Trees for Tough Urban Sites

Learning from Nature

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Abstract

The main body of work in this thesis was to develop and test a working procedure for identification of new tree species and genotypes that holds the potential to diversify urban tree populations. This process has been set in context through a literature review which characterise species-specific information about the tolerance of trees to the environmental stresses in urban paved sites.

With a Scandinavian focus, a review of literature was made in order to characterise species-specific information concerning site tolerance for urban paved environments as it is disseminated in scientific papers, dendrology literature, books addressing plant use in urban environments, plant nursery catalogues. The information was evaluated against the requirements of urban tree planners which should ideally be; contextual; local, referring to existing urban plantings, specify the urban site type(s) for which a given species can be recommended, and include the full range of tree species that are well adapted to the urban paved environment in a given climate region. In the analysis of the literature, abundant restrictions and misleading guidance were apparent. The results showed that existing information is piecemeal and that most is either too general (dendrology literature) or too specific or contradictory (scientific literature) to meet the requirements of urban tree planners, while books intended for plant use in cities do not sufficiently integrate the regional perspective. Moreover, contextual information local to the Scandinavian region is mainly provided for already much used species.

With a focus on the northern parts of Central Europe and the adjoining milder parts of Scandinavia (CNE-region), a working procedure for the identification of potential tree species and genotypes for in inner-city environments was developed. The procedure was made through two case studies; in the Qinling Mountains, China, and in north-east Romania and neighbouring parts of the Republic of Moldavia. In total, 27 tree species were identified as tolerable for warm and periodically dry habitats. Of these tree species, only four are currently much used or used to some extent in northern Europe. Accordingly, the reaming 23 tree species identified hold potential to supplement and diversify the urban tree populations in the CNE-region.

Keywords: Urban trees, Site adapted species choice, Dendroecological studies, Diversification, Abiotic stress, Natural habitats, Landscape architecture, Urban Forestry, Urban paved sites.

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Dedication

To Henset and it´s magic…

”If we knew what it was we were doing, it would not be called research”

(Albert Einstein)

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Sjöman, H., Nielsen, A.B. 2010. Selecting trees for urban paved sites in Scandinavia – A review of information on stress tolerance and its relation to the requirements of tree planners. Urban Forestry and Urban Greening 9: 281-293.

II Sjöman, H., Nielsen, A.B. Pauleit, S., Olsson, M. 2010. Habitat studies identifying trees for urban paved environments: a case study from Qinling Mt., China. Arboriculture and Urban Forestry 36 (6): 261-271.

III Sjöman, H., Nielsen, A.B., Oprea, A. 2011. Trees for urban environments in northern parts of Central Europe – a dendroecological study in north-east Romania and Republic of Moldavia. Urban Ecosystems, *published online July 1, 2011*.

IV Sjöman, H., Gunnarsson, A., Pauleit, S., Bothmer, R. Selection approach of urban trees for inner-city environments – learning from nature (*Accepted for publication in Arboriculture and Urban Forestry*)

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Trees for Tough Urban Sites

“No town can fail of beauty, though its walks were gutters and its houses hovels, if venerable trees make magnificent colonnades along its streets. “

(Henry Ward Beecher, 1887)

Trees constitute an important element in the cityscape (Arnold, 1993). The natural, graceful shapes of trees provide an architectural transition between human size and the scale of buildings and streets (Jacobs, 1995; Bell et al., 2005), and over the ages urban tree plantings have been regarded as a mirror of the prosperity and achievements of society. While beautification has traditionally been the main argument for planting trees in towns and cities, recent decades have seen numerous reports of a number of other effects provided by trees that are beneficial for the quality of life in urban areas. Trees 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 subsequent damage to property and infrastructure (McPherson et al., 1997). They 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 (Tyrväinen et al., 2005). However, the above-mentioned aesthetic, social and microclimatic ameliorations are only possible if the urban tree stock is vital.

Traditionally, a limited number of species and genera dominate the urban tree population, especially in streets and other sites with paved surfaces. However, the severe consequences of *e.g.* Dutch Elm Disease, where many cities lost large parts of their tree stock, show the importance of using a broad range of species in order to increase resilience towards such host-specific pests and diseases. A growing proportion of the tree species that have replaced the elm, which are now amongst the most common urban trees, are having increasing difficulties in coping with the complex stresses at urban sites. This illustrates that species diversity contributes to resilience only to the extent that the individual species or cultivars are adapted to the complex stresses at urban sites.

With the focus on inner-city environments in northern parts of Central Europe and the adjoining milder parts of Northern Europe, in the following abbreviated to the CNE-region (Ellenberg, 1988), this thesis presents research on new potential tree species and genotypes adapted to urban environments. Since water stress is argued to be one of the main constraints for tree growth and health in urban environments (*e.g*. Whitlow et al., 1992; Craul, 1999; Hoff, 2001; Sieghardt et al., 2005; Nielsen et al., 2007; Roloff et al., 2009), the work focuses particularly on species and genotypes which can tolerate warm and periodically dry growing conditions.

SITE-RELATED TREE USE

The average lifespan of street trees and of other trees living in paved environments exposed to high stress is often rather short (Sæbø et al., 2005), and can be as low as only 10 years (Foster and Blaine, 1977; Gilbertson and Bradshaw, 1990; Nowak et al., 1990). Furthermore, surviving trees are often in poor condition. The main reason for tree decline and death in urban environments is the harsh site conditions, which are different from the growing conditions under which many of the trees traditionally used in the urban environment have evolved (Sieghardt et al., 2005). Due to elevated temperatures (urban heat island effect), restricted rooting space, impervious surfaces and poor growth medium, trees planted along streets and in paved sites suffer from lack of water and oxygen in particular, as well as imbalanced provision of nutrients (*e.g*. Craul, 1999; Hoff, 2001; Sieghardt et al., 2005; Roloff et al., 2009; Figure 1). The current trend for urban expansion, which is leading to a further increase in the area of impervious surfaces, and climate change-induced elevation of temperatures combined with longer periods of drought during the growing season will impose further stresses on urban trees (IPCC, 2007; Gill et al., 2007).

Trowbridge and Bassuk (2004) stress that provision of good growing conditions is an imperative for sustainable development of the urban tree stock. Much of the recent research in the field of urban tree planting has concentrated on the development of methods and techniques for improving habitat conditions in the city. The soil and rooting zone has been particularly well studied (*e.g*. Grabosky and Bassuk, 1996; Kristoffersen, 1998; Pedersen et al., 2000; Trowbridge and Bassuk, 2004; Ridgers et al., 2006; Roberts et al., 2006; Morgenroth and Visser, 2011). Results from a recent survey in Copenhagen, Denmark, show that street trees planted over the past 15 years in well-designed soils and larger planting pits are performing significantly better than conventionally planted trees (Bühler et al., 2007). However, while these results are very promising, even improved methods for street tree planting will not be able to provide similar growing conditions as in forests and parks (Sieghardt et al., 2005). Therefore, the selection of a broad range of hardy species and genotypes for urban sites remains an important task, particularly if climate conditions become more adverse for urban tree life through climate change. As a result of climate change, air temperatures are predicted to rise in Central and Northern Europe and periods of drought during summertime will increase (IPCC, 2007; Gill et al., 2007; Allen et al., 2010).

*Figure 1***.** Trees in urban paved sites in inner-city environments experience higher temperatures, restricted rooting space, impervious surfaces and poor growth medium, causing the trees to suffer from lack of water, oxygen and a nutrient imbalance. These growing conditions are very different from those in forests and parks. In order to provide urban greenery that is economically and ecologically sustainable, the use of site-related species is crucial.

DIVERSICATION OF THE URBAN TREE POPULATION

Beside site-tolerant trees, a high diversity of species and genera has been proposed as a key solution in order to have a healthy and sustainable urban tree population (*e.g*. Duhme and Pauleit, 2000; Andersson, 2006; 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 attacking the most commonly used tree species. The CNE-region is currently experiencing serious damage to trees of *Aesculus, Fraxinus* and *Ulmus* (*e.g*. Coakley et al., 1999; Tello et al., 2005; Garrett et al., 2006; Tubby and Webber, 2010). This damage is expected to become even more severe due to predicted climate change (Yang, 2009). Raupp et al. (2006) present a detrimental scenario where the following tree genera act as hosts for one of the most devastating insect pests, the Asian longhorned beetle (*Anoplophora glabripennis*): *Acer, Aesculus, Albizzia, Betula, Celtis, Fraxinus, Platanus, Populus, Salix, Sorbus* and *Ulmus*. From a CNE perspective, attacks by this tree borer would have horrifying consequences, since *e.g*. Tampere, Finland, has 39.1% *Betula* in its urban tree population, while Stockholm, Sweden, has 21% *Acer* in the central parts of the city (Sjöman et al., 2011). This scenario of enormous tree losses in urban environments is not highly unlikely for the CNE-region. In summer 2011, the Asian longhorned beetle was found for the first time in Denmark and was believed to have escaped from a Dutch nursery as early as 2009 (M. Gråberg, pers. comm. 2011).

