). However, in practical management frameworks, some elements (types of green spaces) of urban green infrastructure (UGI) are valued less than others (Bonthoux et al. 2019; Seppänen 2019). One example of such neglected habitats are traffic-related urban green spaces.

Complex mosaics of UGI are interconnected with architecture, water bodies, and transportation networks. Patches of forests, parks, flower beds, green areas in cemeteries, meadows, balcony greeneries, green spaces (and much more) are elements of UGI (Tzoulas et al. 2007). All these elements vary in the type of ownership, management, scale, vegetation, degree of fragmentation and pollution, and their suitability for conservation purposes (Kowarik and von der Lippe 2018; Bulldock 2020). Roads and highways occupy substantial territories and interacts with UGI. For example, in Finland, the traffic areas themselves are 8200 km^2, which is 2.7% of the Finnish land area (Peltola 2013). The interconnection of roads and adjacent habitats create other common types of urban green spaces—traffic-related habitats such as road verges, middle of roundabouts, traffic islands, or parking lots. Essential ecological aspects of traffic-related habitats and associated vegetation in urban environments were highlighted multiple times in the scientific literature while still neglected in practice (Seppänen 2019). Traffic was shown as a dispersal vector of seeds in an urban–rural gradient (von der Lippe and Kowarik 2008). Spontaneous vegetation on the roadsides was proven to improve connectivity by providing food and habitats for threatened species (Milton et al. 2015). Also, vegetation in traffic-related green spaces is improving the quality of soil and air (Baldauf 2017), controlling soil erosion on the roadsides (Kollarou and Kollaros 2014), and acting as a water retention and pollution filter (Kaighn and Yu 1996). In addition, it was revealed that habitats along linear infrastructure (e.g., roads or electric power lines) can have high local plant biodiversity (Dániel-Ferreira et al. 2022). Despite a substantial theoretical background, the ecological role of traffic-related green spaces in practice often remains underestimated (Bretzel et al. 2016; Seppänen 2019). As pointed out by Jakobsson et al. (2018), "*it is essential to inform management practice on road networks for biodiversity conservation*". Species-rich communities of wildflowers help to revegetate degraded soils and increase the aesthetic value of urban landscapes with low management costs (Kollarou and Kollaros 2014; Bretzel et al. 2016). Properly designed plant communities in urban areas need less maintenance compared to lawns (Seppänen 2019) and assist urban ecological restoration—returning degraded lands to the condition of diverse and functional ecosystems (Anderson and Minor 2021).

In cities, spontaneous vegetation forms diverse and widely represented assemblages (Bonthoux et al. 2019). Those assemblages are often dominated by insect-pollinated vascular plant species, maintaining plant-pollinator networks (Jakobsson et al. 2018; Dylewski et al. 2020). In the face of global pollinator decline (Potts et al. 2010), cities were suggested as conservation hot spots for pollinators (Bulldock 2020; Theodorou et al. 2020). However, to improve the provision of proper nesting and food resources, evaluation of all elements of UGI including traffic-related habitats should be performed for benefits and threats. In traffic-related green spaces such as road verges, traffic intensity was one of the key factors affecting the suitability of those habitats for pollinator conservation. This is due to the mortality risks for the insects from colliding with cars (Dániel-Ferreira et al. 2022) and potentially due to pollution. City roads with more than 5000 vehicles/day generate more pollutants than highways due to the frequency of traffic lights (cars release more pollutants from brake materials when braking; Huber et al. 2016). It has been recommended to prioritize roadside greeneries alongside roads with lower traffic densities and areas more than 2 m from the road edge (Phillips et al. 2021). Also, other types of traffic-related habitats such as parking lots and traffic islands have their own specifics. For example, heavy metal runoff from parking areas differs from that in other urban habitats depending on location, spatial configuration, and proportion of asphalt cover of a parking lot. (Huber et al. 2016). Traffic islands are fragmented and isolated microecosystems, exposed to traffic pollutants continuously coming from outside of their borders. The physical properties such as spatial and temporal isolation, low connectivity, limited area, and fragmentation make urban traffic islands or urban green areas a kind of "biological islands" (Itescu 2019).

Before practical urban ecological restoration actions can be implemented to increase pollinator biodiversity and improve environmental quality (in terms of pollution decrease), a detailed assessment of spontaneous vegetation in the areas of interest should be conducted. This is needed to reveal species richness, cover, and composition of floral communities in real-life conditions, and to identify key directions for conservation measures. In this study, we estimated species richness, cover, and composition of vascular plants (focusing further on insect-pollinated plants flowering during the survey time) in three traffic-related urban green spaces (habitats) in Finland. Those were traffic islands, road verges, and parking lots. The assessment was conducted for urban and suburban locations of three highly populated Finnish cities during mean flowering phenophase. We predicted three major trends. First, we expected that richness of plant communities and vegetation cover would differ across locations and habitat types, with isolated traffic islands in urban locations containing the lowest richness and cover. Second, we predicted that plant species richness and cover would increase with an increasing distance from the road and would decrease with an increasing traffic volume. Finally, we hypothesized that the composition of plant communities and the indicator (typical) species would differ between locations. The practical aim of this research is to develop recommendations for urban ecological restoration and increasing floral biodiversity on traffic-related green spaces in Nordic cities.

