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Selection of trees for urban forestry in the Nordic countries

Arne Sæbø[1], Thorarinn Benedikz[2] and Thomas B. Randrup[3]

[1] The Norwegian Crop Research Institute, Særheim Research Centre, Klepp, Norway
[2] Forest Research Branch, Reykjavík, Iceland
[3] The Danish Forest and Landscape Research Institute, Hoersholm, Denmark

Abstract: Trees in the urban environment are subjected to a number of stresses which are very different from those suffered by trees in typical rural conditions. The stresses listed in this paper should be a basis for the selection criteria used in urban tree improvement programs. The basic properties of trees are climatic adaptation, disease resistance and a large phenotypic plasticity. Properties related to the urban situation are related to stresses caused by social factors, the restrictive soil volume and crown space, soil pollution, air pollution, de-icing salt, wind and drought. In addition, aesthetic factors, growth form and growth potential and resistance to breakage of limbs are important selection criteria. The priority ranking of the selection criteria depends on the environment wherein the plants are to be used. The need to broaden the range of species and cultivars planted in Nordic cities should have high priority, and selection programs should, therefore, include new species of urban trees. A practical selection should be made within the four major Nordic climatic regions, which are the northern maritime, northern continental, southern maritime and southern continental regions. The establishment of broad co-operation in the selection of plant materials for urban uses is discussed.

Key words: park trees, plant materials, selection, street trees, urban forestry, urban woodlands

Introduction

The relatively low average lifetime of trees in urban settings has been the focus of great attention (Gilbertson & Bradshaw 1985; Moll 1989; Bradshaw et al. 1995; Harris et al. 1999). The relationship between location and stress has been central issue of many studies (Forrest et al. 1999; Konijnendijk et al. 2000). According to Nilsson et al. (2000), *street trees* are exposed to a relatively high stress level and because of their exposure to multiple stresses their average life span is short. *Park trees* are exposed to moderate stress and compared to street trees their average lifespan is relatively high. However, the trees are often exposed to anthropogenic influences such as pollutants and related stresses from humans and domestic animals. Trees in *urban woodlands* are subjected to a relatively low stress level and may reach a considerable age. In urban woodlands the level of stress depends more on the climate, soil conditions, recreational patterns and biotic damages than on anthropogenic causes. Activities related to trees in the urban environment are: (i) policy making, planning and designing etc., (ii) technical focus, such as selection programs and establishment techniques and (iii) management aspects (Konijnendijk & Randrup 2002).

Address for correspondence: Arne Sæbø, The Norwegian Crop Research Institute, Særheim Research Centre, 4353 Klepp ST, Norway. E-mail: arne.sabo@planteforsk.no

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Successful urban forestry depends on the plants functioning as intended, even under stressful environments. Thus, the selection and use of suitable tree species and genotypes are important factors in a strategy aimed at improving quality and decreasing costs in the establishment and management of urban green areas. The effect caused by the choice of species and designs of plantings will contribute to a city's distinct aesthetic expression.

Pauleit et al. (2002) showed that, throughout Europe, there existed a poor diversity of tree genera and species being planted in urban areas, especially as street trees. Although planners in Central and North-Western European countries use a relatively broad range of species, only three to four genera predominate in urban areas, namely *Platanus*, *Aesculus*, *Acer* and *Tilia*. In the Mediterranean countries, e.g. in Spain, 56 percent of all trees planted in paved areas are represented by only five genera (García-Martín & García-Valdecantos 2001), whereas many more are planted in parks and gardens.

It can be assumed that the use of a broad genetic diversity will lead to a greater aesthetic variation and healthier trees in urban areas. Based on the fact that only a few species comprise 60–80 percent of the trees planted in cities, a major aim for planners of urban green areas should be to decrease the reliance on the most popular species and cultivars that dominate too much of today's urban forests. In view of the large number of indigenous species growing in Europe, especially in the south eastern region, where 10–30 percent of the trees are endemic (Duhme & Pauleit 2000), the potential for enlarging species diversity in the cities does not seem to be limited by the availability of adapted genera and species. Many of the species of interest have geographical ranges determined more by former glaciations than by present day climates (Duhme & Pauleit 2000).

Plant materials, which have been selected for commercial forestry, can also be used with some success in urban areas. However, we will argue that "traditional commercial forestry selection programs" are not suitable for urban forestry. This is explained by the obvious major differences between urban and "traditional" forestry. In "traditional" forestry focus is often on wood quality, volume production and resistance to pests and diseases. Thus, few selection criteria are used. In urban forestry very little focus is on wood quality, volume production or even on growth rates. Instead, more focus is on aesthetic qualities, such as shape and form, flowering, fruiting, leaf colours, bark structure and colour, resistance to urban stresses and so forth. In traditional Nordic forestry few species are used, or indeed desired, at least in the same stand, whereas in urban areas high species diversity is sought, primarily for aesthetic reasons. We believe that there is a strong requirement to increase efforts in systematic work on selection and on breeding trees and shrubs adapted to urban conditions. Many factors must be considered in the choice of good plant material for urban situations. Although aesthetic factors and the function of the plants are important, we have chosen to mainly focus on the stresses of urban trees as a basis for the selection.

Stresses affecting trees in urban areas

The stress physiology of plants provides important knowledge as to which selection criteria to look for in a tree improvement program. Although much knowledge can be found on environmental tree physiology (Kozlowski et al. 1991), the stress physiology of urban trees has until now been given little attention.

