Negative relationship between woody species density and size of urban green spaces in seven European cities

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Highlights

- We recorded 418 woody species in 225 urban green spaces (UGSs) in 7 European cities
- Selected cities cover a latitudinal gradient and UGSs vary in size and connectivity
- Alien species were abundant ranging from 40% in Antwerp to 64% in Lisbon and Zurich
- There is a strong negative correlation between UGS size and species density

Title Page (with Author Details)

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Declaration of interests

☒The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abstract

Urban green spaces (UGSs) are important elements of urban landscapes. Woody vegetation is a key component of UGSs, providing many socio-ecological benefits such as habitat provision and human well-being. Knowing plant diversity and vegetation configuration that underpin urban ecosystem processes and functions is critical to maximize nature contributions to city dwellers. Here, we present a well-replicated multi-city study showing a detailed description of taxonomic and structural diversity of woody vegetation in 225 UGSs distributed across seven European cities along a NE-SW gradient. Our aim was to understand how UGSs attributes, including size and fragmentation, influence woody vegetation features. A total of 418 woody species belonging to 76 families were identified. UGS size displayed weak positive correlations with woody species richness, but a strong negative correlation with woody species density. Alien woody species were abundant in all cities (from 40% of all species recorded in Antwerp to 64% in Lisbon and Zurich). Among the native tree species we found a predominance of *Pinus* spp. in southern cities and *Acer* spp. in cooler climates. On average, tree canopies extent was 56% of UGSs. This paper provides insights on the plant diversity and woody vegetation composition in UGSs of different size, climate and urban planning history. Our results encourage and contribute to future urban ecology studies involving different taxa and ecosystem services as well as support effective urban planning and management practices.

Keywords

Urban vegetation; species richness; above-ground biomass; canopy cover; species-area relationship

Introduction

Plants constitute the vast majority of biomass in terrestrial ecosystems including highly anthropogenic ecosystems, and support directly and indirectly biodiversity (Bar-On et al., 2018). Particularly, plants provide food, shelter and create microenvironmental conditions for other taxa in most ecological systems. Humans have been and are still transforming natural ecosystems into human-dominated biomes (Ellis & Ramankutty, 2008). Therefore, plant species richness in urban ecosystems mainly depends on human practices (Kühn et al., 2004) and on the type of built-up area (Godefroid & Koedam, 2007) and not only on natural processes related to dispersal, filtering and interactions (Nielsen et al., 2014).

Planting non-native species highly contribute to more diverse woody vegetation communities in urban areas – almost half of the non-native woody species in urban ecosystems are deliberately planted (Aronson et al., 2014; Kowarik, 2011). Around 40% of plant species in European cities are non-native (Pyšek, 1998), although lower (30%; Salinitro et al., 2018) and higher (66%; Säumel et al. 2010) proportions have also been reported (Kowarik et al., 2013; Tsiotsiou & Christodoulakis 2010). Plant diversity provides various ecological niches for a wide variety of birds, insects, cryptogams and other biota (e.g. Grote et al., 2016; Grove et al., 2013). Also composition and structure of vegetation and landscape attributes contribute to the overall biodiversity (Threlfall et al., 2016). Higher vegetation biomass can provide greater resources for many different organisms (e.g. Großmann et al., 2020), which consequently allows for larger and thereby more viable and stable populations. A global meta-analysis on biodiversity in cities (Beninde et al., 2015) concluded that in addition to patch size, vegetation structure together with species richness, tree cover and vegetative biomass play significant roles in providing better habitat for other organism groups that inhabit urban green spaces.

The role of woody vegetation in urban areas is especially crucial in providing habitat for other organisms (Baruch et al., 2020), and ecosystem services (Capotorti et al., 2019). Vegetation of UGSs provides regulating ecosystem services (ESs) such as local climate regulation and air pollution removal (Grote et al., 2016; Locosselli et al. 2019), supporting and provisioning ESs (e.g. primary production and food, respectively) as well as cultural ESs (e.g. recreation activities, Bjerke et al., 2006). Therefore, municipalities have the opportunity and responsibility to implement ecosystem-based management and planning strategies for providing a higher quality environment for both humans and other organisms (Beery et al. 2016).

European cities share common standards in the planning of green spaces based on transforming densely built-up cities -with a scarce consideration of ecological factors in the urban design process- into more sustainable living environments (Kohout et al., 2020). As part of the new EU Biodiversity Strategy 2030, cities with a minimum population of 20,000 were requested to elaborate Urban Greening Plans by the end of 2021 with a special focus on increasing biodiversity among green infrastructure elements such as UGSs (EC, 2020). Therefore, knowing the current plant diversity and functioning in UGSs is a key tool for stakeholders involved in the urban planning process.

Many urban ecology studies focus on urbanization effects on biodiversity across urban-rural gradients (e.g. McKinney, 2002). Other studies have typically focused on single cities or locations, mainly assessing specific applied research goals using intra-urban transects, and meta-analysis conducted at broader scale commonly use existing data from different sources (Beninde et al. 2015). Systematically sampled comparable data on woody vegetation in UGSs is relatively scarce, especially on large scales and at high resolution level that would comprise data from urban settlements in different countries (Beninde et al. 2015). Thus, there is a knowledge gap on the taxonomic and structural diversity of woody vegetation stemming from common standardized surveys and at fine-grained detail comprising different urban spaces at the continental scale (Yang et al., 2015) which we aim to fulfill. Here we also follow research directions highlighted by Pinho et al. (2021) aimed at enhancing our understanding on urban biodiversity and ecosystem functions and services, particularly by including several key plant traits in our study and providing high resolution urban habitat maps.

Several studies in urban areas have found positive correlation between species richness and patch area (Cornelis & Hermy, 2004; Shwartz et al., 2013). Nonetheless, different patterns of diversity in urban parks and other green spaces have been found (Talal et al., 2019), suggesting that the increase in the number of woody species is not always proportional to the increase of UGS size, but other factors play a role in shaping urban biodiversity (e.g. urbanization degree, McKinney (2008)). UGSs tend to have lower diversity than expected from their size. Woody species density (i.e., number of species per unit area) is thus expected to be negatively correlated with UGS size. However, such analyses for urban vegetation are so far missing from the literature.

We studied 225 UGSs in 7 European cities along a SW-NE latitudinal gradient, from Portugal to Estonia. We systematically sampled and mapped woody vegetation in UGSs with different degrees of size and fragmentation, as both landscape metrics have an effect on ecological processes (e.g. Shanahan et al., 2011). Our main aim was to understand the influence of UGSs size on woody vegetation features. We tested this looking at i) species richness (expecting a relatively weak positive relationship), ii) species density (expecting an overall negative relationship), and iii) tree cover and biomass (expecting a non-significant effect).

Methods

Sampling sites selection

We selected 225 UGSs belonging to 7 European cities from Lisbon (38º N) to Tartu (58º N), covering most of the climatic variability in mainland Europe (Fig. 1). Selection was based on patches classified as 'Green urban areas' category (code 1.4.1. of the Urban Atlas) in the Pan-European Urban Atlas (2012), providing high-resolution land use and land cover maps for urban areas across Europe. To avoid major management differences between sites, we also manually excluded patches that were predominantly occupied by cemeteries and zoos, which are included in the 'Green urban areas' class. Other vegetated areas such as 'Forest' class (code 3.1. of the Urban Atlas, included in natural and semi-natural areas category) and private UGSs with no public access were left out in order to minimize heterogeneity due to type and intensity of management practices. Site selection was conducted based on two independent gradients: i) size of UGSs, and ii) their structural connectivity with other green elements embedded in the urban matrix (i.e., discontinuous low density urban fabric (10-30%), discontinuous very low density urban fabric (<10%) and forests), as landscape configuration plays a role in shaping several urban taxa diversity and distribution (e.g. insects and birds). Thus considering both size and connectivity degree in our sites selection allows cities and taxa comparison. The degree of connectivity was calculated using the Proximity Index in Fragstats software within a 5 km radius from every patch.

