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Full Length Research Paper

Key street tree species selection in urban areas

Ying Ying Li[1], Xiang Rong Wang[1] and Cheng Lin Huang[2]*

[1]Department of Environment Science and Engineering, Fudan University, Shanghai 200433, China.
[2]Department of Forestry and Landscape Architecture, Anhui Agricultural University, Hefei 230036, China.

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Street trees in cities display a varied pattern that shape the city's physical fabric. This article presented the methodological aspects of a proposed selection process for the key urban street tree species. The process of this study was twofold: first it was aimed at selecting the appropriate tree species through field trip and data analysis of the street trees in streets and parks of the natural secondary forests, the ancient and famous trees in Hefei. Secondly, a selection among alternative tree species in the inventory was made using the Analytic Hierarchy Process (AHP) method and the expert knowledge approach. In the methodology, the weights of the selection criteria were determined by pair-wise comparison matrices of AHP. The priority ranking of the selection trees depended on expert evaluation of the comprehensive quality of the trees. Based on the use of subjective and objective data sources, the selection process could be adapted for use in the street tree planning of Hefei, as well as other cities.

Key words: Urban tree, street tree, species selection, urban green space, AHP.

INTRODUCTION

Street trees are one of the most important components of urban green space and they play an important role in street aesthetics. People's first impression of a city comes from its street landscape (Jacobs, 1993). So tree species selection and planting design will strengthen the feeling of identity and distinctiveness of a city. As an integral component of urban green infrastructure, street trees, especially key street trees selection is crucial to successfully shaping a better urban environment. Herein, key street trees refer to the tree species, which are widely used on streets and form the style of street landscape.

Broad species diversity will lead to greater aesthetic variation and healthier trees in urban areas. But the general picture is that a few species make up a large proportion of the street tree population. The criteria for selection of street trees are unclear. Throughout Europe, a survey showed a poor diversity of tree species being planted in urban areas, especially in street trees (Pauleit et al., 2002). In the USA, the three most common species constitute almost two-thirds of the street trees in Syracuse (Sanders, 1981), and in Chicago the four most common species comprise two-thirds of the entire population (McPherson et al., 1997). In other highly populated cities in developing countries, little diversity in street tree selection is occurring, including Mexico City where the four most common species constitute 49% of the trees (Chacalo et al., 1994). In China, street trees have the lowest species diversity and the most significant dominance by a small group of common species compared with other urban forest type in Guangzhou (Jim and Liu, 2001). In view of the indigenous species which grow in the south eastern region of Europe, only 10 - 30% of the trees are endemic (Duhme and Pauleit, 2000). A study about central European urban floras showed that the urban areas generally exhibit a higher representation of aliens when compared to other habitat types (PyŠek, 1998). Many parks, arboreta, botanical gardens, private gardens, road plantings and landscapes present a variety of potential plant resources which may be used to increase tree species diversity (Sæbø et al., 2003). The potential for increasing species diversity in urban street tree selection is not limited by the availability of adapted genera and species.

Miller (1997) proposed a Species Selection Model for selecting species for urban uses. Important factors in the

*Corresponding author. E-mail: lyyforward@gmail.com. Tel/Fax: 0551-5786261.

Abbreviations: DBH, Diameter at breast height; **UGSSP,** urban green space system planning; **AHP,** analytic hierarchy process.

model include the site factors, economic factors and social factors. However, he did not give priorities for these factors. Design qualities, longevity, ease of cultivation, and mass propagation were identified as the main criteria for the selection of tree species by Pauleit (2003). Street trees are easily subject to stresses due to their proximity to atmospheric pollutants, poor drainage, inhospitable soil, mechanical damage, high and low ambient temperatures, and lack of space for growth (Ware, 1994; Jim, 1999; Sæbø et al., 2005; Thaiutsa et al., 2008). These factors should also be considered in the selection of street tree species.

A combination of factors must be considered in a successful street tree selection program. A common method to quantify expert knowledge for suitability modeling is Analytic Hierarchy Process (AHP), which involves the use of structured iterative pair-wise comparisons to allow the users to simplify the process of a complex decision (Saaty, 1980). AHP is an integrated assessment approach to decision making, one that can account for the complexity of multiple criteria (Duke and Aull-Hyde, 2002; Wu and Wang, 2007; Wang et al., 2010).

Santamour (1990) describes the 10-20-30 formula for maximum protection of an urban forest against pests (the urban forest should contain no more than 10% of any single tree species, no more than 20% of species in any tree genus and no more than 30% of species in any tree family). Areas with a diverse mix of species are believed to be more robust than locations dominated by a small set of species (Nagendra and Gopal, 2010).

Hefei, China was selected as the case study of this project because of its diverse urban forest and its rapid expansion that will require the selection of tree species for street and park planting. The city has developed rapidly in recent decades, with a congested inner city with densely packed buildings and roads. With the transformation of the old city and the construction of the new city, there is an opportunity for the development of urban green space, especially for the green spaces along urban streets, which are one of the most important aspects enhancing a city's image. The aim of this paper is to develop a methodology that can be used in Hefei as well as other cities to select key street tree species which are adapted to the urban environment, and meet landscape, ecological and social functions.

METHODS

The selection and use of suitable key street tree species are aimed at enhancing the city's image, improving urban environment quality and decreasing costs in the establishment and management of urban green areas. Key street tree species selection is based on an analysis of what kinds of species exist in the urban area and the neighboring natural areas, the landscape features of the trees, tolerance to the stresses in the urban street, and the management costs of the trees. The process for selecting species for urban street uses can be summarized by the key street tree species selection model (Figure 1).