In order to analyse the susceptibility of the tree population to outbreaks of pests and diseases and its tolerance to a more stressful climate, the composition of the urban tree stock has been studied and evaluated in many cities and regions (*e.g*. Sanders, 1981; Miller and Winer, 1984; Welch, 1994; Jim and Liu, 2001; Pauleit et al., 2002; Frank et al., 2006; Raupp et al., 2006; Jim and Chen, 2009; Negandra and Gopal, 2010; Sjöman et al., 2011; Figure 2). The general conclusion in these studies is that there is an obvious lack of diversity in many urban areas of the world, with the CNE-region being no exception. In Oslo, Norway, one clone of lime tree (*Tilia x europaea* ‘Pallida’) represents 70% of all newly planted street trees, while in Reykjavik, Iceland, 90% of all newly planted street trees are from one species of poplar (*Populus trichocarpa* Hook.) (Pauleit et al., 2002). In Copenhagen, Denmark, London plane (*Platanus x acerifolia* Willd.) and *Tilia* spp. represent 61% of all street trees planted between 1990 and 2000 (Bühler et al., 2007), while *Tilia x europaea* stands for 44.3% of all street trees in Helsinki, Finland (Sjöman et al., 2011).

This awareness of the risks associated with a limited range of tree species has intensified the argument for a greater focus on selection for improved diversification (*e.g*. Grey and Deneke, 1986; Gerhold and Porter, 2000; Raupp et al., 2006; Roloff et al., 2009). A number of studies make recommendations on increasing the diversity of urban tree species. Barker (1975) was one of the first to suggest the use of a broad range of species and 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 proportion of any species should be less than 10% of the population. Grey and Deneke (1986) present a similar view, *i.e*. that one species should not account for 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 adds 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, namely that no species should represent more than 10%, no genus more than 20% and no family more than 30% of the population. Although such strategic recommendations for species diversity are important in the campaign for a greater assortment of tree species in the urban environment, few cities can respond to these percentage levels, particularly in street environments. In our inventory of the urban tree populations in 10 major Nordic cities, only two complied with the recommendation that no species should account for more than 10% of the tree population (Sjöman et al., 2011). However, this was only for park environments, while for street environments no city in the study reached the 10% level. This phenomenon of fewer species within the population in street environments compared with park environments reflects the superiority of parks in providing favourable conditions similar to those in woodlands. Furthermore, finding species that can withstand the challenging conditions in street environments and at other paved sites is much more difficult (Pauleit, 2003).

Summarising the above, arguments on the necessity for diversifying the urban tree stock have been proposed since the 1980s, but they have had a limited effect in reality. 'Overuse' of a limited number of well tested and well known species/cultivars continues (Sæbø et al., 2005). From discussions and interactions with urban tree planners, it is clear that the unvaried choice of species is partly a reflection of local experiences/traditions and unwillingness to take the risks associated with using non-traditional plant material in intensively used and prestigious streets and public spaces. To deal with urban tree planners' perception of risks being involved when selecting non-traditional tree species for use in paved sites, information about stress tolerance has to be comprehensive, easily accessed and communicated in a format that appeals to professionals beyond academia.

While the recommendations on minimum percentage levels of species diversity are important in increasing diversity, an essential 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 correct course, since the adaptability and longevity of species in stressful urban habitats must weigh heavily in the selection (Raupp et al., 2006). Poor or incorrect choices may increase mortality, reduce the lifespan of trees and ultimately increase costs when failed or failing trees must be removed or replaced (Richards, 1983; Thello et al., 2005; Raupp et al., 2006).

*Figure 2 – next page***.** Four tree species which have an unhealthy dominance in urban environments in different parts of the world. Top left: *Acer saccharum* in Concord, New Hampshire, USA; maple is the dominant tree genus in north-east America (Raupp et al., 2006). Bottom left: *Styphnolobium japonicum* in Xi an, Central China; pagoda tree dominates in urban street and park environments in China (Wang, 2005; Xu and Zhang, 2006). Top right: *Betula pendula*, Umeå, Sweden; birch dominates in the north of the Scandinavian region (Sjöman et al., 2011). Bottom right: *Tilia x europaea*, Malmö, Sweden; lime is by far most common city tree in southern Scandinavia (Sjöman et al., 2011).

OBJECTIVES

There is an urgent demand for supplementary tree species for urban environments and for information concerning the growth and performance of tree species in different urban site conditions. Therefore the overall objectives of this thesis were to:

- Characterise species-specific information about the tolerance of trees to the environmental stresses to which they are exposed at urban paved sites in order to: 1) Assess its dissemination and quality in books and papers; and 2) discuss the available information in relation to the requirements of urban tree planners.

- Test and evaluate a working procedure for identification of tree species and genotypes to be included in selection programmes for urban environments. The working procedure is rooted in the hypothesis that studies of natural vegetation systems and habitats where trees are exposed to environmental conditions similar to the inner-city environment can: 1) Identify new tree species and genotypes adapted to urban environments; and 2) supply information and knowledge about the adaptability of tree species and genotypes already in use.

These objectives were researched in four studies. First, a review was made of the literature in order to characterise species-specific information concerning site tolerance for urban paved environments in the CNE-region. This information was thereafter evaluated in relation to the requirements of urban tree planners (Paper I). To achieve the second objective, a working line/procedure for the identification of potential tree species through dendroecological studies in natural environments, where trees are exposed to similar stressors as in inner-city environments, was tested and evaluated. The working line was tested through two case studies; in the Qinling Mountains, China (Paper II), and in north-east Romania and neighbouring parts of the Republic of Moldavia (Paper III). Based on the experiences from the case studies, the working procedure and its theoretical background were discussed in Paper IV

Since water stress is argued to be one of the main constraints for tree growth and health in urban environments (*e.g*. Whitlow et al., 1992; Craul, 1999; Hoff, 2001; Sieghardt et al., 2005; Nielsen et al., 2007; Roloff et al., 2009), the work focused particularly on species and genotypes which can tolerate especially warm and periodically dry growing conditions. Moreover, in the two case studies the aim was to identify 'new' or non-conventional tree species and genotypes for urban environments, these being defined as species which have the potential to be successfully grown in urban environments in the CNE-region but are currently rare or absent in this type of application. This includes species and genotypes that are well-known but have hitherto been restricted to a specific use, *e.g*. park environments. With greater knowledge of the site tolerance of these species and genotypes, their use can be expanded to street environments, as 'known species in a *new* application'.

The geographical region examined in this thesis was inner-city environments of the northern parts of Central Europe and the adjoining milder parts of Northern Europe, *i.e*. the CNE-region (Ellenberg, 1988). However, in the review (Paper I) the geographical restriction was the Scandinavian countries (Denmark, Norway and Sweden) owing to the focus group investigated and to the literature obtained being primarily in these languages as well as in English.

GUIDANCE IN SELECTION OF A GREATER DIVERSITY OF SITE-ADAPTED TREES

"Diversity may be the hardest thing for a society to live with, and perhaps the most dangerous thing for a society to be without"

(William Sloan Coffin, Jr.)

In selecting suitable trees for urban paved environments, urban tree planners in Scandinavia have a large amount of available literature (Paper I). Such literature includes scientific papers, dendrological and taxonomic literature, specialist literature on tree use in urban environments and tree nursery catalogues. The question examined was how good the dissemination and quality of this available information is for different species divided through their present use potential in northern Europe (Sæbø et al., 2005), and how this available information is presented in relation to the requirements of urban tree planners. The scientific literature and urban tree planners both emphasised that in order for information to encourage urban tree planners to use a broad range of species and to support them in making adequate decisions when selecting non-traditional tree species and in feeling confident about their decision, species-specific information should ideally:

• Be contextual; *i.e.* experience-based information from urban situations and for urban situations. Species which have demonstrated broad and longstanding adaptation to *e.g.* urban paved sites are more likely to be successful in the future than species for which *in situ* experience is lacking (Richards, 1983; Pauleit et al., 2002; Pauleit 2003). Information from existing plantations of a given tree species create the possibility for urban tree planners to determine whether a certain tree species might perform well in a given setting.

• Be local; *i.e.* information from/for urban situations in the CNE-region. Caution is required in transferring information on trees tested in other regions (Sæbø et al., 2003).

• Refer to existing urban plantings. Researchers (Bühler and Kristoffersen, 2009) and practitioners both consider the firsthand impressions that can be obtained from local plantings with a given tree species to be important reference material from which tree planners can gain inspiration, knowledge and confidence about the use of a given tree species in urban paved sites.

• Specify the site type(s) for which a given species can be recommended. Depending on site type and surrounding land use, the urban environment represents extreme variations in the conditions for tree growth (Sæbø et al.; 2003; Sieghardt et al., 2005). Urban tree planners emphasise the need for literature to specify the site type(s) for which a given tree species can be recommended, *e.g.* parkland, square, courtyard, street environment, paved site, and so forth.