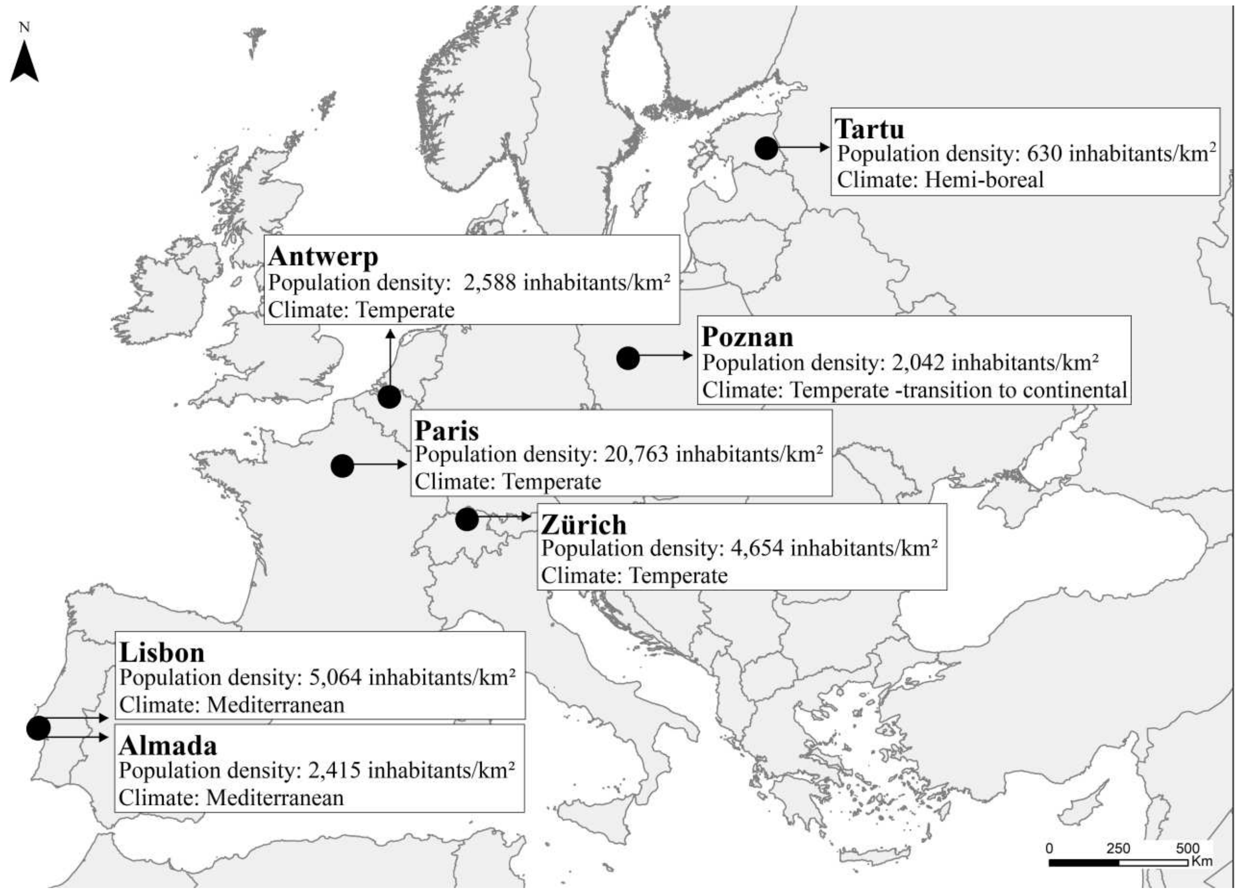
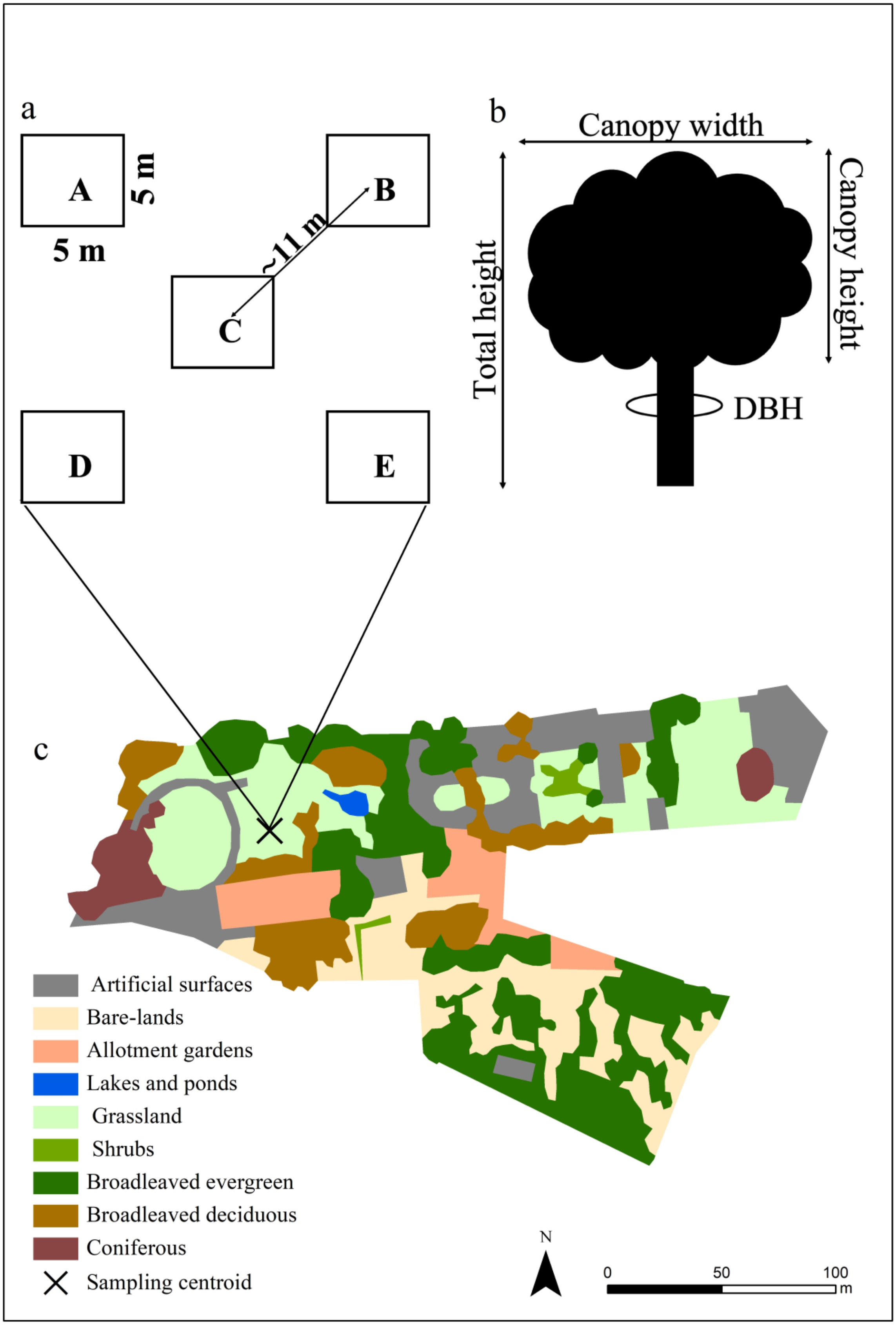


Figure 1. Location of the selected cities, with information on demography and climate provided.

