

Urban ornamental trees: a source of current invaders; a case study from a European City

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Abstract Human made habitats are considered to be important hotspots of biodiversity of native as well as alien plant species. Due to high propagule pressure caused by human activities they serve as a source of introduction of alien plant species. We used the database of planted ornamental trees and shrubs for Brno, Czech Republic, to determine the significance of introduction effort given by intensity of planting as a factor in woody plant naturalization. Of all planted woody taxa, 15% were recognized as spontaneously growing in the urban area and there was a significant relationship between the number of planted individuals and the ability of a species to spontaneously occur in the urban area. The most often spontaneously escaping species originated in Europe (55%), followed by neophytes from North America (21%) and Central and Eastern Asia (14%). Although only a minor portion of planted woody species is able to escape from cultivation, this still could represent a potential risk for the native vegetation.

Keywords Archaeophytes · Europe · Invasive biology · Native species · Neophytes · Propagule pressure

Introduction

Escape from cultivation is an important pathway of introduction of alien plant species (Dehnen-Schmutz 2007a; Hulme et al.

2008; Essl et al. 2015). In the Czech Republic, the vast majority of alien vascular plants was introduced as ornamental plants and crops which subsequently escaped from cultivation (Pyšek et al. 2002). Focusing on woody species, the proportion of alien species that were introduced to new regions as a traded commodity is high in comparison with other pathways (Křivánek and Pyšek 2006; Pyšek et al. 2011). The probability that planted alien species escape from cultivation depends on the propagule pressure, which means that with high number of planted individuals the risk of escape and establishment becomes even higher (Williamson 1996, 1999; Lockwood et al. 2005; Dehnen-Schmutz et al. 2007a, b; Hanspach et al. 2008). For example Mulvaney (2001) showed that more frequently planted woody ornamental alien species in Australian cities were more likely to escape from cultivation than the less frequently planted species. Once introduced, alien species may spread across the region through natural dispersal. Over time, it is quite likely that species successfully introduced to a single location will spread over a large area (Hulme et al. 2008) and impact biodiversity of adjacent habitats (Gaertner et al. 2009; Taylor et al. 2016).

Urban areas with tree avenues and parks and gardens full of planted plants are hotspots of introduced alien species (Moro and Castro 2015). Planting of alien species helps overcome dispersal barriers that species with poor dispersal abilities would hardly pass through. Once have been introduced, we know quite a lot about their invasion success (e.g. Clement and Foster 1994; Kühn et al. 2004; Lambdon et al. 2008; DAISIE 2009; Pyšek et al. 2012), but there is a gap in our knowledge about the first stages of introduction, e.g. escape, establishment success and possible failures that are not recorded later in the case that escaped species survived only few seasons and thus are not usually detected without systematic monitoring.

Woody species are planted in urbanized areas, these include native species, alien species and species known only from cultivations, usually hybrids. While native species are

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adapted to the conditions of their region of origin, alien species are more limited especially by climate match. Among alien species limitation by winter temperature could favour those from the same biome (Jenerette et al. 2016). Native species which are well established in their native range should easily spread from cultivation, however it is unlikely that these species will negatively impact biodiversity of particular habitats (Simberloff et al. 2012). Alien species often grow larger and more densely in their introduced range (Parker et al. 2013), and once successfully established might have negative impact on plant biodiversity through changing biotic interactions. Finally, hybrids and other species known only from cultivation are less likely to spread and consequently impact adjacent habitats, although there are some notable exceptions (*Rhododendron ponticum*, *Populus × canadensis*, etc.). The probability of establishment and spontaneous spread of plant species also increases with their residence time. Species with longer residence time usually have a larger area of occurrence (Pyšek et al. 2014; Pyšek et al. 2015; Křivánek et al. 2005).

In our study we tested the invasion success of planted ornamental trees and shrubs in Brno city. We used the number of planted woody plants in public urban areas as a proxy for propagule pressure. We determined the influence of propagule pressure, origin of species (broadly defined regions), their residence

time (native/alien status) and number of planted individuals on the risk that planted woody species would escape from cultivations.

