Urban trees in university campus: structure, function, and ecological values

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Abstract
University campuses usually have more trees and can provide various ecosystem services. However, there are few reports on tree ecosystem services of Chinese university campuses, especially in northern China. This study investigated the trees in the campus of Shenyang Institute of Technology and analyzed its ecological benefits and monetary value through i-Tree Streets. The campus trees contained a total of 5193 trees of 66 species, of which Catalpa ovata G. Don, Acer mono Maxim., Rhus typhina Nutt, and Salix babylonica L. accounted for 59.7% of the total number. The age structure of the trees in the campus was not ideal, with 71.5% of young trees, 24.0% of maturing trees, 4.5% of mature trees, and only 0.04% of old trees. The trees in the campus provided more energy saving benefits ($60,850, $11.7/tree), carbon reduction benefits ($34,318, $6.6/tree) and aesthetic benefits ($30,150, $5.8/tree). The benefits resulted from air pollutant removal ($12,889, $2.5/tree) and rainwater runoff interception ($15,534, $3.0/tree) were smaller. In addition, tree species with more maturing trees and mature trees (i.e., with larger diameter at breast height) and large leaf area in the campus contributed significantly to ecosystem services. Our results can provide suggestions and certain insights for Chinese campus greening managers in tree species selection and tree management.

Keywords University campus · Tree · i-Tree Streets · Ecosystem service

Introduction
Urbanization has developed rapidly in recent years. About 68% of the world’s population will live in cities by 2050 (UN 2018; Wang et al. 2019). Due to the reform and opening up, China’s urbanization process has also been accelerated and urban population will increase to 255 million by 2050 (UN 2018; Wu et al. 2014). In addition to population growth, rapid urbanization would increase the number of buildings, roads, and motor vehicles, and the use of fossil fuels in cities (Carpentieri and Robins 2015; Huang et al. 2016), accompanied by increased emissions of air pollutants (Xu et al. 2018) and carbon dioxide (Wang and Su 2019), decreased water quality (Liu et al. 2018a), degraded ecosystems (Grumbine
fragmented urban landscapes (Dobbs et al. 2017), and other negative effects (Yang et al. 2020). Although both the government and the general public have recognized the series of adverse effects brought by the increase in urban population and urbanization, no effective solution has yet been found.

In cities, planting trees and other plants can alleviate urban environmental problems by providing various ecosystem services. Urban trees can reduce the ambient temperature through shading and transpiration to reduce the urban heat island effect (Cao et al. 2010; Lee et al. 2013; Scholz et al. 2018). They therefore can reduce the use of air conditioning to save energy and improve the quality of life of urban residents (Hardin and Jensen 2007; Nowak et al. 2016). Urban tree leaves can absorb pollutants, intercept particulate matter, and release oxygen through photosynthesis to reduce air pollution levels (Escobedo et al. 2006; Nowak et al. 2016; Selmi et al. 2016). Urban forests can reduce rainwater runoff by leaf and branch surfaces, which in turn reduces water pollution levels (Berland et al. 2017; Kirnbauer et al. 2013; Xiao and McPherson 2002; Zhang et al. 2012). To some extent, the greening level of urban community can increase the attractiveness of the community by reducing noise and providing entertainment and leisure venues (McPherson and Simpson 2002). In addition, urban forests can increase the biodiversity of urban ecosystems (Prather et al. 2018).

At present, scholars have not unified the definition of urban forest. However, urban forests have three characteristics. First, in terms of spatial scope, urban forests exist in both urban built-up areas and urban suburbs, and there is no urban-rural dual structure feature. Second, in terms of resource structure, urban forests are dominated by trees, but at the same time, forest biomes include animals and plants. Third, the urban forest is a part of the forest, but in terms of space and resources, it intersects with the urban park green space and is closely connected (Wang et al. 2018a). At present, the scope of urban forest research includes not only nature reserves in suburban areas such as forest parks and protected areas but also green areas in urban areas such as auxiliary green areas in residential areas, urban parks, and private garden (Hepcan and Hepcan 2018; Wang et al. 2018b; Xie et al. 2019). The research trend is gradually extending into the urban inner space, and is more and more closely related to the life of urban residents (Wang et al. 2018b).

The university campus is known as a “small-scale city” and has a critical position in the city because of its high-density buildings, large population, and full-featured facilities (Guerrieri et al. 2019; Wibowo et al. 2019). Currently, more and more attention has been paid to the impact of university campuses on the environment (Srivinit and Hokao 2013). Campus trees can not only increase the plant coverage in the campus, maintain fresh air, improve the microclimate, and campus ecological indicators, but also maintain the physical and mental health of teachers and students (Liu et al. 2018b). University campuses share the benefits with the entire city and provide ecological benefits for local residents (Colding and Barthel 2017).

