The structure and sustainability of street trees in Changzhou, China

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Abstract. Street trees provide essential ecosystem services and are important to local residents’ life, but there has not been much research on the structure of street trees in the city of Changzhou, China. This research surveys the structure of street trees in Changzhou with the aid of geospatial technologies and field sampling surveys. An investigation of the street trees on the 220 sampled transects of streets across the four districts of Changzhou reveals prominent problems with the species diversity, distribution, age structure, and density. Though street tree density in the city is approximately 177/Km, higher than many other cities in the world, with only 29 street tree species in 19 families and 27 genera, the diversity is lower. Among the tree species, only a limited few are planted widely. Young trees account for 43.2% of the total tree population, while large old trees decrease in number. Close spacing between trees, caused by unreasonably high density, results in enormous government expenses on pruning. These findings highlight the need for careful selection of appropriate tree species on the part of municipal administrators and planners. Suggestions are given on how to achieve a sustainable structure of street trees in Changzhou in the long run. Both the problems found and the corresponding suggestions are of referential meaning to the street tree development of other cities in China.

1. Introduction

Street trees are important components of urban forestry, and the benefits provided by street trees are well documented and categorized as environmental, economic, and social benefits [1]. Street trees play an integral role to increase the quality of life for urban residents [2], they can improve air quality, cool down the street, ameliorate the urban heat-island effect, provide habitat for urban fauna [2-4]. Street trees also help to conserve energy, and increase house prices in economic benefits [5-8]. In the meantime, they provide healthy and social benefits of reducing stress, encouraging physical activity, promoting contact between community residents, decreasing crime and increasing community safety [9-12]. Street trees influence the lives of many residents in the city [13]. Green space and urban trees become increasingly important because the rate of urbanization is greatest in developing countries.

Effective resource management depends on managers having the information they need of making an effective decision [14]. For street trees managed by a municipality, species composition and age structure are indices of future costs. High species diversity can reduce large maintenance costs brought
about by monocultural diseases, and age structure indicates the relative need for replacement planting and future removals [15]. Size and density are used to assess age structure and the need for replacement planting [16]. The health condition of street trees helps decision-making concerning maintenance costs and removals. Unfortunately, in many developing countries, the department of urban forestry lacks these street tree inventories [14, 17, 18], or the existent inventories are rarely upgraded, curbing the development of street tree management. However, the situation is getting better because many cities have begun to establish street tree inventories. For instance, Bangkok, Thailand has improved its green infrastructure with the help of inventories of street trees, green space, and large heritage trees in the city [18].

The creation of street tree inventories depends on scientifically designed surveys. Both sample surveys and virtual surveys, however, have their limitations if employed alone. Sample surveys indeed provide an effective alternative to survey the street tree resources and inform planning [19], but they are costly, labor-intensive, time-consuming, and pose safety risks to field crew. Indeed, these problems can be mitigated through the use of geospatial technologies and remote image sensing. For instance, Google Street View has been employed by researchers to conduct a robust virtual survey of street trees [20-22]. But the virtual survey is not fit for all researchers. For example, if street images are captured in the winter, it is difficult to recognize the species of deciduous trees; Also, estimation of DBH (trunk diameter taken at breast height, or 1.2 m from the base of a tree) through street view is likely to get inaccurate results.

Given the above-mentioned strengths and limitations, the combination of sample surveys and virtual surveys is more suitable for street tree research, which can draw on their advantages and reduce their deficiencies. In this study, such an integrated survey method is applied. MAPWORLD CHANGZHOU (http://www.mapcz.com.cn), a website providing high resolution Chinese urban remote sensing images, is used to provide the basic layer for the survey. With the help of the MAPWORLD, investigation of street length and the number of street trees can be conducted with better efficiency and accuracy. The rest of the work is completed by field survey.