Material and methods

For our analyses, we compiled two separate lists of species. First list contained information about planted trees and high shrubs (mean height over 1 m) and was compiled based on information about planted individuals in public areas (streets and urban parks), the botanical garden of Masaryk University and Arboretum of Mendel University. The number of planted individuals in public area was used as a proxy for propagule pressure of planted species. Three groups of woody species are not included in the list. First group consists of taxa that were found spontaneously growing in the urban area, but data about planted individuals within the city are not available, such as shrubby species of genera *Amorpha*, *Berberis*, *Budleja*, *Chaenomeles*, *Colutea*, *Cotoneaster*, *Forsythia*, *Ilex*, *Kerria*, *Lonicera*, *Philadelphus*, *Physocarpus*, *Pyracantha*, *Rosa*, *Rubus*, *Spiraea*, and *Symphoricarpos*. Second group of woody plants excluded consists of taxa for which recent data on planted individuals are not available,

Table 1 List of 20 most often planted trees and shrubs (A) in descending order according to planted individuals and 20 most often escaping trees and shrubs (B) in descending order according to the percentage frequency of grid cells occupied (from 113 grid cells)

(A) Planted trees and shrubs			(B) Escaping trees and shrubs		
Taxon	native/alien status	number of planted individuals	Taxon	native/alien status	% frequency of grid cells
<i>Prunus serrulata</i>	known from cultivation	1314	<i>Sambucus nigra</i>	native	72.6
<i>Acer platanoides</i>	native	1102	<i>Robinia pseudoacacia</i>	neophyte (invasive)	70.8
<i>Tilia cordata</i>	native	905	<i>Acer platanoides</i>	native	67.3
<i>Acer campestre</i>	native	826	<i>Cornus sanguinea</i>	native	67.3
<i>Robinia pseudoacacia</i>	neophyte (invasive)	549	<i>Ligustrum vulgare</i>	native	64.6
<i>Quercus robur</i>	native	514	<i>Fraxinus excelsior</i>	native	63.7
<i>Acer pseudoplatanus</i>	native	483	<i>Acer pseudoplatanus</i>	native	61.9
<i>Carpinus betulus</i>	native	433	<i>Corylus avellana</i>	native	61.1
<i>Hibiscus syriacus</i>	known from cultivation	375	<i>Juglans regia</i>	archaeophyte (naturalised)	61.1
<i>Prunus hillieri</i>	known from cultivation	364	<i>Acer campestre</i>	native	60.2
<i>Tilia platyphyllos</i>	native	359	<i>Prunus avium</i>	native	60.2
<i>Fraxinus excelsior</i>	native	343	<i>Prunus domestica</i>	archaeophyte (naturalised)	59.3
<i>Platanus × hispanica</i>	neophyte (casual)	314	<i>Euonymus europaeus</i>	native	56.6
<i>Fagus sylvatica</i>	native	302	<i>Carpinus betulus</i>	native	55.8
<i>Tilia tomentosa</i>	neophyte (casual)	283	<i>Quercus petraea</i>	native	54.9
<i>Sorbus × thuringiaca</i>	native	278	<i>Tilia cordata</i>	native	53.1
<i>Pyrus calleryana</i>	known from cultivation	273	<i>Betula pendula</i>	native	53.1
<i>Prunus fruticosa</i>	native	259	<i>Salix caprea</i>	native	52.2
<i>Prunus × gondounii</i>	known from cultivation	247	<i>Pinus sylvestris</i>	native	51.3
<i>Crataegus monogyna</i>	native	230	<i>Acer negundo</i>	neophyte (invasive)	51.3

