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Indigenous and alien vascular plant species in a northern European urban setting (Tallinn, Estonia)

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Abstract. In recent decades ecologists have accorded special attention to urban areas as loci for the introduction and possible invasion of alien species. Data are lacking on urban flora that would allow having an overview of these phenomena in the Baltic Sea region including in all Scandinavia. This study seeks to address this missing information by establishing the species composition of indigenous and spontaneous alien vascular plants on the territory of Tallinn city, Estonia, and comparing the presence of alien species in the city's greenery-rich areas with their presence more generally in Tallinn. In order to accomplish this, vegetation inventories were conducted on 10 greenery-rich 1 km² quadrants in the city and then a database of vascular plant species in Tallinn was compiled using these data together with those from other studies. Inventory data analysed using non-metric multidimensional ordination and permutation tests produced a comparison of indigenous to alien species for the whole of Tallinn. A greenery-rich city, with some tracts having areas of tens of hectares of broad compact forest and semi-natural meadows, Tallinn's green areas account for more than one-third (35%) of its entire territory. The analysis showed that the ratio of indigenous plant species to total species in Tallinn's greenery-rich areas was significantly higher than that for the whole of Tallinn. These green areas offer valuable habitats for the growth of indigenous species; they are centres of biodiversity and act as buffers for the urban areas by presenting obstacles to the distribution of alien species. The current situation of Tallinn with its high proportion of green areas that contribute to the dominance of indigenous species in its flora should be maintained and valued.

Key words: urban flora, spontaneous alien vascular species, indigenous species, distribution, plant geography, Tallinn.

INTRODUCTION

Scientists have been describing and mapping flora and vegetation of contemporary European cities, mainly in central Europe (Kelcey and Müller, 2011). However, there are several gaps in the geographical coverage, notably Scandinavia and the eastern coast of the Baltic Sea are among them (Müller, 2011b). One of the tasks of urban ecology has been assessment of the species composition of the biota and research on the distribution and adaptation of alien species (Chocholoušková and Pyšek, 2003; Wittig, 2004; Lososová et al., 2006; McKinney, 2006; Simonová and Lososová, 2008). Urban environment is characterized by the impacts of various physical disturbances of which the most important with respect to the succession of communities are relocation of ground due to human activities, destruction of life communities, and addition of nutrients into soil (Pyšek, 1998a; Pausas et al., 2003; Rejmánek et al., 2005; Tredici, 2010). Alien species often establish in open areas with sparse vegetation (Walter et al. 2005), which are abundant in urban areas because of numerous brown-fields and wastelands (Godefroid et al., 2007). Several studies have shown that urban flora is more variegated than the flora in the vicinity of towns (Pyšek, 1993, 1998a, 1998b; Kühn et al., 2004). James (2010) summed up the results of the studies related to the distribution of species within urban areas.

The objective of this study was to first identify the species and family composition of indigenous and

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spontaneous alien vascular plants on the territory of Tallinn city and then to compare the presence of alien species in greenery-rich areas of the city, which host natural and semi-natural communities, with the general ratio of indigenous to alien species. We hypothesized that green areas provide stable habitats for indigenous species and, thus, the presence of indigenous species is significantly higher in greenery-rich areas than in the city generally.

MATERIAL AND METHODS

Study area

Tallinn is located in the northern part of the Republic of Estonia at the southern coast of the Gulf of Finland. The geographical coordinates of the city centre are latitude 59º26′N and longitude 24º46′E. Its area is 156 km² (without islands) with a population of 436 000 (2015). According to the land use map compiled by Reimo Rivis based on different spatial data: topographic maps, orthophotos, etc. (https://www.etis.ee/Portal/Projects/Display/672e9e47-a0f0-4af1-8d5a-a1166fa26497), the land-use types and their proportion in Tallinn are as follows: continuous urban fabric 21.8%, discontinuous urban fabric 17.8%, industrial areas 16.9%, forest 14.1%, parks and other green areas 13.4%, degraded raised bogs 3.0%, cemeteries 2.4%, beaches and shore areas 2.3%, inland water bodies (lakes) 8.3%. Ruderal areas comprise 7% of the area of the city (Karro-Kalberg, 2011).

A limestone cliff, North Estonian Klint, divides the territory of Tallinn city into two different units: a limestone plateau and a lowland in front of it (Fig. 1). Therefore the abiotic conditions within the city are variable. The main features of the bedrock topography in Tallinn developed during the course of the preglacial period when the North Estonian Klint, Toompea hill-rock, and the valleys cutting deep into the bedrock formed (Raukas and Tavast, 2010). The North Estonian coastal lowland is quite variegated on the territory of the city; there are a few elevations, beach ridges, and terraces and also other forms of relief occur in several places. On the lowland friable rocks can be found: Ediacaran sandstones, Cambrian clay complex, Ordovician sandstones, and argillite (Pirrus, 2010), which are covered with one to several metres thick Quaternary cover from marine sands, silts, gravel, till, wind-blown sand, or peat (Raukas, 2010). The flat Lasnamäe limestone and dolostone plateaus are covered with a thin, some tens of centimetres thick layer of gravelly soil (in some places it is entirely lacking), and in the depressions sediments of preterit bogs occur.

There are several lakes in Tallinn: Ülemiste (9.6 km^2), hypertrophic Lake Harku (1.65 km^2), small Lake Tooma, part of Lake Raku, and Lake Männiku. The Pirita River and several brooks flow through the territory of the city. On the north-western coast of Lake Ülemiste dune ridges, whose height reaches 7 m, are distributed. The sand fields at Nõmme and Männiku formed as glaciofluvial deltas; these sands are practically free of carbonates. The thickness of the cultural layer in the centre of the city reaches 15 m, being on average 1–8 m (Raukas, 2010).