Abiotic stresses

■ *Climate*

Growth cessation of most trees in cold temperate regions is under photoperiodic control (Heide 1974; Håbjørg 1978). This response is an indirect adaptive character to the climate on the site of origin of the plants. After growth is terminated, the gradual decrease in temperature is important for the winter hardiness (Kozlowski et al. 1991). The climate is usually more stable in continental regions than in maritime areas. Plants from continental climates tend to start growth soon after temperatures are sufficient, enabling them to use the full growing season. Maritime plants are slower off the mark and this protects them against damage from the spells of frost, which repeatedly occur during a mild winter and spring. Thus, if plants adapted to a continental climate are moved to the coast, they are often susceptible to spring frost damages. Plants from a maritime climate, on the other hand, may suffer from autumn frost if transferred from a maritime to a continental climate, i.e. towards a shorter growing season. The same effects may be observed if plants are moved from south to north (in the Northern Hemisphere). This implies that moving plants far away from their original site, where natural selection has occurred, should be avoided, or the consequences must be at least thoroughly analysed.

The average temperatures in cities are 1–3 °C higher than those in the countryside (Harris et al. 1999). This may cause bud break in woody ornamentals to occur as much as 5 to 20 days earlier, as compared to outside of the city (Chronopoulos et al. 1996). Early bud break makes the plants more susceptible to spells of late spring frosts. On the other hand, this increase in temperature in cities may offer the opportunity to choose from a wider range of exotic species and phenotypes than that normally would be expected for the Nordic climates (Bengtsson 1998). The effects of global climatic change are difficult to evaluate, but phenological responses in tree collections in Europe indicate that the growing season has been extended by almost two weeks over the last 30 years (Menze & Fabian 1999).

In a selection program for Ponderosa pine, *Pinus ponderosa* Dougl. ex Laws., a significant correlation was found between growth increment and the duration of active growth (Rehfeldt 1992). Thus, the selection for increase in growth also led to the selection of plants that ceased growth later. In this way, the selection of one parameter may decrease the suitability of the plants to the climate in which they are to grow (Rehfeldt 1992). Often an interaction between climate adaptation and susceptibility to diseases is found. Continental genotypes of trees are more prone to diseases after they have been moved to coastal climates. This is frequently caused by primary damage to the plants by the climatic conditions, rendering the trees more susceptible to disease (Kozlowski et al. 1991).

Water stress

City trees are often under stress due to too limited water supply. This is caused by the large water use in response to higher temperatures within the cities, by restricted root systems and/or because less water reaches the trees than precipitation would indicate. Some trees are by nature effective in the uptake of water and utilise large soil volumes, by making extensive and heavily branched root systems. However, this may be impossible for trees in the urban situation, where root growth is often restricted by utility infrastructures, by small rooting volumes, soil compaction and other factors. Amounts of water available to trees at various locations are therefore often not correctly represented by annual or seasonal precipitation and the evapotranspiration ratio. The management program, the choice of plants and the placement of the trees all must be decided by planners taking into account extreme situations and the frequencies of their occurrence (Duryea & Dougherty 1991). However, water may be economised within plants through adaptations in the stomatal apertures, both through a decrease in the number of stomata per unit leaf area or through an efficient response by the stomata to water stress (Kozlowski et al. 1991). In the coastal regions of the Nordic countries a surplus of precipitation, combined with a poor drainage, may lead to oxygen deficiency to the roots, in some cases, killing newly planted trees.

Light

Trees planted between tall buildings may suffer from low light levels during a larger or smaller part of the day or the year. At relatively high temperatures and high transpiration rates, a low light intensity is a severe stress factor. Species with a low photosynthetic compensation point (shade plants) could be used under such conditions, but under extreme shade conditions, there is little sense in planting trees. The selection or breeding for extreme shade conditions is in our opinion a poor use of limited resources. Street lighting and lighting from buildings may also disturb the natural processes of photoperiod response within trees. Delayed leaf fall in the autumn, close to streetlights, can often be observed. Whether the disturbance to the timing of autumn hardening in urban trees is a serious problem has not been extensively examined.

Soil conditions

Although different trees are more or less adapted to different soil conditions, the variations in soils in urban areas are probably much larger (e.g. Craul 1992) than those which can be gained through a tree improvement program. Furthermore, new, promising urban planting techniques and planning methods have been introduced in recent years (Grabosky & Bassuk 1996; Randrup & Dralle 1997; Kristoffersen 1999). The soil should therefore be amended to suit the tree species and treated to supply roots with oxygen and to avoid water stress, nutrient deficiency, soil compaction and limited rooting volumes. Therefore, we suggest soil conditions to be considered more of a planning and a management problem, rather than factors to be considered in tree improvement programs. However, during a selection program, the range of soil conditions that the phenotypes in question can tolerate (pH, soil types, nutrient demand, water conditions) should be tested and described, in order to make it easier for the planners to choose the best trees and establish the best possible growing conditions.

De-icing salt

The use of salt, to prevent ice forming on streets and pavements, causes many problems in cities in the Nordic countries (Hvass 1985; Pedersen & Fostad 1996; Pedersen et al. 2000). The resistance of plants to salt damage is either through tolerance or avoidance. In woody species, an important mechanism seems to be the exclusion of Na^+ and Cl^- ions being taken up by the roots or by preventing the ions reaching vulnerable parts of the trees (Allen et al. 1994). Significant differences among poplar clones with regard to salt tolerance have been observed (Fung et al. 1998; Sigurgeirsson & Jonsson 1999). The tolerance of salt is a quantitatively inherited property and mechanisms seems to be coupled with or analogous to the tolerance of drought, water logging and cold (see Winicov 1998 for references). Differences between genotypes in salt tolerance have been found in several species (see Allen et al. 1994; Fostad & Pedersen 2000). Both planted and naturally occurring trees in coastal regions, which are continuously exposed to salt spray and high wind speed, may offer unexplored genetic resources for use in urban forestry. However, although there is potential for successful development of salt tolerant forest trees, little progress has been made to date (Allen et al. 1994). In conclusion, the damage to trees from de-icing salt should mainly be avoided by technical measures taken at the time of establishing the plants in the streetscape, by preventing salt runoff. However, it is regarded as almost impossible to prevent salt spray from reaching the trees, and salt spray behaves thus as an air pollutant.