Materials and methods

Study locations and habitats

Field data were collected for two weeks, between 23rd July and 5th of August 2022, along an urbanization gradient in three Finnish metropolitan areas (population > 170 000 people). Those were Helsinki (60°0.19 N, 24° 95 E) with 665,558 inhabitants, Tampere (61°0.29 N, 23° 47 E) with 244 029 inhabitants, and Turku (60°0.45 N, 22° 26 E) with 175 645 inhabitants. Data collection was performed during the mean aggregated flowering phenophase for insect-pollinated vascular plants in the boreal zone (Templ et al. 2017). There is a confirmed seasonal correlation between flowering plants and pollinators (Rathcke and Lacey 1985). Thus, we considered that period the best time to estimate the potential of traffic-related green spaces for the improvement of pollinator biodiversity in terms how much resources those areas are offering for pollinating insects.

The sampling was conducted in urban and suburban locations considering the distance to the central part of the city (central marketplace) and average daily traffic volumes (ADT)—yearly averages of daily traffic estimated as number of vehicles per day. A detailed explanation on the traffic data is given in subSect. "Data estimation of traffic volumes (ADT)". In each city, we had two types of location (i) *urban locations* close to the city center (distance to the city center in km Mean ± standard deviation (SD):3.17 ± 1.79) with intense traffic (ADT Mean ± SD: 6577 ± 5754) and (*ii*) *suburban locations* in city vicinities (distance to the city center in km Mean ± SD:8.18 ± 3.64) with light traffic intensity (ADT Mean ± SD: 427 ± 232). In each city, three types of traffic-related small-scaled urban green spaces (habitats) were studied. These were traffic islands, road verges, and car parking lots. Five replicates per habitat type were taken in each location per city, resulting in a total of 90 sampling points. Coordinates of the exact sampling points, addresses, description of the study locations and data on flowering plant species are available in the dataset deposited in the Dryad data repository https://doi.org/https://doi.org/10.5061/dryad.0zpc86741. Maps with the sampling points' coordinates and a figure with the examples of traffic-related urban green spaces are available from the supplementary information Figs. SI 1.1 and SI 1.2.

The selection of habitats and sampling points was a challenging task. We first preselected candidate places in each city using the Google Maps service. However, while in the field we observed that in many areas of traffic-related habitats, the vegetation had been cut down. Grass mowing is a common practice of green space management in Finland (Hellström et al. 2006; Jantunen et al. 2007). Therefore, we had to search for suitable locations at a given site and thus established the following methodology. In each city, we first travelled to the actual city center. From that point we started making random driving rounds, searching for a particular habitat type with flowering plants. For the road verges and elongated traffic islands, we selected a smaller area for the survey (about 20 m × 1.5–5 m, the narrowest being for traffic islands and widest for road verges). Due to the same number of quadrats and same distance between them in most of the studied locations, our sampling points are highly similar to each other in size. Selected parking lots were covered with asphalt or ground and were always possessing side vegetation. All habitat types contained established spontaneous vegetation, typically grasses and herbaceous plants, with no visible signs of recent grass cut. The sampling locations were selected at the closest level of similarity to each other in terms of size and spatial configuration.

Analyzing richness, cover, and composition of plant species

To measure richness, cover, and composition of vascular plants in each sampling location, we randomly placed five quadrats (1 × 1 m) in one or two rows or in a triangle, depending on the habitat size and spatial configuration. The efficiency of this method was recently confirmed for urban vegetation (Itani et al. 2020). In narrow (when the width was about 2.5 m) traffic islands we placed quadrats in one row. The triangle arrangement was used for two traffic islands in Turku. The distance between the quadrats was 2.5 m and every sampling point had in almost all cases five quadrats. In both Helsinki and Tampere, there were 150 quadrats in total. In Turku, there were 146 quadrats because two small traffic islands contained three quadrats. Altogether, from 90 sampling points there were 446 quadrats processed.

Taxonomic identification of all vascular plant species was performed in the field using the field plant identification guide (Kurtto and Helynranta 2018), Pl@ntNet and INaturalist apps. From each quadrat, we first took a photo and then scored in the field the following parameters: (*i*) total vegetation cover (%); (*ii*) total cover of vascular plants flowering during the survey (%); (*iii*) total number of plant species, with flowering species during the survey recorded separately; (i*v*) distance from the road (m). As our data contained some wind-pollinated species, we excluded them from further analysis on flowering plants and focused on insect-pollinated species only. A complete list of all vascular plant species encountered during the survey is available in the supplementary material with the wind-pollinated species excluded from the study indicated separately (Table SI 1). To *characterize* the diversity of floral communities, we calculated the Shannon index that considers the relative abundances of different species and the Simpson index that weights abundant species more than rare ones. These calculations were based on insect-pollinated flowering plants in the survey, and were implemented using vegan::diversity (Oksanen et al. 2022) in R software (R 4.1.3; R Development Core Team 2022).