However, on previous studies mainly focused on the ecological benefits of street trees, urban parks, and residential areas, etc., only few studies existed on campus trees and focused on the single function of campus trees. For example, California State University, Dalhousie University, and Ankara University Tandogan Campus studied carbon sequestration of campus trees (Cox 2012; Dilaver et al. 2017; Ritchie 2017). The University of Pennsylvania studied the carbon sequestration of campus trees and calculated the reducing heating and cooling costs (Bassett 2015). In addition, researchers investigated the trees in the campus of Auburn University and the related carbon sequestration and air pollutant removal of trees (Martin et al. 2012; Martin et al. 2013).

Here, we first applied the i-Tree Streets to study the structure and benefits of trees in Shenyang Institute of Technology. Our main objectives include (1) analyzing the tree structure in the campus of Shenyang Institute of Technology; and (2) quantifying its ecosystem services in monetary terms, including energy savings, carbon reduction, air pollutant removal, rainwater runoff interception, and aesthetic benefits. We hope to provide a certain basis for the management of urban trees in the campus through the investigation and research on the trees in the campus of Shenyang Institute of Technology.

Methods

Study area

The research was conducted in the campus of Shenyang Institute of Technology (SIT), a university located in Shenfu New City, Fushun, China (41° 52′ N, 123° 55′ E, elevation 70 m) (Fig. 1). Fushun is a national forest city with an urban area of 713 km² and a population of 2.19 million. The study area is dominated by temperate continental monsoon climate with distinct seasonal variation, characterized by hot, humid summer and long, cold winter. Annual precipitation is 787 mm (from 478 to 1149 mm), mostly falling in summer (China Meteorological Data Service Center (CMDC), 1981–2010). Mean annual temperature was 7.0 °C, and ranges from −13.6 °C in January to 23.6 °C in July (Kong et al. 2011).

Shenfu New City is the central area of Shenyang Economic Zone. The current urbanization rate in this area is relatively high, maintaining at around 90%. The air environment quality of Shenfu New City is in a relatively unstable state, which can only meet 60% of the year’s air quality and maintain it at level 2 or above. In addition, the per capita park green area in Shenfu New City is low (Qi 2018).
Data collection

A complete tree inventory was conducted to collect the information of all tree populations in the campus of Shenyang Institute of Technology in 2019. The tree information was recorded according to the i-Tree Streets manual, including tree species, diameter at breast height (DBH), and crown width.

According to previous study, i-Tree Streets (STRATUM) was used to assess the structure, ecosystem services, and values of trees in the campus of SIT. The “US Northeast climate zone” was selected as the most suitable climate zone. The annual ecosystem service benefits of the trees in the campus were calculated based on the economic data collected, including electricity prices (Liaoning Price Bureau 2017), natural gas prices (Zhang et al. 2016), CO2 removal costs (Du 2013), and average house resale values. In this study, the numerical modeling technology in i-Tree Streets was used to analyze the surveyed tree information and other economic data into ecosystem service benefits, including air pollutant removal, energy savings, carbon reduction, rainwater runoff interception, and aesthetic benefits (McPherson et al. 2016; Soares et al. 2011). In addition, the economic data involved converted the Chinese Yuan (CNY) into US dollars at a 6.9:1 exchange rate, and some geographic and economic data from the New York area were also used in this study (McPherson et al. 2007).

Structure

Importance value

The importance value is an index used to measure the dominance of species in the forest community (Kim and Coseo 2018). It is calculated from the average of the three indicators of percentage of total tree numbers, percentage of total leaf area, and percentage of total canopy cover of a tree species (Peper et al. 2001).

Age structure

The management costs and ecological benefits produced by urban forests are affected by their age structure (Peper et al. 2007). The ideal degree of urban tree age structure is closely related to the budget allocation of urban managers to urban trees (Millward and Sabir 2010). Because the individual age of the tree population is difficult to determine, the method of

Fig. 1 Location of the study area

Legend
- Fushun
- SIT
replacing time with space is often used, that is, the tree breast diameter is used instead of the age structure for analysis (Yang et al. 2001). According to previous research, we divided the trees in Shenyang Institute of Technology into four classes, with a target proportion: 40% of young trees (0–15 cm), 25% of maturing trees (15–30 cm), 25% of mature trees (30–60 cm), and 10% of old trees (> 60 cm) (Peper et al. 2001).