Air pollution

Saxe (1991) made a comprehensive review of the physiological effects of air pollutants on different plant species. Air pollution damages trees in two ways: (i) by absorption of chemical pollutants through stomata and (ii) from dust deposition on leaf surfaces. Dust deposition is especially hazardous for evergreens because its effects are cumulative. However, the trees' ability to remove dust from the atmosphere is one of the important benefits of planting trees in cities. During the last decades the concentration of sulphurous compounds has decreased considerably in European countries. Even so, local emissions may still create problems in some areas. It has been shown that SO_2, and possibly O_3 pollution, predisposes plants to frost damage (Barnes et al. 1996) and the interactions between pollutants and abiotic factors may thus be relevant. Evergreen conifers are more affected by SO_2 than broadleaved species. For defence against air pollution the anti-oxidants in plants seem to be important. Although differences in susceptibility to air pollution (SO_2) have been found within populations (Barnes et al. 1999; Davison & Barnes 2002), breeding for a greater tolerance of air polluting agents in trees is probably not the best use of resources. Great progress has been made in cleaning the emissions at their source and the choice of tolerant species is a preferable measure at sites with heavy air pollution.

Street architecture

Large crowned species, e.g. within the genera *Acer*, *Aesculus*, and *Tilia*, are often planted on narrow pavements. Branches may reach the buildings, casting deep shade and creating other problems. The common solution is heavy pruning, which impairs the natural beauty of the tree and can predispose the trees to attacks by diseases. In such conditions small trees or trees with narrow crowns should be planted. Choosing species or varieties that do not become too large can in principle solve the problem. Furthermore, selection of phenotypes with narrow crowns may allow the use of tall growing species in relatively narrow streets. Clones of diverse growth forms are already available for many of the common urban species, but at present we find that, in order to secure the stability of urban plantings, there are too limited possibilities of changing between the different genotypes of similar phenotypic forms.

Security hazards and stresses caused by severe pruning

As trees grow to large sizes and great beauty concern often arises for safety in the streets or parks. Ageing and decline in trees are natural processes and the solution may be to fell and replace the tree, rather than heavily prune the mature specimens, as is often and unnecessarily, done. After severe pruning, the trees may begin a rapid and irreversible decline. Such results illustrate two serious problems in urban tree management, firstly that the wrong tree species or cultivar was chosen initially for the site and secondly the very poor judgment in the choice of management methods. There is an urgent need for greater knowledge among planners and practitioners to avoid those problems.

Biotic stresses

Dutch elm disease (DED, *Ophiostoma ulmi*) represents a good example of a serious and often lethal disease of urban trees. As a result of the epidemics, elm trees have been replaced today by other species in many of the urban areas of Europe. Care must be taken when importing living specimens to avoid the introduction of vectors, and with them the inoculums, of dangerous diseases. The lesson hopefully learned is to take precautions through the use of a broad spectrum of species and genotypes. Spider mites and aphids are nuisances, causing leaf discoloration and exudation of honey, which disfigure and dirty underlying vehicles. However, measures are seldom taken to combat such pest problems. Interactions between biotic and abiotic factors affecting the plants are not unusual. For example, plants not well adapted to the climate are usually more susceptible to disease, even to the less aggressive pathogens. It is also well known that certain combinations of species or genera should not be placed close to each other, because diseases or pests may alternate between them (Wennström & Eriksson 1997). Good examples are provided by the poplar rust (*Melampsora*) which alternates on poplars and larch and various aphids of the *Adeles* genus which need two distinct species (e.g. spruce and larch) to complete their life-cycle.

Resistance against pests and diseases

The traditional breeding methods for resistances rely on crossing within the species to gather resistance genes. This method is most often directed towards single gene resistances, which usually are easily broken by adaptations in the pest or pathogen genomes. The breeding for multiple-gene resistance, usually only partial resistance, is a rather slow process, especially in species with a long juvenile phase. However, hybridisation and breeding may yield resistance against serious diseases. Examples can be found in *Ulmus* (DED) and in *Platanus* (Antrachnose; *Apiognomonia veneta*). Although the deployment of multiple-gene resistance is difficult to deal with for the breeder, it gives a more long lasting resistance in the plants as compared to single gene resistances. Multiple-gene resistance implies at least two independently acting resistance processes in the plants. As an example, resistance to an insect may be based on genes encoding two or more toxins with different modes of action (Jouanin et al. 1997). The use of gene transformation in trees opens new possibilities in the breeding for important properties, although the methodology is still at an early stage. Furthermore, more time is needed to change the public's sceptical attitude, before genetically modified trees can be taken into use in the streetscape. A careful evaluation of the consequences of genetic modifications must be done beforehand. As of yet, national legislation prevents the use of genetically altered genotypes in most countries. This will not change until documentation is at hand, showing that the technology and its products are safe. For the time being we suggest that problems with pests and diseases should be dealt with by using the methodologies already at hand, i.e. low tech. Firstly, plants that are hosts for serious diseases or pests should not be used in urban areas. Secondly, many species and cultivars of trees are sufficiently resistant to pests and diseases if they are used within the climatic region to which they are properly adapted. Thirdly, plants should be given optimal growing conditions by practising good establishment techniques and management programs. If these precautions are taken, the trees will generally remain healthy. However, the selection strategies should include breeding for resistances against pests and diseases.

What species and genotypes are used in urban forestry of the Nordic countries today?

A study of urban forestry practises in selected European cities (Pauleit et al. 2002) showed that too few species make up too large a proportion of street trees, especially in the Nordic countries (Table 1). Information on trees used in parks and urban woodlands were not given for all countries, but the results from Iceland and Denmark indicate that only a few more species are used on these locations as compared to street trees. In Sweden, Finland, Norway and Iceland, urban woodlands were typically designed for commercial forestry production. *Picea abies* (L.) Karst. and *Pinus sylvestris* L., and to some extent *Betula pendula* Roth, are thus the main species on the Scandinavian Peninsula, whereas *Betula pubescens* Ehrh., *Picea sitchensis* (Bong.) Carriére, *Larix sibirica* (Münch) Ledeb. and *Pinus contorta* Dougl. ex Loud. dominate in Icelandic urban woodlands. In Denmark, urban woodlands were established later and the afforested areas are often dominated by broadleaved trees.

