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Original scientific article

PLANT SPECIES DIVERSITY AND INVASIBILITY OF (PERI-)URBAN FORESTS OF LJUBLJANA, SLOVENIA

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ABSTRACT: Vascular plant species were assessed in the (peri-)urban forests of the Ljubljana region. Among the forests investigated were alluvial and riparian forests with high levels of plant species diversity. However, due to the vicinity of urban areas, the human impact on these forests is intense, and they are also highly exposed to the invasion of alien species. Within three forest locations in urban and peri-urban forests in the Ljubljana region, the vascular plant species were recorded, and their cover and origin status were estimated. In total, 161 vascular plant species were recorded at three study sites. Among them, 13 alien species were recognized. The majority of them were declared to be invasive species in Slovenia, which adversely affect the forest habitats and outcompete native plant species, and consequently, decrease the provisioning of some important ecosystem services such as erosion protection, recreation usage, biodiversity hosting, etc. The most abundant invasive species in the studied sites were *Solidago gigantea* Ait. and *Fallopia japonica* (Houtt.) Ronse Decr. The (peri-)urban forests of Ljubljana are under the significant impact of invasive plant species. The dynamics of expansion of invasive species should be carefully monitored.
Keywords: plant species, diversity, invasive species, (peri-)urban forest, Ljubljana.

1 INTRODUCTION

In urban environments, the proportion of alien species is closely related to the disturbance level (Chytrý *et al.*, 2008; Kowarik, 2008). In many heavily disturbed habitats (brownfields, urban wastelands, railway corridors, and industrial sites), alien species may appear as dominant species. Late-successional habitats are expected to host smaller populations of aliens; however, woody vegetation on urban sites may also include a surprisingly high amount of aliens (Kowarik, 2008).

In Slovenia, there are roughly 50 invasive vascular plant species (Jogan *et al.*, 2012). Black locust (*Robinia pseudoacacia* L.) with 0.6% of the total forest growing stock is the most widespread alien (non-native or non-indigenous) tree species in Slovenian forests (Kutnar & Pisek, 2013). It is widely distributed in lowlands and hilly areas, and in some urban areas. Due to ongoing climate change, even higher share of black locust (Kutnar & Kobler, 2013) and some other invasive plant species can be expected in the future (Dakskobler *et al.*, 2016).

Habitats vary considerably in the level of invasion (number or proportion of alien plant species they contain), which depends on local habitat properties, propagule pressure, and climate (Chytrý *et al.*, 2008). Lowland forests in Slovenia, such as riverine and floodplain forests woods, are highly exposed to the invasion and sub-spontaneous spread of invasive alien species (Dakskobler *et al.*, 2013, 2016). Rivers may act as the dispersal corridors of invasive alien species (Säumel & Kowarik, 2010). These invasive species may adversely affect the forest habitats and outcompete native plant species. Many invasive taxa have transformed both the structures and functions of ecosystems (Rejmánek *et al.*, 2005).

Among the (peri-)urban forests of the Ljubljana region, there are also alluvial and riparian forest types with high level of plant species diversity. However, due to the vicinity of urban areas, the human impact on these forests is intense, and they are also exposed to the invasion of alien species. Therefore, the aim of this study is to address the plant species diversity and to determine the number of alien plant species in selected urban and peri-urban forests in the Ljubljana region. Within the same EMoNFUr Project as in the Ljubljana region, the vegetation and flora in urban forests of Lombardy, Italy were also studied (Digiovinazzo & Padoa-Schioppa, 2014).

2 STUDY AREA AND METHODS

2.1 Study plots and vegetation assessment

In the Ljubljana region, plots for the plant species assessment were set in three different forest sites: i) Gameljne site-1 (G1), ii) Gameljne site-2 (G2), and iii) Rožnik site (R) (Fig. 1).