• Include the full range of tree species that are well adapted to the urban paved environment in a given climate region (Richards, 1983; Pauleit, 2003).

In the analysis of the literature, abundant restrictions and misleading guidance were apparent. The existing information is piecemeal and spread throughout large quantities of literature, which makes it difficult and time-consuming to acquire an overview. Furthermore, the information differs clearly between the different categories of literature. Dendrological and taxonomic literature is often too general, while scientific literature is often too specific. The information provided in dendrological and taxonomic literature mainly concerns optimal growth (*e.g.* Bean 1980), while information on species growth and performance at harsher sites is lacking. Such information is essential when planning for greater species diversity in street environments, where the growing conditions are far from optimal (Sieghardt et al., 2005). In order to obtain information from the scientific literature, extensive knowledge of *e.g.* plant physiology is required, but is seldom deeply developed among practitioners and urban tree planners. Furthermore, individual scientific papers tend to concentrate on one particular stress factor only, generally in a limited number of species, which makes it difficult to compare the ability of various tree species to tolerate the range of environmental stresses at urban paved sites (*e.g*. Higgs and Wood, 1995; Tissier et al., 2004; Percival et al., 2006). Specialist literature on tree use in urban environments and tree nursery catalogues provide species-specific information about the tolerance of tree species and cultivars in urban environments, especially concerning soil conditions and water supply, as well as for polluted areas (*e.g*. Bengtsson, 1998; van den Berg et al., 2002; Bassuk et al., 2009). However, the information in nursery catalogues and in literature on plant use in cities is generally presented without references to other sources, which gives the impression that the information is mainly based on the authors' own experiences and qualitative observations of existing urban plantings. Furthermore, much of the information presented in these two categories of literature refers to different geographical regions with climates different to the Scandinavian region, which makes the recommendations difficult to interpret for Scandinavia. Information relevant for the Scandinavian region is limited, especially with regard to rare species, and is not grounded in scientific research. For example, among four species with very limited use in the region, only *Fraxinus ornus* L. and *Quercus cerris* L. are recommended specifically for urban paved sites, by only one author (Bengtsson, 1998; Paper I).

The question remains of how to develop a greater knowledge of 'new' or non-conventional tree species and genotypes suitable for urban environments in Scandinavia, since documented local experiences of rare species in the region are sparse. The suggestion in Paper I and in Sjöman et al. (2011) is that local experience of existing rare tree species and genotypes in urban environments compiled in local urban tree databases should be analysed in order to evaluate their future use potential for the region. For example, the urban tree database in Malmö, Sweden, shows a great number of rare tree species that have shown long-term development in the region. Of the total number of species in Malmö, 42.6% represent species with a frequency of less than 2% of the total tree population. These rare tree species are very interesting as a local base of knowledge and experiences for local tree planners when searching for complementary tree species for urban tree plantings in Malmö (Sjöman et al., 2011). However, data on local urban trees compiled in databases are mainly for the organisation's own use and not for public use. Sharing this information provides important guidance for nearby cities in their work on diversifying the urban tree populations. An example of such sharing is presented by Bühler and Kristoffersen (2009), where the website connected to the Urban Tree Arboretum at Hörsholm, Denmark, also has a function that allows users to post information on reference plantings of different species.

This database gives valuable insights into the long-term development of various species in different sites and climates.

There are other species that have not been planted and directly tested for *e.g.* street environments but that have potential. Over history, new tree species have typically been introduced through arboretums or botanical gardens (Spongberg, 1995). Many of these species have not been transferred from these collections into public use and have therefore remained as rare specimens in these tree collections. These reference plantings in *e.g*. botanical gardens can act as an important knowledge base on the hardiness and health status of the species in the region (Sæbø et al., 2003). However, since the growing conditions in arboretums and botanical gardens in principle are far better than *e.g*. in urban street environments, these tree collections are an inadequate reference base for site-related information. Combined approaches are needed in order to obtain site-related knowledge that is complementary to the compilations in local urban tree databases and tree collections in botanical gardens and arboreta (Figure 3). The starting hypothesis in this thesis was that dendroecological studies of natural habitats with similar climates and site conditions to inner-city environments of the CNE-region could add such complementary information and thereby identify promising tree species and genotypes for future urban use and also their use potential in cities.

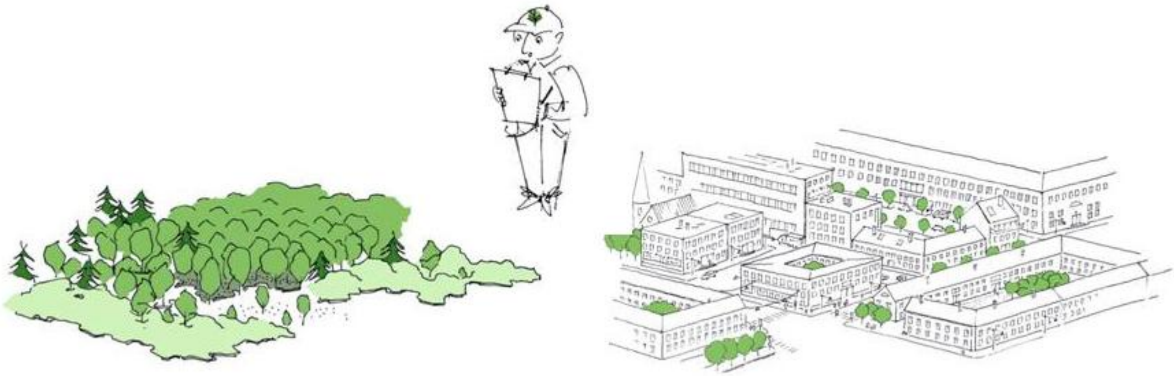


*Figure 3***.** In order to increase the diversity of tree species in urban environments, information on existing rare tree species in *e.g*. street environments has to be analysed to provide further evidence of their use potential at these sites. For rare species where existing experiences of their site tolerance is lacking, habitat studies can give valuable guidance on their future use potential. Illustration by Johanna Deak.

HABITAT STUDIES IN THE SELECTION OF POTENTIAL URBAN TREES

The grand old man in the sphere of modern arboriculture, Alex Shigo (1991), said about the use and maintenance of city trees that: *"…we must understand the tree as it grows in its natural site first. To try to treat a city tree without understanding the tree as it grows in its natural site is like drawing a data curve with only an y axis; and no base line!"*

Research on the selection and testing of alternative tree species, genotypes and provenances is underway in a number of countries, but with different agendas. In forestry, the main focus in plant selection and breeding has been, and still is, on fast-growing and high-performing genotypes of already well used forest trees and on resistance to different pests and diseases (*e.g.* Perry, 1998; Lu and Charrette, 2008; Buriánek et al., 2011). In the selection of urban trees the focus does not differ greatly from that in forestry, except as regards the economic aspects of timber production. Some examples of species selection programmes for urban trees in Europe are presented by Sæbø et al. (2005). In this field two main strategies are suggested. The first is to concentrate on the genetic aspect of already much used species and search for the best varieties and genotypes for city habitats and for resistance to species-specific pests and diseases (Townsend and Douglass, 2004; Sæbø et al., 2005; Santini et al., 2010). This strategy is particularly well used in practice in the Nordic countries (Sweden, Denmark, Norway, Finland and Iceland), where the plant selection programmes mainly focus on winter hardy genotypes of already much used species and pest and disease resistance (Brander, 1990; Lagerström and Eriksson, 1996; Väinölä and Joy, 1996; Halldórsson et al., 2001; Sæbø et al., 2003; 2005). The second strategy involves broadening the range of urban tree species through focused selection of species and genotypes found in habitats displaying similar conditions to city habitats (Sæbø et al., 2005; Raupp et al., 2006). In this strategy, Sæbø et al. (2005) describe a project in Greece where species are recommended after analyses of their natural occurrence regarding soil conditions and climate. Another example is presented by Ducatillion and Dubois (1997), who base their selection on information from bibliographies, archives and observation of living plants in southern France where habitat information is included (Sæbø et al., 2005).

A central theory in this thesis is that there is much to learn from how different tree species and genotypes grow and perform in their natural settings when it comes to developing knowledge and guidance on their use potential for urban environments.

In natural habitats, trees have been stress-tested and selected over evolutionary periods of time. Investigating the ecological background and performance of species and genotypes growing in habitats with drought during the growing season and winter temperatures similar to those of inner-city environments in a particular area can assist in identifying alternative tree species and genotypes (Levitt, 1980; Flint, 1985; Ware, 1994; Ducatillion and Dubois, 1997; Broadmeadow et al., 2005; Sæbø et al., 2005; Roloff et al., 2009). In a compilation by Sæbø et al. (2005, based on a survey by Pauleit et al., 2002), eight tree species, *Acer platanoides* L., *A. pseudoplatanus* L., *Aesculus hippocastanum* L., *Betula pendula* Roth., *Betula pubescens* Ehrh., *Populus trichocarpa* Hook., *Sorbus x intermedia* (Ehrh.) Pers. and *Tilia x europea* L., were presented as the most common tree species in street environments in Northern Europe. However, the main natural habitats for these species, except *Betula pendula* and *Sorbus x intermedia*, are nutrient-rich and moist sites, where they develop into large and tenacious trees, while they show noticeably weaker development in inferior conditions (Ellenberg, 1988; Påhlsson, 1998). Due to the current trend for urbanisation, which will lead to a further increase in the area of impervious surfaces, combined with longer periods of drought based on predicted climate change, the site conditions for these species will become even more stressful and hence they are not suitable for these sites. Instead, a logical and highly relevant direction would be to focus on tree species and genotypes which are growing and performing well in natural habitats with similar site conditions to those in street environments (Figure 4).