The development plan of greenery in Tallinn (Tallinn City Council, 2005) gives an overview of the presently existing green areas of the city. In the sandy areas of the coastal lowland dry *Pinus* forests (mostly oligotrophic boreal heath forests and oligo-mesotrophic boreal forests), strongly influenced by human activity, are growing. At places *Pinus* mixed forest, paludifying *Pinus* forest, and at terrace feet minerotrophic mobile water swamp forests occur. In some places where forest was destroyed in the course of excavating gravel and sand dry boreal heath grassland has developed. On till mixed forest and *Picea* forest can be met in places. In damp places at the foot of the klint and at the banks of streams on paludified soils meadows and wooded meadows, and in places stands of *Alnus glutinosa* and *A. incana* occur. Biologically diverse Nordic alvars with xeric vegetation occur on the limestone plateau with a thick soil cover. The freeze and melt cycle gives rise to soil movements and produces small vegetation-free areas where terophytes can grow. Cliff talus areas are covered with dense deciduous forest, mostly of *Tilia cordata*, *Ulmus glabra*, *Fraxinus excelsior*, and *Acer platanoides*.

The climate in Tallinn is characterized by moderately cold winters, cool springs with a small amount of precipitation, moderately warm and during the second half rather rainy summers, and long warm autumns (Prilipko, 1982; Tallinn City Council, 2005). Cyclones originating on the Atlantic Ocean have a great influence, making the weather in the whole of Estonia extremely changeable. Besides the maritime location of Tallinn, the climate parameters of its different parts are influenced by the relief, architectural features, cover of the streets, greeneries, etc. The average annual air temperature is 4.7 °C. July is the warmest (16.6 °C) and February the coldest (–6.0 °C) month. In summer months, air temperatures in shadow may rise as high as 33 °C. During the whole year in the densely built up areas of the city the average daily temperature is 0.5–1.0 °C higher than in open areas with no buildings or with sparsely located buildings (Prilipko, 1982; Tallinn City Council, 2005).

The duration of the frost-free period in the air (measured 2 m above the surface) is on average 175 days on the coast and 164 days on the limestone plateau. On soil surface the frost-free period is on average 35 days shorter than in the air (Estonian Weather Service, 2015). On the coastal lowland the freezing depth in winter is 13–73 cm; on average the ground freezes to a depth of 34 cm. In higher parts of the city the freezing depth is deeper because in these areas sandy soils predominate.