Vegetation survey

Vegetation survey was conducted between June 2018 and June 2020. The survey consisted of a field assessment in each selected UGS, and subsequent analysis based on land cover maps of UGSs. All woody species throughout the UGSs were identified (i.e., woody species richness, Table 1) and separated by provenance into native and non-native species (see Supplementary Table S1 for source information). Species-specific mean height was recorded for each woody species (i.e., mean height of woody layer, Table 1). Then, a more detailed vegetation survey was carried out in the centroid of each selected UGS (Fig. 2a). If the geometric centroid was not available for sampling (e.g. inaccessible area, water bodies, area without trees), then the closest available area was chosen. The new sampling centroid had to accomplish two criteria: i) include woody vegetation that was representative of the UGS, and ii) occur as close as possible to the original centroid. Sampling in centroids was used in order to minimize the effects of surrounding urban non-green areas. From the five 5m x 5m plots in the sampling centroid all woody species were identified, the height, diameter at breast height (i.e., diameter of the trunk at 1.3 m from the ground, only for trees, DBH, Table 1) and crown or hedge size were measured on each woody individual in each plot (Fig. 2b). Woody species richness, both at the centroid and at the site scale were compared to UGS size to determine if the same relationship among total richness and patch size was also found at the plot level (i.e., if the patch size had an effect on species richness at every level, as expected in natural systems, or it rather depends on UGS design and management). When we refer to the percentages of native and non-native species, we mean the whole woody species pool in each city (i.e., all the species recorded across the UGSs of a given city) not to its predominance among UGSs.


a
A
5 m
5 m
B
~11 m
C
D
E
b
Canopy width
Total height
Canopy height
DBH
c
Artificial surfaces
Bare-lands
Allotment gardens
Lakes and ponds
Grassland
Shrubs
Broadleaved evergreen
Broadleaved deciduous
Coniferous
Sampling centroid
N
0
50
100
m

143

Figure 2. Sampling design (a), quadrat C is located in the sampling centroid of the urban green space (UGS). Plant traits measured for tree plants (b). Example of one of the studied UGSs in Lisbon (size=31868.26 m^2), land cover map and location of the sampling centroid (38°46'13.7"N, 9°10'33.9"W) (c).

Land cover maps

A land cover map of each sampled UGS was made by photo-interpretation of the high resolution (i.e., 0.5 m) World Imagery basemap from 2015 using ESRI ArcMap 10.4. Photo-interpretation was done at a scale of 1:600 which allowed to distinguish between the different land cover types within the UGS (Fig. 2c). Tree species types (i.e., coniferous, broadleaf deciduous and broadleaf evergreen trees) were separated by checking images provided by Google Earth Pro v.7.3.2.5776 and street view in Google Maps from different phenological stages. The resulting vegetation maps were validated during the vegetation survey. Satellite imagery does not allow to precisely classify the extent of all land cover types due to overlapping vertical layers. Therefore, our land cover maps provided accurate information about the upper layer (i.e., tree canopy cover and canopy percentage, Table 1). Tree canopy cover was used to extend the aboveground biomass results of measured trees to the entire tree cover of each UGS.

Aboveground biomass calculation

Above-ground biomass (AGB, Table 1) of trees was calculated by using species-, genus- or plant functional type-specific allometric equations (see Supplementary Table S1 for source information). Species-specific allometric equations were used, but if not available, then genus-specific models were used, or generalized equations for either broad-leaved and coniferous trees were applied. The allometric models used were based on combinations of the measured plant traits, specifically DBH and plant height and calibrated across specific ranges of these plant traits. Therefore, we considered the trees whose traits fitted such ranges. This avoided possible under- and over-estimations of AGB, but restrained the AGB results to 154 UGSs from which 139 were used for analysis (i.e., 15 UGSs were outliers, see *Statistical analysis* section). When more than one equation was available, the mean was used.

Statistical analysis

All analyses were conducted in R v. 3.6.1 (R Core Team, 2019) (see Supplementary Table S1 for packages source information). In order to avoid distortions in descriptive metrics and statistical tests, AGB outliers highlighted in boxplots were removed from the dataset prior to analysis. The overall variables are described in Table 1, namely: UGS size, AGB, canopy cover (both in absolute and relative terms), mean height of the woody layer, woody species richness and species density.

Linear regression models for all cities together and separately were made for exploring the response of woody species richness, woody species density (number of woody species per unit area of UGS), canopy cover and AGB (i.e., response variables) to UGS size (i.e., explanatory variable). Logarithmic transformations were applied to both response and explanatory variables to better fit linearity. Coefficients of determination are shown as R^2. Then, we performed linear mixed effects models (LMM) of those above mentioned relationships including cities as a random factor in order to account for variation of woody vegetation features in the studied cities. P-values for model comparison were obtained by likelihood ratio tests of the full model with the city effect against the model without the city effect.

Table 1. Description of the variables included in the analysis, their units, type of variable, scale of measure and data source.

Variable	Description	Units	Scale	Source
UGS size	Urban Green area extent	m^2	UGS	Urban Atlas 2012
AGB	Tree above-ground biomass derived from allometric models	kg	Tree	(see Supplementary Table S1 for source information)
Canopy cover	Absolute coverage of tree canopies	m^2	UGS	Photo-interpretation
Canopy percentage	Relative coverage of tree canopies	%	UGS	Photo-interpretation
Mean height woody layer	Species-specific mean height of the woody layer	m	UGS	Vegetation survey
DBH	Diameter at breast height (~1.3m)	cm	Tree	Vegetation survey
Woody species richness	Woody species richness	-	UGS centroid	Vegetation survey
Species density	Amount of woody species per unit of UGA	nr. of spp./m^2	UGS	Vegetation survey

Results

An overview of European UGSs vegetation

A total of 418 woody plant species from 76 families were identified across 225 European UGSs (Table 2 and Supplementary Table S2). Each UGS had a mean of 13 ± 0.8 species of woody plants with big differences among cities (i.e., from 6.1 in Poznan to 27.2 in Paris) and 9.3 species per hectare ($9.3 \cdot 10^{-4}$ spp./m^2). The most commonly found plants were deciduous broadleaved trees. Among them, the most widely represented species were *Acer platanoides* L. (occurring in 79 UGSs, 35% of the total, in five cities) and *Quercus robur* L. (60 UGSs, six cities). The most common conifer was *Taxus baccata* L. (60 UGSs, six cities) (Supplementary Table S2). *Populus alba* L. and *Populus tremula* L., also native in Europe, were very commonly found across the studied cities but presented a low abundance within city boundaries (i.e., they occurred in six cities in a total of 21 and 16 UGSs, respectively). In addition, the North American species *Robinia pseudoacacia* L., that is currently a widely-spread invasive species in Europe, was found in 55 UGSs from all the sampled cities.