The first objective of this study is to reveal the composition and structure of the street trees in Changzhou city. The second one is to inform municipal administrators and planners of the problems with the development of street trees in the city. The third one is to recommend effective methods for improving the sustainability of street trees. The results of this study will be of referential meaning for urban administrators and planners for future decision-making on street tree management and urban forestry planning.

2. Methods

2.1. Study site

Changzhou is a medium-sized city in southern Jiangsu Province, China, located in the heartland of the Yangtze River Delta, enjoys the landform of the Yangtze River Delta plain. As far as climate is concerned, Changzhou is located in the northern subtropical humid climate [23, 24], and has an annual mean temperature of 15.8°C. Precipitations mainly occur from May to September and the annual mean precipitation reaches 1091.6 ml. This study was conducted in the central area of Changzhou, which comprises four administrative districts: Xinbei (XB) (31.83°N, 119.97°E, population 209,850), Tianning (TN) (31.78°N, 119.97°E, population 412,000), Zhonglou (ZL) (31.80°N, 119.90°E, population 350,700), Wujin (WJ) (31.70°N, 119.94°E, population 442,000).
2.2. Data collection
The integration of sample survey and virtual survey method was carried out from May to November in 2016. Data was collected with the assistance of some undergraduates from the School of Art and Design, Changzhou Institute of Technology. There are four districts in Changzhou, and the main road and districts were delineated out from MAPWORLD CHANGZHOU (MW) in 2016, which has a resolution of 0.5 meters. Firstly, we used the representative sampling approach in this study, an approach proposed by many researchers [17, 25]. 220 sample sites were selected on the main road of research area that could maximize the representation of all street tree species (Figure 1). Each sample site was set up as 200 meters long, every street tree on both sides investigated. Then the number of street trees planted in each main road of four districts were counted through MW, remote investigation increasing the accuracy of the street tree data and improving the efficiency of data collection.

Findings were recorded in detail about the species, DBH, tree height, crown width, and amount of the street trees on the chosen sample site. DBH was measured with diameter ruler rather than calipers to better capture irregularities in shape. Electronic hypsometers were used to measure tree height. Due to the constant spacing of street trees along the road, the canopy may cross each other in the road direction. Therefore, the crown width was measured in the direction perpendicular to the direction of the road. Crown width was measured by laser rangefinder.

Street trees in the central area were counted by MW. Some street types such as bridges, crossings, and ongoing subway construction sections are unlikely to contain street trees and need to be excluded from the total length of the investigated streets. To speed up and increase the accuracy of street tree number, the following equation is explored:

$$S = [2L - 2(Q_1 + \ldots + Q_n) - (K_1 + \ldots + K_n)] \times P / D$$  \hspace{1cm} (1)
In the equation, S is the total number of trees on a street, L is the total length of the street, Q1…Qn the length of bridges and subway construction sections, K1…Kn the length of crossings on the street where no trees are planted, and D the mean spacing between street trees. L and K1…Kn can be accessed by MW. P is the proportion of each street tree species on the surveyed road. Usually, the street tree species of each road is a single species and another species is replaced at the intersection. There are also special cases where several street trees are mixed on a road, therefore, the proportion of each street tree species is estimated at sample survey.

The relative age distribution of street trees were assessed by DBH. Since most street trees in the city center of Changzhou have been planted in the recent 50 years, only a limited number of them have a DBH greater than 40 cm. Therefore, in this study, the street trees in Changzhou were aggregated into five DBH classes: 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and above 40 cm. DBH structure in the four districts of the city was identified as the mean percentage of trees at each DBH size class. Tree height and canopy width of the street trees in each sample site were recorded. Tree height was aggregated into three classes: 0-5 m, 5-10 m and above 10 m.