**Function and value calculations**

**Energy savings**

Campus trees can reduce energy need by cooling, shading, windbreak, and transpiration (Ma et al. 2011a). In this study, based on building information, climate data, and shading effects, computer simulations were used to calculate the energy saving benefits of trees in Shenyang Institute of Technology. Reference city information includes building information, climate data, and energy consumption (McPherson and Simpson 1999). The average electricity price of Fushun used in this analysis was $0.26/GJ, and the price of natural gas was $1.0746/Therm.

**Carbon reduction**

Campus trees can sequestrate CO₂ as biomass and release O₂ through photosynthesis and therefore alleviate global warming. In addition, trees can reduce CO₂ emissions indirectly by energy savings (Wang et al. 2018c). However, it is inevitable that after the trees die, the stored carbon will be decomposed and released into the atmosphere (Soares et al. 2011).

The carbon storage of urban trees was calculated according to the biomass equation (McHale et al. 2009). The annual carbon sequestration was calculated from species-specific growth curves and biomass equations (McHale et al. 2009). The carbon dioxide released during the decomposition and maintenance activities was calculated based on the decomposition rate and consumption of gasoline and diesel in the reference city and the default values of i-Tree Streets. CO₂ emission reduction by energy savings were calculated by energy saving benefits and CO₂ emission factors. The CO₂ reduction value was calculated by $150/t carbon (Du 2013).

**Air pollutant removal**

Campus trees can improve air quality by trapping particulate matter and absorbing harmful gases. For example, trees can absorb and filter large amounts of particulate matter (PM), nitrogen oxides (NOₓ), and sulfides every year (Ma et al. 2002), or reduce air pollutant emissions due to energy savings. The amount of air pollutants removed by trees was calculated from the deposition velocity, meteorological data, and the concentration of NO₂, SO₂, PM₁₀, volatile organic compounds (VOCs), and ozone (O₃) (Nowak et al. 2000; Nowak et al. 2008). These data are the default values of i-Tree Streets. In addition, the reduced air pollutant emissions were calculated based on the default values in i-Tree Streets.

In addition, campus trees would release biological volatile organic compounds (BVOCs), which in turn affects air quality by increasing O₃ concentration. BVOC emissions were calculated based on the adjustment factors of tree leaf biomass and pollutant emission. Air pollutant removal benefits were calculated according to the default values of reference city as follows: NO₂ = $10.10/kg, PM₁₀ = $18.28/kg, SO₂ = $7.66/kg, VOC = $5.09/kg, and BVOCs = $5.09/kg; values for O₃ were equal to the NO₂ (McPherson et al. 2007).

**Rainwater runoff reduction**

Campus trees play a pivotal role in reducing rainwater runoff (Tao 2009). The annual rainfall interception of campus trees was calculated according to the numerical interception model of i-Tree Streets (Xiao et al. 2000). The data in the model such as the canopy projection area and leaf area were derived from field survey data, while the relevant meteorological data were derived from the default values of i-Tree Streets. The value of rainwater runoff interception was calculated based on the annual control cost of the reference city ($2.11/m³) (Peper et al. 2007).

**Aesthetic benefits**

The aesthetic benefits of urban forests are closely related to human activities and physical and mental health (Wang et al. 2018c). At present, i-Trees software uses the willingness to pay method to estimate the aesthetic benefits. The aesthetic value of each tree is related to the geographic location and growth of the tree (Nowak and Crane 2002). The aesthetic value of a single tree can be calculated as the product of tree contribution to home sales price ($/tree), tree location factor, and annual increase in tree leaf area (m²), and then divided by the total tree leaf area (m²) (Soares et al. 2011; Wang et al. 2018c). The median home price of $59,000 in Fushun was used in the model.

**Results**

**Structure**

**Tree numbers, species composition, and importance values**

There were 5193 trees in the campus of SIT and 66 species were identified (Table 1, Supplementary Table 1). The top ten tree species accounted for 76.5% of the tree population in the
campus. And the predominant tree species were *Catalpa ovata* G. Don (19.7%), *Acer mono* Maxim. (18.4%), *Rhus typhina* Nutt (11.2%), and *Salix babylonica* L. (10.4%) (Table 1). In addition, among the top ten tree species, there were 5 *Acer* species, accounting for 30.8%; among all tree species, there were 13 *Acer* species, accounting for 34.8%.

Ecosystem services produced by campus trees are directly proportional to the number of trees, canopy coverage, and plant leaf surface area. In the campus of SIT, the predominant tree species occupied 74.0% of the total leaf area and 69.9% of the total canopy cover. The importance value (IV) of all predominant tree species was 73.6. Among the predominant tree species, the IVs of *C. ovata* and *S. babylonica* were 21.0 and 20.1, indicating that the campus was too dependent on these two tree species (Table 1). While among all tree species in the campus, the IV of *Acer* species was 20.6 (Table 1, Supplementary Table 1).