At city level, more than 50% of the species recorded were non-native, except in Antwerp (Table 2). More than 60% of woody species in UGSs from Lisbon, Zurich, Paris and Tartu were non-native. The woody layer (i.e., trees and shrubs) had a mean height of 8.7±0.2 m (ranging from 6.5m in Almada to 11.3m in Antwerp) and trees covered around 56% of the UGSs, ranging from 40% of UGSs in Almada and 74% in Tartu. Mean woody species density (number of species per unit area) in UGSs per city was distributed as follows: Antwerp 4 spp./ha, Lisbon 4.7, Poznan 4.7, Almada 6.5, Zurich: 9.5, Tartu 10.6, Paris 23.2. Distribution patterns of woody species richness and density, coefficient of variation of woody plants height, mean height of the woody layer, relative canopy cover and AGB across all the studied cities are displayed in Fig. S2. The response variables (i.e., woody species richness and density, coefficient of variation of woody plants height (CV), canopy cover and AGB) accounted for 68.4% of the overall dataset variation (Fig. S3). A main trend was formed by tree cover and AGB, while CV, woody species richness and density displayed a different trend.

Woody species richness and UGS size

We found clear latitudinal differences in the predominance of species with different species being the most common in different cities (Table 2). Highest woody species richness in a single UGS was found in Paris and Tartu (i.e., 101 and 48 woody species, respectively) (Table 2). Mean woody species richness per UGS in Paris was 27.2±3.3 and, in the rest of the cities, it ranged from 6.1±0.3 in Poznan to 15.3±1.4 in Tartu.

Table 2. Woody species richness per city: total woody species (n species), mean and range (minimum and maximum) of species richness; percentage of non-native species; most predominant woody plant taxa per city; and number of UGSs investigated.

	Woody species richness					
City	n	Mean	Range	Non-native species (%)	Most common genus and species (n UGSs)	UGSs (n)
Almada	65	9.5 ± 1	4-18	54	*Pinus* spp. (13), *Olea europaea* (12)	15
Antwerp	74	8.9 ± 0.6	1-18	40	*Acer* spp. (25), *Quercus robur* (17),	35
Lisbon	102	8.2 ± 0.6	3-19	65	*Pinus* spp. (18), *Olea europaea* (17)	34
Paris	231	27.2 ± 3.3	3-101	65	*Acer* spp. (27), *Taxus baccata* (24)	36
Poznan	56	6.1 ± 0.3	3-11	54	*Acer* spp. (27), *Acer platanoides* (21)	36
Tartu	116	15.3 ± 1.4	4-48	61	*Acer* spp. (28), *Betula pendula* and *Quercus robur* (23)	34
Zurich	137	12 ± 1.2	2-27	64	*Acer* spp. (26), *Carpinus betulus* (19)	35

Overall, large green spaces hosted slightly more woody species (Fig. 3a). At the city level, this correlation was significant in Antwerp, Lisbon, Paris and Tartu (Fig. 3a and Supplementary Table S3). In the other cities (i.e., Poznan, Zurich and Almada), UGS size did not show significant effect on woody species richness (Fig. 3a). Centroid woody species richness was not related to the size of the UGS (p>0.05) (Supplementary Fig. S1).

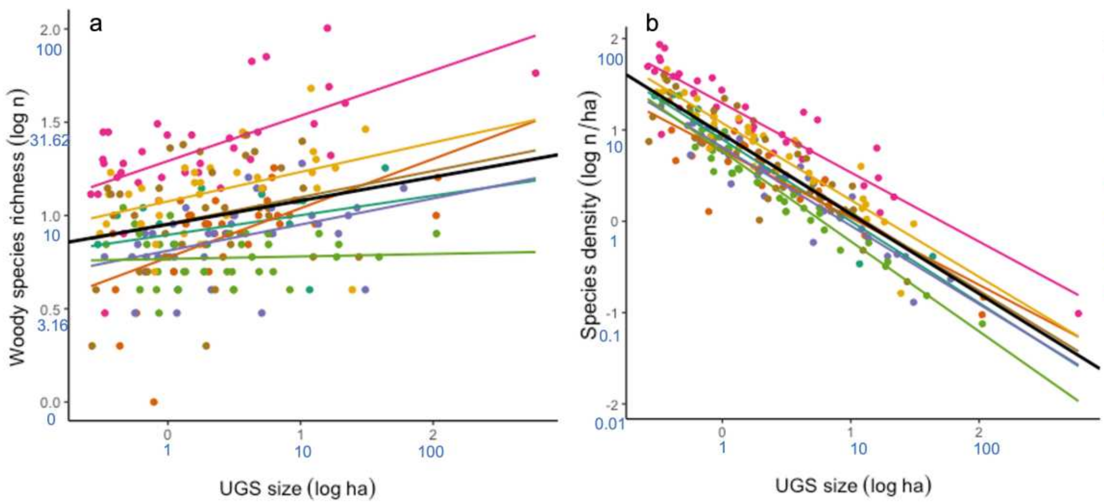


Figure 3. The relationship of UGS size with woody species richness (a) and woody species density (b) per city. Both plots are on log-scale (black numbers) and absolute scale (blue numbers). Each dot is one UGS. The species richness data comprises all the woody species found in each urban green space. The overall relationships are described by the black regression lines. Estimates of the linear mixed effect model a: $\beta = 0.16$, SE=0.02, t= 6.7, $p < 0.0001$; b: $\beta = -0.84$, SE=0.02, t= -34.8, $p < 0.0001$. Regression coefficients and significances of simple linear models are displayed in Supplementary Table S3 for each city.

Woody species richness of the whole UGS was positively related to UGS size and city had a significant effect ($\beta = 0.16$, SE=0.02, t= 6.7, $p < 0.0001$). Woody species density was negatively correlated with the size of UGSs across all cities (R^2=0.77) (Fig. 3b) with city having a significant effect (β = 0.98, SE=0.08, t= 11.9, p = 0.08). Within individual cities, the correlation coefficient varied from 0.72 in Zurich to 0.95 in Poznan (Fig. S3).

Tree cover and aboveground biomass

Bigger UGSs had generally more AGB and wider tree canopy cover (Fig. 4). Both correlations were significant in all the studied cities (Supplementary Table S3). The relationship between UGS size and canopy cover varied among cities (β = 1.03, SE=0.03, t= 34, $p < 0.0001$) (Fig. 4a), while UGS size and AGB relationship (Fig. 4b) was independent of the city (β = 0.98, SE=0.08, t= 11.9, $p > 0.05$). Not surprisingly, these two variables were highly correlated among them (Fig. S3), implying that wider canopies -normally belonging to bigger trees- inherently harbors more vegetative biomass. The strongest associations were observed between size and tree canopy cover, especially in Paris and Tartu (i.e., R^2>0.90), indicating that tree cover in these cities was generally more correlated with the size of UGS than in other cities (e.g. Antwerp, R^2=0.76). Size had also a strong effect on the amount of AGB contained in tree structure, especially in Paris (R^2=0.76) and Almada (R^2=0.66) compared to Lisbon (R^2=0.43).