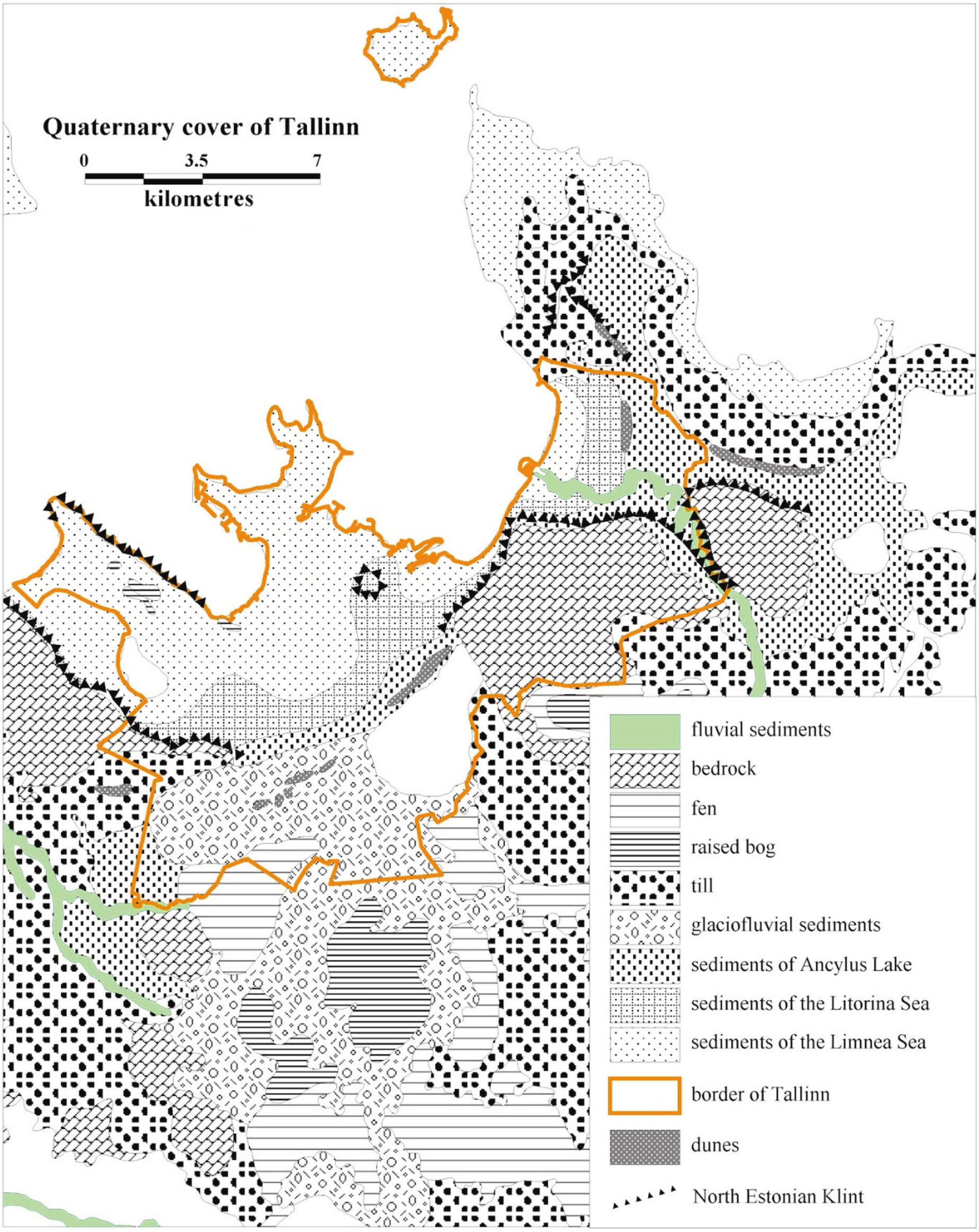

Fig. 1. Quaternary cover of Tallinn. Compiled by K. Kajak (Eesti Kvaternaarisetted 1:40 000, 1999; http://www.egk.ee/wp-content/uploads/2011/04/Pinnakate_400_Seletuskiri.pdf.

The average thickness of the snow cover is 14 cm, and the snow-cover duration is 3 months: from the second half of December to the second half of March (Tallinn City Council, 2005).

Principles of compiling the general list of vascular plants

The list of vascular plant species of Tallinn is drawn mainly from two sources. The main source was Kukk (1991), which summarizes data on herbaceous and woody plants found in published works, manuscripts, and herbariums of botanists whose work covers several centuries. The earliest written data on Tallinn (=Reval) flora date from the first half of the 19th century (Fleischer and Lindemann, 1839; Seidlitz, 1849; Heugel, 1850). The most comprehensive research from the early era is Russow's *Flora der Umgebung Revals* (1862). Herborized material collected in Tallinn during the 19th and 20th centuries is available in the *Herbarium Balticum* and the *Herbarium Estonicum* at the Estonian Natural History Museum, Tallinn (http://www.loodusmuuseum.ee/en/botanical-collections; http://natarc.ut.ee/en/index.php). This museum also houses the 11 500 sheet herbarium of Lehbert (1858–1928), a significant portion of which was collected in urban Tallinn (see also Kukk, 1991). Intensive studies of Tallinn flora were conducted at the end of the 19th century, in the early 20th century, during the era of the Estonian Republic (1918–1940), in the 1950s, 1960s, and 1980s (Kukk, 1991). Kukk's list (1991) contains 1509 taxa (species, subspecies, and hybrids), of which over a hundred species were not included in our database because by our observation these are not spontaneous or because their occurrence in Tallinn is not confirmed according to Kukk. The other main source for our Tallinn vascular plant species database was Ploompuu and Laansoo (2001), who studied ornamental and food plant species growing spontaneously in the grounds and small parks in the garden suburbs of Tallinn. Almost 100 species from this list were included in the database. Another 20 species were added to the database based on information in an unpublished manuscript of O. Abner (2005) and personal field notes of T. Ploompuu. Investigation by Robal (2006–2008) offered evidence to add several species. During the inventory of the regions, the authors gathered evidences, which were used to amend the database. Our final list of spontaneously growing vascular plants in Tallinn comprises 1435 species.

The status of species, whether indigenous or spontaneous neophytes, is based on Kukk (1991, 1999), Kull et al. (2001), or field observations by this paper's authors. The categories of invasiveness of spontaneous neophytes follow Kukk (2001) and Kull et al. (2001). We simplified their system of categories and re-estimated the category of several species.

Spontaneous plants are defined in this study as species that have not been planted or sown by humans and whose seeds are frost resistant or who reproduce vegetatively and whose vegetative parts survive our winters. For example, *Cucumis sativus*, whose seeds are sensitive to frost, was not considered as spontaneous.

First two groups of plants were distinguished: (1) *indigenous* species (or *natives*) together with *archeophytes* and (2) *alien neophytes*. Indigenous species together with archeophytes arrived in the Estonian area after the last glaciation and before the middle of the 18th century (the first list of vascular plants growing in Estonia and Livonia was published by Hupel (1777)). We use in our database the same categories of alien neophytes as it has been done by other Estonian authors (Ööpik et al., 2008): alien neophytes include (1) *casuals*, the alien species that do not form self-replacing populations and that rely on repeated introduction; (2) *naturalized* (*non-invasive*) *species*, the alien species that reproduce consistently in a vegetative or generative way and sustain populations over many life cycles without direct intervention by humans, they often recruit off-spring freely, usually close to adult plants; (3) *invasive species*, the naturalized plants that produce reproductive offspring often in large numbers, and thus have the potential to spread over a sizeable area at a considerable distance from parent plants. *Anecophytes* or *neogene plants* are defined as plants found only in human-created habitats.

The families, genera, species, and micro-species of vascular plants were determined according to Kukk (1999) and Krall et al. (2010). Our data regarding indigenous and neophyte species and families of Tallinn flora were compared with data for the entire country of Estonia (Kukk, 1999; Ööpik et al., 2008).

The ratio of indigenous to alien species was obtained without taking into account micro-species from the genera *Alchemilla*, *Hieracium*, *Pilosella*, *Taraxacum*, *Euphrasia*, and *Lotus*. In the genera with micro-species, the number of species included in this calculation was: *Hieracium*, 5 species; *Taraxacum*, 3 species; *Euphrasia*, 1 species; and *Lotus*, 1 species (all previously described as indigenous). In the genus *Alchemilla*, one species is indigenous and one is alien. This is also the case for the genus *Pilosella*: one indigenous and one alien species. However, in the entire database of vascular spontaneous plants in Tallinn these genera include the following number of species: *Alchemilla*, 14; *Hieracium*, 10; *Pilosella*, 10; *Taraxacum*, 75; *Euphrasia*, 5; and *Lotus*, 5.

