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Diversity and distribution of the urban tree population in ten major Nordic cities

Henrik Sjöman^{1*}, Johan Östberg¹, Oliver Bühler²

¹Swedish University of Agricultural Sciences, Faculty of Landscape Planning, Horticulture and Agricultural Science, Department of Landscape Management, Design and Construction, Box 66, SE-23053 Alnarp, Sweden

²Division of Parks and Urban Landscapes, Danish Centre for Forest, Landscape and Planning, Faculty of Life Sciences, University of Copenhagen, Rolighedsvej 23, DK-1958 Frederiksberg, Denmark

*Corresponding author. E-mail addresses: Henrik.Sjoman@slu.se (H. Sjöman), Johan.Ostberg@slu.se (J. Östberg), olb@life.ku.dk (O. Bühler).

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Abstract

In order to have a healthy and sustainable urban tree population, a high diversity of species and genera is needed. This study examined (1) the diversity and distribution of genera and species of urban trees in the Nordic region; (2) the diversity in different sites of the city, distinguishing between street and park environments; and (3) the presence of native versus non-native tree species in urban environments in the Nordic region. The analysis of tree diversity was based on urban tree databases comprising a total of 190 682 trees in 10 Nordic cities – Aarhus and Copenhagen in Denmark; Espoo, Helsinki, Tampere and Turku in Finland; Gothenburg, Malmö and Stockholm in Sweden; and Oslo in Norway. The tree databases for Copenhagen, Espoo, Helsinki, Stockholm and Tampere only record street trees, while the remaining databases also include park trees. *Tilia* was the most dominant genus in Arhus, Copenhagen, Espoo, Gothenburg, Helsinki, Oslo and Stockholm, while *Sorbus* was the most dominant in Malmö and *Betula* in Tampere and Turku. *Tilia × europaea* was the most common species, comprising 16.0% of the total number of tree species. There was a higher proportion of species in parks than in street environments. The number of non-native species was higher than the number of native species in both street and park environments. However, the number of individuals belonging to native species was higher than the number of non-native individuals in all cities and environments except park environments in Arhus. The concluding recommendation from this study regarding greater diversity of genera and species is to exploit local experiences of rare species from local urban tree databases. After appropriate evaluation, urban tree planners can evaluate these rare species in larger numbers for e.g. street environments, where the need is greatest.

Introduction

Urban trees have a number of effects that are beneficial for the quality of life in urban areas. They help reduce the urban heat island intensity (King and Davis, 2007), and thus decrease the need for energy for cooling buildings (Akbari et al., 2001; Maco and McPherson, 2003). Urban trees are capable of reducing storm water runoff and thereby reduce flooding and damage to urban property (McPherson et al., 1997). They also act as noise filters and purify the air through capturing particulate matter, carbon dioxide, ozone and other air pollutants originating from traffic and industrial activities (McPherson et al., 1997; Becket et al., 2000; Nowak et al., 2006). Urban trees also play an important role in recreation for the urban population since they are an important element in green spaces in residential and commercial areas (Tyrvainen et al., 2007). However, the above-mentioned effects are only possible if the urban tree stock is vital and unaffected by pests and diseases.

In order to have a healthy and sustainable urban tree population, a high diversity of species and genera has been proposed as a key solution (e.g. Duhme and Pauleit, 2000; Raupp et al., 2006; Bassuk et al., 2009). The imperative and most frequent argument for high diversity is the recurring outbreaks of diseases and the threat of invasive pests and diseases in the most commonly used tree species (e.g. Sun, 1992; Tello et al., 2005; Raupp et al., 2006). Climate change, with predicted increased average temperatures, more frequent heat waves and periods of drought during summer (IPCC, 2007), is another important issue to take into consideration. Barker (1975) was one of the first to suggest the use of a broad range of species. He recommended that no given species should account for more than 5% of the total tree population. Smiley et al. (1986) and Miller and Miller (1991) recommend that the maximum share of any species should be less than 10% of the population. Grey and Deneke (1986) present a similar view, that one species should not amount to more than 10–15% of the total population. In a refined model, Moll (1989) recommends that no species should exceed 5% of a city's tree population and that no genus should exceed 10%. Santamour (1990) extends the recommendations even further to include a recommended maximum use of species and genera from the same family; no species should represent more than 10%, no genus more than 20% and no

family more than 30% of the population. Such strategic recommendations for species choice are important guidelines for more diverse use of tree species in the urban environment.

In order to analyse the susceptibility of the tree population to outbreaks of pests and diseases and its tolerance to more stressful climates, the composition of the urban tree stock has been studied in many cities (e.g. Sanders, 1981; Jim and Liu, 2001; Pauleit et al., 2002; Sabo et al., 2005; Frank et al., 2006; Raupp et al., 2006; Negandra and Gopal, 2010). However, no such studies have been made exclusively for the Nordic region. Pauleit et al. (2002) carried out a European survey in order to evaluate tree establishment and management practices in 17 countries and nearly 100 towns and cities. In the Nordic region, the study included Denmark (Copenhagen), Finland (Helsinki and Kuopio) and Norway (Oslo). However, the study was limited to newly planted trees in urban areas. In that particular survey Oslo stood out, as 70% of all newly planted trees in street environments belonged to one clone of *Tilia* (*Tilia ×europaea 'Pallida'*; Pauleit et al., 2002). This lack of diversity clearly indicates the importance of a full review of the tree population in order to avoid future risks. However, since that survey was restricted to newly planted trees and since the data were taken from only a small sample of the total urban area, a complementary study for the Nordic countries is necessary in order to evaluate regional risks for the urban tree population, including both old trees and newly planted trees.