Icelandic research shows that exotic trees often grow and perform better in the country than do the indigenous species. In Iceland (with only three native tree species) and the northern parts of Finland, Norway and Sweden, the range of species may be broadened by introducing new species. However, the new species need to be evaluated and monitored, to ensure that they do not become invasive. Numerous examples can be mentioned and good examples for Scandinavia are illustrated by the behaviour of *Tsuga heterophylla* (Raf.) Sarg. and *Acer pseudoplatanus* L. In the southern parts of the Nordic countries there may still be a potential for using

Table 1. The most common tree species used in paved areas in the Nordic countries. The numbers are the percentage planted (2000) in five cities in each country (Pauleit, personal communication)

Country	% of planted street trees
Iceland	
Populus trichocarpa Torr. et Gray ex Hook.	30–90
Betula pubescens Ehrh.	10–15
Sorbus aucuparia L.	7–20
Salix caprea L.	1–15
Norway	
Tilia x europaea L.	40–70
Acer platanoides L.	7–10
Aesculus hippocastanum L.	5–10
Sorbus spp	4–15
Betula pendula Roth and *B. pubescens* Ehrh.	3–50
Populus spp	1–50
Finland	
Tilia x europaea L.	35–50
Betula pendula Roth	10–50
Sorbus spp	8–12
Acer platanoides L.	7–10

the natural populations of trees to expand the range of species. In this context, arboreta and botanical gardens in different climatic regions should be used more than today, to test and compare new and traditional species and phenotypes.

In Finland there is a trend to use smaller trees as the building density increases. However, in many places the large tree species are still being planted, in spite of complaints that they have too little space for both roots and the crown. In Denmark the different cities listed different species as "the most used species". This may reflect adverse growing conditions, but the choice may also be the "footprint" and personal preferences of the city planners.

The species choice for street trees (Pauleit et al. 2002) shows that the number of species used increases towards the south of the European region, which also applies within the Nordic countries, reflecting the more amenable climatic conditions. However, the number of species that *can* be used is much larger and this probably also applies to most Nordic cities. In fact this is the general picture for most cities over the world (Chacalo et al. 1994; García-Martín & García-Valdecantos 2001). However, it is rare to find places with such poor species choice as within the two largest Norwegian cities, where 70% of the street trees planted were of one clone, *Tilia x euopaea* 'Pallida'. The limited number of species planted in urban areas is often a result of the use of well-tested cultivars, that have proved to be the most hardy and aesthetically-pleasing and are also easily propagated and cultivated.

It should be a priority task for Nordic urban forestry co-operation to increase the number of species. This will decrease the risk of failure caused by pests and diseases in the future. It will also increase diversity and aesthetic qualities of the urban forests, as well as strengthening the feeling of identity and distinctiveness in the Nordic cities.

The choice of species

Santamour (1990) describes the use of a model for urban plantings, with the aim of securing greater species diversity and guarding against large-scale insect attacks or diseases. To ensure maximum protection against such pests the urban forest should contain no more than 10% of any single species, no more than 20% of species of a single genus and no more than 30% of species within a single family. These guidelines are probably impossible to follow in large areas of the Nordic countries. For street trees we suggest that if several suitable clones within a species are available then they should be used in different parts of the city. Homogeneity within single units could still be maintained. In parks, clones with pronounced characteristics, such as columnar, erect and pendulous growth or spectacular leaf coloration for example, are used in addition to a basic assortment of seed propagated trees. In urban woodlands clones are probably not needed at all, since it is of great interest to keep a large biodiversity and to meet demands for the broad spectrum of functions of the plants.

Species recommendation in Greece is based on an analysis of what species occur in the neighbouring nature areas and on soil conditions, temperatures and precipitation of the area (Hatzistathis, personal communication). This tool for the choice of species emphasises the ecological conditions. The process for selecting species for urban uses may be facilitated through the use of a Species Selection Model (Miller 1997, Fig. 1).

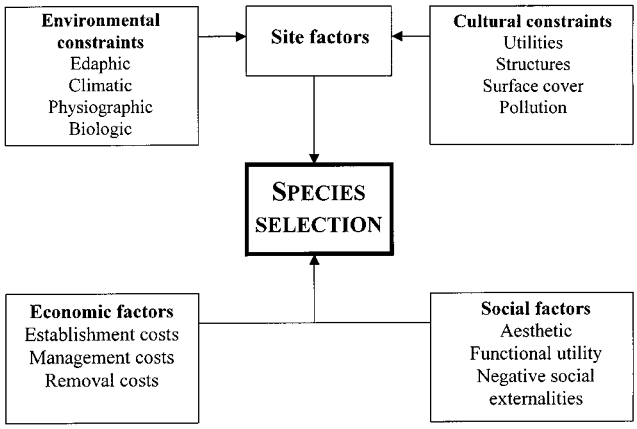

Fig. 1. Factors important in a model for selection of species for urban areas (Miller 1997).

Site factors include cultural constraints as well as environmental ones, where cultural constraints refer to physical limitations of the site caused by human structures and activity and the environmental constraints refer to insects, diseases, climate, microclimate and soils. Social factors include neighbourhood and community values, functional utility, species aesthetics, public safety, and negative social externalities. Economic factors include establishment, management, and removal costs. However, Miller (1997) did not prioritise between the factors.