Inventory data

In 2009 the fieldwork was carried out between May and September. The vegetation inventories were conducted on 10 areas, each 1 km^2, within the borders of Tallinn (Fig. 2).

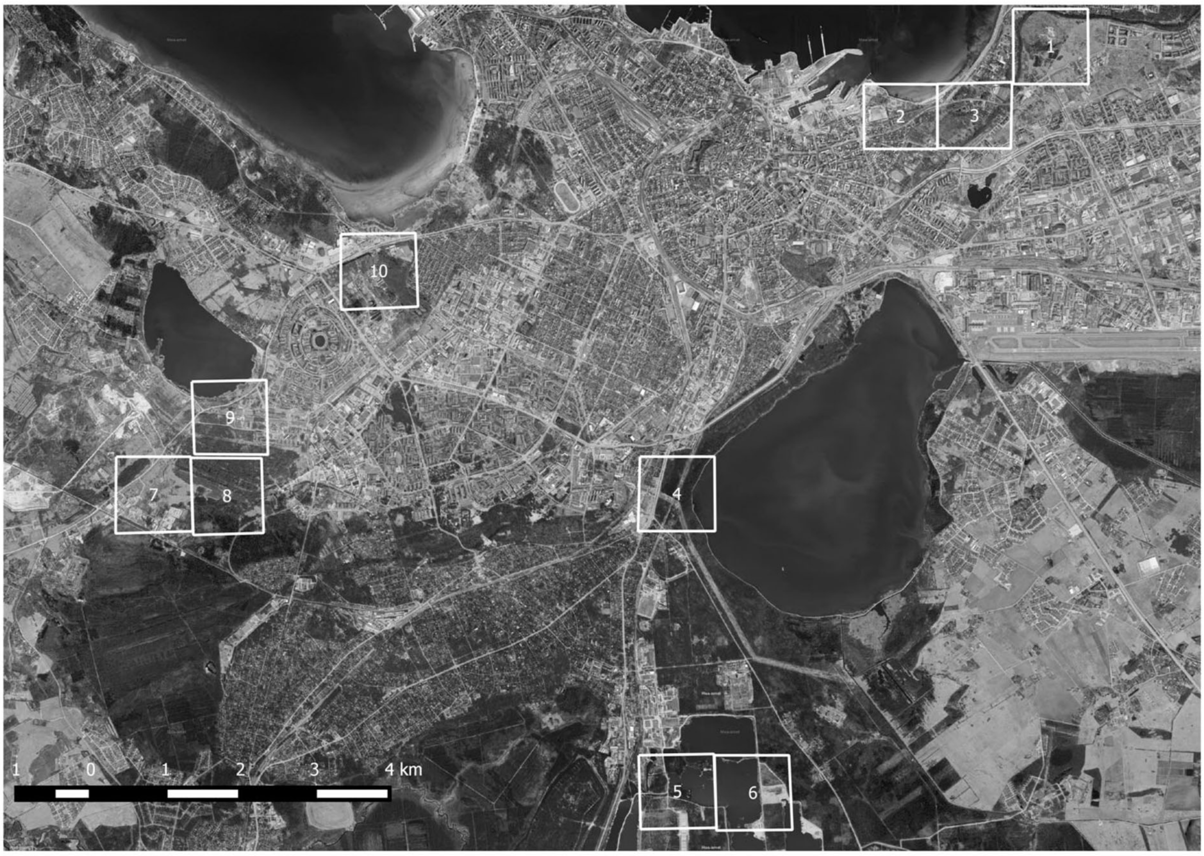

Fig. 2. The studied 1-km^2 quadrants.

The quadrants selected are situated in greenery-rich areas of the city. These host natural and semi-natural communities: Nordic alvar meadows, paludified meadows, natural lakeside plant communities (reed-beds etc.), sea-shore plant communities, xeric communities on sandy slopes, dense deciduous forests on cliff talus, hemiboreal broad-leaved deciduous forests, herb-rich forests with *Picea abies*, *Pinus sylvestris* forests on sandy soil, paludifying deciduous and mixed forests, and bog wood-lands. Areas with urban fabric occur in all quadrants. Seven of the ten studied plots included a waterbody, sea or lake, with between 1% and 51% of the total quadrant a water body, the average being 19%. The proportion of forest and other green areas (without urban fabric) on these quadrants ranged between 31% and 100% (average 65%). Plant species present in the ten quadrants were recorded (Elvisto and Paluoja, 2011). Random studies in Tallinn in 2011, 2012, and 2015 completed the earlier findings.

Data analysis

The ratio of indigenous to alien species in the inventory data was compared with that of the whole of Tallinn (both with and without micro-species) using the permutation test. The casual alien species were not taken into account in this calculation because they have seldom been found with none registered during this inventory. (The list of casual alien species in our database is based on data gathered over the last two centuries.) From the 1280 vascular plant species of Tallinn (the number of Tallinn vascular plant species excluding casual alien species) and from the 1168 species (the number of Tallinn vascular plant species excluding both micro-species and casual alien species), 10 000 random samples of 562 species were drawn (562 is the number of species recorded on 10 areas of our field inventories). The share of indigenous species in each sample was estimated and compared with that of inventory data. All statistical tests were performed at the significance level $p < 0.05$ by using the statistical package R 3.1.0 (R Core Team, 2014).