In another study, Sabo et al. (2005) summarised the most common street and park trees in three geographical regions of Europe (Northern, Central and Southern Europe). That survey showed that the range of species was greater in parks than in street environments, indicating that a large number of species are well adapted to the often favourable growth conditions in urban woodlands and parklands, but that finding species able to withstand the challenging conditions in street environments and at other paved sites is much more difficult. In street conditions and other paved environments trees are exposed to a number of stressful elements, e.g. exposure to heat, low air humidity, periods of drought, high lime content and high soil pH, limited soil volume, de-icing salt and other pollutants (Pauleit, 2003; Sieghardt et al., 2005). Even if a city contains high numbers of species in street

environments, normally a group of a few species typically dominates the urban tree population (Raupp et al., 2006). Urban tree inventories contain valuable, local information about e.g. rare species used in small numbers. If accessible, this information can help increase the number of rarely used species and thereby increase the diversity of the urban tree population.

Another recent issue in planning for greater diversity of tree species and genera is the question of whether non-native species should be used in urban plantations. There have been extensive discussions about the risk of non-native species spreading from the urban environment to natural environments, thereby risking extinction of native species (Parker et al., 1999; Alien Plant Working Group, 2010; Hitchmough, 2011). Chytry' et al. (2008) and Pyšek et al. (2009) conclude that for a species to successfully escape from cultivation into

natural environments and there develop into a potential invasive species, there are two essential factors: propagule pressure (the number of individuals of a species existing in a region) and residence time (how long a species has been cultivated in a region). The longer a species has been in an area, the greater the chances of it escaping. Therefore it is essential to know the number of non-native species present in an area in order to identify eventual invasion threats at an early stage.

Against this background, the objectives of the present study were three-fold: (1) To obtain basic information on the diversity and distribution of genera and species of urban trees in the Nordic region; (2) to examine the diversity at different sites within cities, distinguishing between street and park environments; and (3) to analyse the presence of native versus non-native tree species in the urban environments of the Nordic region.

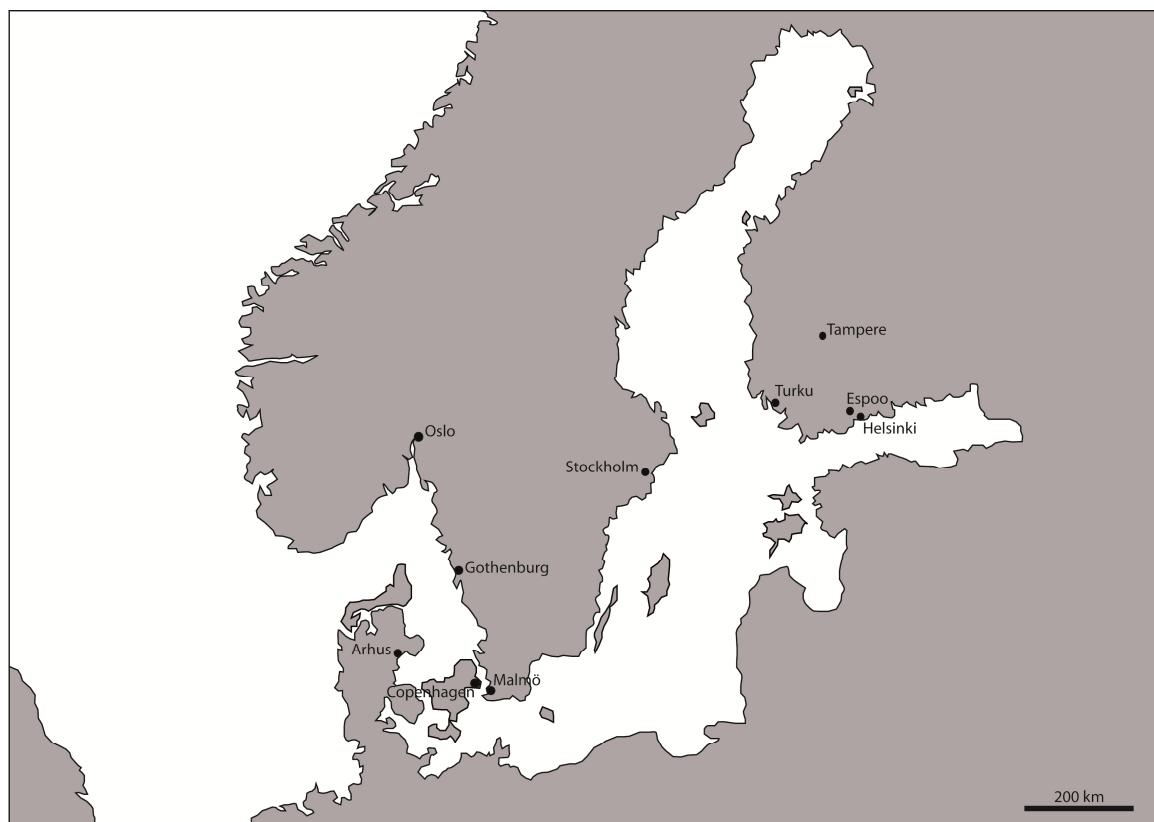


Fig. 1. Map of the 10 Nordic cities studied (illustration by Bjorn Wiström 2010).

Materials and methods

The analysis of tree diversity was based on urban tree databases obtained from 10 Nordic cities. A request was sent out to all cities in the Nordic region with more than 200 000 inhabitants, in total 10 cities (SCB, 2010; SSB, 2010; STAT, 2010; Statistikbanken, 2010). These cities were Aarhus and Copenhagen in Denmark; Espoo, Helsinki and Tampere in Finland; Gothenburg, Malmo and Stockholm in Sweden; and Bergen and Oslo in Norway (Fig. 1). However, Bergen did not have a developed urban tree database and thereby did not participate in the study. Instead, Turku (176 087 inhabitants) in Finland was selected in order to include 10 major Nordic cities with rather well developed urban tree databases in the study. The selected cities are partly located in the southern maritime region (Aarhus, Copenhagen, Gothenburg, Malmo and Oslo) and partly in the southern continental region (Espoo, Helsinki, Stockholm, Tampere and Turku) of the Nordic region (Sabo et al., 2003).