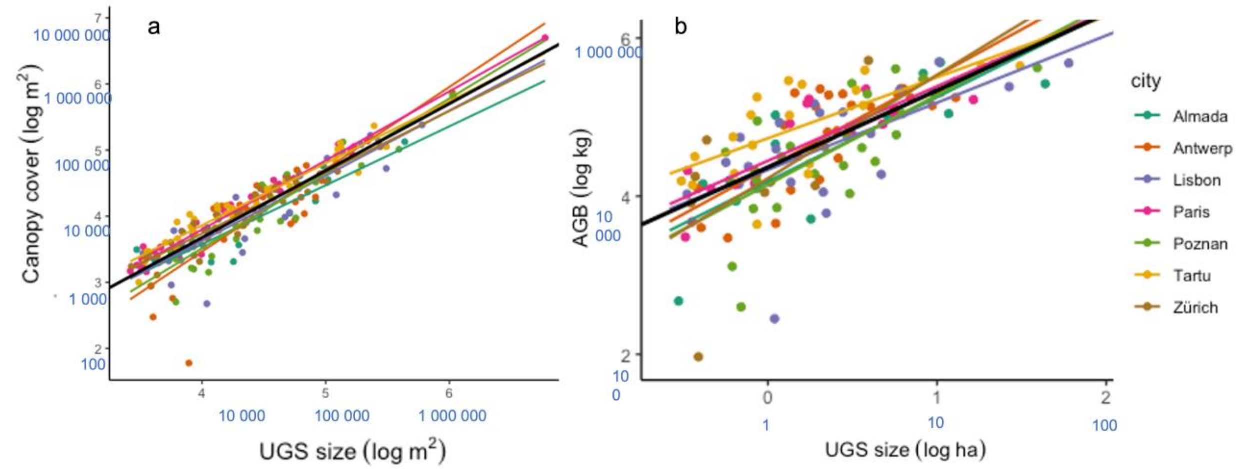


Figure 4. The relationship of UGS size with canopy cover (a) and AGB (b) per city. Both plots are on log-scale (black numbers) and absolute scale (blue numbers). Each dot represents an UGS. The overall relationships are described by the black regression lines. Estimates of the linear mixed effect model a: β = 1.03, SE=0.03, t= 34, p < 0.0001; b: β = 0.98, SE=0.08, t= 11.9, p = 0.08). Regression coefficients and significances of simple linear models are displayed in Supplementary Table S3 for each city.

Table 3 displays the distribution of tree cover and AGB in the seven cities. Despite Almada displayed the lowest tree cover percentages, it had the highest mean tree biomass per UGS after Tartu. Heights of trees (i.e., woody plants higher than 3m) ranged from 8.2±0.4 m in Almada to 11.3±0.4 m in Antwerp, on average (Table 3). Tree DBH varied considerably between cities, with a mean ranging from 20 ± 2.3 cm in Zurich to 35 ± 3.3 and 36 ± 2.1 cm in Almada and Tartu, respectively.

Table 3. Percentage of tree canopy cover, mean above-ground biomass, mean height of the woody layer and diameter at breast height (DBH) of tree plants in the seven cities.

City	Canopy cover (%)	Mean AGB (tons)	Mean height (m)	DBH (cm)
Almada	40	133	8.2 ± 0.4	35 ± 3.3
Antwerp	50	120	11.3 ± 0.4	23 ± 2.5
Lisbon	50	105	9.3 ± 0.2	31 ± 1.5
Paris	67	111	9.8 ± 0.2	24 ± 2.6
Poznan	45	92	10.7 ± 0.5	26 ± 1.5
Tartu	74	148	9.8 ± 0.2	36 ± 2.1
Zurich	56	78	10.5 ± 0.3	20 ± 2.3

Discussion

We aimed to understand how different woody vegetation is in differently sized urban green spaces of seven European cities by testing species richness and density on UGSs size gradient. Analyses confirmed our expectations - while the relationship between UGS size and woody species richness was overall positive, the relationship was weak and appeared only in certain cities (Fig 3a), while the species density had a strong negative relationship with UGS size in every studied city (Fig 3b). Bigger UGSs had more biomass and canopy cover only in absolute terms (Fig 4). Thus, woody vegetation that dominates in urban green spaces is currently managed in a way that the potential of these valuable urban areas is not by far fully realized, neither for humans nor other organisms living and visiting urban areas.

An overview of European UGSs woody vegetation

While cities tend to be more diverse in terms of plant species than the surrounding natural ecosystems (e.g. Kühn et al., 2006), a big proportion of that diversity in case of woody species is due to planting non-native species – on average 59 % in our sampled UGSs (Supplementary Table

S2). The proportion of native and non-native species and predominance of the abundance of native species in our sample are in line with previous research from other urban areas (Crosby et al., 2021; Pauleit et al., 2002).

Planting woody individuals is a common practice in urban areas, but the species selection always comprises a trade-off between environmental, social and economic features. For instance, *A. platanoides*, the most commonly found species in our European UGSs, has been shown to be effective in removing particulate matter (PM) and O_3 and storing CO_2 as part of its biomass (Baraldi et al., 2019). Nevertheless, it can also cause damage in urban structures, mainly on kerbs and other impervious surfaces (Scholz et al., 2016). Another example, *R. pseudoacacia*, is also a widespread species among the studied UGSs. It has been planted in cities in the last decades in part due to its resistance to harsh environmental conditions and diseases, even if it is considered an invasive species, especially in Central and Southern Europe (Puchalka et al. 2020). However, it has been shown to be less efficient than native species (*Tilia cordata*) in lowering temperature in cities (Rahman et al., 2019), and it is suffering the negative consequences of climate change and urban air pollution (Wilkaniec et al., 2021). In contrast to the high abundance of *R. pseudoacacia*, *Ailanthus altissima* was only found in four UGSs in Paris. This is surprising given that *A. altissima* is a fast-growing N_2-fixing tree adapted to urban conditions (i.e., it tolerates well high temperatures, drought and poor soil conditions). This species is a widespread invasive species in Europe and an important component of many urban areas across Europe (e.g. Casella et al., 2013). Our results show that its within-city distribution may be restricted to other land cover types rather than to UGSs; for example, Paź-Dyderska et al., (2020) recorded the species in Poznan recently, but only in paved and ruderal areas, claiming that management practices limit their ecological success.

Woody community composition will determine the resilience and effectiveness of UGSs in maintaining urban biodiversity and providing ESs. Our results contribute to knowing the actual species composition in UGSs. This is especially important in the context of global change that will raise temperatures affecting urban ecosystems (e.g. increased climate stress, pathogen threats) and, consequently, their functions and processes that influence the health and well-being of urban residents.

Woody species richness and UGS size

The positive relationship among area and species richness in natural areas has been demonstrated for vascular plants and other taxa also within city boundaries (e.g. Cornelis & Hermy, 2004). According to our results, this correlation is weak and city-dependent suggesting that other local factors may play an important role on shaping urban biodiversity. Since both mean and median woody species richness in the centroid were four and the minimum species recorded in UGSs varied between three and four (with few exceptions), we can say that this is the minimum species richness threshold that the municipalities apply when designing and maintaining UGSs. By testing the relationship between size of UGS and species richness at two different scales (i.e., whole UGS and centroid) we confirmed that the positive relationship between species richness and UGS size did not happen at the centroid level (Supplementary Fig. S1) as expected in natural ecosystems.