RESULTS

The 125 vascular plant families known in the flora of Tallinn include 1435 species, of which 980 are indigenous and 455 alien species. Without considering micro-species, the number of indigenous species registered in Tallinn is 873. The native taxa belong to 104 families and the alien taxa to 68 families. In the flora of Tallinn 50 hybrids are known; both (or more) of their parent species are included in the total number of species, but they themselves are not.

A total of 1441 indigenous species of vascular plants have been described from Estonia (Kukk, 1999), the number of alien vascular plant species known in Estonia is 787 (Ööpik et al., 2008). In consequence, Tallinn vascular plant flora included 68% (980 species) of all species native to Estonia and 58% (455 species) of all the spontaneous alien species. Indigenous species of the whole Estonia belong to 113 families, of which 104 or 92% occur in Tallinn.

The 125 families of the Tallinn flora can be divided into three groups on the basis of the status of the species found: (1) families including only indigenous species, (2) families including only alien species, and (3) families including both indigenous and alien species. The total number of families that include only indigenous species is 57, of which Orchidaceae with 22 species and Ericaceae with 17 species are the most species-rich.

The total number of families that include only alien species is 21. Among them the families Amaranthaceae and Malvaceae are the richest in species, both including eight species.

Several families with both indigenous and alien species have numerous species in both groups. Table 1 lists the 11 families with the largest number of species identified in Tallinn. These families account for 60.7% of the total number of species in Tallinn. The four smallest of the families, Scrophulariaceae, Chenopodiaceae, Lamiaceae, and Ranunculaceae in this table, each account for about 3% of the total number of species in Tallinn. The families not included in Table 1 contain 2% or fewer species. Overall, 16 families, each including more than 20 species, have been registered; 25 families have between six and twenty species and 84 families between one and five species.

The families including the largest number of indigenous species are Asteraceae, Poaceae, and Cyperaceae. A third of the native flora belongs to these three families (Table 1). A third of the species of indigenous and alien species en bloc are from the four largest families: Asteraceae, Poaceae, Rosaceae, and Brassicaceae. The family Asteraceae includes the largest number of alien species, and Brassicaceae is the family with the next largest number of alien species.

Of the indigenous species (including micro-species) growing in Tallinn the family Asteraceae includes 16.6% of the total number of species (Table 1). Of the 1441 native plant species (including micro-species) growing in Estonia 24.6% belong to the family Asteraceae, followed by Cyperaceae with 6.6%, Poaceae 6.4%, Rosaceae 6.2%, Fabaceae 4.1%, Caryophyllaceae 3.5%, Brassicaceae 3.3%, and Scrophulariaceae 3.3% (Kukk, 1999). The percentages of indigenous species by families in Tallinn are similar to their distribution in the whole of Estonia. An exception is the family Asteraceae. The factors accounting for the distribution of this family in Tallinn merit more profound investigation.

Among alien species there are 280 naturalized non-invasive (62% of the alien species) species, 152 (33%) casuals, and 23 (5%) invasive species. Species of indigenous vascular plants make up 66% (without micro-species) and alien species 34%. If we take into consideration the micro-species of the genera *Alchemilla*, *Hieracium*, *Pilosella*, *Taraxacum*, *Euphrasia*, and *Lotus*, 68% of the species in the flora of Tallinn are indigenous and 32% are alien. Of the spontaneous alien species

Table 1. Families with the largest number of species in Tallinn vascular plants database (including micro-species), top 11

Family	Indigenous Species		Alien Species		Total Species	
	N	%	*N*	%	*N*	%
Asteraceae	162	16.6	56	12.3	218	15.2
Poaceae	78	8.0	31	6.8	109	7.7
Rosaceae	56	5.7	43	9.4	99	6.9
Brassicaceae	40	4.1	45	10.0	85	6.0
Cyperaceae	77	7.9	1	0.2	78	5.4
Fabaceae	39	4.0	20	4.4	59	4.1
Caryophyllaceae	39	4.0	13	2.8	52	3.6
Scrophulariaceae	34	3.5	10	2.2	44	3.1
Chenopodiaceae	16	1.6	26	5.7	42	2.9
Lamiaceae	26	2.7	15	3.3	41	2.9
Ranunculaceae	31	3.2	10	2.2	41	2.9
Total	598	61.3	270	59.3	868	60.7
Total number of vascular plant species listed in Tallinn database	980		455		1435	100.0

64% can be grown culturally (for human and animal food, as ornamental plants), the rest have been brought to Tallinn accidentally through human activity (ruderals).

The inventories in 2009 (with additional fieldwork later) on the ten 1 km^2 quadrants registered a total of 488 indigenous species and 74 naturalized species (together with invasive species). Micro-species were not identified and casual alien species were not found. From these 562 species 92 (16%) are widely distributed (identified on eight to ten quadrants investigated). Among widely distributed species nine anecophytes were registered: *Capsella pursa-pastoris*, *Convolvolus arvensis*, *Dactylis glomerata*, *Elymus repens*, *Plantago major agg.*, *Poa annua*, *Polygonum aviculare agg.*, *Taraxacum officinale agg.*, and *Urtica dioica*. The anecophytes *Chenopodium album* and *Stellaria media* were found on half of the quadrants. The proportion of alien species among the most widely distributed taxa was less than 5% or three species. In all quadrants *Conyza canadensis*, *Impatiens parviflora*, and *Sambucus racemosa* were registered. *Bunias orientalis* occurred in nine quadrants. Table 2 lists alien spontaneous species. The proportion of invasive

Table 2. List of spontaneous neophytes registered on the studied ten 1-km² quadrants in Tallinn