In the request sent out to the cities, urban tree departments were asked to provide their complete tree database. However, the amount and type of data differed between the cities and only information on the species diversity and distribution was available from all cities in the study. For street environments, Aarhus, Copenhagen, Helsinki, Malmo and Tampere had the almost complete datasets (considered complete in the analyses), while for park environments the amount of data differed between the cities. The databases of the remaining cities are still under development, but had sufficient data to allow analysis (Table 1). In this study, street trees are defined as trees placed in or close to streets or roads and needing special management in order to meet the demands of the street environment.

Accurate taxonomic identification of the species in the study was carried out according to Alden and Ryman (2009). The Nordic Flora (Mossberg and Stenberg, 2003) was used to determine whether the

species is native to the region. In the classification of native and non-native species, a hybrid where one of the parents is native to the Nordic region was classified here as native. Trees identified only to genus level were excluded from further analyses in the comparison between native and non native species, as well as in the calculation of species diversity index. In the presentation of genera and species diversity data, species with an occurrence of more than 2% are presented separately, while the remaining species are grouped under the heading Frequency of less than 2%.

A total of 190 682 trees was included in the study (Table 1). The tree databases of Copenhagen, Espoo, Helsinki, Stockholm and Tampere only contain information on street trees, while the remaining databases also include park trees. In the case of Aarhus, Gothenburg and Turku, the total number of trees given is higher than the sum of park and street trees due to missing information regarding the site position of some of the trees (Table 1). In the presentation of tree data from Aarhus, park trees were excluded from the general presentation of genera and species distribution because all park trees except 133 individuals are located in a botanical garden and cemeteries, where the majority of the species are represented by only three individuals or less. Including these trees in the distribution presentation would have given a somewhat skewed picture of the species diversity of Aarhus, since the diversity is located to some particular spots in the city. However, the park trees in Aarhus are included in the presentation of numbers of species in street and park environments in the study, since these trees act as important reference trees for park environments in the region. In order to compare this study with other geographical regions, a species diversity index calculation was made distinguishing between street and park environments (Jim and Liu, 2001).

Table 1. Total number of trees in the tree databases of the 10 Nordic cities analysed in the study. Trees situated in street and park environments are listed separately.

City	Total number of trees	Total number of park trees	Total number of street trees	Amount of complete data
Aarhus	15 539	3 377	12 162	95% of all street trees and 10-15% of park trees have been inventoried.
Copenhagen	18 154	0	18 154	95% of street trees have been inventoried.
Espoo	6 088	0	6 088	30% of street trees have been inventoried.
Gothenburg	4 797	1 018	2 154	The central area of the city has been inventoried
Helsinki	22 315	0	22 315	90-95% of all street trees and 10-15% of park trees have been inventoried.
Malmo	48 963	27 037	21 926	The inventory is complete for all trees that are maintained by the city's parks department.
Oslo	11 011	7 881	3 130	The central area of the city has been inventoried
Stockholm	12 693	0	12 693	All street trees in the central area of the city have been inventoried, plus 30% of the trees outside the centre.
Tampere	20 824	0	20 824	All street trees have been inventoried.
Turku	35 095	21 176	13 919	25-30% of the whole urban tree population has been inventoried.
Total	190 682	67 080	123 602	

Results

Number and distribution of species

The number of species used differed greatly between the different cities studied. Among cities with complete datasets in street environments, Aarhus had the third highest diversity, with 57 different tree species, whereas Helsinki, which has a colder climate, had 48 different species. The highest diversity based on the urban tree databases was reported for Malmo, with 133 different tree species, followed by Copenhagen (66) and the lowest amount of species was reported for Tampere (27). Within this compilation trees identified only to genus level were excluded.

Analysis of the number of tree genera in all cities studied revealed a clear dominance of *Tilia*, which accounted for 23.7% of the total tree population (Table 2). *Tilia* together with *Acer*, *Betula* and *Sorbus* represented 58.3% of the total tree stock (Table 2). In terms of the genus distribution of the individual cities, *Tilia* was the dominant genus in Aarhus, Copenhagen, Espoo, Gothenburg, Helsinki, Oslo and Stockholm, while *Sorbus* was the dominant genus in Malmo and *Betula* in Tampere and Turku. The major dominance of *Tilia* was particularly pronounced in Helsinki, where it accounted for 44.7% of the total tree population

(Table 2). In Helsinki the two most common genera (*Tilia* and *Acer*) represented over half (57.4%) the tree population. A situation with two genera representing over half the tree population was also found in Gothenburg, Oslo, Stockholm and Tampere (Table 2).

In terms of species representation in all cities studied, *Tilia × europaea* L. was the most common species, with 16.0% of the total number of tree species. This was followed by *Acer platanoides* L. (9.2%), *Betula pendula* Roth. (9.0%), *Sorbus × intermedia* (Ehrh.) Pers. (4.8%), *Tilia* spp. (4.4%), *Sorbus aucuparia* L. (3.9%), and *Ulmus glabra* Huds. (3.2%) (Table 3). These seven most common species accounted for more than 50% of the total tree population in the 10 cities studied. As regards the number of species in the individual cities, *Tilia × europaea* was the most common species in five of the 10 cities (Copenhagen 23.7%, Espoo 23%, Gothenburg 27.1%, Helsinki 44.3%; Turku 12.5%); in Oslo and Stockholm *Tilia* spp. was the most dominant species (25.1% and 25.6%, respectively); in Tampere *Betula pendula* was the dominant species with 32.1% of the population, and in Aarhus *Sorbus mougeotii* Soy.-Will. & Godr. was the most

common species, accounting for 11.3% while *Sorbus × intermedia* were accounting for 9.1% in Malmo. In Helsinki and Tampere, only two species accounted for over half the total number of trees, *Tilia × europaea* and *Acer platanoides* in Helsinki and *Betula pendula* and *Tilia × europaea* in Tampere (Table 3). In contrast, Malmo reported that 12 species accounted for half the tree population and that no single species represented more than 10% of the total tree stock.