### Age structure

The age structure of campus trees was distributed unevenly, with 71.5% of young trees (0–15 cm), 24.0% of maturing trees (15–30 cm), 4.5% of mature trees (30–60 cm), and 0.04% of old trees (> 60 cm) (Fig. 2). Among the top ten dominant tree species, the proportion of young trees of tree species accounted for more than 40%, but had inadequate representation in maturing and mature trees (Fig. 2), except for *S. babylonica* and *R. pseudoacacia* which had 57.2% and 47.7% of maturing trees and 17.5% and 26.9% of mature trees, respectively. In addition, almost all dominant tree species lacked old trees, which was far from the ideal tree species ratio (Fig. 2).

### Function and value

#### Energy savings

Annual energy savings due to shading and climate effects totaled up to $60,850 or $11.7/tree (Table 2, Fig. 3b). Annual energy savings due to electricity and natural gas could reach $8020 and $52,830, respectively (Table 2). Among the dominant tree species, *S. babylonica* had the highest energy saving benefits, accounting for 20.7%, followed by *C. ovata* (17.4%), *R. pseudoacacia* (8.6%), *R. typhina* (7.2%), and *A. mono* (6.1%) (Fig. 3a).

As for the energy saving benefits of per tree, *R. pseudoacacia* and *S. babylonica* had the highest benefits.

![Fig. 2](image-url) **Fig. 2** The age structure of predominant campus tree species compared to the ideal.
($40.5/tree and $23.2/tree, respectively) as they had more maturing and mature trees (Figs. 2 and 3b), followed by *U. pumila* ($12.3/tree) and *C. ovata* ($10.4/tree). Among the dominant tree species, the energy saving benefits per tree of *A. mono* and *A. pseudosieboldianum* were the least, at $3.9/tree and $1.3/tree, respectively (Fig. 3b).

### Carbon reduction

The trees in SIT stored a total of 856,226 kg of carbon, valued at $128,360 (Table 3). Among the dominant tree species, *S. babylonica* (26.0%) has the most carbon storage, followed by *C. ovata* (14.9%), *R. typhina* (7.2%), *A. mono* (6.5%), and *R. pseudoacacia* (6.1%) (Fig. 4a).

Annual carbon sequestration of campus trees totaled 105,296 kg, valued at $15,785 (Table 3). CO₂ emissions avoided due to energy savings totaled 151,345 kg, valued at $22,689 (Table 3). In addition, annual release of CO₂ through decomposition and maintenance totaled 27,727 kg, valued at $4157. Therefore, annual net removal of CO₂ from trees in the campus totaled 228,915 kg, producing benefit of $34,318 (Table 3). Among the predominant tree species, *S. babylonica* (20.1%) contributed the most to carbon sequestration, followed by *C. ovata* (17.5%), *R. pseudoacacia* (8.5%), *R. typhina* (7.0%), and *A. mono* (6.6%) (Fig. 4b).

For the carbon reduction benefits generated per tree, the average benefit of all trees in the campus was $6.6/tree (Fig. 4c). Among the predominant tree species, *R. pseudoacacia* had the highest average carbon reduction benefit, valued at $22.4/tree, followed by *S. babylonica* ($12.8/tree) and *U. pumila* ($8.3/tree). The average carbon reduction benefit of other predominant tree species was lower than the average benefit of all trees (Fig. 4c).

### Air pollutant removal

Trees in the campus of SIT absorbed or intercepted 509.6 kg of air pollutants directly, valued at $6048 (Table 4). Among the dominant tree species, *S. babylonica* contributed the most in air pollutant removal, accounting for 22.3%, followed by *C. ovata* (17.4%) (Fig. 5a). The air pollutants reduced by campus trees due to energy savings amounted to 740.1 kg, valued at $7107 (Table 4). *S. babylonica* removed the most air pollutants, accounting for 21.3%, followed by *C. ovata* (16.9%) (Fig. 5a). The BVOC released by trees in the campus was 52.3 kg, offsetting the total benefits by $266. Among the dominant tree species, *S. babylonica* and *C. ovata* accounted for 30.8% and 29.3% of the BVOC emissions, followed by *A. mono* (4.1%).