Figure 1: Position of studied locations in Ljubljana region (Google Earth); G1 - Gameljne site-1; G2 - Gameljne site-2; R - Rožnik site

The Gameljne site-1 was selected on the upper terrace of the Sava River. It is a relatively dry site (gravel bedrock) without direct river influences (Fig 2). The second location, the Gameljne site-2 was selected in the flood area on the lower terrace of the Sava River (Fig 3). Both Gameljne sites are in the peri-urban area. The third

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location was the Rožnik site in an urban area, close to the city centre (Fig 4).

Figure 2: Forest stand on the Gameljne site-1 with *Pinus sylvestris* L. in the upper tree layer, and various broadleaves in the lower tree layer (Photo: L. Kutnar)

Figure 3: The Gameljne site-2 near Ljubljana in spring aspect; it is under direct impacts of the Sava River (Photo: L. Kutnar)

Figure 4: Forest stand at the Rožnik site is located in Ljubljana urban area (Photo: L. Kutnar)

The size of each study site (location) was 2,500 m² (50 meters × 50 meters). Within each site, two different plots were installed; the large plot (400 m²) was set in the centre; 10 small plots (4 m²) were randomly selected around the large plot (Fig. 5).

In April 2013, and between June and July 2013, the assessments of plants and vegetation were performed on large and small plots.

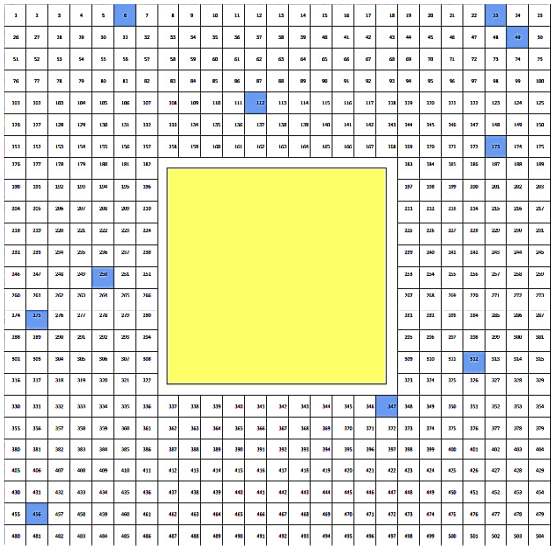

Figure 5: Sampling design; distribution of large plot (in the centre) and 10 randomly distributed small plots around the centre

The cover of all vertical vegetation-layers (moss, herb, shrub, and tree layer) was estimated. The vertical vegetation-layers were defined according to the ICP-Forests protocol (Canullo *et al*., 2011). The percentage cover of each of the above-mentioned layers, as well as the cover of bare soil and of surface rocks, were visually estimated.

All vascular plant species were recorded separately in each vertical layer (herb, shrub, and tree layer) (Canullo *et al*., 2011). On large plots, the plant species cover was estimated using the Barkman *et al*. (1964) method, and the modified Londo (1975) method for small plots. The sources of the plant species nomenclature were Flora Europaea (Tutin *et al*., 1964-1980; 1993) and national flora (Martinčič *et al*., 2007).

2.2. Data analysis

The field data (vegetation relevés) of two temporal repetitions (spring and summer 2013) were merged into one common dataset for each plot. For further vegetation analysis, the cover estimations, for example from r to 5 of the Barkman (1964) scale and from 0.1 to 10 of the Londo (1975) scale, have been transformed to cover estimations in percentage, for example from 0.01% to 87.5% of the Barkman scale, and from 0.5% to 97.5% of the Londo scale.

The following measures of diversity were investigated:

1) Species richness (N) refers to the number of all plant species within a given plot;

2) The Shannon diversity index (H´) is a measure that describes the structural composition of communities:

$$H' = -\sum_{i=1}^{R} p_I \ln p_i$$

where p_i is a relative cover of species i in a record.

The plant species diversity, diversity index, and share of invasive alien species were analysed for all large and small plots. Based on the plant species composition in vertical vegetation layers, 30 small plots and main diversity gradients were plotted in non-metric multidimensional scaling (NMS ordination) (McCune & Mefford, 2011).