Examples of selection programs

In Europe outside the Nordic countries

In France a project has been initiated which aims at identifying wild species with a potential for use in urban areas. The factors evaluated were: the environmental and functional properties of the urban site (biotic and abiotic factors), the natural biodiversity of the trees flora at the site and the knowledge on their properties. It was also considered essential to consult with the general public, planners and practitioners. A multi-criterion sorting system was evolved for planners, wherein the important criteria are taken into account; namely:

(i) the site – both the natural and urban environment and functions (Ducatillion & Dubois 1997);
(ii) amenity and ornamental values;
(iii) ecological limits for the plants (climatic adaptability, edaphic factors etc.);
(iv) interaction with humans at the site (toxicity, allergy etc.) and
(v) environmental risks (e.g. invasive plants).

The species were planted for testing and demonstration purposes at different places in southern France. Growth characteristics, morphology, tree phenology and susceptibility to pests, pathogens and climatic stresses are all considered. *In situ* testing of species may successfully be done when large areas are afforestated in or near cities, preferably when there is available funding because of a special arrangement. A good example was the Expo98 in Lisbon, Portugal (Rego & Castel-Branco 1998), where more than a thousand trees belonging to 182 species, were planted and evaluated for survival under rather tough soil conditions. Such plantings can be established and studied for many years, yielding valuable information.

In the Netherlands a large proportion of acorns (of *Quercus robur* L.) have been harvested from roadside plantings (Vries & van Dam 1998). Such trees grow relatively unaffected by neighbouring trees and their growth form should therefore reflect their phenotypic potential as related to the selection criteria of interest. Dutch tree nurseries have selected 2–5 percent of the trees from roadside trees as seed sources for the new generation of oaks. Selection is rigorous and gives the possibility of a gradually improving tree quality. Systematic selection work is continuously done, by evaluating stands as potential seed sources and by evaluating stands and provenances in comparative trials in progeny tests.

Selection work in the Nordic countries

Typical for plant improvement activity for urban green areas in Scandinavia is the large emphasis on shrubs, often with the same species within the different countries (Väinölä & Joy 1996). Only a few of the species have reached the stage of actual breeding and for most of them improvement work has not gone beyond the initial selection of elite clones and the testing of their progeny.

In Denmark seed sources of a number of tree and shrub species have been recommended and much of the selection work on trees and shrubs is done through the "Dafo" (Danish Research) system. The characteristics recorded are growth habit, ornamental value, climatic fitness and disease status (Brander 1990). More than 100 clones of *Tilia cordata* Mill., *T. x europaea* L., and *T. platyphyllos* Scop. have been selected in the improvement program with *Tilia spp.* In addition trials have been initiated in Denmark to test hybrids of *Ulmus* for resistance to Dutch elm disease. There is still a great need to test progenies from seed sources of both trees and shrubs.

Planting trials with various species of shrubs and trees for use in urban areas have been started in Finland (Lindén, personal communication). Improvement work on *Acer platanoides* L., *Quercus robur* L., *Sorbus intermedia* (Ehrh.) Pers., *Tilia* sp., and *Ulmus laevis* Pall. is in progress at the University of Helsinki. This university initiated another program in 1984, which included 20 tree and 60 shrub genera, with the aim of developing winter hardy ornamental plants, which are resistant to different diseases (Väinölä & Joy 1996). Clonal trials have been laid out at five test locations in Finland, which range from the southern coast to the Arctic Circle.

A large number of provenances and progeny trials with forest tree species have been laid out in rural areas in Iceland, where comparison of their performance for afforestation purposes is the main aim. Breeding trials have been initiated with Alaskan black cottonwood (*Populus trichocarpa* Torr. et Gray ex Hook), both to compare their forestry performance and also to test their resistance to poplar rust (*Melampsora*) (Halldórssson et al. 2001), which has recently been discovered in Iceland. The only tree improvement work in Iceland which is designated for urban forestry are trials with the native birch, where tree form and bark coloration are the characteristics under improvement (Tómasson 1995).

There has been a special interest in *Sorbus* species in Norway, where a range of endemic species occurs in the southern regions. The genetic variation occurring in *Sorbus aucuparia* L. has been under study (Sæbø & Johnsen 2000). However, intensive selection is not being made in trees for urban areas in Norway, although the potentials for improvements are undoubtedly large. The nursery industry is also involved in the selection through the E-Plant (elite plants) system (a Swedish system).

In Sweden the evaluation of trees for urban purposes is more or less left to the nursery industry, who are cooperating with Swedish authorities within the E-Plant system. This system entails testing the selected plants in trial plots in rural or urban green areas or in the nurseries. However, this system is not aiming at intensive selection. Lagerström & Eriksson (1996) have suggested a tree improvement model for Sweden, which includes five steps. This system has been taken in use for a number of species today.

In the first step the trees are visually evaluated in the nurseries for their growth characteristics, phenology and healthiness. Rigorous selection is applied to the seed mother trees during the second stage, in order to reduce the variability of the growth habits of the approved seed stands. Delineation of the climatic breeding zones, based on phenological studies, constitutes the third step. At the fourth level, selection of individuals based on good phenotypic characteristics is carried out and seed orchards are established with the selected individuals. In the fifth step, simple recurrent selections are carried out, without keeping track of the pedigree. Depending on the commercial value of the species this scheme is followed either until step three, for those trees sold in smaller numbers, or until step four or five, for those species sold in large numbers. The program includes 25 native and 26 non-native species (Lagerström & Eriksson 1996) and is run in conjunction with the E-Plant system.

Furthermore, improvement work has begun on several broadleaved species of interest for urban forestry. Plus trees of *Fraxinus excelsior* L., *Prunus avium* L., *Tilia cordata* Mill., *Acer platanoides* L. and *Sorbus aucuparia* L. have been on trial since 1992 on two locations in Sweden (Stener & Werner 1997). A comprehensive study of species within *Tilia* is also in progress in Sweden.

In Sweden and Denmark landscape laboratories were initiated during the past decade (Gustavsson 2000). Although the main objective of the laboratories is to explore design features and management techniques, the use of landscape laboratories may be a good way to test, demonstrate and, finally, to introduce new species, designs and methods for selection of trees for urban woodlands (Gustavsson 2000).