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**Table 2** Annual total energy saving benefits produced by campus trees

| Number of trees | Total electricity (GJ) | Electricity value ($) | Total natural gas (GJ) | Natural gas value ($) | Total value ($) |
|-----------------|------------------------|-----------------------|------------------------|-----------------------|-----------------|
| 5193            | 398.8                  | 8020                  | 5186.9                 | 52,830                | 60,850          |

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**Fig. 3** Annual energy saving benefits (a) and average value per tree (b) produced by predominant campus trees
Based on the above three parts, annual air pollutant removal of trees in the campus was 1197.4 kg, and the benefits valued at $12,889 (Table 4). Among the dominant tree species, *S. babylonica* had the most air pollutant removal benefits, accounting for 21.6%. *C. ovata* contributed 16.8% of air pollutant removal benefits. In addition, *R. pseudoacacia* (8.7%), *R. typhina* (7.0%), and *A. mono* (6.1%) also contributed more benefits (Fig. 5b).

In terms of the air pollutant removal benefit per tree, the average air pollutant removal benefit of trees in the campus of SIT was $2.5/tree (Fig. 5c). Among the predominant tree species, *R. pseudoacacia* had the highest air pollutant removal benefits per tree, up to $8.6/tree, and *S. babylonica* followed, up to $5.1/tree. In addition, the benefit generated by each tree of *U. pumila* ($2.8/tree) was also above the average benefit of trees in the campus. However, the benefits of *A. mono* and *A. pseudosieboldianum* per tree were relatively low, only $0.8/tree and $0.3/tree, respectively (Fig. 5c).

### Rainwater runoff interception

The intercepted annual rainfall of trees in the campus of SIT was 7362 m³, and the benefit produced was valued at $15,534 (Table 5). Among the predominant tree species, *S. babylonica* and *C. ovata* produced the greatest reduction in rainwater runoff, accounting for 25.5% and 22.0%, respectively (Fig. 6a).

The average rainwater runoff interception benefit of all trees in the campus was $3.0/tree. Among the predominant

| Species              | Storage (kg) | Sequestration (kg) | Decomposition release (kg) | Maintenance release (kg) | Total released (kg) | Avoided (kg) | Avoided ($US) | Net total (kg) | Net total value ($US) |
|----------------------|-------------|--------------------|---------------------------|--------------------------|---------------------|--------------|---------------|----------------|------------------------|
| S. babylonica        | 105,296     | 15,785             | -19,009                   | -8718                    | -4157               | 151,345      | 22,689        | 228,915        | 34,318                 |
| C. ovata             | 128,360     | 10,200             | -19,009                   | -8718                    | -4157               | 151,345      | 22,689        | 228,915        | 34,318                 |
| R. pseudoacacia      | 85,467      | 12,087             | -16,286                   | -8068                    | -3951               | 94,164       | 17,479        | 111,643        | 21,291                 |
| R. typhina           | 80,379      | 11,512             | -15,785                   | -8068                    | -3951               | 94,164       | 17,479        | 111,643        | 21,291                 |
| A. mono              | 51,936      | 7,781              | -12,707                   | -6351                    | -3077               | 66,878       | 11,926        | 78,804         | 15,214                 |
| A. pseudosieboldianum| 37,588      | 5,550              | -9,549                    | -5223                    | -2612               | 43,924       | 8,081         | 51,925         | 10,033                 |

**Table 3** Annual total carbon reduction benefits produced by campus trees

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Fig. 4  Carbon storage (a), carbon sequestration (b), and related value and average value per tree (c) for the predominant species growing within campus
tree species, *R. pseudoacacia* produced the highest benefit per tree, at $8.6/tree, followed by *S. babylonica* ($7.3/tree). The average benefits of *C. ovata* and *U. pumila* were above the average benefits of all trees, $3.4/tree and $3.6/tree, respectively (Fig. 6b).

### Aesthetic benefits

The estimated aesthetic benefits of trees in the campus of SIT were $30,150 (Table 6). Among the predominant tree species, *C. ovata* contributed the most aesthetic benefits, accounting...
for 32.4%, followed by S. babylonica (17.0%) (Fig. 7a). The average aesthetic benefits of all trees in the campus was $5.8/tree. Among the predominant tree species, R. pseudoacacia had the most benefit per tree, at $15.7/tree. U. pumila’s contribution ranked second, at $11.8/tree. In addition, the benefits of C. ovata and S. babylonica were above the average benefit of all trees, at $9.5/tree and $9.4/tree, respectively (Fig. 7b).

### Total annual benefits

The total benefits produced by trees in the campus were valued at $153,766 (Table 7), with an average benefit of $29.6/tree (Fig. 8b). Among various ecological benefits, energy savings contributed the most, accounting for 39.6%, followed by carbon reduction (22.3%). Surprisingly, aesthetic benefits also occupied an important position. Air pollutant removal provided the least contribution to the total benefits (Table 7).