The geographical location of the cities studied was reflected in the use of species. In the three most

Number of species in streets and park environments

The number of species used differed greatly between the different cities studied. Among cities with complete datasets in street environments, Aarhus had the third highest diversity, with 57 different tree species, whereas Helsinki, which has a colder climate, had 48 different species. The highest diversity based on the urban tree databases was reported for Malmo, with 133 different tree species, followed by Copenhagen (66) and the lowest amount of species was reported for Tampere (27). Within this compilation trees identified only to genus level were excluded.

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southerly cities, Aarhus, Copenhagen and Malmo, species such as *Platanus × hispanica* Munchh. and *Fagus sylvatica* L. made up a rather high proportion of the population (Table 3). In contrast, in the more northerly cities of Espoo, Helsinki, Oslo, Stockholm, Tampere and Turku, there was a high proportion of species representative of the boreal and nemo-boreal region, such as *Alnus glutinosa* (L.), *Betula pendula*, *Picea abies* (L.) U.Karst., *Pinus sylvestris* L. and *Sorbus aucuparia*.

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Table 2. Proportion of city trees from different genera in the 10 Nordic cities studied.

Genus	Total in the 10 cities	Arhus	Copenhagen	Espoo	Gothenburg	Helsinki	Malmo	Oslo	Stockholm	Tampere	Turku
Acer	12.1%	7.7%	11.6%	19.8%	5.8%	12.7%	8.7%	23.7%	21.0%	10.3%	10.7%
Aesculus	2.7%	6.0%	5.4%		3.3%		4.9%	5.3%	3.0%		
Alnus										4.0%	3.6%
Betula	10.9%			9.4%	4.5%	11.1%	3.0%	11.7%	8.8%	39.1%	14.9%
Carpinus		2.8%			2.0%		2.1%				
Crataegus	2.1%		2.4%			2.1%	4.2%		3.1%		
Fagus	2.1%				3.4%		4.3%				
Fraxinus	2.8%	2.7%	7.5%		2.8%		3.9%	2.5%			2.8%
Malus		2.3%					2.8%				3.5%
Picea	2.0%										8.6%
Pinus	3.2%			2.6%					5.1%	3.5%	9.7%
Platanus	2.1%	5.0%	11.5%				2.9%				
Populus	3.4%	3.3%	2.8%	2.9%		2.2%	6.1%				2.9%
Prunus	3.9%	8.3%	2.1%		3.5%		8.7%	4.4%	5.2%		3.1%
Quercus	3.9%	6.8%	4.6%	3.2%	3.0%	3.4%	5.4%	3.2%	2.1%		3.2%
Robinia			3.7%								
Salix	2.2%	2.0%					3.9%				2.9%
Sorbus	11.6%	18.0%	8.8%	15.9%	4.2%	7.5%	14.0%	2.8%	11.7%	12.7%	9.8%
Tilia	23.7%	24.5%	34.7%	26.9%	46.3%	44.7%	13.3%	27.1%	31.9%	23.7%	14.0%
Ulmus	3.8%			13.2%	8.9%	8.5%		8.9%			5.7%

Genera with a frequency of less than 2%

than 2%

Table 3. Proportion of species found in the 10 Nordic cities studied, irrespective of site situation.

<i>Robinia pseudoacacia</i>			3.3%								
<i>Salix alba</i>		2.3%					2.3%				
<i>Sorbus aucuparia</i>	3.9%	3.7%		9.0%		3.6%				11.9%	5.9%
<i>Sorbus x intermedia</i>	4.8%	5.7%	6.0%	6.0%	2.8%	2.9%	9.1%		8.8%		
<i>Sorbus latifolia</i>		5.0%									
<i>Sorbus mougeotii</i>		11.3%									
<i>Tilia cordata</i>	2.1%	8.0%	4.5%	2.2%	5.3%				2.1%		
<i>Tilia x europaea</i>	16.0%	7.3%	23.7%	23.0%	27.1%	44.3%	8.6%		3.0%	21.2%	12.5%
<i>Tilia platyphylла</i>			3.6%								
<i>Tilia</i> spp.	4.4%		2.9%		11.7%		2.1%	25.1%	25.6%		
<i>Ulmus glabra</i>	3.2%			11.3%	6.4%	8.4%		8.0%			5.3%
<i>Ulmus minor</i>					2.1%						
Species with a frequency of less than 2%	35.3%	18.2%	23.3%	14.4%	27.1%	14.0%	42.6%	21.8%	21.8%	13.0%	28.5%

Number of species in streets and park environments

The highest number of tree species growing in a street environment was found in Malmö, with 113 species, followed by Turku (74) and Copenhagen (66) (Fig. 2). On comparing the number of species in streets and park

environments in the five cities where this subdivision was made, the general conclusion was that there was a higher proportion of species in parks compared with street environments.