In spite of quite similar growing conditions in the regions where most of the Nordic population is living, each country has its own tree selection program. Therefore, the benefits from co-operation on methodology and, even on the selection of the species of mutual interest to urban forestry, are not realised. Within each country separate organisations manage selection for forestry on one hand and for parks and gardens on the other. The differences between the two sectors are many, but co-operation should be encouraged.

Selection programs to find good phenotypes of trees for urban forestry

The adaptation of the tree to the overruling environment, which is characterised by the length of the growing season, precipitation, seasonal temperatures and resistance to or tolerance of pests and diseases, is the most important selection factor (Table 2). However, aesthetic and functional selection criteria need to be included in a selection program.

The careful composition of species in urban situations also requires that planners hold the ecological and epidemiological knowledge necessary for decision-making. An example is the problem caused by the rust (*Gymnosporangium cornutum*), which alternates between the two species, by planting a mixture of *Sorbus aucuparia* L. and *Juniperus communis* L. (Wennström & Eriksson 1997).

A tree-improvement program is a long-term project, but the gains can be considerable. As of yet only fragmented efforts have been made to find improved genotypes for the urban situation. The exceptions are in those species that are of great interest to commercial forestry. In the Scandinavian countries these species are especially *Populus trichocarpa* Torr. et Gray ex Hook (in Iceland), *Picea abies* (L.) Karst. (Norway and Sweden), *Betula pendula* Roth (Finland), *Fagus sylvatica* L. and *Quercus* spp (Denmark), *Tilia* spp (in Denmark and Sweden) and *Pinus sylvestris* L. Although the most important selection criteria for commercial and urban forestry are similar, it should be realised that some of the demands to the plant materials for the urban situation are very specific. The profit from the plant improvement should be measured in terms of better performance and establishment, fewer problematic

Table 2. Selection criteria for trees in street, park and in urban woodlands

Street Trees	Park Trees	Urban Woodlands
Climate adaptation	**Climate adaptation**	**Climate adaptation**
Resistant to diseases	**Resistant to diseases**	**Resistant to diseases**
Large plasticity*	**Large plasticity**	**Large plasticity**
Aesthetic characteristics	Aesthetic characteristics	Timber quality
Social factors	Social factors	Growth rate
Root quality	Root quality	
Growth; potential and form	Growth; potential and form	
Wind resistance	Wind resistance	
Drought resistance	Resistant to limb breakage	
Resistant to limb breakage		
Tolerance of air pollution		

*Plasticity: Ability to thrive well in different growing environments.
Criteria shown in bold font: basic criteria which should be present in any program.

diseases and pests, lower costs of management and generally better qualities and longer life spans of the trees in the urban green areas.

The physiological responses of trees to stresses are the key to selection criteria. However, the selection criteria must also be based on social aspects, taking into account possible negative aspects concerning human beings, for example allergy. The qualities associated with the origin of the seed are of great importance to the nursery industry. Often, only a small proportion of the seedlings will achieve acceptable standard to be sold as street or park trees, or too much effort and time is needed to achieve a good result. Thus, the trees often become expensive and the users will then rather buy less suitable plant material at a lower price.

Selection criteria

Although the focus of this paper is on trees, shrubs should also be included in the comprehensive selection program of plants for the urban green areas. However, most of the considerations for selection in shrubs are the same as for trees.

The selection criteria (Table 2) can be categorised into three groups:

1. Basic features of the trees, which are climate adaptation, tolerance of diseases and pests and phenotypic plasticity.
2. Tolerance of the stresses in the urban situation.
3. Selection criteria related to the amenity values and functions of the trees in urban areas.

The basic properties (bold font in Table 2) of the trees must always be present in order to secure a good result. Which tolerances, amenity aspects and functional aspects that should be built into the selection and breeding program, however, must be evaluated in light of the proposed use of the trees and the resources of the programs.

■ *Selection criteria for street trees*

The need for uniformity of shape and growth is especially emphasised for street trees. Trees of specific shapes and growth characteristics should be made available to urban forestry authorities and most growing conditions. Also the responses to pruning and other management techniques may be important characteristics in street trees. Therefore, the needs for specific tree qualities may often be best served through the selection of clones or by narrowing the variation in a seed orchard to get uniform offspring (Lagerström & Eriksson 1996). Genetic diversity should preferably be obtained using a number of clones in each city or region. At present, clones of similar properties hardly exist and the development of parallel clones may be difficult due to the high costs of the trees. Thus, commercial and ecological interests are in conflict. However, clones should not be introduced until the plant material is well tested beyond the juvenile phase. In many cases improved seed sources can be as good as clones and the selection work may be relatively fast and cheap. In order to enhance the biodiversity in the urban forests it should be a goal to make selections in non-traditional species. The non-traditional species can be found in natural habitats, in arboreta and botanical gardens and in some private gardens. The use of hybrids between species could be a useful approach and has been explored in elm to obtain resistance to DED (Pinon et al. 2002).

Street trees should possess strong apical growth, strong branching angles, an overall high aesthetic value, predictable growth rates and, in general, have a potential for a long life span. The trees should not pollute the streets with their fruits and pollen release should be in moderate amounts and not of an allergy creating type. To meet the variable requirements of the different streetscapes a wide variety of shapes, sizes and forms are needed. Both large and small trees and trees with crown shapes ranging from narrow to relatively wide are desirable. In order to secure the supply of the most suitable plant materials, both the nurseries and the users of that material should be involved in the selection program.

■ *Selection criteria of park trees*

Park trees often have similar properties as the street trees, but a larger variation is tolerated and even preferred in parks. Different styles as well as different functions cause a demand for a large diversity in age, size and structure; elements that create the values of a highly appreciated park.

