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Street Trees in a Chinese Forest City: Structure, Benefits and Costs

Xueyan Wang [1,2], Jing Yao [1], Shuai Yu [1], Chunping Miao [1], Wei Chen [1,*] and Xingyuan He [1,*]

1 CAS Key Laboratory of Forest Ecology and Management, Institute of Applied Ecology, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110164, China; 15710591658@163.com (X.W.); avril_y@foxmail.com (J.Y.); 13998265480@163.com (S.Y.); miaochunping316@163.com (C.M.)
2 College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China
* Correspondence: hexy@iae.ac.cn (X.H.); chenwei5711@163.com (W.C.)

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Abstract: Street trees provide critical ecosystem services and economic benefits that are often disregarded, due to their unknown monetary value. This study analyzed the structural characteristics of Dalian's street trees and estimated the monetary value of structural and functional benefits by i-Tree Streets. Dalian's street trees encompassed 28 species and were dominated by *Ginkgo biloba*, *Platanus acerifolia* and *Sophora japonica*, comprising 64.1% of a total of 57,699 trees. The age structure of street trees was distributed somewhat unevenly, with 18% young trees, 56% maturing trees, 25% mature trees and 1% old trees. These trees provide annual functional benefits valued at US$4.9 million and delivered a benefit-cost ratio of 3.2:1. The largest values associated with energy savings and property value were $1.7 million ($29/tree) and $1.5 million ($25/tree), respectively. The net carbon reduction benefits were valued at $935,205 ($16/tree). Smaller benefits resulted from air quality improvement ($381,088 or $7/tree) and stormwater runoff ($459,457 or $8/tree). The structural benefits were valued at $130 million, with the value of $4.5 million for carbon storage. These findings suggested that the benefits produced by street trees were worth the management costs. Our results provide a thorough understanding of the benefits produced by street trees to policy-makers and managers, and help them make informed policies to maximize and sustain the flow of benefits.

Keywords: i-Tree Streets; ecosystem services; functional value; structural value; benefit-cost ratio

1. Introduction

Urbanization is a spreading phenomenon across the world and promotes economic development and poverty reduction [1]. However, rapid urbanization has disturbed the natural urban ecosystem and degraded the urban environment [2–4]. The deteriorating environment in cities has generated the urgent need for a comprehensive study of urban forests as they can alleviate environmental deterioration and improve quality of life [5–8].

Street trees (trees growing in the urban street), as part of the urban forest, play a vital role as they provide ecosystem services that improve the quality of the environment and life. Environmentally, street trees can conserve energy, sequestrate CO_2, remove air pollutants, and reduce stormwater runoff [9–13]. Additionally, street trees can also increase business income and real estate values by increasing community attractiveness and recreational opportunities [14].

Numerous studies have highlighted the importance of street trees in improving the urban environment and have performed comprehensive research into their structure [15–18]. However, ecosystem services and benefits provided by street trees are often disregarded by urban managers due to their unknown monetary value [19]. In contrast, the management costs and other damage caused by street trees have been widely reported [20], driving urban managers to reduce the financial budgets of tree management. A computer program called i-Tree Streets was used to quantify the structure, function and values of street trees as well as their management costs. Numerous studies have been conducted in the United States, Canada, and Europe [10–12,21], which found that the benefits returned annually by street trees ranged from $1.4 to $5.9 for every dollar invested in management, thereby demonstrating that street trees are worth the management investment.

To date, however, limited studies exist on the structure, benefits and values of street trees in China. Since reform and opening-up, rapid urbanization, industrialization, and rural–urban migration in many Chinese cities have generated many environmental problems [22]. However, there is a lack of relevant policies and management practices regarding street trees. Inadequate financial budgets have also imposed pressures and constraints on the management of street trees [23], partly due to the poor understanding of their importance. Thus, to make Chinese cities more livable and sustainable, it is the first step in understanding the ecosystem services and economic values produced by street trees [24].

In this study, we describe the first application of i-Tree Streets in Dalian, China. Dalian, a Chinese forest city in Liaoning Province, has suffered from rapid urbanization in recent years. Our objectives were as follows: (1) to analyze the structure of street trees in Dalian; (2) to quantify their ecosystem services in monetary terms including energy savings, carbon reduction, air pollutants removal, storm water runoff reduction and property value; and (3) to estimate the costs of management. The ultimate purpose of our study was to generate objective data on the economic values produced by street trees in Dalian as the baseline data for assessing the return on management investment.