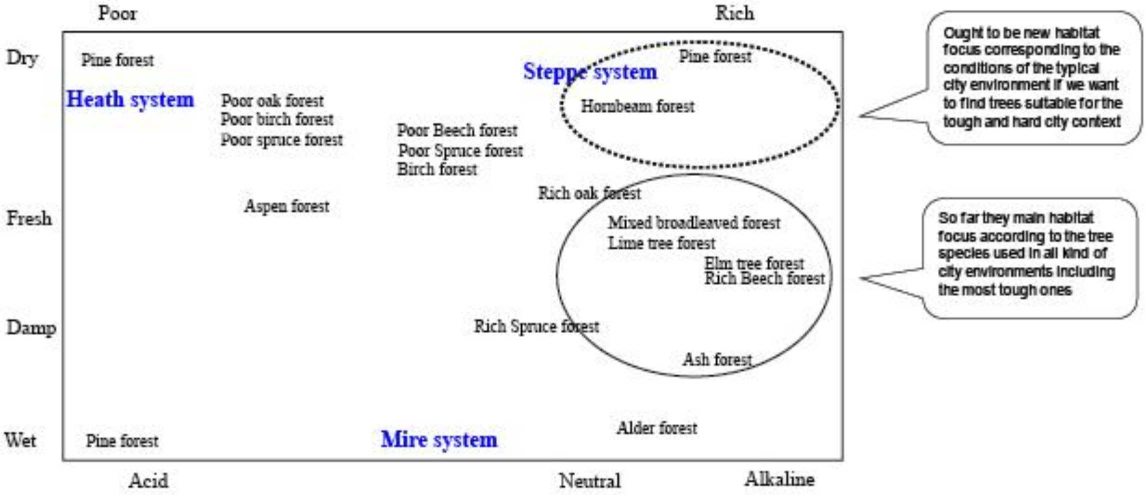


*Figure 4***.** Ecological position of some important Scandinavian woodland communities based on Påhlsson (1998). Some of the most frequently used city and street trees have their main natural habitats in fresh, damp and wet vegetation systems (solid oval). The trees for the future should be sought in drier and slightly acid to alkaline habitats (dashed oval) (Allen et al., 2010).

Choosing plants according to *fitness for site* reduces the need for drastic and resource-intensive site manipulation and subsequent demands for resource-intensive management (Dunnet, 2004). Plants from habitats that share similar environmental constraints tend to share common traits or characteristics, which can be fully exploited in the use of the species in *e.g.* urban environments. Through the evolution of plants, some species have developed an extensive plasticity and tolerance to a range of environmental conditions, while others have specialised in certain habitat types (Rabinowitz, 1981; Oliver and Larson, 1996; Grime, 2001; Gurevitch et al., 2002). For instance, steep south-facing mountain slopes with shallow, rocky soil layers or warm and dry steppe environments represent distinct habitat types where the environmental parameters that define the particular habitat and distinguish it from other habitats have shaped the evolution of plants (Breckle, 2002). Consequently, in the search for species and genotypes tolerable for dry urban sites, information on the ecological strategy and performance of a species in different habitats can give valuable first-hand guidance (Allen et al., 2010).

There are several ecological models or theories available which can be of high value in finding the right '*codes*' of species tolerance and performance for different site conditions (Craine, 2009). An example of such a model is presented by Grime (1979; 2001) and can be readily adapted in the selection process for species with the potential to cope with *e.g*. urban paved environments (Dunnet, 2004). This model is based on the recognition of three major categories of life history traits based on their strategies in competing for space, establishment, reproduction, stress tolerance, *etc*. These categories are Ruderals (R), Stress tolerators (S), and Competitors (C). Ruderals are characterised by high reproductive effort and high growth rates, and are predicted to occur in disturbed, productive habitats. Stress tolerators are characterised by low reproductive effort and low growth rates, and are predicted to occur in undisturbed, unproductive (stressful) habitats or in late successional productive habitats where the resources per individual are low. Competitors are characterised by low reproductive effort and high growth rate, and are predicted to occur in undisturbed, productive habitats (excluding late successional phases, which are deemed to be biotically stressful) (Grime, 2001).

For urban environments and especially for paved sites, stress-tolerant species that specialise in warm and dry habitats and have a combination of stress tolerance and competition strategies are of the highest interest. Stress-tolerant species (S) make the most of captured resources by sitting tight rather than investing in rapid growth to capture more resources (Grime, 2001; Craine, 2009), a useful strategy during warm, dry summer periods. An example of a valuable stress strategy for warm, dry environments is the development of leaves with a thick cuticle to prevent excessive transpiration, which is the case for *Koelreuteria paniculata* Laxm. (Balok and Hilaire, 2002; Figure 5). Another valuable stress strategy is to be wintergreen, *e.g*. the evergreen oak species *Quercus ilex* L. which can photosynthesise during cooler, moister periods of the year, allowing it to reduce activity in periods with severe water stress (Levitt, 1980; Corcuera et al., 2002; David et al., 2007). However, in the CNE-region the majority of broad-leaved evergreen trees are not hardy and the frozen ground during winter causes serious dehydration problems, especially at dry, urban paved sites. Beside stress-tolerant species, combined stress-tolerant and competitive species are also highly relevant. Instead of only surviving, they also invest in *e.g*. a large and deep penetrating root system to capture more resources. The competitors are resource capture specialists (Grime, 1989), since investing in *e.g*. a large and deep penetrating root system increases the chances of the plant capturing larger amounts of resources (*e.g*. water) and hence being more successful in coping with *e.g*. drought. This is the strategy used *e.g*. by *Quercus petraea* (Matt.) Liebl. (Gale and Grigal, 1987; Grime, 2001).

Figure 5**.** The Golden Rain tree (*Koelreuteria paniculata*) has developed leaves with a thick cuticle to prevent excessive transpiration (Balok and Hilaire, 2002). This makes it tolerant and successful in warm and periodically dry sites – which is the main habitat of the species in the Qinling Mountains, China (Paper II).

By including these ecological theories in the selection of trees for *e.g.* urban paved environments early in the selection process, species and genotypes which have the right strategy can be identified and included in the next round in the selection process. Moreover, this direction of classifying species depending on their ecological strategies or traits can also be of great value when communicating the use potential of the species with urban tree planners in their selection of untraditional species for the region. However, in the Competitor-Stress tolerator-Ruderal model developed by Grime (1979), few tree species have been classified where available information in this direction is mainly on herbaceous species (*e.g*. Grime, 1987; Hitchmough, 1994: Dunnet, 2004; Grime et al., 2007). The few trees which are classified are all well known and native to central Europe (Grime et al., 2007), whereas corresponding information is lacking for exotic species, especially those which have been in cultivation for a short time.

The fact that few tree species have been classified might reflect the time perspective, since it takes a much longer time to identify and understand tree species traits and strategies than those of herbaceous plants. In order to obtain such information, Roloff et al. (2009) suggest that dendroecological studies can be a complementary method in identifying the strategies and performance of tree species in different habitats. Dendroecological descriptions are seldom or never available for most tree species. By starting the selection process with dendroecological studies in natural habitats with similar climate and site conditions to inner-city environments, first-hand information can be gained on the growth and performance of species in these climates and habitats (Roloff et al., 2009). This first step can screen out species and genotypes which display slow and/or underdeveloped growth in habitats similar to urban inner-city environments, and the focus can instead be directed towards species which develop more rapidly into large trees in this type of habitat (Figure 6).