Case study area

Hefei is the capital of Anhui province which is situated in the center of the province, with the Chaohu River flowing on the southeast side of the city. It is located in the north subtropical humid monsoon climate zone with annual average temperature of 15.7°C. Rainfall averages 981.4 mm per annum and falls mainly between June and August. The Hefei area lies on the transition of the north subtropical zone to the warm temperate zone, so the main vegetation types in Hefei are characterized by mixed broadleaved forests of deciduous and evergreen species.

Currently, the "141" spatial development strategy of the Hefei area, namely the formation of "a major city, four city groups and a new lakeside district" is being implemented to shape the new metropolis. Therefore, there is need to develop and apply comprehensive methods for sustainable urban tree plantings and specifically for street tree plantings.

Survey of species

In 2008 the Department of Forestry and Landscape Architecture of Anhui Agriculture University conducted an inventory of street trees along the main streets and parks in Hefei. A 2008 Hefei Guide Map was used to spatially distribute sampling locations and the Outer Ring Expressway was used to define the limit of the area within which sampling was conducted. The survey of 145 main streets was conducted in different administrative districts. Based on the character of the street, a typical 200 m long transect was located for sampling the street trees. An intensity sampling strategy was adopted in 6 older city parks. All street trees in these older parks were examined. The data collected for each tree included the species name, tree height, diameter at breast height (DBH) and health conditions. The DBH of the top five most common species were plotted as a frequency distribution histogram. The DBH measurements were categorized into eight classes: 7-11, 11-15, 15-19, 19-23, 23-27, 27-31, 31-35, and larger than 35 cm.

In addition to an evaluation and analysis of the existing street trees, the existing forested areas and a native vegetation history of the city's forests are necessary for the identification of potential street trees (Phillips, 1993). Currently, there is very little natural secondary forest left due to human activities in the Hefei area. In order to find native tree species which could potentially serve as street trees, a survey of the natural secondary forest was carried out. Seventeen sample sites representing the features of natural secondary forest in the Hefei area were chosen. Most sampling was undertaken from June to August of 2008 by the students and staff of the Department of Forestry and Landscape Architecture of Anhui Agriculture University. Sites were sampled using the point-centered quarter method (Cottam, 1956).

Various authors (Randall and Clepper, 1977; Jim, 1994a; Van Pelt, 1996; Lewington and Parker, 1999; Browne, 2001) reported that trees with heritage value are often identified in urban area and are variously labeled as ancient, champion, famous, heritage, historic, old and remarkable trees. The species represented by these trees should be considered in the selection of species for urban street planting. In our study, the trees which were more than 100 years old or had important historical and scientific research values were called ancient and famous trees (Ministry of Housing and Urban-Rural Development of the Peoples' Republic of China, 2000). Such trees survive for decades to centuries, bring ecological, amenity and cultural values, make significant contributions to the cityscape, and furnish living landmarks that have witnessed the history of human

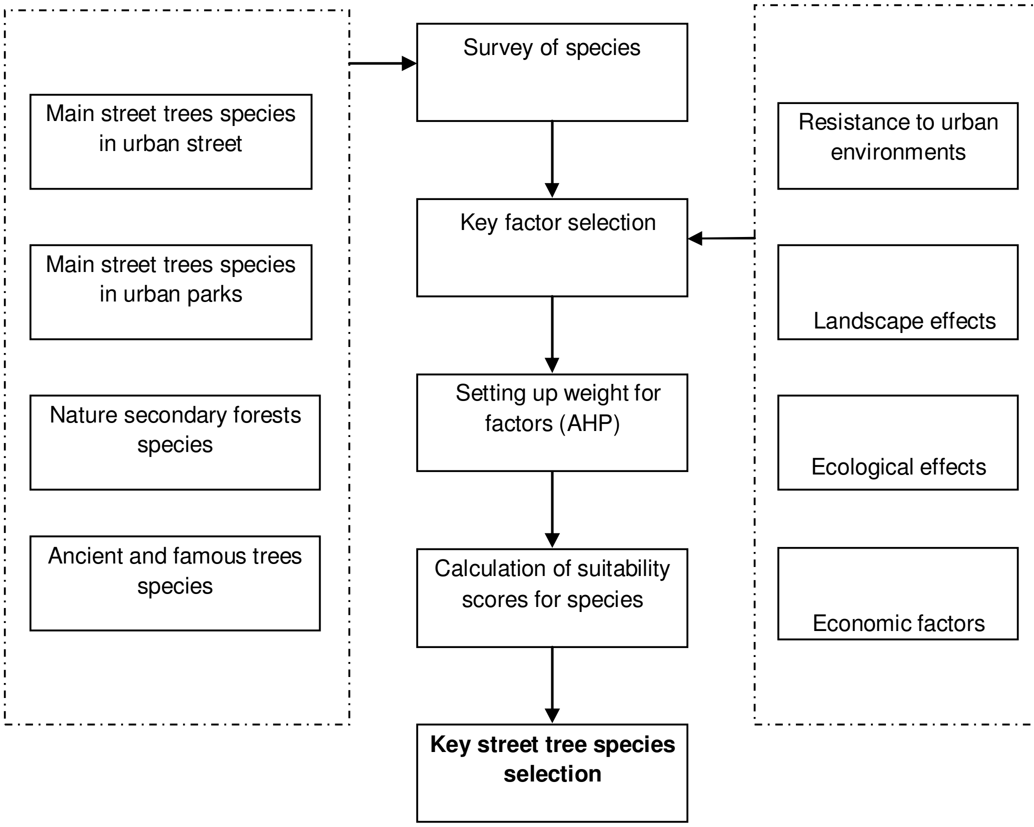

Figure 1. Procedures and criteria adopted in the selection of key street tree.