C. ovata and S. babylonica produced the most total benefits ($31,946 and $31,366, respectively) among the predominant tree species, accounting for 20.8% and 20.4% of the total benefit of all trees, while the benefits provided by R. pseudoacacia ($12,445) accounted for 8.1% (Fig. 8a). The benefits produced by these three tree species were close to half of the total benefits of all trees. Among the predominant tree species, R. pseudoacacia produced the most benefits per tree, up to $95.7, S. babylonica ($57.9/tree), U. pumila ($38.7/tree), and C. ovata ($31.2/tree) also provided significant benefits (Fig. 8b).

### Discussion

#### Structure

Campus trees of SIT were estimated to be 5193, with an average of 102 trees/hm². Our results were much higher than the reported number of some agricultural and forestry colleges (Li 2012; Zhu 2016), indicating that SIT pays more attention to the campus greening. However, the tree density and species abundance of SIT were lower compared to foreign universities. For example, Ankara University’s Tandogan Campus had an average of 238 trees/hm² and had a very high plant diversity (Dilaver et al. 2017). The high diversity of tree species can enhance the stability of campus trees (McPherson and Kotow 2013). Although campus trees of SIT belonged to 66 species, the top ten tree species accounted for 76.5% of the tree population (Table 1). In addition, campus trees were overly dependent on Acer species (34.8%), which exceeded the widely accepted diversity rule (any one species should not account for more than 10% of the total tree numbers, any

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**Table 5** Annual total stormwater runoff reduction benefits produced by campus trees

| Number of trees | Total rainfall interception (m³) | Total ($) |
|----------------|---------------------------------|-----------|
| 5193           | 7362                            | 15,534    |

**Table 6** Annual total aesthetic benefits produced by campus trees

| Number | Total aesthetic benefits ($) |
|--------|------------------------------|
| 5193   | 30,150                       |

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**Fig. 6** Annual stormwater runoff reduction benefits of predominant campus trees. **a** Avoided runoff. **b** Average value per tree.
one genus more than 20%, and any one family more than 30%) (Santamour 1990).

The importance value (IV) is another robust indicator to reflect the degree of dependence on a tree species. The IV is between 0 and 100, when the value is closer to 100, it means that the tree species provides more benefits (Peper et al. 2001; Peper et al. 2007). However, when the IV is greater than 10, it indicates excessive dependence on a tree species (Kim 2016; Kim and Coseo 2018). Our results suggested that the campus of SIT was highly dependent on *C. ovata* and *S. babylonica*. The IV of the two tree species was 41.1, accounting for 56% of the dominant tree species. This was attributed to the large number, large canopy area, and large leaf area of the two tree species (Millward and Sabir 2010). *C. ovata* and *S. babylonica* are native species in Liaoning, which have strong drought resistance (He et al. 2014). In addition, previous studies have demonstrated that *C. ovata* has better comprehensive ecological benefits among the dominant species (Sun 2016), this may be the reason why these two trees were widely planted in the campus. However, overreliance on a single tree species can cause serious ecological and management problems, such as vulnerability to pests and diseases, so ensuring the diversity of campus trees is crucial (Wang et al. 2018d).

The age structure of urban forest is critical to the management practices, planning, policy formulation, and ecosystem services of urban forests (Morgenroth et al. 2020). Previous studies have highlighted that the ideal age structure can maintain the stability and flow of benefits by offsetting establishment-related mortality (Millward and Sabir 2010). However, in our study, campus trees of SIT failed to approach the ideal age structure, with 71.5% of young trees, 24.0% of maturing trees, 4.5% of mature trees, and 0.04% of old trees. Among ten dominant tree species, the proportion of young trees of tree species exceeds 70%, except *S. babylonica* and *R. pseudoacacia* (Fig. 2). Although young trees provide less ecosystem services than large trees, a larger number of young trees can still play an important role in providing ecosystem services in the study campus (Kim 2016). In addition, the large proportion of young trees in the campus can offset the age-related mortality as 40% of young trees to die within their first 10 years (Nowak 1990; Roman 2006), suggesting that

![Fig. 7 Annual aesthetic benefits of predominant campus trees. a Aesthetic benefits. b Average value per tree](image)

| Table 7 | Total annual benefits produced by campus trees |
|---------|-----------------------------------------------|
|         | Energy savings ($) | Carbon reduction ($) | Air pollutant removal ($) | Rainwater runoff interception ($) | Aesthetic benefits ($) | Total values ($) |
| Value   | 60,850            | 34,318              | 12,889                   | 15,534                           | 30,150                | 153,766          |
| % of total benefits | 39.6              | 22.3                | 8.4                      | 10.1                             | 19.6                  | 100               |
campus trees were the “growth type” and will provide more ecosystem benefits in the future (Kim and Coseo 2018; Suo 2016).