■ *Selection of trees for urban woodlands*

Tree species selected for urban woodlands and recreational forests will share many of the selection criteria used in commercial forestry. However, the range of species should be much larger than that which can be found in forests established and managed for timber production and many of their characteristics will be selected for their recreational and amenity values. However, production aspects (growth rate, volume production, wood quality, etc.) should count as important for selection of trees in urban woodlands. Society can benefit from that, because an extra incentive would be present for the landowners, which thus may want to increase the establishment of urban woodlands.

The list of selection factors (Table 2) shows that the number of selection criteria is greater for the harsher environment we offer the plants. The social factors may be related to allergens and poisonous substances in the plants, their litter, etc. The growth rate should be moderate and extremely rapid growth is not an objective. The shape of the tree is also an important factor related to growth. Wind resistance is necessary in coastal regions of the Nordic countries, but also in trees used near vehicles on roads with relatively high speed limits. Drought resistance may be needed for the continental regions.

The selection factors and the added comments show that there is a need to differentiate the selection factors according to the region where they will be planted. Ware (1994) suggests selecting trees for the urban environment from tree stands found on inhospitable sites, such as floodplains, swamps, savannahs and dry habitats. However, trees adapted to tough sites due to one selection factor in their native habitat, will still have their specific needs, which may not be met in another tough urban site. The growing conditions in the cities must, at least, be ameliorated for the trees. The growing medium should not be compacted, the soil must be well drained and the trees must be supplied with sufficient water and nutrients. However, under harsh conditions some pioneer species may have higher tolerance of certain stresses than others. Such trees should be tried in the urban situation, but more knowledge is needed on their stress physiology in order to use them at the right places.

Potential definitely exists with regards to native species and gene pools. However, when collecting trees from the native vegetation it is important to consider, that in many places a negative selection has been made through harvesting of the best specimens for building materials, furniture, and so forth (Vries & van Dam 1998). The properties of the trees in the adult phase are of greater interest in urban areas than those in the juvenile phase, because the trees must function over a long time span. For the production of trees with special growth forms or leaf characteristics propagation by cloning is necessary. Clonal propagation of trees is most often done during the physiological adult phase, although cloning of juvenile plant tissues is usually much easier and gives higher rooting rates. Further information on selection criteria can be found in Zobel & Talbert (1991), Phillips (1993) and Stoecklein (2001).

In the different regions, both the species and the various selection factors will have different emphasis and priority placed on them. The selection in the Nordic countries should be made out from the perspective of four climatic regions: namely the northern maritime, northern continental, southern maritime and southern continental (Fig. 2). Within these very roughly designated regions, large climatic variations are found and species and provenances from outside as well as inside the regions need to be tested. However, if the species has a large phenotypic plasticity, it should be possible to select trees suitable for the regions. Some selected trees will probably have to overlap each other, regionwise. However, the regions need to be discussed and examined further in the future co-operation between the Nordic countries. Therefore, we chose not to be more specific at this stage on the "borders" between different regions.

The list of species shown in Table 3 is in no way final and should be considered to be a starting point. The specific selection programs need to find the most relevant species to work with and the lists may therefore be longer or shorter than suggested here. However, the number of potential species to work with is probably longer in southern parts and in the maritime areas of the Nordic countries as compared to the northern and continental regions, respectively. The decision on species and selection criteria in each program should be discussed with planners, practitioners and nurseries before final plans are made.

Future activities in selection in trees for urban areas in the Nordic countries

When selecting trees for the future the selection program should be based on a wide perspective. It is im-

Table 3. Some of the species and genera in which there is potential to make selections for the different regions of the Nordic countries. The regions are shown on the map in Fig. 2

Northern maritime	Northern continental	Southern maritime	Southern continental
Alnus spp	*Betula pubescens* Ehrh.	*Acer campestre* L.	*Acer campestre* L.
Betula pubescens Ehrh.	*Pinus sylvestris* L.	*Acer pseudoplatanus* L.	*Acer platanoides* L.
Populus spp	*Populus spp*	*Carpinus betulus* L.	*Pinus sylvestris* L.
Salix spp	*Prunus padus* L.	*Prunus avium* L.	*Prunus avium* L.
Sorbus aucuparia L.	*Salix spp*	*Quercus spp*	*Quercus spp*
	Sorbus aucuparia L.	*Sorbus spp*	*Salix spp*
		Tilia spp	*Sorbus spp*
			Tilia spp