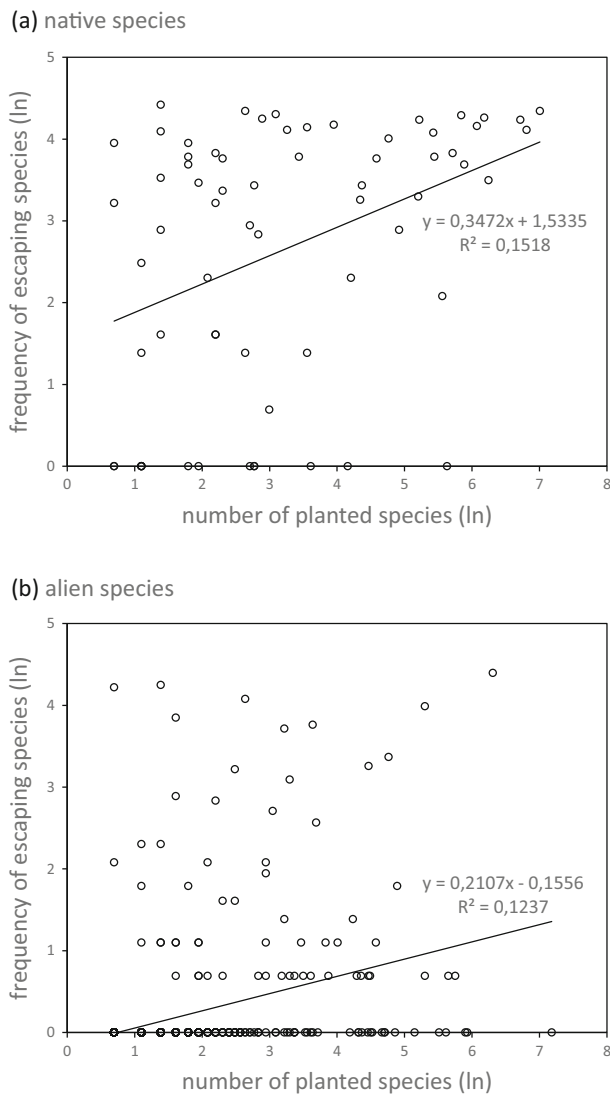


Fig. 1 Relationship between number of planted and frequency of escaping species

such as *Ailanthus altissima*, *Populus × canadensis* and *P. × canescens*. These species are no more planted for a few decades, but are still spontaneously occurring due to older individuals planted in the past. Third group of excluded species is a large specialized collection of exotic individuals of the *Salix* genus in the Arboretum, containing more than 100 taxa. This species could artificially inflate the number of taxa which can “escape”.

Second list contained information about escaping woody species and was obtained from the floristic database of flora of Brno (<http://www.sci.muni.cz/botany/vraticka/www/>). The database includes information about the presence of species in 113 grid cells of the size 1.1×1.5 km covering the whole urban area. The number of grid cells occupied by each woody species, i.e. the frequency of escaping species, was used to characterize its capacity to escape from cultivation.

The species were divided into groups according to their origin, residence time and invasive status following Pyšek et al. (2012), information on origin of some species missing there were obtained from the regional floras (Wu et al. 1994–2012; USDA, NRCS 2017). Based on the origin and residence time native species, archaeophytes (introduced before the discovery of America, ~1500 AD) and neophytes (after 1500 AD) were distinguished. In origin-based analysis species originated from more than one region were excluded, as well as species recognized as anecophytes (species with unknown region of origin; 14 species in total; Pyšek et al. 2012). Based on invasive status, archaeophytes and neophytes were further divided: casual species (species that do not form self-sustaining populations, their persistence depending on repeated introductions of propagules), naturalized species (forming self-sustaining populations, their persistence independent of introduction of propagules), and invasive species (species that produce large numbers of offspring and have the potential to spread over long distances; for details see Pyšek et al. 2012). Species which were absent in the database of alien flora of the Czech Republic, but

Table 2 Numbers and proportions of species planted and escaping from the cultivation. The invasive status followed Pyšek et al. (2012)

	Number of planted species	Proportion of all planted species	Number of escaping species	Proportion of all escaping species	Proportion of escaping species within given native/alien status
natives	67	9.5%	53	46.5%	79.1%
archaeophytes	12	1.7%	10	8.8%	83.3%
casual	5	0.7%	4	3.5%	80.0%
naturalized	6	0.9%	5	4.4%	83.3%
invasive	1	0.1%	1	0.9%	100%
neophytes	59	8.4%	36	31.6%	61.0%
casual	42	5.9%	22	19.3%	52.4%
naturalized	11	1.6%	9	7.9%	81.8%
invasive	6	0.9%	5	4.4%	83.3%
known from cultivation	566	80.4%	15	13.1%	2.7%
Total	704		114		

were planted in public areas of Brno were categorised as “known from cultivation”. Nomenclature follows Danihelka et al. (2012); names of species not present in this checklist were (<http://www.theplantlist.org/>). All taxa are hereafter referred to as species.