Data estimation of traffic volumes (ADT)

Traffic volumes were estimated as yearly averages of daily traffic volumes (ADT) and were measured as vehicles/day. Data has been obtained from the Finnish Transport Infrastructure Agency (Vayla, 2021). The traffic volume map provides the yearly average of daily traffic on the main roads in Finland in 2021. The Road Network Maps do not cover the smallest streets. Thus, the estimate of traffic volume used as a proxy for traffic pollution on each study location was based on the traffic volume of the closest available street. The selection of the ADT was made considering the estimated size of the street. In 80% of cases, traffic estimates were scored from the actual locations. For the remaining ones, average distance (Mean ± SD) from the actual study location to the known ADT index estimated from the map was 2.6 ± 2.2 km. Generally, traffic volumes (ADT) were quite similar between cities and locations in Helsinki (urban: 4264 ± 1692; suburban: 461 ± 235), Tampere (urban: 10,477 ± 8161; suburban: 358 ± 271), and Turku (urban: 4989 ± 3143; suburban: 464 ± 179). However, ADT in urban locations in Tampere was more variable due to the much higher traffic load in three locations. For the field surveys like ours (possessing many sampling locations), retrieving traffic data from open sources might be the only option to reveal the existing trends.

Statistical analysis

Richness, cover, and composition of plant species in relation to locations, habitats, and environmental variables

To explore the associations between vegetation and environmental variables, we conducted a linear mixed model (LMM; lme4::lmer) in R software for total vegetation cover, cover of flowering plants during the survey (sqrt(x + 1)-transformed), total number of vascular plant species, and number of flowering plant species (log(x + 1)-transformed). These separate tests were justified as the four variables were not strongly correlated ($r = 0.08$–0.66). All models contained sampling location (urban, suburban), habitat type (parking lot, road verge, traffic island), city (three levels), and all possible interactions between them as fixed explanatory variables. Distance from the road (m) and traffic volume (ADT, log-transformed) were included as fixed continuous explanatory variables. Sampling site was included as a random factor. Traffic volume was log-transformed due to its large scale. We did not use site nested within city to ensure model convergence, and we also excluded diversity indices from the analysis due to their strong correlation with the number of flowering species ($r = 0.87$ for Shannon and $r = 0.71$ for Simpson). We verified the model assumptions visually from residual plots and transformed the response variable when necessary (see above for details). We evaluated the significance of the fixed variables with an *F* test based on the Kenward-Roger method (lmerTest::anova; Kuznetsova et al. 2017), and assessed pairwise differences in mean values between habitats with Tukey's test (emmeans::emmeans; Lenth 2022).

Species composition of floral communities

We investigated differences in the composition of floral communities with permutational multivariate analyses of variance (PERMANOVA, implemented in vegan::adonis2). PERMANOVA was conducted, with 999 permutations, based on Bray–Curtis dissimilarities calculated from the cover of flowering vascular plants at the time of the survey per site ($n = 90$), and it contained the same fixed explanatory variables as the LMMs described above. As this analysis does not consider random factors, we calculated an average of the 3–5 quadrats per site and used these mean values for the analysis. To visualize floral communities in relation to categorical variables (sampling location, habitat type, city), we conducted a non-metric multidimensional scaling based on Bray–Curtis dissimilarities with two dimensions (vegan::metaMDS, stress = 0.23), and plotted significant continuous explanatory variables in the ordination (vegan::envfit). We used an indicator species analysis–to identify flowering plant species that were associated with location (urban, suburban), habitat type (parking lot, road verge, traffic island) or habitat type combination (indspecies::multipatt with func = IndVal.g; De Cáceres and Legendre 2009). This analysis determines species representing a particular habitat type, if any (De Cáceres and Legendre 2009).

Results

Richness and cover of plant species

Total richness of vascular plant species was higher in suburban locations than in urban locations regardless of the habitat type (Table 1, Fig. 1a). Richness of insect-pollinated plants flowering during the survey did not differ between cities or locations but differed among habitat types, being higher in traffic islands than in road verges (Fig. 1b). Species richness (both the total and flowering species) was not associated with the other explanatory variables such as distance to the road or ADT (Table 1).

We identified 167 vascular plant species and 93 insect-pollinated plant species that were flowering during the survey. The total list of plants also included tree seedlings and grasses which were usually defined to the family level. The two most common flowering species at the study sites were yarrow *Achillea millefolium* and autumn hawkbit *Leontodon autumnalis*