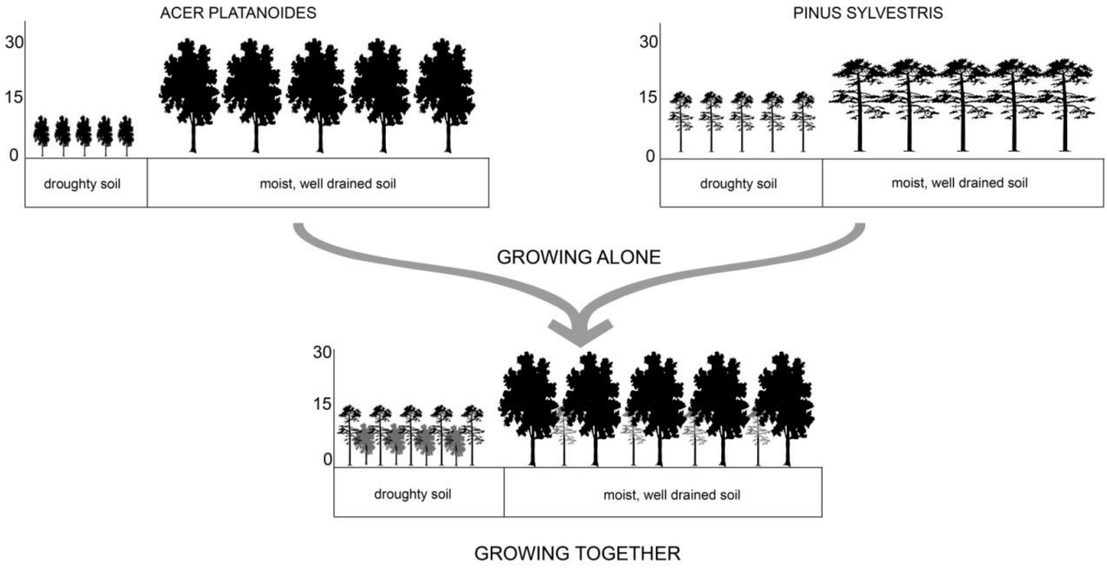


Figure 6. Most species are not found naturally where they grow best, but where they can compete successfully. Species that are weak competitors on rich, moist sites have developed strategies to cope with less favourable sites (Oliver and Larson, 1996; Grime, 2001). In this schematic diagram of the growth and competition of two species, both grow best on moist, well-drained soils. However, on drought-prone soil *Pinus sylvestris* will outgrow *Acer platanoides*. Illustration by Johanna Deak.

SELECTION MODEL - LEARNING FROM NATURE

"As many more individuals of each species are born than can possibly survive; and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be naturally selected. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form."

(Charles Darwin, 1859)

In the selection approach presented in this thesis, the aim was to identify promising tree species and genotypes for urban environments in the CNE-region through dendroecological studies in natural habitats. The key question was how to identify the right species for further testing within the diversity of tree species with limited means and in a relatively short time. For example, the wealth of potentially suitable species from areas such as China is overwhelmingly large, which means that strategies for how and where to start searching and how to make the right choice need to be developed. The two case studies presented were intended to test such a strategy (Papers II and III; Figure 7).

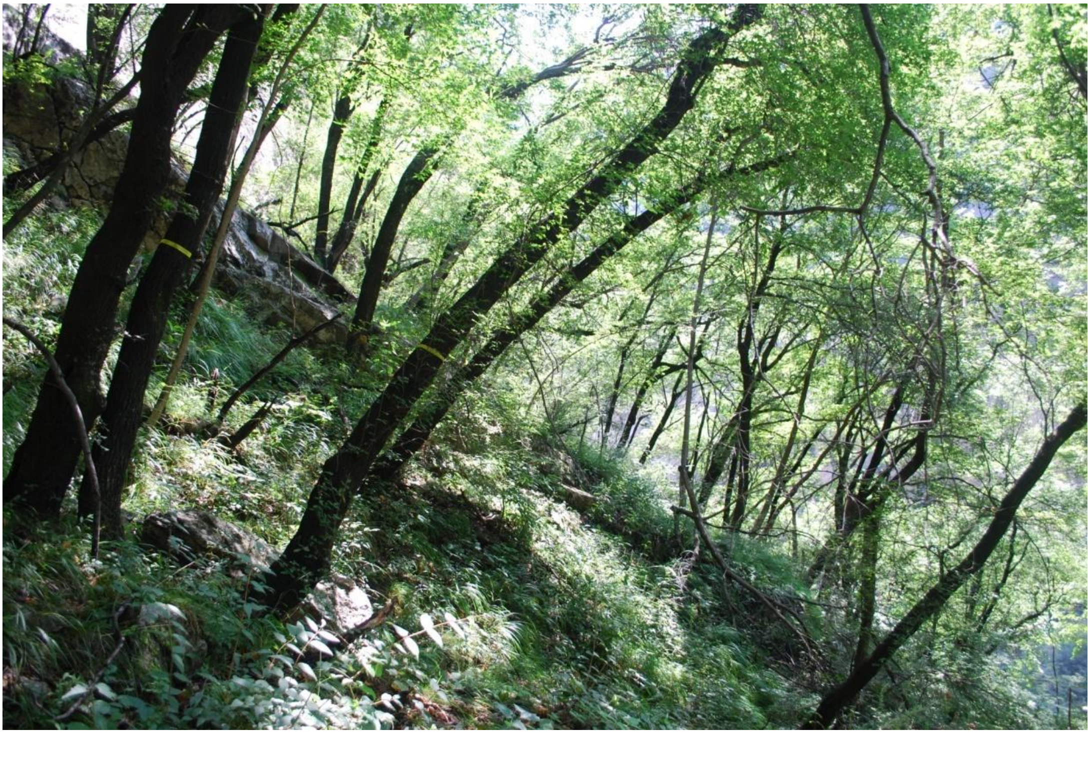


Figure 7**.** The two case study areas. Previous page: The Qinling Mountains, China, 1700 metres a.s.l. with a forest type dominated by *Quercus baronii*. Above: Steppe forest with a forest type dominated by *Quercus frainetto* in north-east Romania.

In the perspective of the CNE-region, it is unlikely that the species-poor native dendroflora can provide a large range of species or genotypes with an extended tolerance of the environmental stresses characterising *e.g.* paved sites within urban areas of the region (Duhme and Pauleit, 2000). However, there are numerous geographical regions world-wide with a comparable climate and with rich dendroflora which can be used as sources in delivering suitable tree species for the CNE-region (Takhtajan, 1986; Ellenberg, 1988; Breckle, 2002; Burga et al., 2005; Sjöman and Richnau, 2009). Figure 8 shows a number of areas with examples of species originating from these areas that have been used successfully as urban trees in the CNE-region.

The case study areas used in this thesis were chosen not only for the climate, in order to study species which have the potential to be hardy in the CNE-region, but also for their content of tree species currently used to a limited extent as urban trees in the region. The Qinling Mountains in central China host an impressive richness of species (Ying and Boufford, 1998), and the potential to detect large numbers of species and genera never used before in cultivation is large. The Romania-Moldavia case was chosen on the basis that many well-known species for the CNE-region occur in that region, but that knowledge about their site plasticity for warm and dry habitats is sparse.

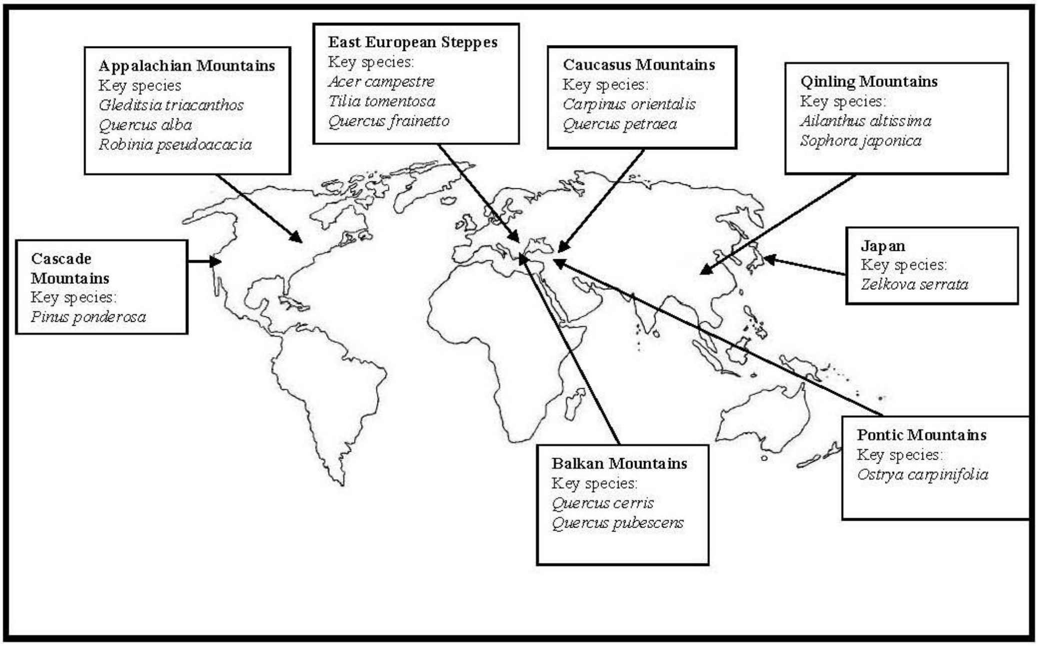


Figure 8. Areas in the world with examples of species that have been used successfully as urban trees in the CNE-region and with the potential to host additional species and genotypes (Paper IV).