Linear models were used to examine relationship between the number of planted individuals of species and the frequency of escaping of given species. The analysis was performed in R program, version 2.14 (R Core Team 2014). To extend the previous analysis to test whether other species characteristics can also affect the frequency of escaping, regression tree (Breiman et al. 1984; De’ath and Fabricius 2000) was applied. Regression tree was selected due its ability to predict interactions between continuous dependent variable and more than one explanatory variable, both continuous and categorical (Breiman et al. 1984; De’ath and Fabricius 2000). Categorical variables used in the analysis were origin (Temperate and boreal Europe, Mediterranean, North America, South America, Central and Eastern Asia, Western Asia, Australia and New Zealand, hybrid) and residence time (natives, archaeophytes, neophytes, known from cultivation), continuous variable included number of planted individuals. The dependent variable, the frequency of escaping species, was hierarchically dichotomously splitted into two homogeneous groups based on explanatory variables and their interactions. Optimal tree size was selected using 10-fold cross-validation with $SE = 1$ rule to minimize the risk of tree overfitting. For each node of the tree possible surrogate variables were calculated based on the similarity to which they mimic the division produced by the main predictor. No surrogates with an associated value >0.2 (i.e. allocating 20% of samples as the main predictor selected) were found. The explained variation in the dependent variable (frequency of escaping species) was calculated from resubstitution relative errors corresponding to residual sums of squares. The importance of explanatory variables for tree divisions are at relative

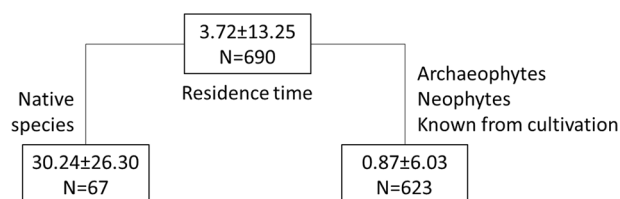


Fig. 2 Regression tree explaining frequency of escaping species. Each node is characterized by mean \pm SD of total frequency of escaping species and the number of cases (N) assigned to the particular node and main predictors (residence time) simultaneously splitting the data set to homogeneous groups. Total variation explained $R^2 = 58.61\%$

scale from 0 to 100, i.e. the best explanatory variable has value of 100. The influence of categorical variables with high relative importance value, but not shown as predictors in the tree, were tested by t-tests. The analyses were performed in Statistica 12 (<http://www.statsoft.com>).

Results

The dataset contains 704 taxa of ornamental trees or high shrubs planted in public areas of Brno city. The most commonly planted and the most commonly escaping species are shown in Table 1. The relative frequency of spontaneously escaping woody species is significantly positively related with the number of planted individuals ($R^2 = 0.27$, $p < 0.001$, $n = 704$, not shown) in the urban area. The same pattern was found also for native and alien species separately (Fig. 1a, b).

The tendency to escape from cultivations differs between species with different residence time (Table 2) and origin (Table 3). The most commonly escaping species are native European species followed by North American species and those originating from Central and Eastern Asia. Species from these regions are also the most commonly planted woody species in the city.

Table 3 Proportions of woody species planted and escaping from the cultivation. Species are divided into groups according to their origin. Species originated from more than one region and anecophytes (species with unknown region of origin; 14 in total) were excluded. Total number of planted species was 690 and total number of escaping species was 104

	Proportion of all planted species	Proportion of all escaping species
Temperate and boreal Europe	15.4%	54.8%
Mediterranean	5.9%	6.7%
North America	24.5%	21.2%
South America	1.0%	0%
Central and Eastern Asia	44.5%	14.4%
Western Asia	3.9%	0%
Australia and New Zealand	0.3%	0%
hybrid	4.5%	2.9%