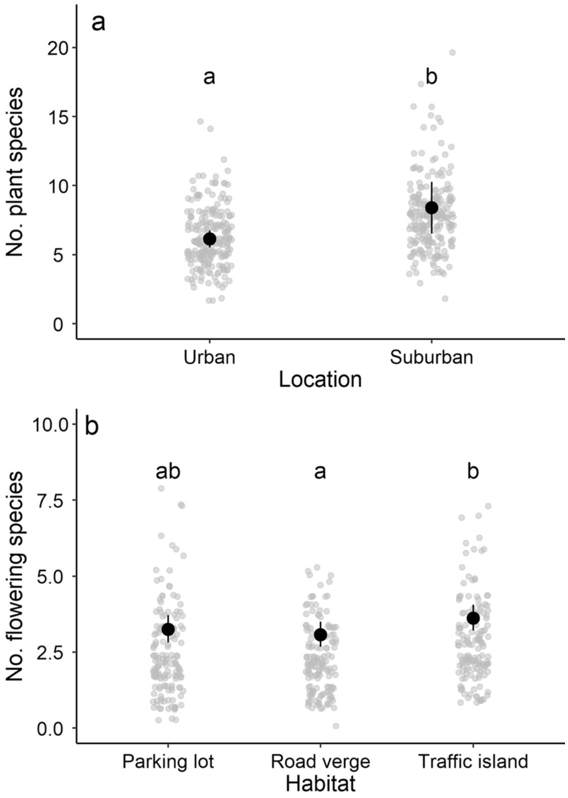


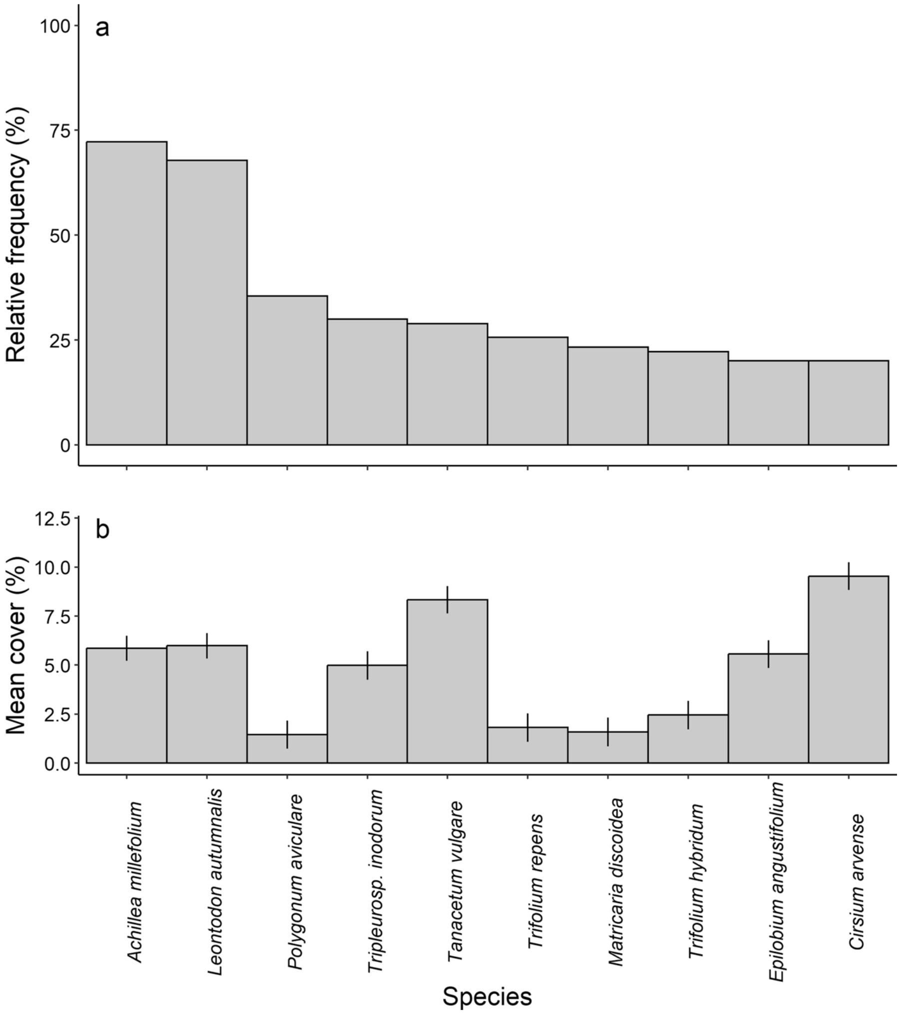
Fig. 1 Total vascular plant species richness **a** across study locations and **b** the richness of flowering species across habitat types (mean ± 95% CL and raw data points in grey). Different letters indicate significant difference between habitats ($P < 0.05$, Tukey's test)

Table 1 Richness and cover of vascular plants (total vegetation) and insect-pollinated species flowering in July and August (flowering sp.) in three types of traffic-related urban green spaces of urban and suburban locations in Finland