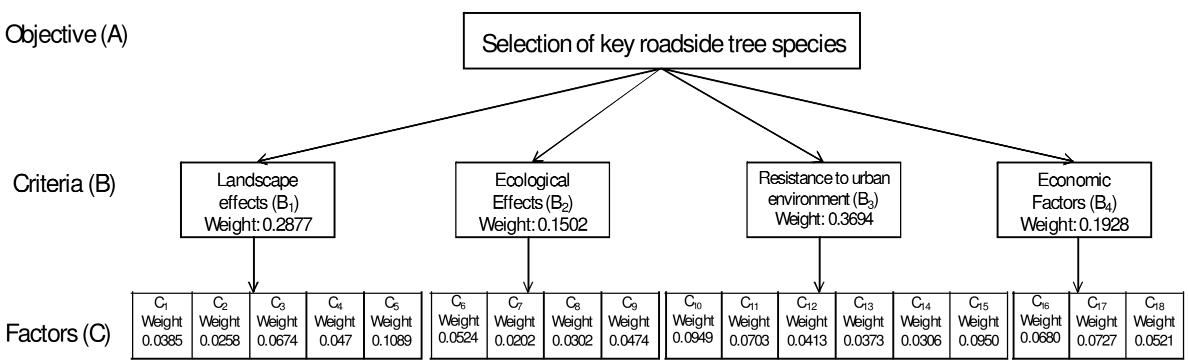

Figure 2. The hierarchy structure and weight of evaluation factors for key street tree species selection. C_1: Flower; C_2: fruit; C_3: trunk; C_4: leaf; C_5: crown shape; C_6: tree crown; C_7: tree height; C_8: DBH; C_9: canopy density; C_{10}: Drought resistance; C_{11}: poor soil resistance; C_{12}: cold resistance; C_{13}: high temperature resistance; C_{14}: diseases and pests resistance; C_{15}: mechanical damage resistance; C_{16}: growth rate; C_{17}: life span; C_{18}: seedling sources.

tenure in cities (Jim, 2004). The Urban Green Space System Planning (UGSSP) of Hefei (Landscape Planning and Design Institute of Hefei, 2008) supplied a detailed list of ancient and famous tree which included tree species name, DBH, age, and location in the Hefei area. The detailed ancient and famous tree inventory of the Hefei area provided insights into the practice of tree selection.

Selection criteria

A three layer AHP decision structure was used in this study to determine the priorities of key street tree species (Figure 2). Selection of key street tree species is regarded as the objective in the first layer (A), four pre-defined criteria including landscape effects (B_1), ecological effects (B_2), resistance to urban environment

(B_3), and economic factors (B_4) are in the second layer and the factors that have the most relevant relationship with the pre-defined criteria are in the third layer (C). Landscape effects were intended for use in the evaluation of the degree to which a tree fulfilled the visual function. Ecological effects evaluate the degree to which a tree is likely to fulfill the function that would improve the urban environment. A tree species' resistance to the urban environments criteria was concerned with a measure of a tree's suitability for planting on streets with environment constraints. Economic effects were concerned with the monetary benefit of selecting a tree.

AHP method was employed to collect the factors weights assigned by experts. Arbor experts were asked to decide which category was the most important by comparing each category against the other three categories. After deciding which category was more important, the experts would then indicate their level of preference for the chosen category on a scale of 1–9, 1 being equally important, 9 being absolutely more important (Saaty, 1980). Then the experts compared each of the factors within the same category on a scale of 1–9 to rate their understanding of the important of one factor over another. That is, a factor from the landscape impacts category would not be directly compared to a factor from the resistance to urban environments category. Once the ordinal hierarchy among all factors was established, AHP computes the priority vector and the relative weights that could be used for suitability modeling.

In this research, the source of expert knowledge came from 50 experts including university professors and senior engineers in both forestry research institutions and management institutions. They were randomly divided into two groups. One group of the experts was asked to give the weights of the factors. At the same time, the other group was asked to give a total of 10 points to each factor based on the characteristics of the tree species in the Hefei area. Amir and Misgav (1990) gave three levels for the measurement of tree species selection. In order to give more choices, we used 5 levels to allocation scores of trees. Criteria and score allocation for the evaluation of trees were indentified in Table 1.

The factor ratings for each of the several factors received a sum-total score, as indicated by the following equation:

$$T_i = \sum_{i=1}^{n} (R_i \times W_i)$$

Where T_i is the total score of the tree species, n is the total number of factors, R and W are the factor rating and weight of the factor i, respectively. The points are summed to indicate selection priority, the higher the score, the more suitable for key street trees.

RESULTS

Street trees survey

The survey found 126,035 street trees which were distributed into 16 families and 22 species. The top five tree species were *Cinnamomum camphora, Magnolia grandiflora, Platanus × acerifolia, Sophora japonica* and *Ligustrum lucidum*, accounting for 80% of the total population. The 12 most numerous tree species are presented in Figure 3. The other ten tree species *Michelia chapensis, Sapindus mukorossi, Ulmus pumila, Liquidambar formosana, Albizia julibrissin, Melia azedarach, Liriodendron chinense Sarg. × L. tulipifera L., Catalpa bungei, Acer buergerianum* and *Acer truncatum* constituted less than 1% of the total population respectively. Of the total 126,035 trees, the ratio of broadleaf evergreen trees to deciduous trees is 5 to 3.

The most common tree species was *C. camphora*, more than 90% of the *C. camphora* trees were in 7-23 cm DBH range (Figure 4), reflecting large plantings of this species in the 1990s in many Chinese cities due to its desirability as an appropriately sized evergreen species. Most of the *M. grandiflora* trees had DBH in 7-19 cm (Figure 4), indicating that it has become more popular since the early 1980s after it was selected as the official tree of Hefei. Although *P. × acerifolia* was the third most common species, more than half of the trees had DBH of 31 cm or more (Figure 4). *P. × acerifolia* is one of the world's most widely used street trees (Chen et al., 2001). It was popular with Hefei's citizens because of its excellent shading and landscape effects. However, during the 1980s there was a trend to remove *P. × acerifolia* in many Chinese cities due to its pollen and fruit hair polluting the environment and endangering human health. So the 27-31 cm trunk diameter classes of *P. × acerifolia* trees were in a relatively scarce numbers because it was no longer planted as a street tree during the 1980s. However, the number of trees in the below 27 cm trunk diameter classes were larger, showing that it has become popular again due to its advantages as an urban street tree.