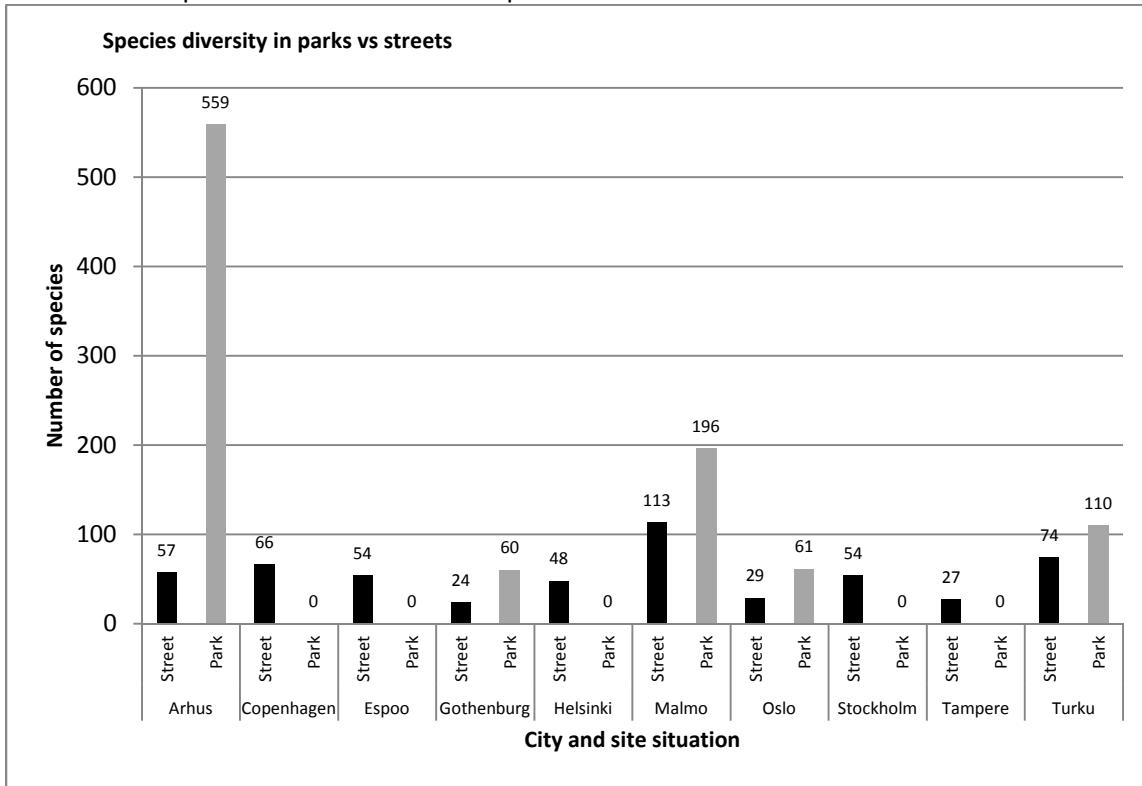


Fig. 2. Distribution of park and street tree species in the 10 Nordic cities studied (no data on park tree species available for Copenhagen, Espoo, Helsinki, Stockholm and Tampere).

Malmö had the highest proportion of species that occurred with a frequency of less than 2% of the total tree population. In park environments this group comprised 45.1% of the total tree stock, while in street environments it accounted for 35.9% of the total population. The second highest distribution of species representing less than 2% of the total tree population was reported from Turku, with 42.8% in park environments but only 13.1% in street environments (Table 4). Oslo had the largest difference between street and park environments, with *Tilia* spp. accounting for 45.3% of the tree population in street environments, followed by *Acer platanoides* with 11.6%. In park environments the situation was reversed, with *A. platanoides* accounting for 21.2% and *Tilia* spp. for 17.1% (Table 4).

Among the cities which had a complete dataset of trees in street environments, Aarhus and Malmö showed the largest species diversity, where six and

seven species, respectively, made up half the tree population (Table 4).

In park environments, the distribution of tree individuals in species was more even. The most notable finding was the high number of species in park environments in Aarhus (Table 4), where the nine most frequent species together only represented 31.3% of the tree population and where 68.7% of the tree stock was represented by species with an occurrence of less than 2% of the total tree population. Aarhus showed a clear difference between the tree population in street and park environments, with the eight most dominant species in street environments being present at a frequency of 2.5% or less in park environments (Table 4).

The largest species diversity index among the cities with complete dataset was found in Malmö and Aarhus with 5.15 and 4.69 respectively in street environment. The species diversity index differed greatly for those cities with incomplete dataset,

ranging from 4.25 in street environment to 58.94 in park environment.