In the two field studies, site-related data, including local climate data and analyses of soil samples, were combined with growth-related data on the trees at the sites in order to determine species growth and performance over time. The site-related data were compared with data on site conditions within inner-city environments in the CNE-region in order to match the study sites against urban sites (Papers II and III). Growth-related data included height and diameter at breast height (DBH), as well as age. Drilling for annual growth count allowed the age of the trees to be determined (Grissino-Mayer, 2003). From the growth-related data, it was possible to calculate the growth development of a species on a site with similar growing conditions to those *e.g.* in urban paved environments. The position of the individual tree in the stand was also documented, distinguishing canopy from understorey. Trees in the canopy layer modify the wind, humidity and temperature microclimate for species in the understorey layer (Niinemets and Valladares, 2006). Canopy species suffer from much higher transpiration due to high amount of wind and direct exposure to sunlight, and thereby warmer temperatures (Oliver and Larson, 1996). Moreover, for a deeper understanding of the species found in the study plots, it was important to examine their occurrence and performance in other types of habitats in the region. This was especially important in China, since available documentation on the occurrence and growth of the species present in different habitats was not available (Paper II).

Through this analysis, species which display slow and/or underdeveloped growth in these types of habitats could be detected and excluded. The following process could then focus on the species that developed more rapidly into rather large trees in this type of habitat (Grime, 2001; Gurevitch et al., 2002). From the two case studies, 27 tree species were identified as specialists growing in habitats with comparable site conditions to those in urban paved environments in the CNE-region (Figure 10; Table 1).

It is interesting to note that among these species, 10 had a yearly mean height increment of 25 cm at the study sites. This might not be very impressive, but gives a valuable insight into the species strategy for coping with this climate and site situation. Trees from dry parts of their habitat range have higher genetic root-crown ratio, with prioritisation of root growth (Kozlowski at al., 1991; Ware, 1994). The more extensive root system provides extra resilience for recovery episodes of drought at the expense of top growth, *i.e*. greater survival ability may come at the expense of reduced top growth, which is typical for stress-competitive strategists (Ware, 1994; Grime, 2001; Craine, 2009).

The results from the two case studies indicated earlier expectations, with 12 out of 14 tree species from the site in China having never been grown, or grown to a very limited extent, in the CNE-region (Paper II). For the case studies in Romania-Moldavia, there was a lack of prior knowledge on the performance of three out of 13 species (Bean, 1980; Paper III). Of the 27 tree species identified in the two case studies (Table 1), only *Acer campestre*, *Carpinus betulus*, *Crataegus monogyna* and *Fraxinus excelsior* are considered much used or used to some extent as street trees in northern Europe (Sæbø et al., 2005). Therefore, 23 tree species were identified as potential supplements to increase the diversity of the urban tree population in the CNE-region.

For the identified species that already exist in urban environments, there is currently knowledge and experience of pest resistance, propagation issues, wood stability, *etc*. These species can be tested directly in urban environments when appropriate genotypes are available and tested (Jones et al., 2001; Mijnsbrugge et al., 2010). For the identified species where previous experience is lacking, a much more thorough evaluation is needed before full-scale trials in urban settings are possible. After collecting appropriate genotypes, the offspring has to be planted in controlled field trials for further evaluation in order to obtain knowledge and experience concerning hardiness, growth and development, wood stability, pest resistance, invasiveness risks and propagation issues. Species may then be tested in full-scale trials in urban environments.

Table 1. Tree species identified in the case studies as specialists for warm and dry habitats, categorised according to the degree of previous experience of their use in the CNE-region (Paper IV)

Species for which previous experience in the CNE-region exists	Species which have never been grown, or grown to a very limited extent, in the CNE-region
Acer campestre L.	*Carpinus orientalis* Mill.
Acer tataricum L.	*Carpinus turczaninowii* Hauce
Ailanthus altissima (Mill.) Swingle	*Celtis bungeana* Blume
Carpinus betulus L.	*Fraxinus chinensis* Roxb.
Cornus mas L.	*Morus mongolica* (Bur.)Schneid.
Crataegus monogyna Jacq	*Ostrya japonica* Sarg.
Fraxinus excelsior L.	*Quercus aliena var. acuteserrata* Maxim.
Koelreuteria paniculata Laxm.	*Quercus baronii* Skan.
Quercus frainetto Ten.	*Quercus dalechampii* Ten.
Quercus robur L.	*Quercus pubescens* Wild.
Sorbus torminalis (L.) Crantz	*Quercus wutaishanica* Magr.
Tilia tomentosa Moench.	*Sorbus folgneri* (C.K. Schneid) Rehder
	Syringa pekinensis Rupr.
	Ulmus glausescens Franch.
	Ulmus pumila L.

In conclusion, even if the debate concerning diversification of urban trees is mainly directed towards new and rare tree species, much of the future work will consist of ‘dusting off’ old favourites when additional knowledge and understanding of their site tolerance and better genotypes are available. The obvious advantage of studying habitats and evaluating well-known species, as in the case study in Romania-Moldavia, is that the subsequent selection process is much shorter and this tree stock can be introduced once appropriate genotypes are tested and available. This process also considers trees which today are exclusively used in park environments, but could possibly be transferred into street environments. When further information on species already used in the urban landscape is obtained by studying them in their natural habitat, the current body of knowledge will increase and new use functions for many well-known species will be identified. However, it is equally important to have a long-term approach where many new and untested species and genera can be identified, in order to increase the diversity of the urban tree population in a long-term perspective.

Delimitations and constraints

It is important to bear in mind that the approach presented in this thesis, with dendroecological habitat studies in order to identify potential urban trees, is just the first step in a long selection process (Figure 9). Further research and evaluation are necessary in order to determine the tolerance of the species and genotypes identified to warm and periodically dry growing conditions in other geographical areas and to other stressors such as de-icing compounds, air pollution, *etc*. Issues such as propagation problems and negative phenological aspects such as weak flowering and autumn colours (aesthetic values) in another region can also limit the introduction of the species or genotypes. Here the case studies were limited to habitats influenced by high summer temperatures and periodic periods of droughts, since drought in particular is a major constraint for many urban trees (*e.g*. Craul, 1999; Hoff, 2001; Sieghardt et al., 2005; Nielsen et al., 2007; Roloff et al., 2009). There are, however, examples of suitable street trees originating from habitats with a combination of wet and dry periods, such as *Platanus occidentalis* L. (Burns and Honkala, 1990; Dirr, 2009), *Alnus cordata* Desf. (Nitzelius, 1958; Bean, 1980; Bengtsson, 1998) and *Catalpa speciosa* Warder (Dirr, 2009). These habitats are clearly interesting to investigate for identification of further species and understanding their strategies to cope with this environment. However, in Papers II-IV the hypothesis was that the probability of identifying a large number of potential species and genotypes tolerant to inner-city environments would be greater when studying matching habitats instead of testing species and genotypes randomly. Habitats with a combination of wet and dry periods are certainly interesting for future research in order to find further species and genotypes for inner-city environments.

Additional research is also undoubtedly needed in order to further develop the approach of dendroecological studies in natural habitats in the search for stress-tolerant tree species. This includes the development and evaluation of field methodology to determine factors such as the number of plots and size of regions needed in the study in order to obtain trustworthy results and guidance on the growth and performance of the species and genotypes. In this regard, the evaluation of genotypes collected in a new region and their tolerance for urban environments is an important complement. Further evaluation is necessary concerning field investigations where complementary techniques can be used in order to detect the physiological reactions of the trees in water balance/water use, in terms of transpiration rates, sap flow measurements *etc*. (*e.g*. Kozlowski et al., 1991; Sperry et al., 1998; Larcher 2003; Breda et al., 2006; Percival *et al*., 2006; David et al., 2007; West et al., 2007). However, the question remains of how to achieve efficient data collection in *e.g*. mountainous terrain.

Furthermore, the results from the case studies and above examples of potential tree species for tough urban sites are all broadleaved species. There are of course a number of conifer species which have the potential to be suitable for inner-city environments. Among conifers, the most promising species include hard pine species, such as *Pinus heldreichii* var. *leucodermis* (Antoine) Fitschen and *Pinus nigra* J.F Arnold, and indeed the latter is already used to some extent in urban paved sites in the CNE-region.