3 RESULTS AND DISCUSSION

3.1 Plant species composition and diversity

In the secondary pine forest of the Gameljne site-1, *Pinus sylvestris* L. was the dominant species in the upper tree layer, and *Carpinus betulus* L., *Tilia cordata* Mill., and *Corylus avellana* L. were recorded in the lower tree layer. In the forest stand of the Gameljne site-2 near the Sava River, *Alnus glutinosa* (L.) Gaertn., *Salix eleagnos* Scop., *Acer pseudoplatanus* L., and *Fraxinus excelsior* L. were among the most abundant tree species. Plots of the Rožnik site were overgrown by *Quercus petraea* (Matt.) Liebl., *Picea abies* (L.) Karst., *Castanea sativa* Mill., and *Robinia pseudacacia* L.

The most abundant shrub species on the Gameljne site-1 were *Ligustrum vulgare* L., *Lonicera caprifolium* L., and *Viburnum lantana* L.; *Rubus caesius* L. and *Cornus sanguine* L. on the Gameljne site-2; and *Rubus hirtus* W. & K. on the Rožnik site.

The most common herb-layer species on the Gameljnesite-1 were *Carex alba* Scop., *Calamagrostis varia* (Schrad.) Host, *Anemone trifolia* L., *Carex flacca* Schreb., *Galanthus nivalis* L., and *Melica nutans* L.. The dominant herb-layer species on the Gameljne site-2 were *Solidago gigantea* Ait., *Galanthus nivalis* L., *Allium ursinum* L., *Aegopodium podagraria* L., *Fallopia japonica* (Houtt.) Ronse Decr., *Lamium orvala* L., and *Ranunculus ficaria* L. The dominant herb-layer species on the Rožnik site were *Anemone nemorosa* L., *Erythronium dens-canis* L., *Pteridium aquilinum* (L.) Kuhn, *Crocus vernus* (L.) Hill subsp. *vernus*, and *Maianthemum bifolium* L.

On all large and small plots on three sites (Gameljne site-1 and Gameljne site-2, Rožnik site), 161 vascular plant species were recorded in total (Table I). The number of vascular species varied between 61 (Rožnik site) and 85 (Gameljne site-2) per site.

Table I: Species diversity at three sites in the (peri)-urban forest

	All sites	Gameljne site-1	Gameljne site-2	Rožnik site
All plots	n=33	n=11	n=11	n=11
N Vascular species	161	69	85	61
Tree species	36	21	14	22
Shrub species	21	14	15	7
Herb species	104	34	56	32
Invasive species	9	0	8	3
Large plot (400 m^2)	n=3	n=1	n=1	n=1
N species per plot	63.3	66	68	56
Shannon H'	3.39	3.17	3.51	3.48
Small plot (4 m^2)	N=30	N=10	N=10	N=10
N species per plot	19.3	17.7	22.1	18.1
Shannon H'	2.24	2.26	2.34	2.09

In total, in all vertical vegetation layers; herb, shrub, and tree layers, 36 tree species were identified. The number of all shrub species, including climbers, was 21. Altogether, 104 herb layer species (including only non-woody species) were documented.

On average, 63 plant species per large plot, and 19 plant species per small plot were documented.

3.2 Alien species

On the Gameljne site-2 near the Sava River, and on the Rožnik urban site, several alien plant species were found (Table I, Fig. 6). The majority of them have been declared to be invasive species in Slovenia. These invasive plant species, which represent 6% of the flora recorded (Fig. 7), probably come from different urban areas, e.g. gardens and parks. The majority of invasive species identified on studied sites are of North American or Asian origin.