Origin of urban trees

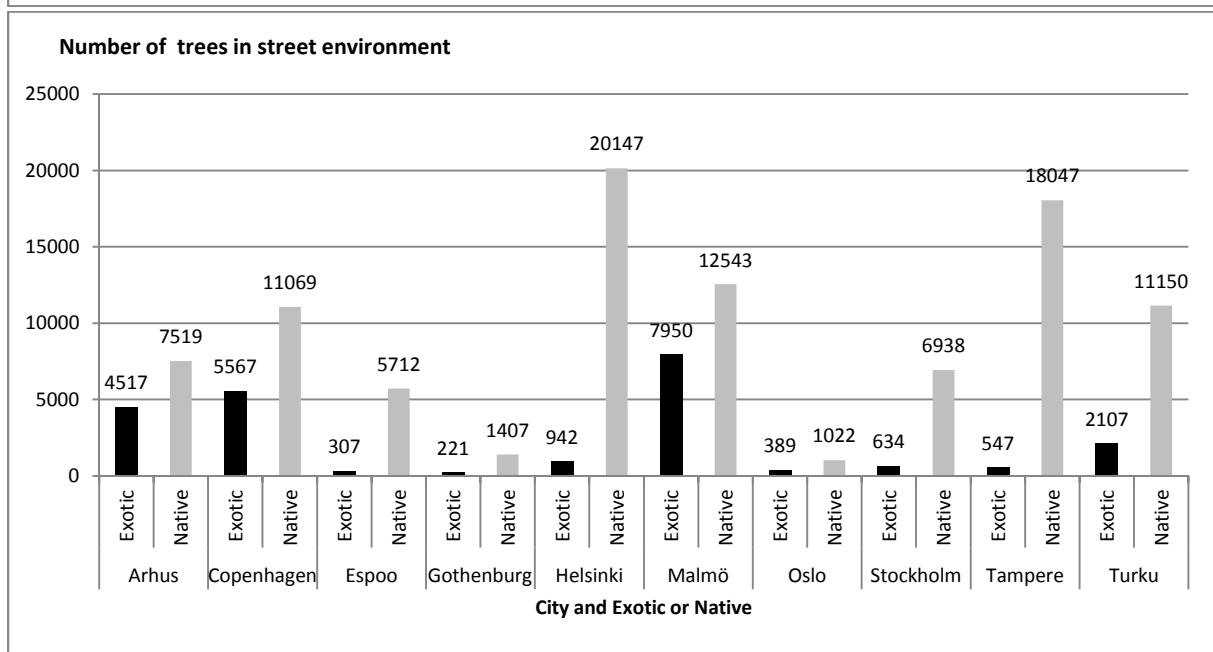
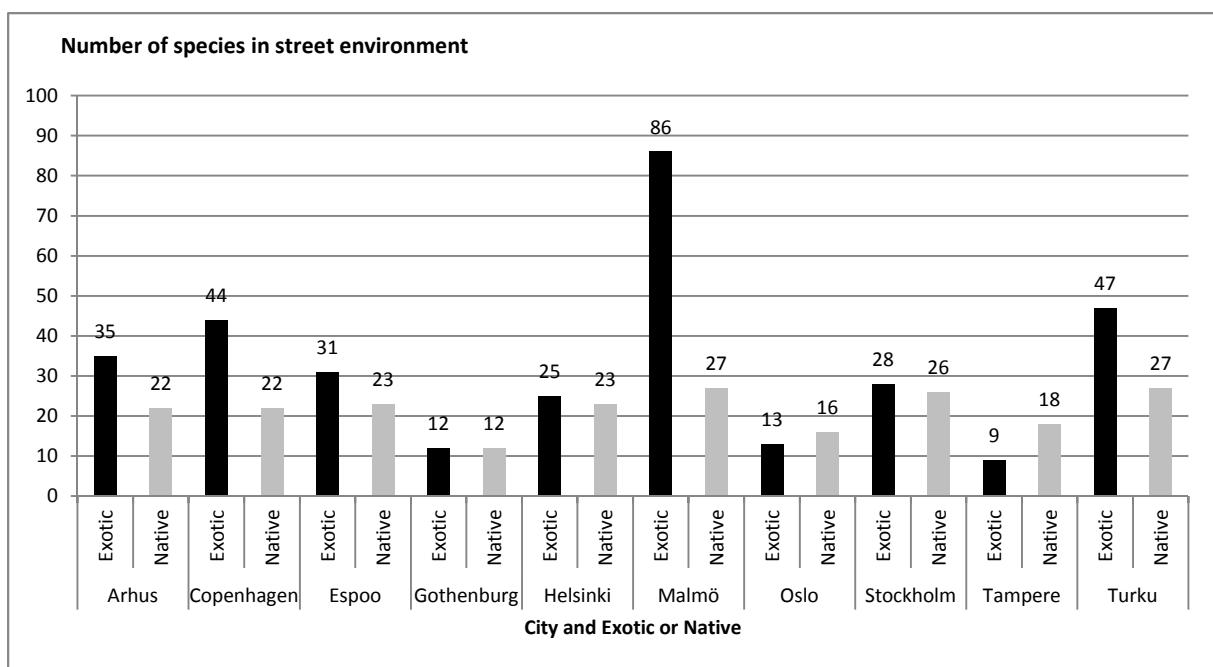
Analysis of tree origins showed that the number of non-native species was higher than the number of native species in both street and park environments in all cities except Oslo and Tampere, where the number of native species were greater in street environments (Fig. 3a and c). However, the number

of tree individuals belonging to native species was higher than the number of non-native individuals in all cities except Aarhus, where non-native species dominated in park environments (Fig. 3d).

The street environments in Malmo and Turku had the highest number of non-native species, while Aarhus had the highest proportion of non-native tree individuals in park environments due to the diverse tree collection at the botanical garden and high species diversity in cemeteries (Fig. 3a and b).

Table 4. Distribution of city trees across the most common species in the five Nordic cities that distinguished between trees growing in street environments and park environments.

<i>Populus simonii</i>					3.0%						
<i>Populus tremula</i>											2.9%
<i>Prunus avium</i>					5.3%	4.2%					
<i>Prunus spp.</i>							3.0%	3.5%			
<i>Prunus padus</i>				2.3%							
<i>Quercus robur</i>	7.9%	2.5%		15.2%	4.0%	3.0%			2.6%	3.6%	
<i>Robinia pseudoacacia</i>											
<i>Salix alba</i>	2.3%					3.4%					
<i>Sorbus aria</i>					2.7%						
<i>Sorbus aucuparia</i>	3.7%								9.3%	3.8%	
<i>Sorbus x intermedia</i>	5.7%		7.7%	5.3%	11.1%	7.6%			2.9%		
<i>Sorbus latifolia</i>	5.0%										
<i>Sorbus mougeotii</i>	11.3%										
<i>Sorbus spp.</i>			3.7%								
<i>Taxus baccata</i>		3.1%									
<i>Tilia cordata</i>	8.0%		7.0%		3.3%				2.6%		
<i>Tilia plathyphylla</i>											
<i>Tilia spp.</i>			13.9%	19.4%	2.9%		45.3%	17.1%			
<i>Tilia x europaea</i>	7.3%		35.5%	10.0%	16.5%	2.3%			16.7%	10.8%	
<i>Ulmus glabra</i>		3.1%	5.8%				4.6%	9.3%	5.9%	5.0%	
<i>Ulmus minor</i>			2.8%								
Species with a frequency of less than 2%	18.1%	68.7%	19.7%	29.1%	35.9%	45.1%	21.8%	23.3%	13.1%	42.8%	