Our results suggest rather similar management practices at European scale, especially in the mean height of planted trees (between 8 and 11m height) and a preference for large trees (DBH>20cm). This is especially true for southern and northern cities (i.e., Lisbon, Almada and Tartu) where larger and older trees (i.e. mean DBH= 31-36cm) are maintained. Conserving old trees is important for ESs provision, natural heritage and cultural identity as well as for biodiversity (e.g. urban tree microhabitats, Großmann et al., 2020). Trees in Tartu displayed the biggest diameters (i.e., mean DBH = 36cm). This could be due to the increase in temperatures during the last decades (especially in urban areas, better known as urban heat island effect) that, combined with management practices that counteract some growth limiting factors, has overstimulated tree growth (Chmielewski et a., 2001). Also, urban trees in high latitudes are known to grow faster than their counterparts in rural areas or in warmer cities (Smith et al., 2019). Higher rain frequency in high latitudes, together with the urban environment (e.g. high CO_2 concentrations), might further foster tree growth rates in northern cities compared to meridional ones (Pretzsch et al., 2017). In warmer latitudes, climate may be a greater stressor for urban vegetation and act as a filter for plant species distribution and growth that is lessened by management.

Woody species density and UGS size

As expected, species density steeply decreased along the size gradient in all the sampled cities (Fig. 3b, Table S3), meaning that the current management policies do not use the full potential of urban parks in increasing biodiversity. Since the minimum amount of woody species used when designing and managing urban green spaces is ~4 woody species, park managers plant more species when more space is available, but only up to a certain limit that depends on the city (e.g.

the maximum species richness in a UGS was 11 in Poznan and 101 in Paris - even though the UGSs in this study were selected based on comparable size classes).

Using species density in urban ecosystems is so far an unexplored practice that can be used as an efficient indicator of how policy instruments have been incorporating biodiversity in UGSs. In our study we included all woody species, i.e., also shrubs when accounting for species richness and density, since they can contribute significantly to the overall diversity and also provide ESs (e.g. noise reduction) (Moudrý et al., 2021).

Tree cover and aboveground biomass

Several studies have focused on how tree canopy properties in urban areas benefit city dwellers (Gillner et al., 2015; Pataki et al., 2011) and increase species richness of other organisms inhabiting urban ecosystems (Moudrý et al., 2021). Mouratidis (2019) found that urban tree cover increased people's feeling of safety. One of the most studied ESs derived from urban trees is their capacity to cool the urban environment by means of evapotranspiration, canopy shadow and reflection of the solar radiation (Venter et al., 2020; Zardo et al., 2017). This cooling effect increases with tree species richness (Wang et al., 2021).

The positive correlation among UGS size and tree canopy cover in absolute terms (i.e., total extent of tree crowns) was not found when relative canopy cover (i.e., percentage of UGS covered by trees) was considered. We argue that analyzing the relative amount of canopy cover in UGSs (usually expressed in %) is misleading in case of smaller UGSs - only a few tree individuals are necessary to provide nearly 100% canopy cover in small UGSs. However it is not sufficient amount of canopy to provide habitat for diverse biota, as the other species are often specialized to certain evolutionary lineages, or woody species types (conifers vs. broadleaf trees) and more specific traits (e.g. ridged bark). In addition, animals often tend to be highly territorial, which means that the high canopy cover percentage in an UGS does not ensure diverse biota inhabiting these UGSs. Which is why we used absolute, and not relative amount of canopy cover in our analysis (Fig. 4). However, relative canopy cover (Table 3) indicated that park designers promote non-tree land cover types (e.g. open lawns, paved surfaces) when planning and designing UGSs. All the studied cities had at least some UGSs that were fully covered by tree canopy (>90% of UGS extent), with 50 of them covering more than 75% of the entire UGS. Percentage of tree canopy cover and vegetation structure have been proven to strongly and directly influence temperature in cities (Chen et al., 2020). Therefore, local planning strategies should consider both horizontal and vertical components of the woody layer when designing management instruments in order to create a better urban environment.

Although large areas are slightly more biodiverse than smaller ones (Fig. 3a), increasing the size of a UGS is most probably not feasible in an already densely urbanized landscape, like in European cities. However, the strong negative relationship between species density and UGS size implicates that the existing UGSs could harbor much more species per unit area than they currently do. Planting more woody plant species that are suitable for the urban environmental condition is a cost-effective way to fulfill the demand for ESs in urban environments. Future policy regarding urban green planning should shift the focus more on community and ecosystem level functioning of UGSs, and woody vegetation is the fundamental foundation for enhancing the functionality and persistence of urban ecosystems (Hirons et al., 2019).

The differences found among the general trends and correlations at city level indicate that other parameters not considered in the study could be influential. For instance, woody species richness displayed a positive relationship with canopy cover when considering all the UGSs together. However, at the city scale, this correlation was only significant in Antwerp. This and other city-specific effects can be overcome if key local factors are known (e.g. socio-economic preferences). Another possible hidden trend is that an underlying mechanism to explain the role of size in multiple vegetation parameters could rely on the influence of UGS management option, i.e., management options of the largest UGSs tend to be similar when compared to smaller sites. Moreover, the selection of the Urban Atlas as an homogeneous basis of LULC information for studied sites selection influences the type of green spaces considered in the study, as they consider different types of urban vegetated surfaces into 'Green urban areas' class. However, since this happens in all the selected cities in comparable proportions, it probably does not imply any bias in our results. Still, we highlight that creating a continental scale comparable cartography with higher thematic classification is necessary to provide more details that allow future studies to separate the 'Green urban areas' class into sub-classes differing on the management practices or type of use.

Conclusion

Urban green spaces are multifunctional elements of the urban matrix, providing several social, environmental and economic benefits. Woody vegetation constitutes the main component of UGSs, providing valuable ecosystem services for humans, but also food and shelter for other organisms. However, there is very little comparable ecological data about vegetation in UGSs.

This topic is of great interest not only for ecological research but also for urban planners and urban landscape designers.

Our extensive field survey in 225 UGSs with different sizes in seven European cities showed at all levels of analysis that: 1) species richness of UGS was only weakly related with UGS size; while 2) the species density had a strong negative relationship with UGS size. Moreover, we provide a complete list of the most common species among the seven European cities. There seems to be a certain threshold of how much effort is put into management of urban green spaces in the context of woody diversity. Thus, there seems to be a so far unseized opportunity to increase species density in the largest parks by management change only. This could create more heterogeneity and thus improve conditions for both other organisms living in UGSs, but also enhance ecosystem services beneficial for humans.

The outcomes of this research will assist urban planners and policy makers through the current biodiversity in urban green spaces and their unused potential. This is especially useful in the frame of the EU Biodiversity Strategy to 2030 which calls on cities to develop Urban Greening Plans by the end of 2021, putting special attention on urban biodiversity. In addition, our findings can also be used in urban ecology research involving a variety of taxa and ecosystem services.

References

Aronson, M.F.J., La Sorte, F.A., Nilon, C.H., Katti, M., Goddard, M.A., Lepczyk, C.A., ... Winter, M. (2014). A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings. Biological Sciences, 281*(1780), 20133330. https://doi.org/10.1098/rspb.2013.3330pmid:24523278

Bar-On, Y.M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. *Proceedings of the National Academy of Sciences, 115*(25), 6506-6511. https://doi.org/10.1073/pnas.1711842115

Baraldi, R., Chieco, C., Facini, N.O., Rapparini, F., Morrone, L., Rotondi, A., & Carierò, G. (2019). An integrated study on air mitigation potential of urban vegetation: From a multi-trait approach to modeling. *Urban Forestry & Urban Greening, 41*, 127-138. https://doi.org/10.1016/j.ufug.2019.03.020.