Explanatory variable	Total vegetation cover		Flowering sp.cover, sqrt (x + 1)		No. plant species (richness)		No. flowering plant sp., log (x + 1)	
	$F_{df,ddf}$	P	$F_{df,ddf}$	P	$F_{df,ddf}$	P	$F_{df,ddf}$	P
Location (2 levels)	$1.159_{1,70}$	0.285	$0.034_{1,70}$	0.850	**$4.119_{1,71}$**	**0.046**	$0.806_{1,70}$	0.372
Habitat (3 levels)	**$3.619_{2,71}$**	**0.032**	$2.234_{2,71}$	0.115	$0.153_{2,71}$	0.858	**$3.373_{2,71}$**	**0.040**
City (3 levels)	$1.663_{2,71}$	0.317	$0.474_{2,71}$	0.624	$1.206_{2,71}$	0.305	$3.774_{2,71}$	0.069
Distance from the road (m)	**$7.783_{1,363}$**	**0.006**	**$11.207_{1,312}$**	**0.001**	$3.321_{1,398}$	0.069^{*}	$0.006_{1,317}$	0.938
log (Traffic volume)	$1.625_{1,70}$	0.207	$0.278_{1,70}$	0.599	$0.313_{1,70}$	0.577	$0.003_{1,70}$	0.959
Location × Habitat	$0.049_{2,71}$	0.953	$1.842_{2,71}$	0.166	$0.321_{2,71}$	0.726	$0.384_{2,71}$	0.683
Location × City	$0.293_{2,71}$	0.747	$0.868_{2,71}$	0.424	$0.100_{2,71}$	0.905	$0.022_{2,71}$	0.978
Habitat × City	$1.129_{4,71}$	0.350	$0.708_{4,71}$	0.589	$0.990_{4,71}$	0.419	$2.089_{4,71}$	0.091
Location × Habitat × City	$1.324_{4,71}$	0.269	$1.333_{4,71}$	0.266	$0.013_{4,71}$	1.000	$0.173_{4,71}$	0.952

Results of mixed models analysing the effects of spatial and environmental variables on the cover and number of insect-pollinated plant species. Site was used as a random factor in all models. df and ddf denote degrees of freedom in the numerator and denominator, respectively. P-values < 0.05 are in bold. City (Helsinki, Tampere, Turku); locations (urban, suburban); habitat (traffic island, parking lot, road verge)

Fig. 2 Top 10 most common plant species flowering during the survey in the three types of traffic-related green spaces (traffic islands, road verges, parking lots) based on their **a** relative frequency calculated from the 90 sampling sites and **b** mean flower cover (±SE) calculated from the sites they were present



that occurred at 70.2 and 67.8% of the sites, respectively, while the relative frequencies of other flowering species were much smaller (Fig. 2a). Overall, the mean cover of the most common flowering species (when present) was low and varied between 1.5 and 9.5% per m^2 for the top ten species (Fig. 2b).

Total plant cover and the cover of flowering plants increased with an increasing distance from the road (Table 1, Fig. 3a and c). Total vegetation cover also differed among habitat types (Table 1), being higher in road verges than in traffic islands (Fig. 3b). The other explanatory variables considered (location, city, traffic volume) were not associated with total vegetation cover or cover of plants flowering during the survey (Table 1).

Composition of floral communities in the studied locations and habitat types

Floral communities differed between locations, habitat types, and cities, although each of these factors explained only a small percentage of the total variation in the communities (Table 2, Fig. 4). Distance from the road also explained part of the variation in the floral communities (Table 2). The visual inspection of the ordination revealed that the floral communities tended to be more homogenous in urban locations than in suburban locations (Fig. 4a).

Based on indicator species analysis, the floral communities in the urban locations were characterized by a single flowering species (*Cerastium fontanum*), while those in the suburban locations were characterized by five flowering species (*Matricaria*