Species	Family	Category[a]	Occurrence (total of 10 quadrants)
Acer negundo	Aceraceae	3	3
Acer pseudoplatanus	Aceraceae	3*	1
Aesculus hippocastanum	Hippocastanaceae	3	4
Alyssum alyssoides	Brassicaceae	2	1
Amelanchier spicata	Rosaceae	1	3
Anaphalis margaritacea	Asteraceae	3	1
Armoracia rusticana	Brassicaceae	2	4
Aster novi-belgii	Asteraceae	2	1
Bellis perennis	Asteraceae	2	4
Bromus inermis	Poaceae	x	6
Bunias orientalis	Brassicaceae	1	9
Camelina microcarpa	Brassicaceae	3	1
Caragana arborescens	Fabaceae	3	1
Carex praecox	Cyperaceae	3	1
Cerastium tomentosum	Caryophyllaceae	3	3
Chaenorhinum minus	Scrophulariaceae	3	2
Chamomilla recutita	Asteraceae	3	1
Chamomilla suaveolens	Asteraceae	x	7
Conyza canadenis	Asteraceae	1	10
Cotoneaster lucidus	Rosaceae	1	7
Doronicum pardalianches	Asteraceae	3	1
Elaeagnus commutata	Elaeagnaceae	2	1
Elodea canadensis	Hydrocharitaceae	x	1
Epilobium adenocaulon	Onagraceae	x	2
Erucastrum gallicum	Brassicaceae	3	5
Galanthus nivalis	Amaryllidaceae	3*	1
Galega orientalis	Fabaceae	1	2
Hesperis matronalis	Brassicaceae	2	6
Impatiens parviflora	Balsaminaceae	x	10
Iris germanica	Iridaceae	3*	1
Lathyrus tuberosus	Fabaceae	3	1
Leucojum vernum	Amaryllidaceae	3*	1
Lilium martagon	Liliaceae	2	1
Lolium perenne	Poaceae	1	5
Lonicera caprifolium	Caprifoliaceae	2	1
Lonicera tatarica	Caprifoliaceae	2	1
Lunaria annua	Brassicaceae	3	1
Lupinus polyphyllus	Fabaceae	1	1
Medicago sativa [b]	Fabaceae	2	6
Muscari armeniacum	Hyacinthaceae	3	1
Myosotis sylvatica	Boraginaceae	3	3
Oenothera biennis	Onagraceae	2	4
Papaver rhoeas	Papaveraceae	3	1
Parthenocissus quinquefolia	Vitaceae	3	3
Physocarpus opulifolius	Rosaceae	3	3
Pinus mugo	Pinaceae	3	1
Polemonium caeruleum	Polemoniaceae	3	1
Populus alba	Salicaceae	2	1
Populus balsamifera	Salicaceae	1	4
Prunus cerasifera	Rosaceae	2	1
Prunus domestica	Rosaceae	2	2
Reynoutria japonica	Polygonaceae	2	4
Rheum rhaponticum	Polygonaceae	3	1
Rhodiola rosea	Crassulaceae	3	1
Ribes rubrum	Grossulariaceae	3	2
Rosa rugosa	Rosaceae	1	6
Rudbeckia laciniata	Asteraceae	3	6
Rumex confertus	Polygonaceae	1	5
Sambucus nigra	Caprifoliaceae	3	3
Sambucus racemosa	Caprifoliaceae	x	10
Saponaria officinalis	Caryophyllaceae	1	7
Scilla siberica	Hyacinthaceae	2	4
Sisymbrium altissimum	Brassicaceae	3	7
Sisymbrium loeselii	Brassicaceae	3	3
Solidago canadensis	Asteraceae	1	2
Sorbaria sorbifolia	Rosaceae	2	2
Swida alba	Cornaceae	2	2
Swida stolonifera	Cornaceae	2	4
Symphoricarpos albus	Caprifoliaceae	2	6
Syringa vulgaris	Oleaceae	3	5
Trifolium hybridum	Fabaceae	1	6
Tulipa sylvestris	Liliaceae	3	1
Viburnum lantana	Caprifoliaceae	2	3
Viola wittrockiana	Violaceae	3	2

[a] Categories: x – common in natural and semi-natural communities; 1 – invasive, distribution area rapidly broadening; 2 – persistent, potentially invasive, distribution area gradually broadening; 3 – naturalized or in the process of naturalization (*), some are persistent but do not yet threaten natural and semi-natural communities.

[b] The invasive hybrid *Medicago × varia* was also registered on the quadrants.

species among all naturalized species is relatively high – 18% (13 species), while persistent, potentially invasive species make up 28% (21 species) of all alien species. Six registered neophytes are presently common in natural and semi-natural communities all over Estonia. The proportion of invasive species among all naturalized species is higher on the greenery-rich areas than in the whole Tallinn – 8% (in the whole Tallinn the number of naturalized species is 303 in our database).

The randomized sampling of 562 species from the total Tallinn plant species list indicates that the ratio of the number of indigenous plant species to the total number of species in the inventory data (87%) was significantly higher than that of the whole Tallinn (74% without micro-species and 76% with micro-species; $p < 0.001$ in both cases). The probability of getting a sample of 562 species with the share of indigenous species 87% was less than 3 per 10 000 samples.

DISCUSSION AND CONCLUSIONS

This article is based on our database of vascular plants in Tallinn, Estonia, a North European city. There is no published research about other urban Estonian areas. Furthermore, there is a lack of data on urban flora in all Scandinavia and other Baltic Sea regions, with St. Petersburg as the only exception (Müller, 2011b).