S. japonica was selected as a deciduous species substitute of *P. × acerifolia* in the 1980s and it maintained a relatively stable rate of planting since then. So in each DBH class, the distributions were relatively uniform, and were all below 23 cm (Figure 4).

L. lucidum was the only native species among the most numerous evergreen street trees in Hefei, but because it is slower growing than *C. camphora* and *M. grandiflora*, and has a relatively narrow crown, it was not as widely used as the other trees. *L. lucidum* size distribution was mainly in 7-15 cm (Figure 4) and the size range of it probably reflects its popularity in the 21th century.

Street trees in urban parks analysis

Street trees in urban parks often had similar properties to the trees on urban streets. However, parks are in a relatively good environment where there is more emphasis placed on landscaping. There were 34 species in 20 families in the survey, and almost all the trees were in good health. Analysis of the most common street species in urban parks showed that the ornamental trees accounted for a large proportion (Table 2).

Natural secondary forest survey

The natural secondary forests surveyed had a distribution

Table 1. Evaluation criteria for key street tree species in Hefei, China.

Criteria	Factors	Description and score allocation				
		10	**8**	**6**	**4**	**2**
Resistance to urban environments	Resistance to drought	Strong	Relatively strong	Medium	Relatively weak	Weak
	Resistance to poor soil	Strong	Relatively strong	Medium	Relatively weak	Weak
	Resistance to cold	Strong	Relatively strong	Medium	Relatively weak	Weak
	Resistance to high temperature	Strong	Relatively strong	Medium	Relatively weak	Weak
	Resistant to diseases and pests	Strong, almost no disease and pests	Relatively strong, few pests and diseases, but does not affect the growth of the trees	Medium, easier to control pests and diseases, affect the growth of the trees	Serious pests and diseases affecting tree growth, but will not cause devastating damage if control in time	Destructive diseases and pests
	Resistant to mechanical damage	Strong	Relatively strong	Medium	Relatively weak	Weak
Landscape effects	Flower	Beautiful, long florescence, good smell	Beautiful, long florescence	Beautiful, short florescence	Less pleasant flower	Not beautiful flower
	Fruit	Beautiful, long fruit period, exotic fruit	Beautiful, long fruit period	Beautiful, short fruit period	Less pleasant fruit	Not beautiful fruit
	Trunk	Straight trunk, beautiful bark	Straight trunk, less beautiful bark	Less straight trunk, beautiful bark	Less straight trunk	Not straight trunk
	Leaf	Beautiful leaf shape, colorful leaf	Average leaf shape, colorful leaf	Beautiful leaf shape	Less beautiful leaf shape	Not beautiful leaf shape
	Crown shape	Tidy crown shape, flourishing branch leaves	Tidy crown shape, less flourishing branch leaves	Less tidy crown shape, flourishing branch leaves	Less tidy crown shape, less flourishing branch leaves	Untidy crown shape, not flourishing branch leaves
Ecological effects	Crown	>12 m	10-12	8-10 m	5-8 m	<5m
	Height	> 15 m	12-15 m	8-12 m	5-8 m	<5 m
	DBH	> 40 cm	30-40 cm	20-30 cm	10-20 cm	<10 cm
	Canopy density	> 80%	60%-80%	40%-60%	20%-40%	<20%
Economic factors	Mature growth rate to	<5 years	6-8 years	9-10 years	11-15 years	>15 years
	Life span expectancy	>60 years	40-60 years	20-40 years	10-20 years	<10 years
	Seedling source	Available, ample	Available, basically enough	Available, hardly find	Unavailable, rich in wild resource	Unavailable, poor in wild resource

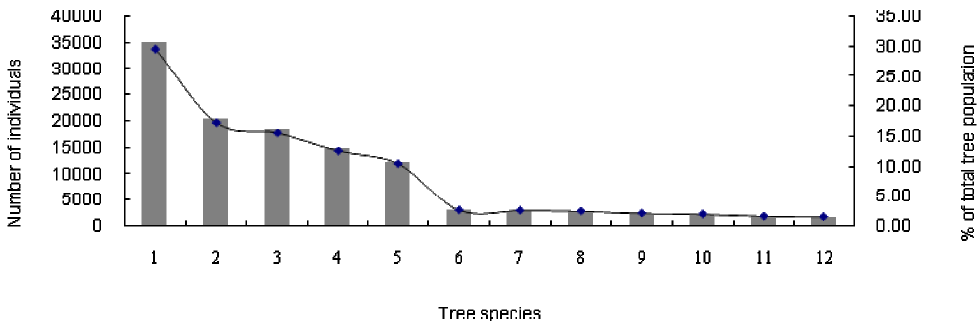

Figure 3. The proportion of the 12 most numerous street tree species in Hefei, China. 1: *Cinnamomum camphora*; 2: *Magnolia grandiflora*; 3: *Platanus×acerifolia*; 4: *Sophora japonica*; 5: *Ligustrum lucidum*; 6: *Koelreuteria integrfoliolai*; 7: *Populus* sp.; 8: *Ginkgo biloba*; 9: *Elaeocarpus decipiens*; 10: *Bischofia polycarpa*; 11: *Magnolia denudata*; 12: *Sapium sebiferum.*