Table 4 Values of relative variable importance of the explanatory variables based on the regression tree. Explanatory variables are ranked according to the decreasing value of the contribution to variance explanation in frequency of escaping species

Variable importance	
Native species	100
Known from cultivation	81
Temperate and boreal Europe	63
Number of planted individuals	47
Central and Eastern Asia	13
Archaeophytes	3
North America	2
Neophytes	2
Hybrid	1
Western Asia	1
South America	0
Australia and New Zealand	0
Mediterranean	0

The optimal regression tree for the frequency of escaping species (Fig. 2) explained 58.61% of variance. The most important characteristics for species escaping from cultivation was being a native species. If the importance of all used variables across all nodes was compared (Table 4), additional variables appear to influence the frequency of escaping species: species known from cultivation ($t = 19.23$, $p < 0.001$), species originated from Temperate and boreal Europe ($t = 15.95$, $p < 0.001$), most of which are also native in Central Europe and number of planted individuals ($R = 0.45$, $p < 0.001$).

Discussion

The presented results provide quantitative evidence for the role of planted ornamental woody species as an important source for plant invasion of woody species. It is shown that not only release (Pyšek et al. 2011; Saul et al. 2016) but also spontaneous escape from cultivation could be an effective pathway for woody species. It is likely that the importance of this source in time could even increase, as showed when considering the effect of the horticultural industry on the invasive process in Britain (Dehnen-Schmutz et al. 2007a, b). The probability of escape of planted woody species increased with number of planted individuals, which is a strongly significant explanatory factor for native species and less important but still significant for alien species. Number of planted individuals is only a rough proxy for propagule pressure, as information about planted woody species in urban private gardens is not available for the analysis and also individual tree species produce different number of seeds with different ability to germinate. Nevertheless our results are in accordance with data coming from East Australian cities (Mulvaney 2001).

Despite of the fact that alien species in Brno are planted more often than native species, the relationship between the number of planted individuals and frequency escaping species is weaker for aliens than for natives. Our results suggest that native species are better adapted to local environmental conditions and so their probability of escaping from cultivations is higher. Their spontaneous occurrence in the city area could be also caused by diaspores originating from surrounding landscape, not only from cultivations. This additional sources of diaspores probably increase propagule pressure, but there is no possibility how to filter this effect. Alien species' success is closely related to their residence time (Pyšek and Jarošík 2005; Pyšek et al. 2015). Among planted woody species, archaeophytes which had a longer time to establish in a new region (Pyšek et al. 2015) are more likely to escape than neophytes (83% vs 61% of woody species).

Most of the commonly planted alien species in Brno originated from North America and Central and Eastern Asia, which illustrates general human preferences towards species

from climatically similar regions (Donaldson et al. 2014). As the main limitation in Central Europe is by relatively low winter temperatures, plants from the same latitudes better withstand local climatic conditions (Jenerette et al. 2016) and are therefore often cultivated (Dehnen-Schmutz 2007b). Their establishment can be facilitated by additional properties preferred by horticulture such as easy propagation or resistance to pests (Dehnen-Schmutz 2007b).

Our findings show that the vast majority of planted ornamental woody species have failed so far to escape from cultivation. We assume that these species are not able or have not been able yet to transit the first step of the invasion process. Well-established native species, which are in their native range, easily escaped from cultivations, but it is less likely that these species will negatively impact biodiversity (Simberloff et al. 2012). In contrary, escaping alien species could potentially have negative impact on adjacent habitats (Parker et al. 2013).

Of the 114 woody species detected as escaping from cultivation in the city, 14 (12.3%) are naturalized and 6 (5.3%) have invasive status. These values are slightly lower than reported for the whole alien Czech woody flora by Křivánek and Pyšek (2006), probably because not all alien woody species are planted in the city and moreover, some of frequent spontaneously occurring invasive tree species were not included to our analyses because of not available data on recent planting.

Conclusions

Most alien species are usually noticed after successful establishment, spread and possible impact in habitats. In present paper we tried to fill the gap in our knowledge about the first step in invasion process – escape and initial establishment of woody species. Many alien tree species are planted in the city parks and gardens and although most of them never escape, they may pose a potential risk for the native vegetation.

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