Table 1. Relative abundance (percentage of each street tree species), relative dominance (percentage of the basal area of each species), relative importance (sum of relative abundance and relative dominance) of street trees in the study area.

| Species                                      | Relative Abundance (%) | Relative dominance (%) | Relative importance (%) | Total number |
|----------------------------------------------|------------------------|------------------------|-------------------------|--------------|
| Cinnamomum camphora (L.) Presl              | 60.75                  | 62.02                  | 122.77                  | 76501        |
| Koelreuteria paniculata Laxm.               | 16.91                  | 16.77                  | 33.68                   | 21263        |
| Platanus orientalis Linn.                   | 5.79                   | 9.38                   | 15.17                   | 7288         |
| Ginkgo biloba Linn.                         | 4.78                   | 3.18                   | 7.96                    | 6025         |
| Magnolia grandiflora Linn.                  | 2.55                   | 1.57                   | 4.12                    | 3029         |
| Zelkova serrata (Thunb.) Makino             | 1.26                   | 1.31                   | 2.57                    | 1592         |
| Elaeocarpus sylvestris (Lour.) Poir.        | 0.94                   | 0.73                   | 1.67                    | 1179         |
| Liriodendron chinense (Hemsll.) Sarg.       | 0.97                   | 0.72                   | 1.69                    | 1219         |
| Metasequoia glyptostroboides Hu et W. C. Cheng. | 0.91                  | 1.18                   | 2.09                    | 1143         |
| Pistacia chinensis Bunge                    | 0.84                   | 0.5                    | 1.34                    | 1060         |
| Ligustrum lucidum Ait                       | 0.70                   | 0.25                   | 0.95                    | 879          |
| Albizia julibrissin Durazz.                 | 0.64                   | 0.36                   | 1                       | 812          |
| Celtis sinensis Pers.                       | 0.72                   | 0.66                   | 1.38                    | 908          |
| Melia azedarach Linn.                       | 0.46                   | 0.34                   | 0.8                     | 583          |
| Acer truncatum Bunge                        | 0.4                    | 0.09                   | 0.49                    | 504          |
| Bischofia polycarpa (Levl.) Airy Shaw       | 0.18                   | 0.11                   | 0.29                    | 232          |
| Michelia chapensis Dandy                    | 0.18                   | 0.14                   | 0.32                    | 228          |
| Ilex chinensis Sims                         | 0.16                   | 0.1                    | 0.26                    | 207          |
| Photinia davidsonia Dandy                   | 0.15                   | 0.02                   | 0.17                    | 192          |
| Pinus elliottii Engelmann                   | 0.15                   | 0.14                   | 0.29                    | 191          |
| Sapindus mukorossi Gaertn.                  | 0.12                   | 0.03                   | 0.15                    | 153          |
| Magnolia biondii Pampan.                    | 0.12                   | 0.04                   | 0.16                    | 150          |
| Cedrus deodara (Roxburgh) G. Don             | 0.10                   | 0.17                   | 0.27                    | 132          |
| Magnolia dudunata Desr.                     | 0.06                   | 0.02                   | 0.08                    | 81           |
| Pterocarya stenoptera C. DC.                | 0.05                   | 0.05                   | 0.1                     | 68           |
| Ulmus pumila Linn.                          | 0.04                   | 0.04                   | 0.04                    | 50           |
| Salix babylonica Linn.                      | 0.03                   | 0.07                   | 0.1                     | 40           |
| Sapium sebiferum (Linn.) Roxb.              | 0.02                   | 0.02                   | 0.04                    | 30           |
| Acer buergerianum Miq.                      | 0.02                   | 0.03                   | 0.05                    | 5            |
3. Results