Baruch, Z., Liddicoat, C., Cando-Dumancela, C., Laws, M., Morelli, H., Weinstein, P., ... Breed, M.F. (2020). Increased plant species richness associates with greater soil bacterial diversity in urban green spaces. *Environmental Research*, 110425. https://doi.org/10.1016/j.envres.2020.110425 *Article in press*

Beery, T., Stålhammar, S., Jönsson, K. I., Wamsler, C., Bramryd, T., Brink, E., ... Schubert, P. (2016). Perceptions of the ecosystem services concept: opportunities and challenges in the Swedish municipal context. *Ecosystem Services, 17*, 123-130. https://doi.org/10.1016/j.ecoser.2015.12.002

Beninde, J., Veith, M., & Hochkirch, A. (2015). Biodiversity in cities needs space: a meta-analysis of factors determining intra- urban biodiversity variation. *Ecology letters, 18*(6), 581-592. https://doi.org/10.1111/ele.12427

Bjerke, T., Østdahl, T., Thrane, C., & Strumse, E. (2006). Vegetation density of urban parks and perceived appropriateness for recreation. *Urban Forestry & Urban Greening 5*(1), 35-44. https://doi.org/10.1016/j.ufug.2006.01.006

Casella, F., & Burro, M. (2013). Ailanthus altissima (tree of heaven): Spread and harmfulness in a case-study urban area. *Arboricultural Journal, 35*(3), 172-181. https://doi.org/10.1080/03071375.2013.852352

Capotorti, G., Alós Ortí, M., Copiz, R., Fusaro, L., Mollo, B., Salvatori, E., & Zavattero, L. (2019). Biodiversity and ecosystem services in urban green infrastructure planning: A case study from the metropolitan area of Rome (Italy). *Urban Forestry & Urban Greening, 37*, 87-96. https://doi.org/10.1016/j.ufug.2017.12.014

Chen, J., Jin, S., & Du, P. (2020). Roles of horizontal and vertical tree canopy structure in mitigating daytime and nighttime urban heat island effects. *International Journal of*

Applied Earth Observation and Geoinformation 89, 102060. https://doi.org/10.1016/j.jag.2020.102060

Chmielewski, F-M., & Rötzer, T. (2001). Response of tree phenology to climate change across Europe. *Agricultural and Forest Meteorology, 108*(2), 101-112. https://doi.org/10.1016/S0168-1923(01)00233-7

Cornelis, J., & Hermy, M.. (2004). Biodiversity relationships in urban and suburban parks in Flanders. *Landscape and Urban Planning, 69*(4), 385-401. https://doi.org/10.1016/j.landurbplan.2003.10.038

Copernicus. Urban Atlas (2012). Available online: https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012?tab=download

Crosby, M.K., McConnell, T.E., Holderieath, J.J., Kjartasson, B.Þ, Traustason, B., Jónsson, Þ.H., ... Oddsdóttir, E.S. (2021). Urban street tree characteristics and benefits in city centre, Reykjavik, Iceland. *Trees, Forest and People, 4*, 100066. https://doi.org/10.1016/j.tfp.2021.100066

Ellis, E.C., & Ramankutty, N. (2008). Putting people in the map: anthropogenic biomes of the world. *Frontiers in Ecology and the Environment, 6*(8), 439-447. https://doi.org/10.1890/070062

EC, (European Commission). (2020). EU Biodiversity Strategy for 2030: bringing nature back into our lives. COM(2020) 380 final. https://eur-lex.europa.eu/resource.html?uri=cellar:a3c806a6-9ab3-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF

Gillner, S., Vogt, J., Tharang, A., Dettmann, S., & Roloff, A. (2015). Role of street trees in mitigating effects of heat and drought at highly sealed urban sites. Landscape and Urban Planning, Volume 143, November 2015, Pages 33-42

Godefroid, S., & Koedam, N. (2007). Urban plant species patterns are highly driven by density and function of built-up areas. *Landscape Ecology, 22*, 1227–1239 (2007). https://doi.org/10.1007/s10980-007-9102-x

Großmann, J., Pyttel, P., Bauhus, J., Lecigne, B., & Messier, C. (2020). The benefits of tree wounds: Microhabitat development in urban trees as affected by intensive tree maintenance. *Urban Forestry & Urban Greening, 55*, 126817. https://doi.org/10.1016/j.ufug.2020.126817

Grote, R., Samson, R., Alonso, R., Amorim, J. H., Cariñanos, P., Churkina, G., ... Calfapietra, C. (2016). Functional traits of urban trees: air pollution mitigation potential. *Frontiers in Ecology and the Environment, 14*(10), 543-550. https://doi.org/10.1002/fee.1426

Grove, J.M., Pickett, S.T.A., Whitmer, A., & Cadenasso, M.L. (2013). Building an Urban LTSER: The Case of the Baltimore Ecosystem Study and the D.C./B.C. ULTRA-Ex Project. In S.J. Singh, H. Haberl, M. Chertow, M. Mirtl, M. Schmid (Eds.). *Long Term Socio-ecological Research*. Springer. https://doi.org/10.1007/978-94-007-1177-8

Großmann, J., Pyttel, P., Bauhus, J., Lecigne, B., & Messier, C. (2020). The benefits of tree wounds: Microhabitat development in urban trees as affected by intensive tree maintenance. *Urban Forestry & Urban Greening*, 55, 126817. https://doi.org/10.1016/j.ufug.2020.126817

Kohout, M., & Kopp, J. (2020). Green space ideas and practices in European cities. *Journal of Environmental Planning and Management, 63*(14), 1–20. https://doi.org/10.1080/09640568.2020.1716698

Kowarik I. (2011). Novel urban ecosystems, biodiversity, and conservation. Environmental pollution, 159(8-9), 1974–1983. https://doi.org/10.1016/j.envpol.2011.02.022

Kowarik, I., von der Lippe, M., & Cierjacks, A. (2013). Prevalence of alien versus native species of woody plants in Berlin differs between habitats and at different scales. Preslia, 85, 113-132

Kühn, I., Brandl, R., & Klotz, S. (2004). The flora of German cities is naturally species rich. *Evolutionary Ecology Research, 6*, 749–764

Kühn, I., & Klotz, S. (2006). Urbanization and homogenization – Comparing the floras of urban and rural areas in Germany. *Biological Conservation, 127*(3), 292–300. https://doi.org/10.1016/j.biocon.2005.06.033

Locosselli, G.M., de Camargo, E.P., Moreira, T.C.L., Todesco, E., de Fátima Andrade, M., de André, C.D.S., ... Buckeridge, M.S. (2019). The role of air pollution and climate on the growth of urban trees. *Science of The Total Environment, 666*, 652-661. https://doi.org/10.1016/j.scitotenv.2019.02.291

McKinney ML (2002) Urbanization, biodiversity, and conservation. *BioScience 52*, 883–890. https://doi.org/10.1641/0006-3568(2002)052[0883:UBAC]2.0.CO;2

McKinney, M. L. (2008). Effects of urbanization on species richness: a review of plants and animals. *Urban Ecosystems 11*, 161–176. https://doi.org/10.1007/s11252-007-0045-4