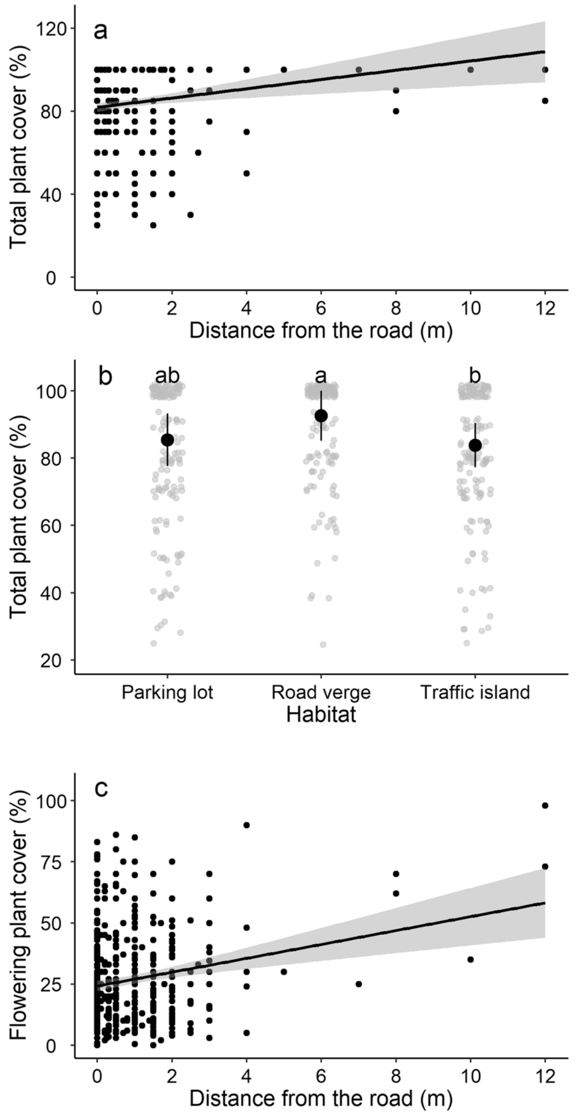


Fig. 3 Total plant cover and the cover of flowering plants in relation to **a** distance from the road (intercept = 37.492, slope = 2.206) and **b** habitat type (mean ± 95% CL), and **c** the cover of flowering plants in relation to distance from the road (intercept = 6.334, slope = 0.249). Lines (± SE) were fitted based on a linear mixed model and raw data points are shown. Different letters indicate significant difference between habitats ($P < 0.05$, Tukey's test)

discoidea, *Tripleurospermum inodorum*, *Trifolium repens*, *T. hybridum* and *Centaurea jacea*; Table SI 2). *Solidago virgaurea* was associated with road verges only, whereas *Tanacetum vulgare* was associated with both road verges and parking lots, and

Table 2 Floral communities in traffic-related urban green spaces in Finland: results of a PERMANOVA for the composition of insect-pollinated plants flowering during the survey (July–August, $n = 90$ sites)

Explanatory variable	$F_{df,ddf}$	R^2	P
Location (2 levels)	**$2.366_{1,89}$**	**0.025**	**0.011**
Habitat (3 levels)	**$1.274_{2,89}$**	**0.039**	**0.008**
City (3 levels)	**$1.885_{2,89}$**	**0.040**	**0.010**
Distance from the road (m)	**$1.901_{1,89}$**	**0.020**	**0.025**
log(Traffic volume)	$0.971_{1,89}$	0.010	0.481
Location × Habitat	$1.138_{2,89}$	0.025	0.218
Location × City	$1.264_{2,89}$	0.027	0.171
Habitat × City	$0.976_{4,89}$	0.041	0.507
Location × Habitat × City	$0.792_{4,89}$	0.033	0.859

Explanatory variables are city (Helsinki, Tampere, Turku); location (urban, suburban); habitat (traffic island, parking lot, road verge)

P values <0.05 are in bold

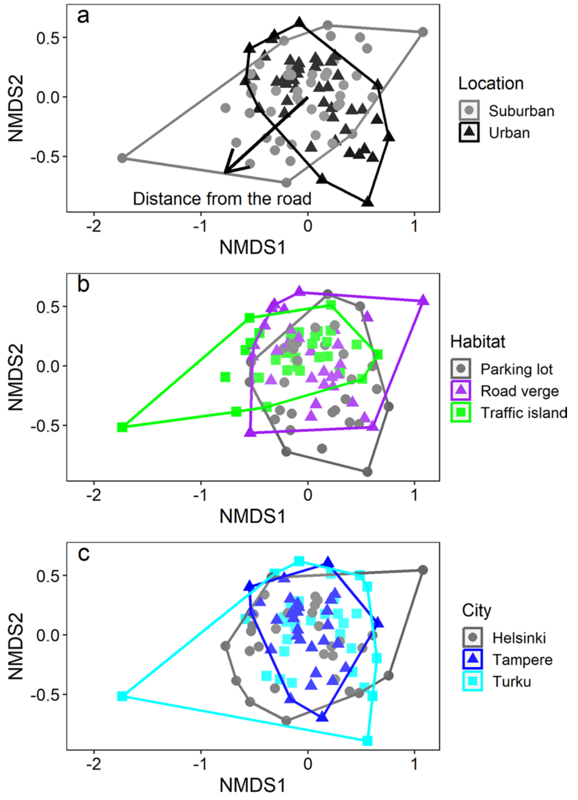


Fig. 4 Non-metric multidimensional scaling (NMDS) ordination based on urban floral communities ($n = 90$) in relation to **a** location, **b** habitat type and **c** city. Convex hulls are drawn around different combinations of the categorical variables. A significant continuous variable ($P < 0.05$) is plotted in the ordination

Polygonum aviculare was associated with both road verges and traffic islands (Table SI2).

Discussion

Our results revealed that during mean time of flowering phenophase of vascular plants in Finland, traffic-related green spaces in urban and suburban locations possess rich and variable floral communities. Indeed, as we predicted, the richness of vascular plants in general (but not the richness of plants flowering during the survey) was lower in urban compared to suburban locations, with the former having more homogenized floral communities. Traffic islands had more flowering plant species than road verges in all cities and locations but did not differ from parking lots.