Figure 6: In summer time, the forest floor of the Gameljne site-2 was covered by a dense layer of invasive alien species, *Solidago gigantea*, *Fallopia japonica*, *Rudbeckia laciniata* L. and others (Photo: L. Kutnar)

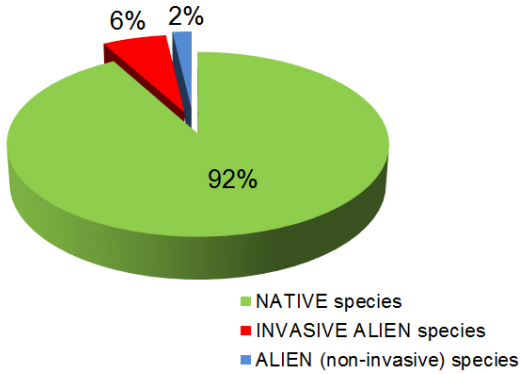

Figure 7: Alien and invasive species in the floristic spectrum of three (peri-)urban forests in the Ljubljana region

Among three sites in (peri-)urban forests in the Ljubljana region in Slovenia, the level of plant invasion was the highest at the Gameljne site-2 (9% or 8 species) (Table I). The most abundant invasive species on this site were *Solidago gigantea* and *Fallopia japonica* (including hybrid *F.* x *bohemica*) (Fig. 8 and Fig. 9). Other invasive species were *Rudbeckia laciniata* (Fig. 10), *Erigeron annuus* (L.) Pers., *Helianthus tuberosus* L., *Impatiens glandulifera* Royle, *Impatiens parviflora* DC., and *Physocarpus opulifolius* (L.) Maxim.

Besides the invasive species *Robinia pseudacacia*, *Berberis thunbergii* DC., and *Impatiens parviflora*, three alien but non-invasive species were also recorded on the Rožnik site, namely *Aesculus hippocastanum* L., *Prunus laurocerasus* L., and *Juglans mandshurica* Maxim.

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Figure 8: *Solidago gigantea*, and similar species *Solidago canadensis* L. are invasive alien species of riverine, floodplain and swamp forests in Slovenia (Photo: L. Kutnar)

Figure 9: *Fallopia japonica* and *F.* x *bohemica* are invasive species that colonize different riparian ecosystems, roadsides, and waste places. (Photo: L. Kutnar)

Figure 10: *Rudbeckia laciniata*is one of the most widespread species on the Gameljne site-2 and also in Slovenia (Photo: L. Kutnar)

3.2 Main ecological and diversity gradients

Distribution of plots in the NMS ordination space reflects the main ecological and diversity gradients (Fig. 11). Axis 2 correlates closely with the gradient of water availability. At the lower values of Axis 2, the Gameljne site-2 plots are placed, which are under significant river impact, including occasional flooding. The forest vegetation of this site belongs to a *Salici-Populetum* s. lat. association.

At the upper part of the ordination space (Fig. 11), plots on the Gameljne site-1 and Rožnik site, where direct water impacts are not pronounced, may be found. The forest vegetation of these two sites may be considered a *Querco-Carpinetum* s. lat. plant community. However, the forest community composition of both sites is rather different, mostly due to differences in soil and bedrock properties. Both sites were exposed to significant human impacts, such as the provision of timber and fuel wood, litter gathering for farm use, collecting of non-timber forest products, and urbanisation, industrialisation, recreation activities mostly in the last decades, and therefore these forest stands were modified or even converted to secondary forests.

Additionally, Figure 11 depicts the main diversity gradients. On average, plots at the bottom of the ordination space are characterized by higher plant species diversity (see also Table I). The abundance of invasive plant species was higher on the Gameljne site-2 than on the Rožnik site, and on the Gameljne site-1 where no invasive species were found. Values of the Shannon diversity index were slightly higher on the Gameljne site-2 (2.34) and the Gameljne site-1 (2.26) than on the Rožnik site (2.09) (Table I, Fig. 11).