The territory of Tallinn is characterized by preconditions for a diverse flora: a seashore location that has several lakes, a river, and brooks; a geology of diverse soil parent materials; and occupation for centuries by people involved in trade by land and sea, landscaping, and horticulture. Although the area of Tallinn (156 km^2) comprises only 0.35% of the total area of Estonia (45 227 km^2), its flora included 68% (980 species) of all species native to Estonia and 58% (455 species) of all spontaneous alien species. Results of our study accord with the studies on other European cities. These studies report that 50% and more of the regional or even national flora is identified in cities; the reason for the high biodiversity of these cities is explained by their location along landscape transition zones and by the presence of rivers in regions that make the landscape naturally highly heterogeneous (Müller, 2011b).

Of the species included in the over-European list of alien species with serious negative consequences for their new environment (Estonian Government, 2007) 11 have been found in Tallinn. These are three species of the genus *Ambrosia* (*A. artemisiifolia*, *A. coronopifolia*, and *A. trifida*), *Bidens frondosa*, *Heracleum mantegazzianum* and *H. sosnovsky*, *Impatiens glandulifera*, *Reynoutria japonica* and *R. sachalinensis*, *Solidago canadensis* and *S. gigantea*. Alien species of the genus *Heracleum* have become established and are expanding their area in Estonia. These species present risk to humans through skin contact with the sap that causes photosensitivity and burns. Since 2005 chemical control coupled with mechanical control has been executed in their habitats all over Estonia (Holm et al., 2009). We observed that in Estonia *R. japonica* and *R. sachalinensis* have formed stable clones that are regenerating and expanding through their rhizomes. The area where *I. glandulifera* and *S. canadensis* grow has significantly expanded in recent years in Tallinn as it has elsewhere in Estonia. In 2011 the Estonian Seminatural Community Conservation Association mapped the distribution of *I. glandulifera* througout Estonia, including Tallinn (Environmental Board, 2012), while students at Tallinn University mapped sites of *S. canadensis* in several Tallinn districts. *Solidago canadensis*, *Reynoutria japonica*, and *R. sachalinensis* have been reported as invasive in most studied European cities (Müller, 2011b).

Species of the genus *Ambrosia* are not able to produce fruit in Estonia due to the rather short and cool vegetation period, but these plants are common on the winter feeding places of birds as the sunflower seeds used there come from southern countries and contain seeds of *Ambrosia* species. These species may cause health problems because their pollen has a strong allergenic effect.

The reason why alien species are expanding successfully in urban conditions is the existence of free resources and vacant growth areas. At the same time, humans bring all the time intentionally new taxa to the urban environment, parks, and gardens, including botanic gardens; besides, through ports, railways, and highways new taxa are brought to the country unintentionally. Urban flora usually differs from the flora of adjacent areas in having a larger proportion of such species that require more light, higher temperatures, and more nitrogen but less water (Chocholoušková and Pyšek, 2003; Walter et al., 2005).

The flora studies in other European cities have shown that deliberate introduction for horticulture, forestry, and landscaping purposes plays the major role in cities, while unintended introductions are of less importance (Müller, 2011b). Analysis by Ööpik et al. (2008) proved that humans have played a more profound role in fostering plant naturalizations than by acting simply as dispersers, as the percentage of naturalization among the deliberately introduced species is considerably higher than among the accidentally introduced taxa. Of the spontaneous alien species included into our database 64% grow in culture (for human and animal food, as ornamental plants), the rest have found their way into Tallinn through some other human activity (ruderals).

On our studied 10 quadrants the neophytes made up 15.2% of the whole list of vascular plant species. Studies in other European cities show similar results. For example, in Augsburg 10% of the vascular plant species are considered as neophytes (Müller, 2011a), in Berlin 20% (Sukopp, 2011), in Maastricht 17% (Weeda, 2011), in Warsaw, excluding diaphytes, 9% (Sudnik-Wójcikowska and Galera, 2011). In Poznan the proportion of neophytes grew from 5% in 1850 to 11.5% in 1990 (Jackowak, 2011). From the neophytes of Tallinn (Table 2) *Bellis perennis*, *Lolium perenne*, and *Conyza canadensis* belong to the 20 most frequent species of 16 European cities (Müller, 2011b); the first two species are native in Europe and the last one is alien.

The floras of cities are often difficult to compare. One group of reasons for this is connected with the size and neighbourhood of the cities, another with the geographical latitude and climate. Moreover, the character and aims of researches carried out differ. Some lists of local flora contain data from several centuries, some databases are composed during relatively short periods. Moreover, floras of cities are in permanent change. A considerable number of alien species may be part of the spontaneous flora for some period without establishing (but may become established after several introductions), some indigenous plant species become extinct, the territories of cities have been broadening in the course of time and incorporate new habitats. Müller (2005, 2010) recommended that the 50 most frequent plants in the cities and not the lists of total floras should be compared. According to his research, there are differences in the proportion of native species to non-native species between the old and the new world. Namely, in European cities the native species form the major part of the vegetation, but in the US cities non-native species predominate. The possible reasons why European vascular plant species have successfully established in the US are by Müller (2010) (1) deliberate and unintended introductions of large quantities of European plant material by the early European settlers and (2) specific biological attributes of European taxa for urban habitats, resulting from millennia of evolution in ruderal and/or disturbed areas. Taxa that have evolved in Europe and are found only in human-created habitats are known as anecophytes or neogene species. Our study showed that anecophytes were widely distributed also in Tallinn.

Urban biota is changing rapidly as a consequence of human direct and indirect activity. The percentage of alien species in the flora of Tallinn has become relatively large. Alien species may be a danger to native communities as well as to human health (causing bruises and allergies). Urban places are one of the centres where species may develop into invasive ones. Therefore, the city with its alien species requires our constant attention.