3.1. Species composition

There are 29 street tree species in Changzhou, belonging to 19 families and 27 genera (Table 1). The top five species are *Cinnamomum camphora*, *Koelreuteria paniculata*, *Platanus orientalis*, *Ginkgo biloba* and *Magnolia grandiflora*, the relative importance is 122.77%, 33.68%, 15.17%, 7.96%, and 4.12% respectively. The top 5 species comprise almost 90% of the entire street tree population in Changzhou. The dominant tree species is *Cinnamomum camphora*, accounting for 60.75% of the total street tree population. It has been widely planted in Changzhou since it is an evergreen and native tree species. *Koelreuteria paniculata*, the next most common species, a deciduous species, represents 16.91% of the total tree population. Moreover, it planted mainly in newly developed city parts, Xinbei and Zhonglou Districts, since the 1990s. In comparison, *Platanus orientalis* has been mainly planted in the old city parts, Tiaoning and Wuji districts, since the 1970s. Due to the spring fly problem, the number of *Platanus orientalis* been reduced to a current percentage of 5.8% in the total street tree population. *Ginkgo biloba* (4.78%) and *Magnolia grandiflora* (2.55%) are both native tree species and the latter one been honored as the city tree of Changzhou. Based on the relative abundance, the evergreen species accounts for up to 65.7%, and deciduous tree species 34.3% of the total street tree population.

3.2. Street tree number and density

The total street tree number in the four districts of Changzhou is estimated by the equation to be 125,924. Wuji District has the largest number of street trees but the lowest density, while Zhonglou District has the least street trees and high density. Compared with the other districts, Xinbei District has the highest street tree density, thanks to the many new roads built there in the past 15 years and efficient urban planning and maintenance. Wuji District, though the largest in both area and population, sees the lowest street tree density due to poor maintenance and severe vandalism (Table 2).

| Category                        | XB  | TN  | ZL  | WJ  | Changzhou (Total) |
|---------------------------------|-----|-----|-----|-----|-------------------|
| Number of species               | 16  | 13  | 17  | 20  | 29                |
| Number of trees                 | 31532 | 29856 | 26061 | 38475 | 125924            |
| Average density(trees/Km)       | 203 | 188 | 200 | 144 | 177               |
| Average DBH(cm)                 | 21.5 | 21.2 | 22.4 | 20.9 | 21.8              |
| Average height(m)               | 8.2 | 7.6 | 8.7 | 7.9 | 8.1               |
| Average canopy width(m)         | 6.0 | 5.6 | 6.1 | 6.0 | 6.1               |

3.3. Age distribution

For sustainable development of street trees, an ideal age distribution for street tree population stability would be 40% of all trees under 20 cm DBH, 30% 20 to 40 cm, 20% 40 to 60 cm, and 10% above 60 cm [15]. An investigation of the DBH classes of the street trees in the four districts of Changzhou shows that young trees (DBH≤20 cm), trees with DBH between 20 cm and 40 cm and mature trees (DBH>40 cm) take up 43.2%, 56.1%, and 0.7% respectively of the total street tree population. The DBH distribution of the street trees in the whole study area, mainly between 10 cm to 30 cm while with very few trees with a DBH less than 10 cm or greater than 40 cm (Figure 2), indicates a stable age structure of the street trees in Changzhou. Trees with a DBH above 40 cm are mainly found in Tianning District, the old urban district of Changzhou where relatively large trees have been retained.
Figure 2. (a) Distribution of DBH classes of street trees in the study area; (b) Comparison of distributions of DBH classes in the 4 districts of Changzhou.

4. Discussion
Scientific development of street trees can maximize their eco-functions and minimize subsequent maintenance expenditure. The investigation of the street trees in Changzhou has revealed prominent problems with the diversity, composition, age structure and density of the street trees, which will hinder the sustainable development of street trees in the city.