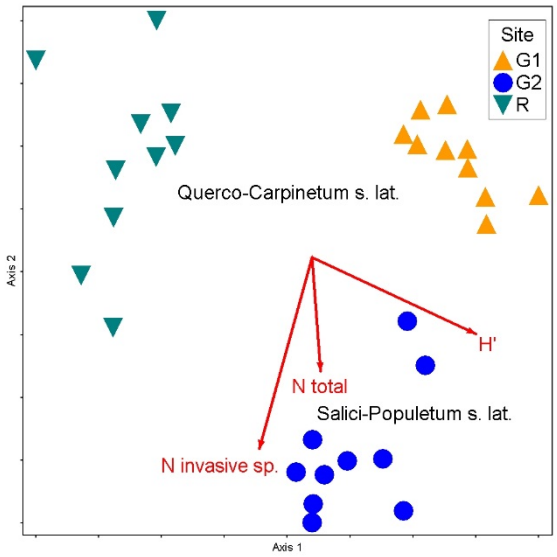

Figure 11: NMS ordination of small plots. Three test sites (locations) are represented by symbols as follows: G1 – Gameljne site-1; G2 – Gameljne site-2; R – Rožnik site. Scaling of plots was based on the plant species composition and species abundance in vertical vegetation layers. The main diversity gradients (the number of all vascular species (N total), the number of invasive alien species (N invasive sp.), and Shannon diversity index (Shannon H')) are plotted. The lengths of arrows depict the increase in species number or in theindex value.

4 CONCLUSIONS

In studied sites of the Ljubljana (peri-)urban forest area, high levels of vascular plant species diversity were determined. If the diversity of these forests is compared with the other main forest types of Slovenia (e.g. ICP

Forest Level II plots; Kutnar, 2006) the species diversity of (peri-)urban forests is, on average, higher.

The total number of plant species (161 species) recorded on three sites in Ljubljana region is also significantly higher than in the sites within different lowland forests, urban plantations, and parks in the Lombardy region, Italy (120 species on 14 sites; Digiovinazzo & Padoa-Schioppa, 2014). In both regions, the same harmonised method for evaluation of plant species diversity was applied.

However, the significant impact of invasive alien plant species was determined in the (peri-)urban forests of Ljubljana. Among all the plant species identified on studied sites 8% were alien and 6% of all were invasive. In comparison to the studied Ljubljana forests, the portion of alien species in Lombardy urban forests and parks was higher (15%; Digiovinazzo & Padoa-Schioppa, 2014). Kowarik (2008) reported an even higher amount of alien species number (33%) in urban stands dominated by *Robinia pseudoacacia*, but it is known that disturbed human-made habitats with herbaceous vegetation are the most invaded by aliens (Chytrý *et al.*, 2008).

It was suggested that there is not necessarily a relationship between the invasibility of a plant community and the number of species present in that community (Crawley *et al*., 1999; Davis *et al*., 2000). Other studies show that such a relationship exists: positive at the landscape scale (Stohlgren *et al*., 1999; Sax, 2002) and negative at scales of < 1 m² (Levine, 2000). Taking into account 30 small plots (4 m²) studied in (peri-)urban forests in the Ljubljana region, the weak positive correlation (Pearson r = 0.254) between total species number and the number of invasive species was established.

Invasive species may outcompete native plant species, may change forest habitats, and may disturb natural forest regeneration, ecosystem services, and functions (Rejmánek *et al*., 2005). Among forest services in urban areas, the recreation use is one of the most significant. Besides the considerable change of the plant species composition of forest vegetation in the Sava River, and partly also in the urban forest on the Rožnik site, we determined that the dense cover of invasive species may negatively affect the accessibility and use of paths along river and the forest alone, and invasive species may affect the whole physiognomy of the riparian forests.

Therefore, in Ljubljana (peri-)urban forests, the dynamics of expansion of invasive species should be carefully monitored, and appropriate measures for its limitation need to be established in the near future. More forest management and silvicultural activities should be engaged with regard to the invasive species that already disturb the forest development, structure, and functions of (peri-)urban forests.

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