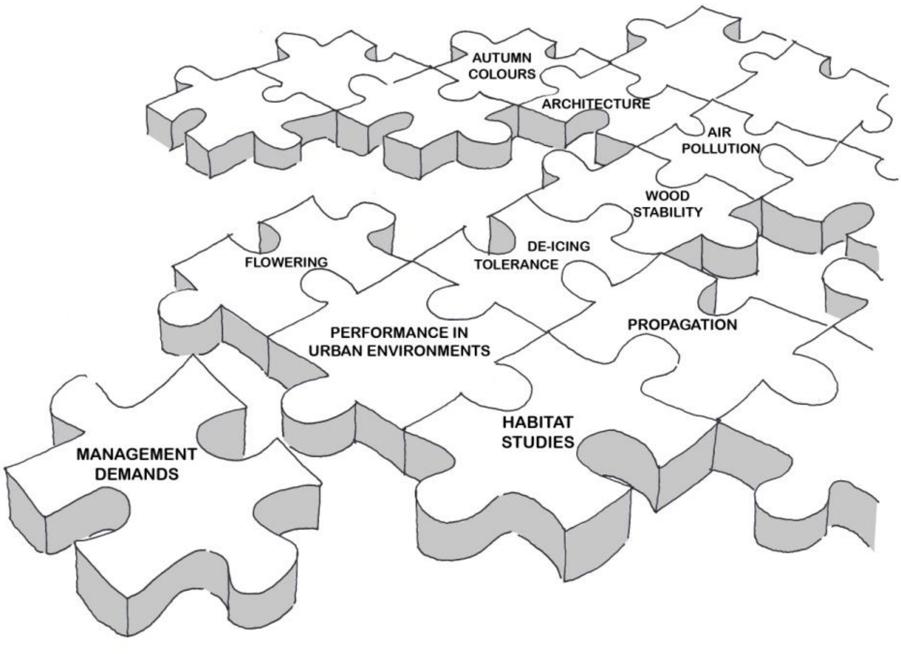
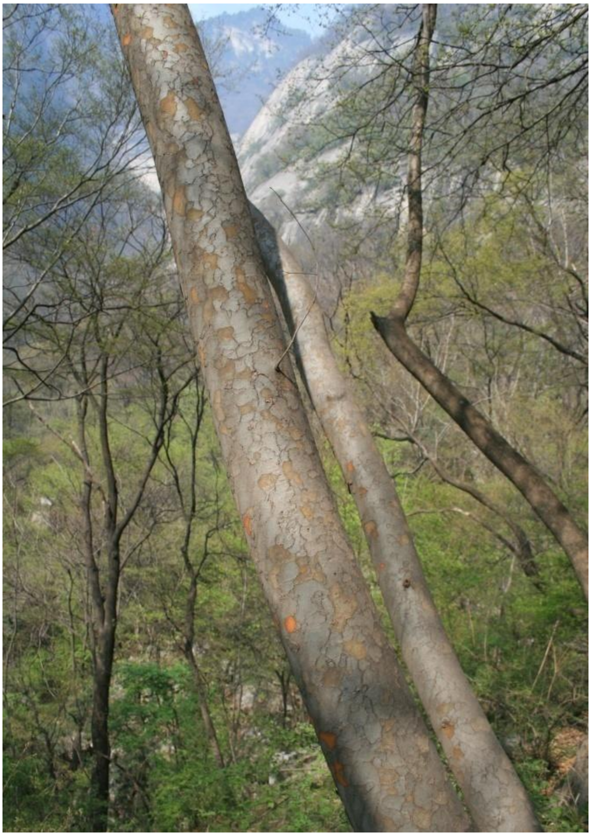


Figure 9**.** In the selection of urban trees, many aspects must be included before any clear recommendations on its use potential can be made, including management demands, propagation issues, flowering *etc*. In this process habitat studies can give valuable guidance on species or genotype performance in different environments. Illustration by Johanna Deak.




PENSIUNE
NO LIMITS

Figure 10 – Previous page**.** Four example of species found in the two case studies, growing in habitats with comparable site conditions to those in urban paved environments in the CNE-region. Top left: *Ulmus glausescens* from Qinling Mt., China. Top right: *Quercus aliena* var. *acuteserrata* from Qinling Mt., China. Bottom left: *Sorbus torminalis* from Iasi, Romania. Bottom right: *Tilia tomentosa* from Codri, Republic of Moldavia.

THE FUTURE VISTA

All planting design must to some extent be a compromise between what is desirable (artistic or creative vision) and what is possible (scientific reality; Dunnet 2004). Even if it is possible to push the boundaries through technology, this often occurs at a considerable environmental cost that is not sustainable, *e.g*. continuous management costs.

The great advantage for an ecologically-informed basis for plantings is that it has the potential to achieve full creative vision with relatively little site modification (Dunnet, 2004; Wiley, 2004).

It has been suggested by several authors that investigating the ecological background and performance of species growing in habitats which naturally experience drought during the growing season and with winter temperatures similar to those of inner city environments can provide a sound and reliable selection method for achieving a high diversity of site-adapted trees for urban environments (Flint, 1985; Ware, 1994; Ducatillion and Dubois, 1997; Broadmeadow et al., 2005; Sæbø et al., 2005; Roloff et al., 2009).

The two dendroecological studies reported in this thesis tested the above suggestions. This resulted in the identification of 27 tree species that experience warmer and drier conditions at their indigenous sites than those occurring in park environments in the CNE-region (Table 1). They therefore have potential for use in street environments and other paved sites in the CNE-region. The next step is to evaluate different genotypes of the species identified at sites in the CNE-region. Based on these plantations, further understanding concerning development in another geographical region can be achieved. This includes technical aspects such as tolerance to different site situations, propagation issues, management demands and aesthetic aspects such as flowering, leaf structure, autumn colours, architectural performance *etc*. Among the species already in cultivation, available new genotypes should ideally be tested to determine whether any differences exist in growth and performance for inner-city habitats in the CNE-region. It will then be possible to confirm the location of geographical regions and sites hosting adequate species and genotypes for warm and periodically dry environments.

There are certainly many other regions of the world where further dendroecological studies could be conducted in order to identify potential urban trees for the CNE-region (Breckle, 2002; Burga et al., 2005; Figure 8). However, it is important to reflect over other issues closely connected to the approach presented in this thesis in order to reach complementary information useful in the communication with urban tree planners in the work of diversification of urban trees.

Collaboration between research disciplines

There is seldom a single approach to use in order to present a wide range of information and guidance and enable urban tree planners to make adequate choices and feel confident with the use-potential of a wider range of species for urban environment. Instead, it is important to combine several disciplines in order to reach a good understanding and guidance of why some species are better than other for *e.g.* street environments.

In previous discussions about habitat studies in the identification of potential species and genotypes for inner-city environments, existing ecological theories were recommended in order to reach a deeper understanding of strategies or traits employed by different tree species to help them tolerate different stressors (*e.g*. Craine, 2009). However, among the ecological models and theories available for analysing plant communities and their structures, much information and methodology already exists, but it needs to be specifically interpreted for tree planting in urban environments. As mentioned earlier, few tree species, especially among newly introduced species, have been classified through these models and theories. In order to provide guidance on the correct '*codes*' of the strategy behind the tolerance of a tree species to different stressors and its potential to become a successfully street tree, further research is essential. Such studies should include examination of the mechanisms behind tree tolerance to *e.g*. drought, including root growth investments, stomata conduction, rapid defoliation *etc*. (Larcher, 2003; Archaux and Wolters, 2006). In this regard, it is important that urban tree researchers collaborate with ecologists. This combination of disciplines can reduce the risk of valuable knowledge and guidance for urban tree use being lost or overlooked (Dunnet and Hitchmough, 2004).

The cross-disciplinary approach is necessary not only when combining ecology-orientated research with urban planning, but also among researchers in the same field of urban tree research. In order to push the boundaries forward regarding the use of non-conventional plant material in urban areas, it is vital that research concerning the establishment of trees or plant beds also includes and tests non-conventional tree species and genotypes. For example, in studies of the establishment and performance of trees in urban environments (*e.g.* Bühler et al., 2007), or when evaluating porous pavements, *etc*. (*e.g.* Morgenroth and Visser, 2011), conventional and well-used tree species are usually included in the studies. By including non-conventional species for urban environments, these studies could also contribute knowledge and experience of these tree species. Through greater collaboration between different research disciplines, reliable results and clear guidance for urban tree planners can be produced – not only towards a greater diversity of species, but also towards their application.

A further research direction connected to this thesis is the understanding and selection of tolerance and performance in different habitat types within the species. This direction was not included in the thesis, but is an important issue for further understanding of the varied tolerance for different climates and habitats within species (Valladares et al., 2007). As highlighted by Hitchmough (1988), selection based on the variation within species (genotypes) is very much a “pandoras box” of opportunities and should enable tree selection to be made far more positively as a means to reduce short-term and long-term management costs. The main reason why some ‘well-known’ species are not used as much could be the uncertain genetic material available at tree nurseries. For example, in Denmark, the use of silver lime, *Tilia tomentosa*, is very sparse due to earlier experiences where genetic material not suitable for the region where used (P. Kristoffersen, pers. comm. 2011). Due to these earlier negative experiences, few tree planners will today recommend silver lime as a street tree, even if it is more suitable for inner-city environments than other lime tree species (Sjöman and Oprea, 2010). In order to reach a greater understanding of the genetic variation within species and selection of suitable genotypes for urban environments, a cross-disciplinary approach is also needed here, including plant physiologists and geneticists. As noted by Mackay et al. (2005) *“Evaluation of plant genetic resources should focus on identifying useful germplasm for specific purposes”*.