**Ecosystem services provided by campus trees**

Urban trees can provide various ecosystem services for urban residents, such as reducing air temperature and removing air pollutants, fixing and storing carbon dioxide, and intercepting rainfall (Declet-Barreto et al. 2013). The trees in the university campus can also provide some invisible help, such as reducing the pressure on students and teachers and improving mental health (Hipp et al. 2016; Lau and Yang 2009; Liu et al. 2018b).

The trees in the campus of SIT provided ecological benefits valued at $153,766 (Table 7). In a previous study, Sichuan Agricultural University’s Dujianyuan (SAUD) Campus also conducted a more comprehensive study and found that 2073 trees in the campus produced a total of $92,428.8, with an average benefit of $44.6/tree. Although the total benefits of trees in SIT were higher than that of SAUD Campus, the average benefit per tree was only 2/3 of that of SAUD Campus, attributed to the higher species diversity and higher proportion of mature trees in SAUD Campus. In addition, SAUD Campus, located in southern China, had more evergreen tree species and therefore great benefits per tree (Li 2012). Interestingly, the proportion of various ecosystem services produced by trees in the campus of SIT was different from the SAUD campus (Li 2012). Similar to our previous research, campus trees of SIT produced more energy saving benefits and carbon reduction benefits, which might be attributed to China’s current rapid economic development and urbanization (Wang et al. 2018d). In addition, this may be related to the industrial background of Fushun City (Liu and Wu 2018).

With the intensification of urbanization, the urban population and buildings continues to increase, which has caused many environmental problems, such as urban heat islands, increasing impervious land cover, and air pollution (Li et al. 2018; Sun et al. 2019). Urban green infrastructure such as parks, urban woodlands, and forest trees plays a key role in mitigating these effects (Morakinyo et al. 2018; Scholz et al. 2018; Wang et al. 2014). Urban trees can adjust the microclimate in a small area through shading and transpiration, thereby reducing the temperature and energy consumption (Gillner et al. 2015; Lehmann et al. 2014). In this study, the energy saving benefits of trees ($60,850) in the SIT Campus accounted for the highest percentage of total benefits, which was 39.6% (Table 7), suggesting that campus trees can contribute to the savings of electricity and natural gas expenses and therefore reduce air pollutants and greenhouse gas emission.

At present, climate change is a difficult problem both globally and regionally, and CO₂ emissions is one of main reasons inducing climate change (Ali 2018; Morakinyo et al. 2018). Generally, urban trees can mitigate global climate change and reduce the energy needs of urban buildings by sequestering CO₂ from the atmosphere (Kim and Coseo 2018). In the current study of urban trees on university campuses, the impact of campus trees on carbon sequestration was mainly investigated. In our study, the net reduction of CO₂ by campus trees in SIT Campus was 44.1 kg/tree. Compared to other campuses,
our results were higher than Ankara University Tandogan Campus and Auburn University ’s Donald E. Davis Arboretum (30.8 and 10.8 kg/tree) (Dilaver et al. 2017; Martin et al. 2012), indicating that the trees in the campus of SIT play an important role in sequestering atmospheric CO2. Urban trees can reduce air pollution by absorbing or retaining air pollutants (Paoletti et al. 2011). Similar to our previous study on street trees in Dalian (Wang et al. 2018d), the benefits of air pollutant removal of trees in the campus of SIT were relatively small (8.4%) compared with other ecosystem services. However, air pollutant removal efficiency of campus trees in SIT was higher than that of the campus trees of SAUD campus and the street trees of Dalian. This may be related to the pollution level in Fushun City, which is more serious than that in Dalian City and Dujiangyan (Li et al. 2013; Liu et al. 2011; Ma et al. 2011b).

Urban trees can reduce the formation of ground runoff by intercepting and evaporating rainfall and absorbing rain at the roots to alleviate the pressure on gray infrastructure in cities (Berland et al. 2017; Kuehler et al. 2017; Shuster et al. 2008). In this study, the benefits of rainwater runoff interception in the campus of SIT accounted for 10.1%, lower than that in SAUD Campus (26.4%). This may be due to the lower proportion of conifers (2.1%) in SIT (Supplementary Table 2). Previous studies have demonstrated that conifers can store more water than broad-leaved trees because the leaf surface of conifers has a higher water storage capacity (Xiao and McPherson 2016). The high ratio of conifers and evergreen broad-leaved trees could maintain a higher canopy retention rate during the deciduous period of deciduous trees (Clapp et al. 2014). These results suggested that a suitable proportion of conifers should be planted in the campus of SIT.