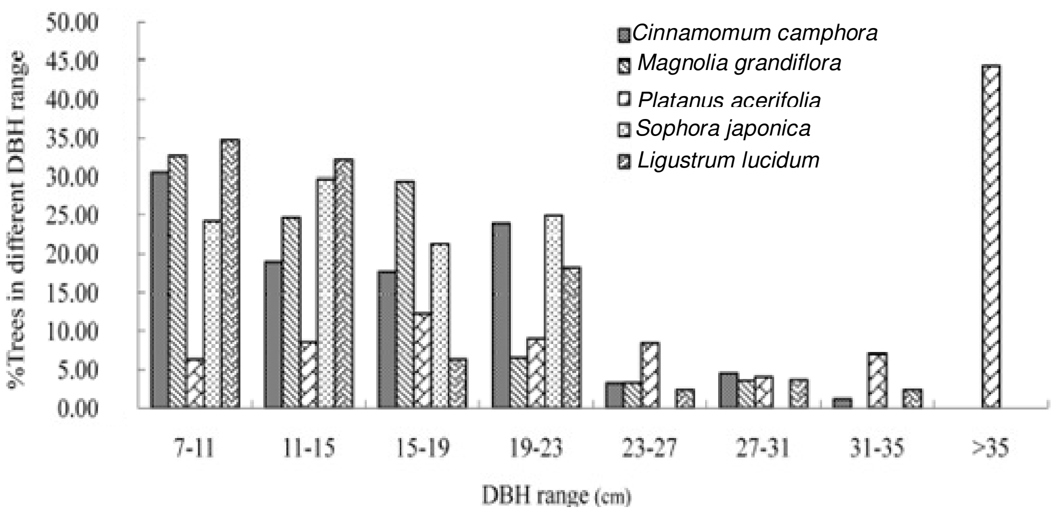

Figure 4. Distribution frequency of trunk diameter (cm) of the five most common species in Hefei, China.

of 33 species in 22 families. The major types of natural secondary forest in the Hefei area are the *L. formosana* community, the *A. truncatum* community, the *Quercus acutissima* community, the *Dalbergia hupeana* community, the *Albizia macrophylla* community, the *Broussonetia papyrifera* and the *Quercus acutissima* community. The common accompanying species included *Zelkova serrata*, *Pinus massoniana, U. parvifolia, Platycarya strobilacea, Pistacia chinensis, Celtis sinensis, U. pumila,* and *M. azedarach*. Almost all the trees species are native except *A. truncatum.* Some of the native tree species have been used as street trees such as *U. pumila, M. azedarach, L. formosana* and *A. buergerianum*.

The ancient and famous trees survey

There are a total of 2040 ancient and famous trees of 53 species including trees, shrubs and liana in the Hefei area, among which 2005 plants of 37 species are tree species, with 23 species having two or more individuals (Table 3). Some species were only represented by one individual such as *Carya illinoensis* and *Pinus bungeana.*

The greatest numbers of ancient and famous species were found on hillsides and in villages. In inaccessible mountain areas, many ancient and famous trees have been relatively undisturbed and the trees existing in the muraguchi, or the street of the village, are associated with the religious issues prohibiting cutting. In contrast, there were few ancient and famous trees in the urban core.

The oldest ancient and famous tree was about 500 years old and the youngest was about 50 years old, the average of all the surveyed trees was over 100 years old. Because of anthropogenic and natural stresses, urban trees seldom realize their biological potentials (Jim and Liu, 1997). However, there were some chances that may

Table 2. Attributes of the most frequently encountered species along the street of main parks in Hefei, China.

Scientific name	Family name	Average Height (m)	Average Crown (m)	Average DBH (cm)	Ornamental qualities
Ailanthus altissima	Simaroubaceae	13.5	12.5	40	Leaves, Fruit
Acer buergerianum	Aceraceae	16	9	25.2	Leaves, Fruit
Aesculus chinensis Bunge	Hippocastanaceae	10	8.5	30.8	Leaves
Acer truncatum	Aceraceae	12	7	27.5	Leaves
Albizia julibrissin	Leguminosae	10.5	8	23.2	Leaves, Flower
Bischofia polycarpa	Euphorbiaceae	30	10	35	Leaves
Camptotheca acuminata	Nyssaceae	16.2	8	31.7	Fruit
Cedrus deodara	Pinaceae	17	7	33.8	Shape
Catalpa ovata	Bignoniaceae	12.5	8	34.5	Leaves, Flower
Celtis sinensis	Ulmaceae	13	11	45.7	Shape, Fruit
Euonymus bungeanus	Celastraceae	10	8	30.5	Leaves, Fruit
Firmiana platanifolia	Sterculiaceae	11	8	26	Bark, Leaves
Ilex chinensis	Aquifoliaceae	10	7.5	32	Leaves, Fruit
Koelreuteria integrfoliolai	Sapindaceae	24	6.5	29.5	Leaves, fruit
Liquidambar formosana	Hamamelidaceae	20	11.5	33.2	Leaves
Magnolia denudata	Magnoliaceae	11	5.5	15	Fragrant flower
Metasequoia glyptostroboides	Taxodiaceae	20	8	45.5	Shape, Leaves
Osmanthus fragrans	Oleaceae	5	5	/	Fragrant flower
Pinus elliottii	Pinaceae	7	6	28	Shape
Pterocarya stenoptera	Juglandaceae	22	13	59	Leaves, Fruit
Salix babylonica	Salicaceae	6	4.5	15	Shape, Leaves
Sapindus mukorossi	Sapindaceae	14	11	29.2	Leaves
Sapium sebiferum	Euphorbiaceae	12.5	8.5	31.3	Leaves, Fruit
Toona sinensis	Meliaceae	9	8	30	Shape, Leaves
Ulmus parvifolia	Ulmaceae	11	10	28.2	Bark
Zelkova serrata	Ulmaceae	9.5	10	32.9	Leaves

permit some trees to survive from decades to centuries. The existence of the ancient and famous trees showed their potential in life expectancy and adaptation to the environment.