Locally conducted research

As stated in Paper I, there is a lack of local rooted knowledge and experience concerning trees in urban environments in the CNE-region. Much of the information available has been developed in different regions of the world, in climates not comparable to that of the CNE-region, making results questionable and difficult to interpret. In order to provide useful knowledge and guidance for the use of urban trees in this particular region, research need to be conducted locally and within its regional context. This in turn will inspire confidence among local urban tree planners when developing urban tree populations, as well as testing rare and untraditional tree species.

Although dendroecological studies in natural habitats will provide a knowledge platform in understanding species and genotype tolerance and performance, evaluations of existing plantations in the urban environment will prove an important complement. As more cities in the CNE-region invest in inventories of their urban tree stock, a continuously increasing amount of local site-related data will be developed. Evaluation of these local existing plantations together with habitat studies and plant physiology studies where the responses of species and genotypes to different stressors have been evaluated in controlled tests can allow comprehensive information and guidance to be developed (*e.g*. Cameron et al., 2006; Percival et al., 2006).

Invasiveness

Since it is unlikely that the species-poor native dendroflora of the CNE-region can provide a large range of species and genotypes with an extended tolerance to the environmental stresses characterising *e.g*. paved sites within its urban areas, it is inevitable that exotic species will be used in the region (Duhme and Pauleit, 2000; Figure 11). There is currently an intensive debate about whether it is appropriate to introduce exotic tree species into public plantations, with the fear of these species escaping and negatively affecting native ecosystems being the main argument against their introduction and use (*e.g*. Parker et al., 1999; Alien Plant Working Group, 2010; Hitchmough, 2011). Much of the debate concerning invasive species is today eagerly seized upon by environmental groups and journalists (Kaufman and Kaufman, 2007), whose opposition to such species is often based on philosophical-political notions rooted in romanticism, rather than solid scientific results (Kendle and Rose, 2000; Hitchmough, 2005; 2011). However, there are many examples of invasive species interacting negatively with native communities and causing vast problems, with severe biological and economic impacts. In the USA alone, the estimated economic impact of non-indigenous plant species is USD 34 billion per year (Pimental et al., 2005). The question which has to be raised in this regard is the extent to which such severe problems with invasive species and the associated biological and economic costs cast a negative shadow over other exotic species with no negative biological or economic impacts. Without a well-informed debate and a thorough risk assessment concerning the use of exotic species and the threat of invasiveness, there is a risk of official regulations requiring the use of only native species being developed, which could severely affect the CNE-region.

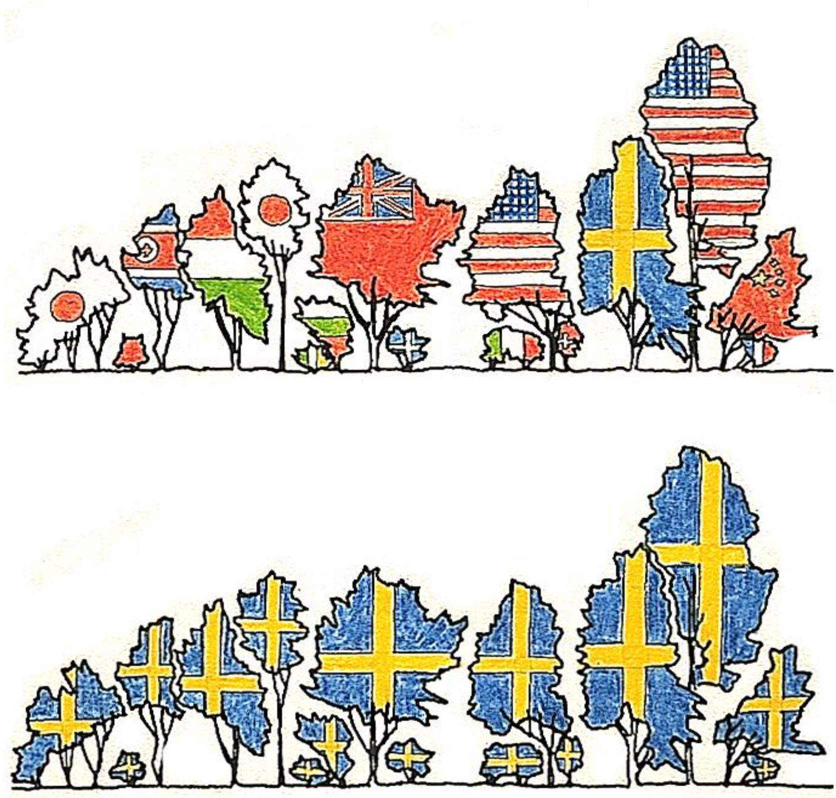


Figure 11. Due to the species-poor native dendroflora in northern parts of central Europe, the use of exotic tree species from many regions of the world is inevitable. Illustration by Roland Gustavsson.

It is therefore important to have parallel research associated with the selection process concerning the invasiveness risk of the species included. Dendroecological studies in natural habitats can provide some guidance on this issue. By identifying the ecological strategies, including disposal and reproductive traits of species and genotypes in their natural settings, it is possible to determine their potential to escape from cultivation and become an aggressive competitor in natural habitats (Pyšek and Richardson, 2007; Pyšek et al., 2009). Dietz and Edwards (2006) present a conceptual model where the invasion phase is divided into two different stages – primary invasion and secondary invasion. Species successful in the primary invasion stage have traits closely connected to Competitor-Ruderal strategies, such as rapid establishment and growth in new disturbed habitats (Grime, 2001). The secondary invasion stage is where a species encounters increased habitat resistance. In order to develop successfully during the secondary invasion phase, traits closely connected to Competitor-Stress tolerator strategies, such as adaptation to relatively undisturbed conditions and tolerance to moderate intensities of stress, are important (Grime, 2001). There may also be other traits of importance for invasiveness, such as time of flowering, germination ability, seed size and dormancy, *etc*. (Aronson et al., 2007; Pyšek and Richardson, 2007; Theoharides and Dukes, 2007; Pyšek et al., 2009). Relevant research on these aspects in parallel with ongoing selection work can help prevent the introduction of invasive species and genotypes. This procedure may in turn diminish the resistance to using exotic tree species in urban environments.

VISION

Urban planning today and in the near future faces complex decision-making with regard to green space distribution and green space qualities. Global changes may create a contradictory dichotomy in providing enough green space to adapt to and mitigate climate change whilst projecting a sustainable urban form suitable for an increasing urban population (Hamin and Gurran, 2009). In the compact city, qualities provided for in larger parks and greeneries will be compromised into smaller scale units or to alternative green structures – all in all, the capacity load and performance level of future urban green space and future urban trees will accumulate. Biological diversity, storm water management, pollution relief, beneficial and recreational impacts on human well-being and urban heat island mitigation are some of the challenges urban green space will face in the near future (Forman and Godron, 1986; Nowak, 1993; Grahn and Stigsdotter, 2003; Geldof and Stahre, 2006). Although various vegetative structures such as green roofs, green walls etc., have been developed and used in sustainable urban development schemes in order to meet some of these challenges, urban trees still provide the dominant capacity to influence and maintain the wider resource diversity needed (McPherson et al., 1997, Pauleit et al., 2005). How development and sustainable longevity of our present and future urban trees will proceed and whether it will be successful are of course dependent on a variety of factors. However, it will need to include a transdisciplinary scope stretching from the initial planning phase to site management and maintenance, where knowledge of habitat design and species composition, plant material and establishment must interlace the entire working process.

Planning the future ‘treescape’ in our urban landscape is complicated in the sense that it prompts us to plan while there are certain factors which we cannot predict. Emerging pests and diseases is a good example of where an outbreak may wipe out an entire species group at a timescale difficult to estimate. Today it is impossible to foresee which species or plant groups hold the brightest outlook in the CNE-region with regard to disease and pests and impacts from climate change. Continuous development of knowledge and research focused towards the development of a wider array of species and genera is one of the most important step towards a sustainable approach. Another step is to acknowledge the spatial framework in which urban trees are set. While the inner city environment differs from the peri-urban environment or rural landscape, it also differs widely within itself. Parks, paved sites, courtyards and streets all provide much different conditions for tree development. Ready information on species and genotype selection for this variety of sites will aid in making sustainable plans, designs, plant selections and management strategies. Such information should ideally be synchronised between municipalities, landscape companies, nurseries and the professionals involved in making our future cities into sustainable urban 'treescapes'.

"Don't waste your life in doubts and fears: spend yourself on the work before you, well assured that the right performance of this hour's duties will be the best preparation for the hours or ages that follow it."

(Ralph Waldo Emerson)

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– what happened in Xi an, stays in Xi an…

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Figure 12. A proud moment when the international team at the Northwest A&F University in Yangling, China, plays the final in the university soccer tournament. The Chelsea FC outfits are sponsored by the Swedish University of Agricultural Sciences – Thank you!

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“Oh you are in my blood like holy wine
And you taste so bitter but you taste so sweet
Oh I could drink a case of you
I could drink a case of you darling
Still I'd be on my feet
And still be on my feet“

(Joni Mitchell)