In addition, previous studies found that the level of green infrastructure in the campus has a positive relationship with students’ mental health and academic performance (Hodson and Sander 2017; Kweon et al. 2017; Li and Sullivan 2016; Lin and Van Stan 2020; Liu et al. 2018b). Although this study did not investigate the academic performance and physical and mental health of school staff directly, the importance of campus trees can also be reflected by the aesthetic value (up to 19.6% of total benefits) (Table 7). Similarly, several studies also quantified the aesthetic benefits of urban trees in other land use type and reported great contributor of this benefit to total benefits. For example, Millward and Sabir (2011) suggested that aesthetic benefits of a forested urban park accounted for 37% of total benefits. Maco and McPherson (2003) found that aesthetic benefits of street trees accounted for 60% of total benefits in a US city.

Ecosystem services produced by trees are related to the structure of trees. Previous studies have found larger trees can bring more benefits than small trees due to their large DBH and large leaf area (Hepcan and Hepcan 2018; Martin et al. 2012; McPherson et al. 1997; Millward and Sabir 2011). In our study, the benefits provided by C. ovata, S. babylonica, and R. pseudoacacia accounted for half of the benefits of all trees in the campus (Fig. 8a). The total benefits produced by C. ovata were the largest among all trees because of its largest population. But on a per tree basis, the average benefit of C. ovata ($31.2/tree) was lower than that of U. pumila ($38.7/tree) due to the lack of mature trees, and slightly higher than the average level of all trees ($29.6/tree) (Figs. 2 and 8b). For S. babylonica and R. pseudoacacia, the benefits of the two tree species were higher than other tree species, attributed to their higher proportion of maturing and mature trees. In addition, the correlation between each ecosystem service benefit and the average leaf area of each tree species was analyzed and found that total ecological benefits were positively correlated with leaf area (Supplementary Table 3), indicating that trees with larger leaf area can contribute more benefits of ecosystem services. In contrast, for A. pseudoieboldianum, although the number of trees ranks tenth (1.8%) among all campus trees, it is dominated by young trees (Fig. 2), so their contribution to the benefits of ecosystem services was scarce (Fig. 8). However, as we mentioned above, young trees in the campus have greater growth potential and therefore provide more ecosystem services in the future.

Conclusions

In this study, we first applied the i-Tree Streets to study the structure and ecological benefits of campus trees in SIT. The campus trees were estimated to be 5193 trees and 66 species have been identified. Among them, C. ovata, A. mono, R. typhina, and S. babylonica were the most dominant tree species, accounting for 59.7% of the total number of trees in the campus. These results suggested that the campus relies too much on C. ovata (IV = 21.0) and S. babylonica (IV = 20.1), easily generating serious management concerns, such as pests and diseases. In addition, the age structure of campus trees was not ideal, with a large proportion of young trees (71.5%), fewer maturing and mature trees (28.5%), and a deficit of old trees (0.04%), suggesting that campus trees were the “growth type” and will provide more ecosystem benefits in the future.

Campus trees provided substantial ecosystem services and ecological benefits. The total benefits produced by campus trees were valued at $153,766 ($29.6/tree). Among the total benefits, energy saving benefits contributed the most, accounting for 39.6%, followed by carbon reduction benefits (22.3%) and aesthetic benefits (19.6%).
Smaller benefits resulted from air pollutant removal (8.4%) and rainwater runoff interception (10.1%). Among the predominant tree species, *S. babylonica* and *R. pseudoacacia* contributed more to the total benefits due to more maturing and mature trees and therefore large leaf area. For *C. ovata*, the per tree benefit of *C. ovata* was lower than *R. pseudoacacia*, *S. babylonica*, and *U. pumila* though it contributed the most to the total benefits because of its large tree population. Furthermore, the proportion of conifers in this campus was too low. In general, campus trees of SIT were in a sustainable and healthy state, which can provide more benefits in the future. However, campus greening managers should consider the ideal proportion of tree species and to plant trees with larger DBH and larger leaf area.

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**Availability of data** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Author contribution** Xueyan Wang, Yanlin Wang, and Xiuying Yang mainly contributed to the study conception and design. Material preparation was performed by Zeming Li, Junjiao Sun, and Xiaoqing Wei. Data collection was performed by Xueyan Wang, Yanlin Wang, Xiaohan Qu, and Bing Huang. Data analysis was performed by Yanlin Wang, Xueyan Wang, and Zeming Li. The first draft of the manuscript was written by Xueyan Wang and Yanlin Wang, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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