Comparing species between the street tree survey and the ancient and famous tree inventory, there were 8 species in common *G. biloba*, *M. grandiflora*, *C. camphora*, *P. × acerifolia*, *A. buergerianum*, *S. sebiferum*, *M. denudata* and *Bischofia polycarpa*.. However, of the top 10 most numerous species used in the urban street, there were only two that were ancient and famous trees (*G. biloba* and *M. grandiflora*).

The comprehensive selection of street trees

A total of 68 species were found in the inventory from the city-wide survey. However, these 68 species were considered a starting point rather than final choices. A three layer hierarchy AHP decision model was applied in this study, including the objective, criteria and alternatives. The AHP method can effectively reduce the influence on factor weights through pair-wise comparisons. By compiling responses and averaging the scores for the AHP methods, different weights were given to different criteria (0.2877 for landscape function, 0.1502 for ecological effects, 0.3694 for resistance to urban environment, and 0.1928 for economic effects) (Figure 2). The landscape function was split into several key components in order to provide a reliable indicator. The results showed that the crown shape and trunk diameter have higher weights than the others. Street trees can provide significant ecological and environmental benefits, including lowering urban temperatures through shading and transpiration cooling (Hardin and Jensen, 2007), and improving air quality through capturing particulate matter, carbon dioxide, ozone and other air pollutants (McPherson et al., 1997; Beckett et al., 1998). The most relevant relationship with the ecological functions such as canopy density, tree height, DBH and crown were chosen as the factors. There are six factors under the resistance to urban environment category. The weights of resistance to drought and mechanical damages are higher than the resistance to low soil nutrition, cold, high temperature,

Table 3. The 23 most numerous heritage tree species in Hefei area, China (LPDIH, 2008)

Scientific name	Family name	Tree number	Estimated tree age		
			Old	Young	Average
Quercus acutissima	Fagaceae	994	300	100	135.9
Pistacia chinensis	Anarcardiaceae	441	400	60	191.3
Dalbergia hupeana	Leguminosae	427	200	100	175.0
Diospyros kaki	Ebenaceae	28	100	200	122.5
Sabina chinensis	Cupressaceae	25	400	100	220.0
Ginkgo biloba	Ginkgoaceae	14	500	100	168.6
Magnolia grandiflora	Magnoliaceae	8	160	100	117.5
Gleditsia sinensis	Leguminosae	7	400	50	172.9
Celtis sinensis	Ulmaceae	6	300	60	218.3
Pyrus betulifolia	Rosaceae	5	270	120	172.0
Platycladus orientalis	Cupressaceae	3	260	100	153.3
Ulmus parvifolia	Ulmaceae	3	105	100	101.7
Pterocarya stenoptera	Juglandaceae	3	150	105	121.7
Cinnamomum camphora	Lauraceae	3	200	100	136.7
Acer buergerianum	Aceraceae	3	110	160	130.0
Platanus × *acerifolia*	Platanaceae	2	100	100	100.0
Bischofia polycarpa	Euphorbiaceae	2	100	100	100.0
Sapium sebiferum	Euphorbiaceae	2	100	300	200.0
Ziziphus jujuba	Rhamnaceae	2	120	120	120.0
Cudrania tricuspidata	Moraceae	2	100	150	125.0
Catalpa ovata	Bignoniaceae	2	150	200	175.0
Magnolia denudata	Magnoliaceae	2	110	120	115.0
Celtis bungeana	Ulmaceae	2	110	150	130.0

disease and pests. The seeding sources, growth rate and life span of tree species are important economic factors as they influence the establishment and management costs.

Eventually, after comprehensively considering the results of the weights of different factors and the analysis of individual tree species in the 68-species assessments, the 18 species which ranked higher than 7.5 points were chosen in the primary selection (Table 4). However, the key street tree species selection programs need to find the most suitable tree species. Among the 18 species *U. parvifolia*, *Z. serrata*, *C. sinensis* belong to the same family and have a similar morphology and habitat, but *C. sinensis* has more advantage in resistance to pests and diseases and a relatively fast growth rate, so *C. sinensis* was chosen as one of the key street tree species. *Koelreuteria integrfoliolai* and *Koelreuteria paniculata* belong to the same genera and live in the similar habitats and their ornamental characteristics are very similar. However, because of its greater use and better availability of seeds, *K. integrfoliolai* was chosen. Finally, 15 tree species were chosen as the key street trees in Hefei, the detailed of characteristics and sources of the selected tree species are presented in Table 5.

There are more evergreen trees than deciduous trees in the street in Hefei. A reasonable balance of evergreen to deciduous trees should be maintained. Two evergreen trees species, *C. camphora* and *I. chinensis* were chosen as the key street trees. It is known that the evergreen trees can increase the landscape effective in winter. However, the deciduous trees can give more light in winter. According to the local vegetation characteristics of the Hefei area, more attention should be paid to the increase in the number of deciduous trees.