Based on our study we can conclude that tens of hectares of broad green areas with forest and semi-natural meadows are stable and valuable habitats for the growth of indigenous species. In the ten inventory quadrants located in greenery-rich areas, the proportion of indigenous species compared with the naturalized species was 85%, which is significantly higher than the proportion for the whole Tallinn, which is 74%. Several factors may account for this discrepancy. First, natural and semi-natural communities provide conditions for species that do not occur in areas of urban fabric and sown lawns. These conditions can be associated with the composition of fungal species in soil, with the water regime of the habitat, and the presence of different age stages in plant populations. For example, such species are representatives of the family Orchidaceae, or a native species of the genus *Dianthus*. As a rule, plant cover of natural and semi-natural plant communities is dense, and the relocation of ground due to human activities is not common. This hinders the invasion of alien species into established communities. However, our study showed that invasive species were common also in greenery-rich areas. Second, the territories of the studied quadrants are situated some distance from the main sources of invasion in Tallinn, which by our observations are commercial harbours, goods terminals, landfills, sites of former grain elevators, tanneries, and slaughterhouses. Besides, in the territories of the studied quadrants streets, roads, paths, and abandoned or active railways were located. Commercial sand extraction occurred in one quadrant, another housed the Tallinn Zoo and also a facility for horse-related recreation with occupied horse stables. Most of the study quadrants were affected by the flora of gardens.

The current situation, which is characterized by the dominance of indigenous species in the flora of Tallinn, should be maintained and valued. Concurrently, cities with their alien species require our constant attention.

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Soontaimede pärismaine ja võõrfloora Tallinnas

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Viimastel aastakümnetel on ökoloogid tähelepanu pööranud linnadele kui aladele, kuhu inimene toob järjepanu sisse uusi võõrliike ja kus osa neist kujuneb invasiivseks. Balti riikide ja Skandinaavia maade kohta ei ole seni küllaldaselt andmeid avaldatud, et neist protsessidest regioonis ülevaadet saada. Puuduva teabelünga täitmise ühe sammuna viidi läbi uurimine, mille eesmärgiks oli kindlaks teha soontaimede pärismaise ja võõrfloora koosseis Tallinnas ning võrrelda võõrliikide esinemust Tallinna rohealade rikastes piirkondades vastava näitajaga kogu linnas. Selleks inventeeriti taimestikku kümnel 1 km^2 suurusel ruudul rohealade rikastes Tallinna osades ja saadud andmeid võrreldi kogu Tallinna territooriumilt teada oleva soontaimede koosseisuga. Tallinna soontaimede andmebaas koostati, kasutades lisaks välitöödel saadud teabele teiste autorite avaldatud andmeid.

Saadud Tallinna soontaimede floora andmebaasi alusel on Eesti pärismaiseid liike sisaldavast 113 sugukonnast Tallinnas esindatud 104 ehk 92%. Koos sugukondadega, kus on teada vaid võõrliigid, on Tallinnas sugukondi kokku 125. Tallinnas on registreeritud 68% Eesti kodumaistest (980 liiki) ja 58% spontaanselt kasvavatest (st need ei ole istutatud ega külvatud) võõrliikidest (455 liiki), samas kui linna territoorium on vaid 0,35% Eesti pindalast. Tallinna soontaimede 1435 liigiga floorast moodustavad 68% pärismaised ja 32% võõrliigid, perekondade kortsleht (*Alchemilla*), hunditubakas (*Hieracium*), karutubakas (*Pilosella*), võilill (*Taraxacum*), silmarohi (*Euphrasia*) ning nõiahammas (*Lotus*) pisiliike mitte arvestades on vastavad suhtarvud 66% ja 34%. Spontaanselt kasvavatest võõrliikidest on 64% inimese poolt tahtlikult sisse toodud (söögi-, sööda- ja ilutaimed), ülejäänud 36% on Tallinna sattunud tõenäoliselt juhuslikult (ruderaaltaimed). Registreeritud võõrliikidest 280 ehk 62% on kodunenud mitteinvasiivsed soontaimed, 152 (33%) juhuslikult esinenud ja 23 (5%) invasiivsed liigid. Kümnel uuritud 1 km^2 suurusel ruudul juhuslikke võõrliike ei leitud, invasiivsetest liikidest kasvasid kõikides ruutudes kanada pujukakar (*Conyza canadensis*), väikeseõiene lemmmalts (*Impatiens parviflora*) ja punane leeder (*Sambucus racemosa*), üheksal ruudul esines harilik tõlkjas (*Bunias orientalis*).

Permutatsioonitesti abil võrreldi pärismaiste ja võõrliikide suhet inventeeritud aladel ning kogu Tallinnas. Tallinna rohealad hõlmavad kokku 35% linna territooriumist. Rohealade rikastes piirkondades esinevad kompaktsed metsaalad koos poolloodusllike niidulaikudega kohati mitmekümnel hektaril. Analüüs näitas, et pärismaiste soontaimeliikide osakaal kogu floorast on Tallinna rohealade rikastes piirkondades oluliselt suurem kui linnas tervikuna. Meie uurimus kinnitab seisukohta, et ulatuslikud rohealad pakuvad pärismaistele liikidele sobivaid kasvukohti, on elurikkuse keskmeteks ja moodustavad puhvri, mis on takistuseks võõrliikide levikule. Võõrliigid võivad kujutada ohtu kohalikele kooslustele ja inimese tervisele (allergia või haavandite põhjustajana). Tallinna iseloomustab ulatuslike rohealade rohkus, see omakorda toetab pärismaiste taimeliikide ülekaalu võõrliikide suhtes. Praegust olukorda tuleb hinnata ja püüda igati säilitada.