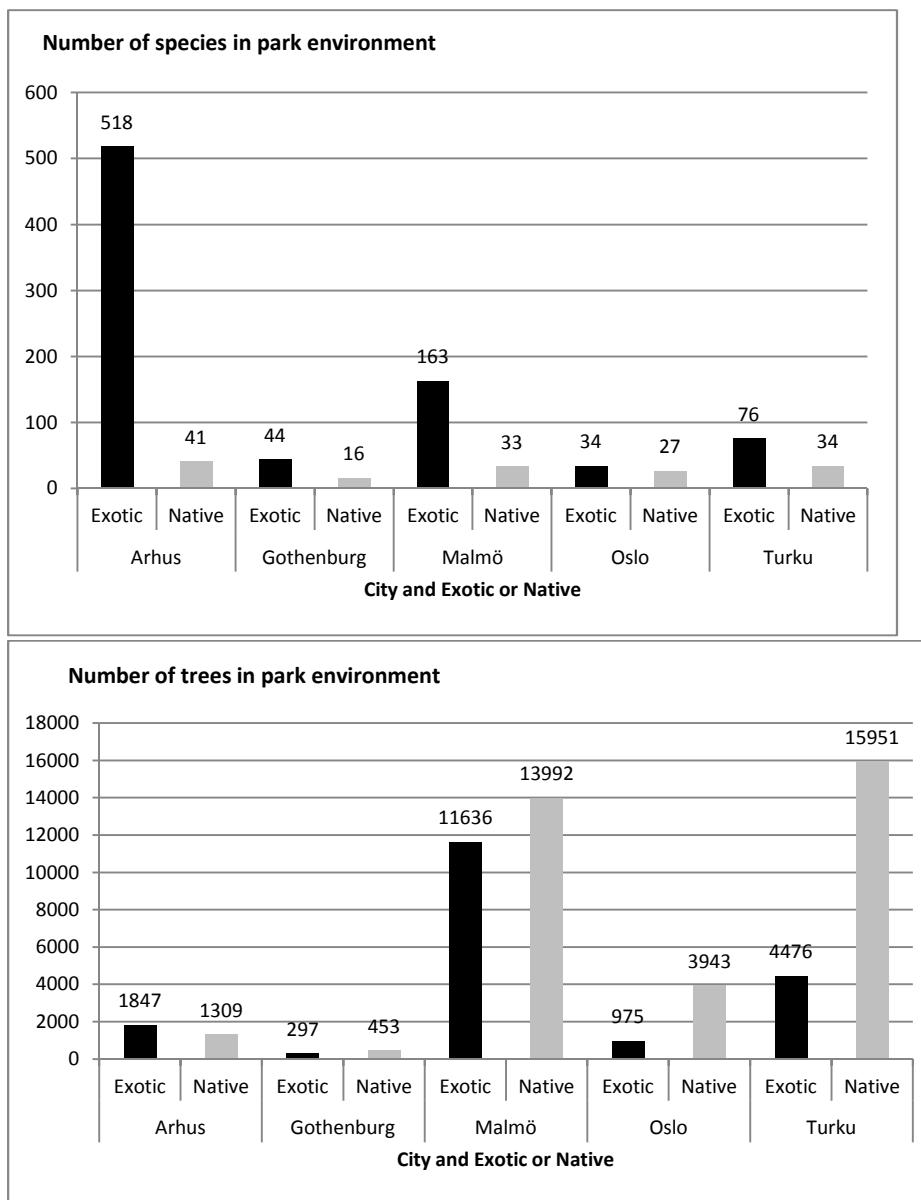


Fig. 3. (a-d) Distribution of native and non-native tree species and number of native and non-native tree individuals found in street and park environments in the 10 Nordic cities studied.

Discussion

This study provides valuable information about the diversity and distribution of urban trees in 10 Nordic cities that can be used e.g. by policy makers when predicting potential risks facing the local urban tree population concerning outbreaks of serious pests and diseases and how well prepared a city is for future climate change. It was not possible to make direct comparisons between the cities studied, since the relevant datasets differed. Complete datasets were only available for street trees in Aarhus, Copenhagen, Helsinki, Malmo and Tampere, while data for park environments differed greatly between these cities. The databases of the remaining cities are still under development and therefore the results from these cities should be interpreted with some caution, since the species distribution could differ after a complete inventory. This is especially apparent in Table 5, where e.g. Gothenburg has a much higher species diversity index than Malmo and Copenhagen, which have complete inventories for street environments. When all trees in Gothenburg are included in the database the results will probably show a different index. Nevertheless, the incomplete datasets provided valuable information about the diversity of species and genera, the difference in diversity between trees in street and park environments and the relative proportions of native and non-native tree species. It is important to visualise such information at an early stage in order to start a debate concerning future risks the local urban tree population might face regarding pests and diseases and predicted climate change.

One of the existing recommendations regarding diversity is that no species in a city should exceed more than 10% of the total tree population (Grey and Deneke, 1986; Smiley et al., 1986; Santamour, 1990; Miller and Miller, 1991). Only Malmo complied with this recommendation in terms of entire tree population, irrespective of site situation (Table 3). In contrast, Helsinki had *Tilia × europea* as the most common urban tree, representing 44.3% of the total tree population (Table 3). The urban tree population of Helsinki is thus highly susceptible to outbreaks of pests or diseases of *Tilia × europea* (Tello et al., 2005; Raupp et al., 2006). This also applies to many Nordic cities, since *Tilia × europea* was one of the most common tree species in five of the 10 cities studied here (Table 3). The Oslo tree inventory contained high numbers of *Tilia* spp.

without further species classification. However, based on earlier studies by Pauleit et al. (2002), it can be concluded that a high proportion of these are probably *Tilia ×b europea*. Moreover, in the comparison between street and park environments (only possible in five of the 10 cities), no city complied with the recommendation that no species should account for more than 10% of the tree population in street environments, although this recommendation was met for park environments in Aarhus and Malmo (Table 4). This illustrates the need for knowledge and experience of a greater catalogue of suitable species, in particular for street environments. While the current recommendations on species diversity with different percentage mixtures of species and genera are more or less based on theoretical grounds, they act as important guidelines and arguments in planning higher diversity. However, today there is no clear knowledge and experience available about sustainable levels of diversity for an urban tree population. The maximum inclusion level of 10% is recommended by several authors (Grey and Deneke, 1986; Smiley et al., 1986; Santamour, 1990; Miller and Miller, 1991), but is rather high, and the recommendation from Barker (1975) and Moll (1989) that no species in a tree population should exceed 5% is perhaps more sustainable. No city in the present study could achieve the latter level.

Although the recommendations cited are important in the argument for greater diversity, an important consideration may be overlooked in the rush to diversify. Simply ordering new tree species and genotypes that are untested for the region is not the right course where adaptability and longevity of species in stressful urban habitats must weigh heavily in the selection (Raupp et al., 2006). Poor or incorrect choices may result in increased mortality, reduced lifespan of trees and ultimately greater costs when failed or failing trees must be removed or replaced (Richards, 1982/1983; Tello et al., 2005; Raupp et al., 2006).