4.1. The structure and stability of street trees
We found in the study that very few species take up a large portion of the total street tree population. With only 29 street tree species in 19 families and 27 genera, Changzhou cannot compare with many other cities in street tree diversity [17, 22, 26]. Such a situation is common in economically developed, densely populated cities such as Shanghai and Nanjing, both within Yangtze River Delta metropolitan area and within a distance of 200 Km from Changzhou. Although there are more than 40 street tree species in Shanghai, Cinnamomum camphora and Platanus orientalis take up about 70% of the total tree population [27]. In the old city area of Nanjing, there are 27 street tree species, among which Cinnamomum camphora and Platanus orientalis take up about 68.86% of the total tree population [28]. The uneven composition of street tree biodiversity is because native tree species were selected and planted in large quantities in the rapid urbanization. It is against the goal of sustainable development of urban greening because it involves lower maintenance costs if the dominant species are good ones, but the practice will incur large costs on the occasion of decline, disease, large-scale removals or replant [13]. Cinnamomum camphora is a native species in the Yangtze River Delta, and Koelreuteria paniculata show strong adaptability to the site condition in Changzhou. The two backbone street tree species can achieve the stability of street trees, but this will bring big trouble in case of an outbreak of disease or replant. Therefore, the city still needs to enrich the diversity of street tree to deal with the potential risks once disease or replant occur in the future.

The composition of DBH class of street tree shows that medium and young trees comprise the bulk of the street tree population. The uneven distribution poses potential risk as good age diversity is essential for population stability [15]. Due to fast urbanization, young trees with 12-15 cm DBH are usually planted on footpaths in Changzhou. Many large old trees were replaced before road construction or widening activities and young trees of similar size were planted after the project for a better streetscape. Large old trees were transplanted to parks or other urban green spaces. Large old trees contain more above-ground biomass than young trees and provide more ecosystem services and scenic beauty [13]. Some may argue that urbanization does not necessarily involve felling old trees because they can be transplanted. But the truth is that transplanting old trees may destroy the ecological balance of their original habitats and will largely increase construction costs [29], let alone the high death rate of the big old trees in transplanting.
The street tree density in Changzhou is approximately 177/Km, higher than many other cities that have appeared in published relevant researches. The average street tree spacing in Changzhou is approximately 7 meters. Street tree density, when it exceeds a reasonable limit, will bring trouble to management. The 7-meter spacing of the street trees in Changzhou is far from enough for the growing canopies of _Cinnamomum camphora_ and _Koelreuteria paniculata_ (DBH>30 cm), only to leave their above-ground stems crossing each other and competing for the solar radiation, and their underground roots competing for water and nutrients, which will affect the overall health of street trees. Fortunately, the street trees with DBH larger than 30 cm take up only 11.8% of the total tree population in Changzhou, but in the near future, the problem will become more prominent with young trees growing larger.

4.2. Projections of sustainable development of street tree

To make the street tree population more sustainable, some necessary strategies should be taken in street tree species selection and management, because high species diversity is one of the bases for street tree population stability [30]. There are three ways to select the right tree species for street trees in the city. The first way is from the tree species grown on the streets. The uneven distribution of street tree species provides chances for those species with lower relative importance. Furthermore, these species can adapt to and have been tested by the local climate and street environment, therefore more street trees with lower relative importance can be planted in the future. Although most street tree species in Changzhou are suitable for the street environment and provide good scenery and ecosystem function, we found that the female _Ginkgo biloba_ provide poor shading function and their falling fruits in autumn cause lots of inconvenience to pedestrians. The _Acer truncatum_, _Acer buergerianum_ and _Zelkova serrata_ provide a colorful streetscape in autumn by the red/yellow leaf, the _Michelia chapensis_, _Koelreuteria paniculata_ and _Bischofia polycarpa_ have colorful flowers in different seasons respectively, but these high quantity street tree species have lower relative importance, therefore, the tree species have great application potential.

The second way is to select tree species from heritage trees, which are the most representative of the native tree species because they have been time-tested and can adapt to local climatic conditions [31]. Some heritage tree species have already been used widely as street trees, some haven't been widely planted, and some even haven't been developed yet. Therefore heritage tree species still have great potential to be included in the species pool for street trees. Based on the heritage tree census, there are 339 heritage trees, which are more than 100 years old and belong to 47 species in 31 families, 43 genera in 2017, the top 5 heritage tree species are _Ginkgo biloba_, _Zelkova serrate_, _Celtis sinensis_, _Osmanthus fragrans_ (Thunb.) Lour. and _Quercus variabilis Blume_. These heritage tree species have not been fully explored as street tree species.