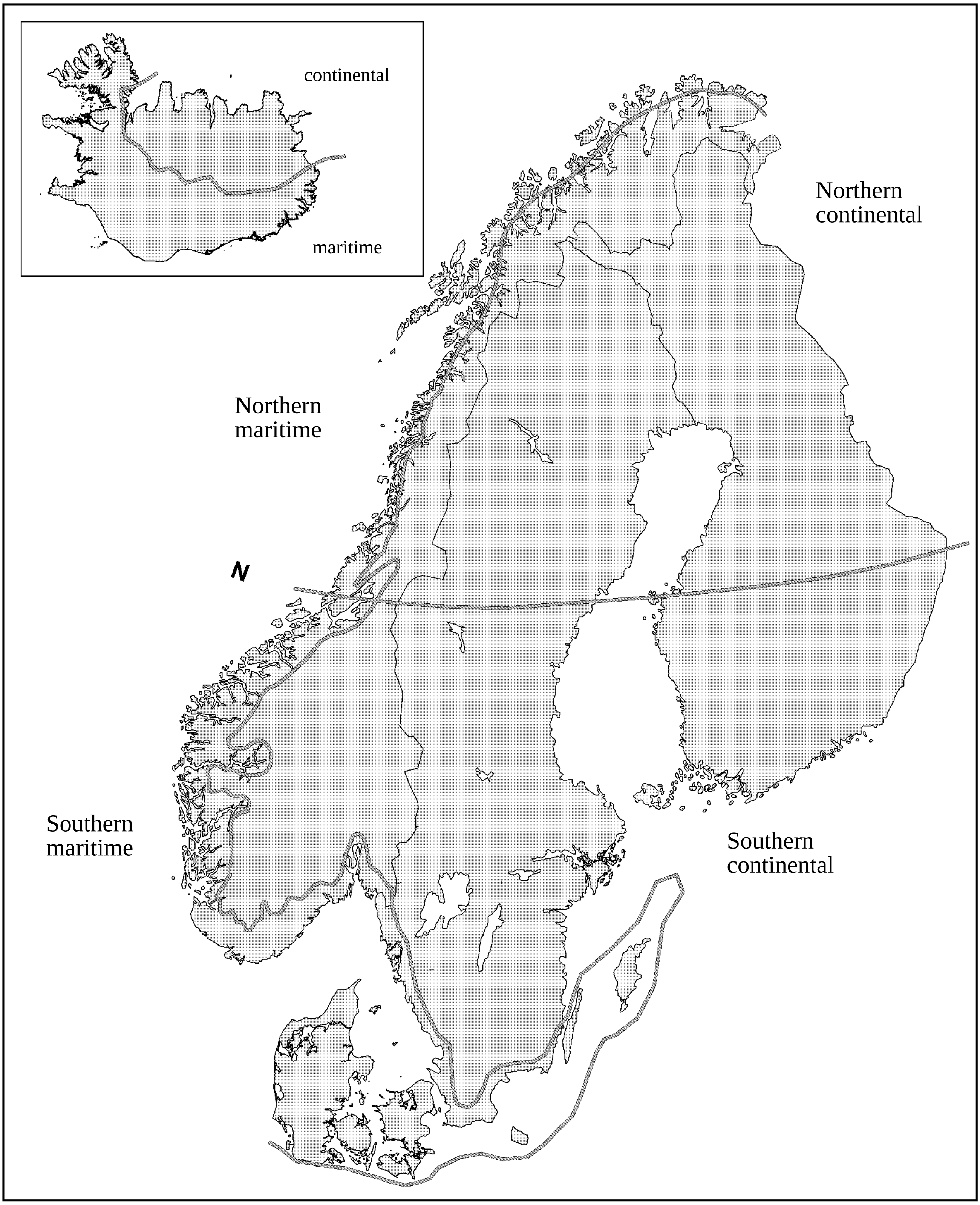

Fig. 2. The map shows a proposition for the characterisation of the climatic regions in the Nordic countries. The borders between Northern maritime, Northern continental, Southern maritime and Southern continental need to be further adjusted before the start of a selection program. The line marked N demarcates the division between North and South Scandinavia.

portant to capture the variation in the gene pool and to map those available traits in the breeding population that are beneficial in a dynamic breeding program. Aims and strategies may change with time, due to changes in the environments and urban needs. Furthermore, the possibility of significant global climatic change should be considered. Since we do not know what changes may occur, the emphasis should be on the preservation of large phenotypic plasticity and genetic diversity in the gene pool of the plant materials we use or are planning to use (Eriksson et al. 1993; Eriksson 1996, 1997). Multi-population breeding (Namkoong et al. 1988) seems to be a good option to prepare for the future. In this system, many populations are conserved, either with the aim of breeding for genotypes of the wanted properties within each population, or to breed for different adaptations among the different populations. Both approaches seem feasible for urban tree improvement programs. However, breeding is costly and time consuming, especially when the number of species is large and the objectives for breeding are so diverse. Therefore, breeding of trees for the urban green areas should be made in regional co-operation. Climatic similarities within the region should be the basis for the co-operation, but does not exclude exchanging knowledge and genetic materials between the south and the north of Europe, because that would be of great value.

A pragmatic model for selection may be the most realistic approach in order to produce results, although the progress would be much quicker in the long term if a comprehensive program could be initiated. The suggested model of Lagerström & Eriksson (1996) described above, seems to be a realistic starting point. The species need to be ranked in priority, and Table 3 shows some of the species of interest.

Conclusions and perspectives

Apart from on the basic properties of urban trees, focus should be on the environmental stresses that the trees must withstand and the functions they should ful fil. The basic properties of the trees are (1) climate adaptation; (2) resistance to diseases; and (3) large phenotypic plasticity in the plant materials. The properties related to the urban situation are (1) aesthetic characteristics; (2) social factors; (3) root quality; (4) growth potential and form; (5) wind resistance; (6) drought resistance; (7) resistance to breakage of limbs and (8) tolerance of air pollution.

Duhme & Pauleit (2000) suggest a pan-European information network on the urban dendroflora of major European cities, in order to compile the already existing information. New knowledge should be collected by making systematic surveys based on a common methodology, which is adapted to the eco-regions of Europe. Such a network may offer new opportunities for testing potential plant resources, which are present in many botanical gardens and arboreta. Co-operation between the Nordic countries may be a first step towards such a network. Such co-operation can be justified by the expected better use of the resources for selection projects and by the offering of a larger market for the trees, which should help to finance the investments in the tree improvement programs.

Better knowledge of physiological processes related to stress is needed and research should be started to fill the gaps in the existing knowledge. This may be an important input for the design of large tree improvement programs.

We suggest the strategies for selecting and breeding urban forest trees should be prioritised. This would enable the development of new initiatives for developing better plant material for urban forestry and horticulture in the Nordic countries:

1. Selection criteria referred to in this paper should be adopted in selection programs to suit the different uses of trees in urban conditions.
2. The Nordic region can roughly be divided into four main climatic regions, within which the selected trees should be tested: northern maritime, northern continental, southern maritime and southern continental regions.
3. Non-traditional species should be tested, improved and demonstrated for planners and practitioners.
4. Pragmatic selection programs are the least expensive alternatives and make use of plant materials in production. Exploration of existing collections in parks, arboreta, botanical gardens, private gardens, road plantings and landscape may be used to broaden the use of species and genotypes.
5. In a tree improvement program, several populations, preferably comprising a broad gene pool, should be maintained and explored. Dynamic selection and breeding of genotypes should be the aim.

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