In general, there were fewer species accounting for the majority of the tree population in street environments compared with park environments, confirming earlier studies (Sabo et al., 2005). This might reflect the situation that a large number of species can be grown in the favourable conditions often found in urban woodlands and parklands, but that identification of species that can withstand the

challenging conditions in street environments and at other paved sites is much more difficult (Pauleit, 2003). Based on this, the use of a small number of species known to survive in these situations is understandable.

Table 5. Species diversity index = [species count/tree count] × 1000 distinguishing between street and park environments.

City	Street	Park	Total
Arhus ^a	4.69	165.53	3.67
Copenhagen ^a	3.64	-	3.64
Espoo ^b	8.87	-	8.87
Gothenburg ^b	11.14	58.94	20.64
Helsinki ^a	2.15	-	2.15
Malmo ^a	5.15	7.25	4.19
Oslo ^b	9.27	7.74	5.81
Stockholm ^b	4.25	-	4.25
Tampere ^a	1.30	-	1.30
Turku ^b	5.32	5.19	3.28

^a Cities for which an almost complete inventory exists

^b Cities where limited parts of the urban tree population are inventoried

Furthermore, much of the information concerning nontraditional tree species that can tolerate street environments and other paved site situations, especially for the Nordic region, is very limited (Sjoman and Nielsen, 2010). Much of the site-specific information available has been obtained in other parts of the world, which makes it difficult to interpret these experiences for the Scandinavian region. However, regional experiences derived from local urban tree databases can act as a knowledge base, with regional evaluations of trees in e.g. street environments providing local and contextual information and guidance on species growth and performance at the specific site. Of special interest are the species that are currently used only in limited numbers and, after positive evaluation, could be used more frequently. For example, 35.9% of the total tree population in street environments in Malmo comprised species with less than 2% occurrence (Table 4). Here, many species have shown a longstanding tolerance to the local site situation and their use could be extended to other sites. For park environments, local arboreta and botanical gardens can act as local knowledge bases providing inspiration for greater species diversity in public parks. In Aarhus, the local botanical garden, which has included its tree population in the city's urban tree database, records a large number of

species with long and sustainable development (Table 4). However, in order to find reliable guidance in this direction, data on e.g. age and DBH (diameter at breast height) provide important information in determining the long-term tolerance of rare species to the local site situation. Such data were only available for one of the 10 cities studied here and were hence not included in the analysis. However, collecting these data exclusively for rare tree species could give fast and reliable guidance on species that have the potential for further introduction into the local urban tree population.

Although this study indicates a high diversity of species in park environments, for example in Aarhus and Malmo, this can provide a somewhat distorted picture, since the high diversity is located in a restricted area of the city or a species is located in one particular place. In the case of Aarhus, the botanical garden in the city significantly increases the number of species in park environments in the city, but this is linked to a specific place, whereas other parks and public woodlands can have much less diversity. In Malmo, some species are associated with a specific area. For example, *Fagus sylvatica* represents 7.2% of the total tree population in park environments (Table 4), but is more or less restricted to one park, Pildamms Park, where it dominates almost totally (A. Mattsson, personal communication, 2010). Information on the distribution of species in the cities was not available for this study, but in order to develop a healthy and sustainable urban tree population, a diversity of species must be evenly distributed throughout the city.

Concerning species origin, great numbers of non-native species occurred in all the cities studied, especially in street environments (Fig. 3). However, although there were high proportions of non-native species, the majority of the tree population consisted of native tree species. Aarhus was an exception in park environments due to its botanical garden's large tree collection, with many non-native tree species (Fig. 3). At present, there is an intensive discussion on whether it is appropriate to recommend non-native tree species in public plantations, with the fear of these species escaping and negatively affecting native species and ecosystems being the main counter-argument (Parker et al., 1999; Alien Plant Working Group, 2010; Hitchmough, 2011). The time during which a species has been cultivated in an area combined with the number of individuals of the species

present in a region determines the risk of that species escaping from cultivation into the natural environment and becoming a potential invasive species (Chytry' et al., 2008; Pyšek et al., 2009). Since native species dominated the urban tree stock in the cities studied, this might not be a current threat (Fig. 3b and d). However, due to outbreaks of pests and diseases in many of these overused native trees the use of non-native species will increase in the near future, so it is reasonable to expect that more non-native species will escape from cultivation into the natural environment in the future. Much more research is needed to provide tools to predict the interactions of non-native species with native ecosystems and thus help with early identification of potentially invasive species.

Furthermore, restricting the urban tree population to native tree species is scarcely practicable, especially in street environments. From the perspective of the northern parts of Central Europe and adjoining milder parts of Northern Europe, it is unlikely that the species-poor native dendroflora can contribute a large range of tree species with extended tolerance to the environmental stresses characterising streets and other paved sites (Duhme and Pauleit, 2000). Other regions with a comparable climate but a richer

dendroflora may have the potential to contribute new tree species and genera that are equally or even better adapted to the growing conditions at urban paved sites (Takhtajan, 1986; Breckle, 2002; Roloff et al., 2009; Sjoman and Richnau, 2009). This will be even more important in view of future climate change, with predicted increases in average temperatures and more frequent heat waves and periods of drought during summer (IPCC, 2007).

The concluding recommendation from this study regarding greater diversity of genera and species for the Nordic region is to exploit local experiences of rare species from local urban tree databases. After appropriate evaluation, urban tree planners can evaluate these rare species in larger numbers for e.g. street environments, where the need is greatest. Saying this, it is important to collect additional data such as age, dbh and height of the trees, which will give a much more detailed guidance of which species that could be further recommended for e.g. street environments. The use of non-native tree species in public plantations is inevitable, so special interest and research should be devoted to identification of species and strategies which could pose a threat of invasiveness and negative impact on native species and ecosystems.

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