Considering the current situation of street trees and the development request in Hefei, three phases were suggested in the planning of key street trees. In the first phase, the most common street tree species such as *C. camphora, M. grandiflora , L. lucidum , P. × acerifolia* and *S. japonica* were still chosen as the key street trees. In the second phase, in order to satisfied construct new lakeside districts in Hefei, the tree species which have fast growth rate and landscape effects were chosen as the key street trees, for example *K. integrfoliolai, L. chinense Sarg. × L. tulipifera L., C. sinensis, A. chinensis Bunge, A. altissima,* and *G. biloba.* In the third phase, in order to build a sustainable structure of street tree species, the tree species which have long life spans, moderate growth

Table 4. The calculated results of each evaluating factors weight for tree species higher than 7.5 points

Serial number	Alternatives																		
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	Synthetic evaluating value
1	0.35	0.23	0.67	0.47	1.09	0.42	0.20	0.30	0.47	0.95	0.70	0.31	0.37	0.33	0.86	0.68	0.73	0.52	9.65
2	0.39	0.26	0.61	0.47	1.09	0.47	0.20	0.30	0.47	0.95	0.63	0.28	0.34	0.33	0.86	0.54	0.65	0.52	9.36
3	0.39	0.26	0.61	0.47	1.09	0.47	0.20	0.30	0.47	0.85	0.63	0.24	0.34	0.33	0.86	0.54	0.65	0.31	9.02
4	0.31	0.23	0.67	0.47	0.98	0.47	0.18	0.27	0.38	0.85	0.63	0.21	0.30	0.29	0.76	0.54	0.73	0.52	8.81
5	0.31	0.21	0.67	0.42	0.98	0.42	0.16	0.24	0.38	0.85	0.63	0.28	0.34	0.25	0.86	0.61	0.65	0.47	8.73
6	0.31	0.21	0.67	0.47	0.98	0.42	0.14	0.21	0.38	0.76	0.63	0.28	0.34	0.33	0.86	0.48	0.73	0.52	8.70
7	0.31	0.21	0.61	0.47	0.98	0.47	0.20	0.30	0.38	0.76	0.56	0.24	0.30	0.33	0.76	0.54	0.73	0.52	8.67
8	0.27	0.18	0.47	0.38	0.87	0.42	0.14	0.24	0.38	0.85	0.63	0.28	0.34	0.37	0.76	0.61	0.65	0.52	8.37
9	0.27	0.23	0.54	0.38	0.87	0.37	0.18	0.24	0.43	0.85	0.63	0.28	0.30	0.37	0.86	0.54	0.65	0.36	8.36
10	0.31	0.18	0.67	0.47	0.87	0.42	0.16	0.24	0.38	0.76	0.56	0.24	0.26	0.41	0.67	0.48	0.65	0.42	8.16
11	0.35	0.18	0.54	0.38	0.87	0.42	0.16	0.24	0.38	0.76	0.56	0.24	0.30	0.37	0.76	0.54	0.73	0.31	8.10
12	0.31	0.23	0.54	0.38	0.87	0.42	0.16	0.21	0.33	0.76	0.56	0.24	0.30	0.17	0.76	0.54	0.65	0.52	7.96
13	0.27	0.18	0.47	0.33	0.76	0.37	0.18	0.21	0.33	0.85	0.63	0.28	0.34	0.33	0.86	0.68	0.36	0.52	7.95
14	0.27	0.21	0.54	0.42	0.87	0.42	0.16	0.24	0.38	0.66	0.49	0.21	0.26	0.37	0.67	0.48	0.65	0.47	7.78
15	0.23	0.21	0.54	0.47	0.76	0.37	0.12	0.21	0.33	0.66	0.49	0.21	0.26	0.37	0.67	0.41	0.73	0.52	7.56
16	0.39	0.23	0.61	0.42	0.87	0.37	0.14	0.21	0.28	0.57	0.42	0.18	0.22	0.41	0.57	0.48	0.65	0.52	7.55
17	0.39	0.21	0.54	0.47	0.87	0.42	0.16	0.24	0.33	0.57	0.42	0.18	0.22	0.37	0.57	0.41	0.65	0.52	7.55
18	0.31	0.26	0.47	0.47	0.76	0.37	0.16	0.21	0.33	0.66	0.49	0.21	0.26	0.37	0.67	0.54	0.58	0.36	7.50

1: *Platanus acerifolia*; 2: *Koelreuteria integrfoliolai*; 3: *Koelreuteria paniculata* ; 4: *Cinnamomum camphora*; 5: *Ulmus parvifolia*; 6: *Zelkova serrata*; 7: *Celtis sinensis*; 8: *Ailanthus altissima*; 9: *Ligustrum lucidum*; 10: *Aesculus chinensis Bunge*; 11: *Pistacia chinensis*; 12: *Sophora japonica*; 13: *Populus sp.*; 14: *Ilex chinensis*; 15: *Ginkgo biloba*; 16: *Magnolia denudata*; 17: *Liriodendron chinense Sarg. × L. tulipifera L.*; 18: *Magnolia grandiflora*.

rates and strong resistance characteristics should be emphasized in the planting of street trees. So, tree species such as *I. chinensis, M. denudata, S. japonica, A. chinensis Bunge, G. biloba, P. chinensis* and *C. sinensis* should be gradually used as key street tree species in long-term street tree planning.

DISCUSSION

Hefei has been considered one of the first three garden cities of China since 1992 and is widely known for its ring park around the city as a pearl necklace of Hefei (Wu et al., 2002). However, in recent years, for street construction and widening activities, and especially for the new lakeside district project, there has been a big change in urban street greening. It is not clear what species will be chosen as street trees. The selection of the appropriate tree species is of critical importance in Hefei and also in many other cities which have similar situations. This study aims to develop a methodology to find the appropriate tree species to plant on urban streets.

Due to the stresses of the urban environment, street trees tend to have shorter life spans (Nilsson et al., 2000; Nowak et al., 2004; Harini and Divya, 2010), and under such stress, the trees are more prone to attacks by insects and other pests (Nagendra and Gopal, 2010). High species diversity is one of the key ways to protect against such pest attacks (McPherson and Rowntree, 1989; Thaiutsa et al., 2008). However, Hefei's street trees seem to have a limited diversity, with the most common species constituting about 22%

Table 5. Characteristics and sources of the selected key tree species for the street trees in Hefei, China.