Urbanization can both increase and decrease plant species richness (McKinney 2008). A direction of this effect might depend on the taxonomic group of plants, scale of the assessment, or urbanization intensity. Williams et al. (2008) listed four urbanization filters for floral communities. Those are (i) *habitat transformation* (changing of a habitat quality) and (ii) *habitat fragmentation* (an increase in spatial disconnections), (iii) *specific features of urban environment* such as urban heat island effect, increased water stress or pollution, and (iv) *human preferences* (for example, active management of alien species). Decreased plant species richness in urban locations observed in our study might be due to increased abundance of "urban-adaptable" plants. Those are species highly adaptable to urban biodiversity filters which can easily replace native but less-adaptable ones (Singh et al. 2018). For example, common mouse-ear (*C. fontanum*)—an indicator species of urban locations in our study—is a typical representative of urban flora in Northern Europe and North America (LaPaix and Freedman 2010; Ranta 2014). The survival of native plant species in cities may be reduced due to isolation from rural populations, leading to local extinction of some native species and, consequently, lower plant species richness than in suburban locations (Čeplová et al. 2017). However, no difference in the richness of flowering plants between urban and suburban locations during the survey period might highlight the overall importance of the functions provided by spontaneous vegetation for pollinators in urban environments.

The environmental factors such as atmospheric pollution, urban heat island effect, soil type or soil contamination might also modify floral communities in urban and suburban locations. It has been previously noticed that in city centers, there is an increased richness of warmth-preferring or thermophilic plant species (Singh et al. 2018; Schmidt et al. 2014). Urban soil is dry and contains high levels of nitrogen due to atmospheric pollutants (Schmidt et al. 2014). It was shown that the presence of trees does not decrease nitrogen dioxide (NO_2) in urban soils (Yli-Pelkonen et al. 2017) which might also benefit nitrophilous plants (increase species richness). While aiming to increase richness of insect-pollinated plant species in the city centers, the adaptability, thermophily, soil preferences, and pollution-resistance of plants should be considered.

High richness of flowering plants in traffic islands was another interesting finding that contradicted our predictions. In cities, traffic islands are the most fragmented and polluted habitats (they are exposed to traffic from multiple sides), which often experience grass mowing. According to the study by Perry et al. (2021), monthly mowing may support early successional forbs, including white clover (*T. repens*), red clover (*T. pratense*) as well as broadleaf plantain (*Plantago major*). However, it was shown that grass mowing at the frequency at least twice a year decreased the total number of flowering and seed-producing plants in Finland (Jantunen et al. 2007). We consider that grass mowing should be ecologically justified—if traffic-related habitats are cut too often, there will not be any floral resources available for pollinators. In the present study, an indicator species associated with traffic islands and parking lots was knotgrass (*P. aviculare*) which is a low-growing plant species tolerating high disturbance and mowing (Ranta 2014). Also, this plant species grows on sites that are frequently walked on and it shows a high adaptation to ruderal habitats (Costea and Tardif 2003).

Unfortunately, the mowing frequency of the study sites is unknown. But can we speculate that traffic islands are cut more often than road verges or parking lots (personal observation) as a part of a common practice in management of urban green spaces. Species richness often increases with an increasing area, and landscape green corridors decrease fragmentation and increase biodiversity (Damschen et al. 2006). In the present study, traffic islands generally represented smaller habitats than road verges that tended to form continuous linear habitats. Although habitat size was not explicitly considered in the present study, the actual area sampled was similar for nearly all studied locations. Therefore, it seems unlikely that habitat size would have been a key factor contributing to high richness of plants flowering during the survey in traffic islands. The above-mentioned point about soil nitrification due to the traffic is also relevant for traffic islands where pollutants might act as fertilizers. It has been shown that small and isolated urban patches can possess the same species richness, but even higher beta-diversity (absolute species turnover) compared to larger green spaces (Vega and Küffer 2021). Such habitats might increase connectivity between different elements of UGI, favor species colonization, and create relatively inexpensive solutions for ecological restoration of urban environments (Klaus and Kiehl 2021). Planchuelo et al. (2020) previously showed that the survival rate of endangered herbaceous species in cities was the highest for the most competitive ones demonstrating preferences for the driest soils. Harsh environments might benefit urban floral communities. Therefore, traffic islands and other isolated types of urban traffic-related green spaces should receive special attention in urban green planning and management.

Our results demonstrated that plant cover of the most common plant species was low (meaning high presence of voids) and increased with an increasing distance from the roads. Also, distance from the road explained part of the variations in floral communities. Total plant cover was higher in road verges than in traffic islands, while cover of flowering plants did not differ across the three studied habitat types. Urban voids, which are unused, underused, and misused urban spaces including vacant lots and derelict areas, create challenges for managing urban environments (Hwang and Lee 2020). For example, soil in vacant lots (patches free from vegetation or with low vegetation cover) is contaminated by heavy metals and have simplified plant and soil fauna communities (Perry et al. 2021). Moreover, levels of soil traffic-related metal pollutants gradually decrease with an increasing distance from the road (Bućko et al. 2011; Phillips et al. 2021). De-icing salts (NaCl) used for the road maintenance during winter also affect vegetation within 10 m of the road edge (Blomqvist 1998). In the long term, salt application might lead to the simplification of plant communities (Equiza et al. 2017). De-icing salts and traffic heavy metals might also explain an increase in the plant cover with the distance increase from the road in our study. Richness and cover of flowering plants are essential for plant reproduction and functional diversity of pollination networks (Fontaine et al. 2005). Increasing understory cover of plant species can raise local biodiversity of insects, bats, and birds up to 140% (Threlfall et al. 2017). On the other hand, high plant cover of competitive non-target plant species would displace low-competitive ones (Anderson and Minor 2021); and open soil is essential for soil breeding insects (Schmitt and Burghardt 2021). To summarize, reducing sizes of urban voids with an increased plant cover might assist urban ecological restoration in terms of improving biodiversity and diminishing pollution. However, plant species and methods for the increase in plant cover (either selective grass mowing or plant seeding) should be specifically adjusted for different habitat types (Anderson and Minor 2021).