The third way is to select tree species by utilizing the software of i-Tree Species tool (https://species.itreetools.org/) to identify species that are suitable for the city. i-Tree Species is designed to help urban foresters select the most appropriate tree species based on the potential environmental services and geographic area. The tool recommends the following street tree species such as _Aphananthe aspera_ (Thunb.) Planch., _Ailanthus altissima_ (Mill.) Swingle, _Liriodendron chinense_, _Koelreuteria paniculata_ and _Platanus orientalis_.

The evergreen species take up 65.7% of the total street tree population and dominate the canopy of street trees, and there is a need to increase the percentage of deciduous species as they can provide shade in summer and warm sunlight in winter. It is also significant to reduce the number of species which are over-represented, susceptible to disease or is an undesirable street tree. Reasonable arrangement of selecting tree species from species pool can help. _Cinnamomum camphora_ is the most popular native tree species, but over represented in Changzhou, judging by the “10-20-30” rule [32]. The total number of _Cinnamomum camphora_ should not increase but gradually be replaced by other appropriate species.

The average street tree spacing in Changzhou is approximately 7 meters. Street tree density, when it exceeds a reasonable limit, will bring trouble to management. We can find lopsided pruning on the
street because of the high density of street trees, keeping the roadside crown and pruning the other side, to leave growth space for the other trees. Lopsided pruning offsets the tree’s gravity center, make the tree very prone to falling or breaking branches in heavy snow or winds, and pose major security risks to pedestrians and traffic. Planting big canopy and narrow canopy trees, or fast-growing tree and slow-growing trees at intervals will solve the insufficient space for street trees. Enlarging the spacing distance is also an alternative method when planting a single big crown tree species on the street. To make well-informed management decisions, street tree inventory needs to be updated with new information as the street tree population changes, and each tree should be visited at least once every 3-5 years. The good news is that the municipal authority in charge of greening, the CLA, has begun to take measures to improve the status quo of street trees in Changzhou. Trial tests have been carried out on heritage tree species such as *Sophora japonica*, *Pteroceltis tatarinowii*, *Quercus variabilis*. Alien species such as *Celtis julianae*, *Michelia figo*, *Carya cathayensis* have been planted on some short streets to test their adaptability. These measures help solve the problems of low species diversity and imbalanced species distribution. In future, intense efforts should be made to protect old trees and practice interval planting.

5. Conclusion
Changzhou is an epitome of numerous fast-expanding cities in China. Little is known about its urban forestry. This paper has reported the diversity, tree density and age distribution of the street trees in this thriving medium-sized Chinese city. We found that the street trees of Changzhou is high in density but low in diversity compared with other cities. Native tree species of *Cinnamomum camphora* has a very high relative importance, other tree species lower than it. This uneven distribution of tree species brings potential threats to the sustainability of street trees in the city. This research reveals the structure and potential problems of street trees in Changzhou city, which may also exist in many other cities of the country, and the recommended solutions also bear referential significance to the sustainable development of street trees in other developing cities.

Further research should look at the ecosystem service and the influence of climate change to street trees. Street trees provide cooling service by conversion of incident solar radiation to latent, rather than sensible heat [33], absorbing pollutants and improving air quality [18]. Climate change will modify the growing conditions of plants and influence which species will persist in future. A great number of weather events such as snowstorms, significant rain episodes are likely to occur. In the past half century, rainstorms or extreme heavy rainfall have increased in both number and intensity in the middle and lower reaches of Yangtze River [34]. The snowstorm has a great impact on the evergreen street tree species, bringing great safety hazards to urban traffic and troubles for urban management. Further studies are required to understand the importance of street trees and the impact of climate change on street trees, the different tolerance levels of tree species. Such study can select the right tree species to maximize the ecosystem services and resilience to climate change, which is useful in street trees management and planning.

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