Species name	Foliage type	Average crown (20-30years)(m)	Average DBH (5 years)(cm)	Average DBH (10 years) (cm)	Average growth rate per year(cm)	Sources
Aesculus chinensis Bunge	Deciduous	6.0~10.5	12.0	17.0	0.7~1.5	II
Ailanthus altissima	Deciduous	6.0~10.5	14.0	21.0	1.5~2.0	II
Ligustrum lucidum	Deciduous	5.0~7.0	9.5	12.0	0.5~1.0	I
Celtis sinensis	Deciduous	6.0~10.0	13.5	20.5	1.0~2.0	II, III, IV
Cinnamomum camphora	Evergreen	5.5~9.0	11.0	18.0	0.8~2.0	I, II, IV
Ginkgo biloba	Deciduous	5.0~7.0	10.5	15.0	0.5~0.8	I, IV
Ilex chinensis	Evergreen	5.5~7.5	10.5	13.0	0.7~1.5	II
Koelreuteria integrfoliolai	Deciduous	6.5~10.5	14.0	20.5	1.0~2.0	I, II
Liriodendron chinense Sarg. × L. tulipifera L.	Deciduous	7.0~11.0	14.5	21.0	1.5~2.0	I
Magnolia denudata	Deciduous	6.0~8.0	10.3	13.6	0.7~2.0	I, II, IV
Magnolia grandiflora	Evergreen	5.0~7.0	10.4	13.8	0.6~1.5	I, IV
Pistacia chinensis	Deciduous	6.0~9.5	11.0	14.5	0.8~2.0	III, IV
Platanus × acerifolia	Deciduous	7.0~13.0	17.0	27.0	2.0~3.0	I, II, IV
Populus spp.	Deciduous	5.0~6.5	19.5	32.0	2.0~4.0	I
Sophora japonica	Deciduous	6.5~11.0	14.5	22.0	1.5~2.0	I

Ⅰ = Urban street trees survey; Ⅱ = street trees in old parks survey; Ⅲ = natural secondary forest survey; Ⅳ = ancient and famous trees inventory.

of the total number of tree species and about 80% of the total tree population. There is a trend of overuse of a few tree species that are well-tested in urban areas and have proven to be most adaptable, aesthetically pleasing and are easily propagated (Sæbø et al., 2003). However, some cities are moving away from this trend when choosing tree species. For example, species recommendations for cities in Greece are based on an analysis of what tree species occur in the neighboring natural areas (Sæbø et al., 2003). The results of our study showed that the tree species found on urban streets, in urban parks, in natural habitats and from the ancient and famous tree inventories can suggest general guidelines for appropriate tree species selection practices.

Figure 1 illustrates step by step, the pragmatic approach of key street tree species selection. The crucial consideration is to inventory the tree species in the city and its surrounding areas. Duhme and Pauleit (2000) suggested a pan-European information network in order to compile the already existing information of urban dendroflora in the major European cities. Co-operation promoted in the other cities for such a network may offer new opportunities by supplying rich resources for testing potential plant resources and offer a large tree market for a selection program, which would decrease the investment in tree planting.

Successful street tree plantings can only be achieved on the condition that many criteria are met (Pauleit, 2003). While in our study street tree selection criteria was based mainly on basic factors such as the tree habits and landscape functions, further research is needed to identify final size of trees in relation to habitat conditions, especially in the limited urban street spaces, where suitable tree species need to be adopted to balance between trees and sites. Because of the complexity of stressed environments and diversity of the streets, testing the tree species under the local biotic and management conditions to identify their adaptation to specific site and cultural variables in a community is very important (Richards, 1983).

The AHP and expert knowledge method proved useful in selecting the most suitable tree species in our study. The source of expert knowledge came from a group of experts who have between 5 and 20 years of experience in the Landscape Architecture Industry. In any future study, public participation could be implemented by allowing all participants to perform their own pair-wise comparisons. This would result in new alternatives from the participants' viewpoints and probably include more street tree species in the selection process.

Nevertheless, it does not mean that selecting a good street tree will create a good street landscape. In addition to tree selection, one must consider the aesthetic value of the tree, the landscaping objective, and the health of the urban street tree population. Seedling availability, site condition, planting techniques, and maintenance management must also be considered. In any follow-up study, more consideration should be focused on the tree species selection and the design of specific sites, such as different land use (commercial land, residential land, etc.), different road configurations (width and growth space type and dimension), and different types of street habitats (street planting strip, road median, tree pit, etc.) for tree planting.

The European tree survey of COST Action E12 showed that there was a lack of qualified staff at all levels of tree planning and management (Pauleit, 2003). And in many developing countries, forest managers in charge of maintaining urban tree populations do not have the knowledge necessary for appropriate species selection, care and maintenance (Chacalo et al., 1994). In order to improve the situation, local authorities should pay more attention to adopting comprehensive strategic approaches for urban tree planning and management, especially to the selection of tree species planted in urban street.

Conclusion

In this article, we present the methodology of the key street tree species selection process. The sources of proper tree species and the selection criteria are two important components in the selection process. Overall, the survey of tree species was a first step in collecting the information needed for selecting street tree species on a city level. The limited tree species used in the street from the survey showed that there is a need to implement guidance on best practices for tree selection and establishment. The AHP method can easily be used to reduce subjective influence on factor weights through pair-wise comparisons, allowing users' participation in street tree species selection. Any street tree species criterion needs to be adapted to local environments and has to be based on empirical information. The final decision on species and selection criteria in the tree species selection program should be discussed with planners and managers in order to secure the supply of the most suitable plant material. With the changes in environmental and urban needs, the aims and strategies of the tree selection program may change. The selection of the key street tree species is a starting point, and in any long term the comprehensive selection program could be initiated for a large area. The results of this study give an important guide to the street tree planning program in Hefei. The selection of key street tree species are given only for illustration, but the method of selection and the process of species evaluation should be applicable elsewhere.

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