Moudrý, V., Moudrá, L., Barták, V., Bejček, V., Gdulová, K., Hendrychová, M., ... Šálek, M. (2021). The role of the vegetation structure, primary productivity and senescence derived from airborne LiDAR and hyperspectral data for birds diversity and rarity on a restored site. *Landscape and Urban Planning, 210*, 104064. https://doi.org/10.1016/j.landurbplan.2021.104064

Mouratidis, K. (2019). The impact of urban tree cover on perceived safety. *Urban Forestry & Urban Greening, 44*, 126434. 10.1016/j.ufug.2019.126434

Nielsen, A.B., van den Bosch, M., Maruthaveeran, S. van den Bosch, C.K. (2014). Species richness in urban parks and its drivers: A review of empirical evidence. *Urban Ecosystems, 17*, 305–327 . https://doi.org/10.1007/s11252-013-0316-1

Pataki, D.E., McCarthy, H.R., Litvak, E., & Pincetl, S. (2011). Transpiration of urban forests in the Los Angeles metropolitan area. *Ecological Applications, 21*(3), 661–677. https://doi.org/10.1890/09-1717.1

Pauleit, S., Jones, N., García-Martín, G., García-Valdecantos, J.L., Marie Rivière, L., Vidal-Beaudet, ... Randurp, T.B. (2002). Tree establishment practice in towns and cities – Results from a European survey. *Urban Forestry & Urban Greening 1*, 83-96. https://doi.org/10.1078/1618-8667-00009

Paź-Dyderska, S., Ladach-Zajdler, A., Jagodziński, A.M., & Dyderski, M.K. (2020). Landscape and parental tree availability drive spread of Ailanthus altissima in the urban ecosystem of Poznań, Poland. *Urban Forestry & Urban Greening. 56*, 126868. https://doi.org/10.1016/j.ufug.2020.126868

Pinho, P., Casanelles-Abella, J., Luz, A. C., Kubicka, A. M., Branquinho, C., Laanisto, L., Neuenkamp, L., Alós Ortí, M., Obrist, M. K., Deguines, N., Tryjanowski, P., Samson, R., Niinemets, L., & Moretti, M. (2021). Research agenda on biodiversity and ecosystem functions and services in European cities. *Basic and Applied Ecology*, 53, 124–133. https://doi.org/10.1016/j.baae.2021.02.014

Pretzsch, H., Biber, P., Uhl, E., Dahlhausen, J., Schütze, G., Perkins, D., ... Lefer, B. (2017). Climate change accelerates growth of urban trees in metropolises worldwide. *Scientific Reports 7,* 15403. https://doi.org/10.1038/s41598-017-14831-w

Puchałka, R., Dyderski, M. K., Vítková, M., Sádlo, J., Klisz, M., Netsvetov, M., ... Jagodziński, A.M. (2020). Black locust (*Robinia pseudoacacia* L.) range contraction and expansion in Europe under changing climate. *Global Change Biology, 27*(8), 1587-1600. https://doi.org/10.1111/gcb.15486

Pyšek, P. (1998). Alien and native species in central European urban floras: a quantitative comparison. *Journal of Biogeography, 25*(1), 155–163. https://doi.org/10.1046/j.1365-2699.1998.251177.x

R Core Team. (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rahman, M.A., Moser, A., Rötzer, T., & Pauleit, S. (2019). Comparing the transpirational and shading effects of two contrasting urban tree species. *Urban Ecosystems, 22*, 683-697. https://doi.org/10.1007/s11252-019-00853-x

Säumel, I., Kowarik, I. & Butenschön, S. (2010). Green traces from past to future: the interplay of culture and ecological processes in European historical parks. *Acta Horticulturae 881*, 933-938. https://doi.org/10.17660/ActaHortic.2010.881.156

Salinitro, M., Alessandrini, A., Zappi, A., Melucci, D., & Tassoni, A. (2018). Floristic diversity in different urban ecological niches of a southern European city. *Scientific Reports, 8*, 15110. https://doi.org/10.1038/s41598-018-33346-6

Scholz, M., Uzomah, V.C., & Al-Faraj, F.A.M. (2016). Potential tree species for use in urban areas in temperate and oceanic climates. *Heliyon, 2*(9), e00154. https://doi.org/10.1016/j.heliyon.2016.e00154

Shanahan, D.F., Miller, C., Possingham, H.P., & Fuller, R.A. (2011). The influence of patch area and connectivity on avian communities in urban revegetation. *Biological Conservation, 144*, 722-729. https://doi.org/10.1016/j.biocon.2010.10.014

Shwartz, A., Muratet, A., Simon, L., & Julliard, R. (2013). Local and management variables outweigh landscape effects in enhancing the diversity of different taxa in a big metropolis. *Biological Conservation, 157*, 285–292. https://doi.org/10.1016/j.biocon.2012.09.009

Smith, I.A., Dearborn, V.K., & Hutyra, L.R. (2019). Live fast, die young: Accelerated growth, mortality, and turnover in street trees. *PLoS ONE, 14*(5): e0215846. https://doi.org/10.1371/journal.pone.0215846

Talal, M.L., & Santelmann, M.V. (2019). Plant Community Composition and Biodiversity Patterns in Urban Parks of Portland, Oregon. *Frontiers in Ecology and Evolution, 7*, 201. https://doi.org/10.3389/fevo.2019.00201

Threlfall, C.G., Ossola, A., Hahs, A.K., Williams, N.S.G., Wilson, L., & Livesley, S.J. (2016). Variation in Vegetation Structure and Composition across Urban Green Space Types. *Frontiers in Ecology and Evolution, 4*, 66. https://doi.org/10.3389/fevo.2016.00066

Tsiotsiou, V., & Christodoulakis, D. (2010): Woody plants in urban biotopes: studies in Patras (Greece). *Fresenius Environmental Bulletin, 19*(12a), 2958–2965.

Venter, Z.S., Krog, N.H., & Barton, D.N. (2020). Linking green infrastructure to urban heat and human health risk mitigation in Oslo, Norway. *Science of The Total Environment, 709*, 136193. https://doi.org/10.1016/j.scitotenv.2019.136193

Wang, X., Dallimer, M., Scott, C.E., Shi, W., & Gao, J. (2021). Tree species richness and diversity predicts the magnitude of urban heat island mitigation effects of greenspaces. *Science of The Total Environment, 770*, 145211. https://doi.org/10.1016/j.scitotenv.2021.145211

Wilkaniec, A., Borowiak-Sobkowiak, B., Irzykowska, L., Breś, W., Świerk, D., Pardela, Ł., ... Wielgus, K. (2021). Biotic and abiotic factors causing the collapse of Robinia pseudoacacia L. veteran trees in urban environments. *PLoS ONE, 16*(1), e0245398.

Yang, J., La Sorte, F., Pyšek, P., Yan, P., Nowak, D. and McBride, J., 2015. The compositional similarity of urban forests among the world's cities is scale dependent. Global Ecology and Biogeography, 24(12), pp.1413-1423. https://doi.org/10.1111/geb.12376

Zardo, L., Geneletti, D., Pérez-Soba, M., & Van Eupen, M. (2017). Estimating the cooling capacity of green infrastructures to support urban planning. *Ecosystem Services 26, Part A*, 225-235. https://doi.org/10.1016/j.ecoser.2017.06.016