Parking lots usually have lower traffic volumes compared to roads or highways, but instead are exposed to high levels of exhaust gas and heavy metal emissions due to car braking and acceleration (Huber et al. 2016). On the roadsides, emissions also depend on the proximity of traffic signals which modify traffic patterns (Huber et al. 2016). Here, we did not find any association between studied traits and traffic volumes, which might indicate that urban floral communities are generally well adapted to traffic in Finnish cities. The alternative explanation might be that the estimated traffic volumes used in the study were a poor proxy for urban traffic pollution, and traffic volumes in the Finnish cities were perhaps too “low” to affect vegetation. In the future, more explanatory factors, such as soil metal deposition, age of the habitats, frequency of grass mowing, should be considered.

The most common urban plants flowering during our survey were *A. millefolium* and *L. autumnalis,* followed by *T. inodorum*, *T. vulgare*, *T. repens*, *T. hybridum*, *M. discoidea*, *Chamaenerion angustifolium,* and *Cirsium arvense*. However, their cover when present was not particularly high. In addition, four of the mentioned species and *C. jacea* were revealed as indicator species for suburban landscapes. While city centers were characterized by a single species—*C. fontanum*. Most of the revealed plant species can benefit urban landscapes by reduction of atmospheric and soil pollutants, increasing pollinator diversity, and improving the scenic beauty of cities (Przybysz et al. 2021; Memmot 2002). *C. arvense* has a controversial role, being pollinator-friendly plant and an invasive weed at the same time. Urban wildflower meadows accumulate significant amounts of atmospheric particulate matter and act for air filtration more efficiently than traditional lawns (Przybysz et al. 2021). Certain plant species in spontaneous vegetation (e.g., *A. millefolium*) possess phytoremediation capacity and can uptake metals and other pollutants from soil (Radanović et al. 2002; Antoniadis et al. 2021). Most of the plants in our study belong to the family Asteraceae followed by Fabaceae which attract diverse pollinating insects (Torres and Galetto 2002). One of the plant species common across locations, *C. arvense*, is visited by a diverse group of pollinators including bees, wasps, butterflies, hoverflies, and beetles (Memmot 2002; Ghazoul 2006; Orford et al. 2016). Our own observations during the field work also confirm diverse insect pollinator communities associated with studied plant species in Finnish cities. Use of spontaneous vegetation in urban landscape design proved to be a low-cost while socially recognized and rewarding technique for managing green areas and increasing pollinator abundance and diversity (Saarinen et al. 2005; Younis et al. 2010; Phillips et al. 2020).

However, our work is based on the survey conducted in July and August only. Different flowering species would have been found in early and late summer. To get a better understanding of urban floral communities during the entire season, it is important to determine the seasonal variations. Although this task might be highly time consuming and resource intensive, it will reveal the essential traits in seasonal dynamics and indicate further directions for the more comprehensive urban ecological restoration.

Conclusions

The results of our survey confirm that Finnish traffic-related green spaces possess rich communities of insect-pollinated plants and should be considered in urban ecological restoration projects. Although urban and suburban locations differed in total plant richness, richness of flowering plants was not different in July and the beginning of August. This might be a clear sign for the equal importance of ecosystem services provided by flowering plants in cities irrespective of location. Traffic islands and parking lots should receive more attention in urban planning due to their capacity to maintain high species richness. It might be beneficial to increase richness and cover of the most common urban plant species flowering in July–August in Nordic cities. Suggested plant species are *Achillea millefolium*, *Leontodon autumnalis, Triplosperum inodorum*, *Tanacetum vulgare*, *Trifolium repens*, *Trifolium hybridum*, *Matricaria discoidea*, *Centaurea jacea, and Chamaenerion angustifolium.* Many of those plants attract pollinators, reduce pollution, and possess aesthetic value for citizens. By increasing cover and number of insect-pollinated plants on the roadsides, traffic islands, or parking lots in the city centers it will be possible to increase biodiversity of pollinators and improve urban environmental quality in terms of pollution reduction. To support pollinator biodiversity in urban restoration processes, it is not necessary to sow flower or grassland mixtures, which often contain alien species. Our results show that supporting spontaneously growing plant species is a suitable way to increase biodiversity for pollinators on urban traffic related greenspaces.

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Data availability Data supporting the results in this article can be found in the Dryad data repository https://doi.org/https://doi.org/10.5061/dryad.0zpc86741.

Declarations

Competing interest The authors declare no competing interests.

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