2. Materials and Methods

2.1. Study Area

This study was conducted in the main urban area (Zhongshan, Xigang, and Shahekou District) of Dalian (38°43′–40°10′ N, 120°58′–123°31′ E), which approximately covers 118 km^2 with a population of 1.33 million. The study area experiences a warm temperate continental monsoon climate with maritime features [25]. The mean annual temperature is 11.3 °C, and ranges from −3.6 °C in January to 24.5 °C in August [26]. The mean annual precipitation is 580 mm, mostly falling in summer (China Meteorological Data Service Center (CMDC), 1981–2010).

2.2. Data Collection

A field sample inventory was conducted to collect tree characteristics in the study area from June to September 2016. One hundred and twenty-one street segments were selected based on the statistical principles of random sampling, accounting for 4% of all street segments. All the trees along the selected segments were inventoried, a total of 3178 trees. Then the total tree number and information were calculated by analyzing the field data. Information regarding species, diameter at breast height (DBH), crown breadth, condition, maintenance recommendations and tasks, and other related attributes described in the i-Tree Streets Manual was recorded. Additionally, general information was also collected to aid in record management, e.g., street address, Global Positioning System (GPS) coordinates, survey date.

2.3. i-Tree Streets

In this study, i-Tree Streets (STRATUM) was used to assess the structure and function of street trees in Dalian. However, an estimate of benefits by i-Tree Streets depends on tree growth curves and other regionally specific data (e.g., geographic and economic data) for 16 climate zones in the U.S. Thus, the application of i-Tree Streets in Asian cities needs to select a "best fit" climate zone [27]. McPherson [27] proposed a method to select the best city match using four criteria: species composition, heating and cooling degree days (HDDs and CDDs), and annual precipitation. First, five candidate reference cities were selected by comparing the reference city data with Dalian. Second, the root mean squared error (RMSE) was calculated for each reference city, and the city with the lowest RMSE is the best match. The method to calculate RMSE requires two-steps: data normalization and assigning weight values to each criterion. We set 0.25 to species composition, 0.3 to HDD, 0.2 to CDD, and 0.25 to annual precipitation. Finally, the best match city for Dalian was Queens, New York (RMSE = 1.76). Thus, the "US Northeast climate zone" was used for i-Tree Streets analysis.

Street tree species in Dalian were matched with species of the reference city using the species-to-species or genus-to-genus approach for the specific growth curves. In addition, economic data collected in China was used to calculate the annual benefits including electricity price [28], natural gas price [29], the value of CO_2 reduction [30], and the median home price of Dalian. Economic data in the form of Chinese Yuan (CNY) were converted to dollars by an exchange rate of 6.9 to 1. Other geographic and economic data of New York were also used in this study [31]. Annual benefits were calculated by using numerical modeling techniques in i-Tree Streets [10–12,21], including energy savings, carbon reduction, air pollutants removal, stormwater runoff reduction, and property value.

2.4. Structure

2.4.1. Importance Value

Importance value (IV) is a more robust indicator to reflect the street tree species dominance in a city than tree numbers alone. The importance value is calculated by the mean of three important values: percentage of total tree numbers, percentage of total leaf area, and percentage of total canopy cover [32,33].

2.4.2. Age Structure

The age structure of street trees affects the current and future costs of management as well as the benefits produced by street trees [33]. Having an ideal age structure of street trees helps urban planners allocate the street tree management budget uniformly each year and ensure the continuity of tree canopy cover [34]. An ideal age structure of street trees should have an abundance of young trees to offset planting-related and age-related mortality [35]. In our study, street trees were classified into four classes by using DBH, 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) [32].

2.5. Function and Value Calculations

2.5.1. Energy Savings

Street trees in cities can reduce the energy needs of building cooling and heating by producing shade, reducing wind-speed, and reducing air temperature through tree transpiration [36–38]. Energy savings by street trees were calculated based on computer stimulations that incorporate building information, climate data, and shading effects. The building information, climate data, and energy consumption of a reference city were used in our analysis [39]. However, the average electricity ($20.10/GJ) [28] and natural gas ($10.17/GJ [29]) price in Dalian was used in our analysis.

2.5.2. Carbon Reduction

Street trees can play a critical role in mitigating global warming by reducing CO_2 [10–12]. Street trees can be a sink for CO_2 by directly sequestrating CO_2 as tree biomass, or can reduce CO_2 emissions indirectly by energy savings [38,40,41]. Conversely, CO_2 is released by vehicles and other equipment during tree maintenance [12]. Moreover, the accumulated CO_2 in tree biomass is released into the atmosphere through decomposition when trees die [12].

Carbon storage was calculated by using biomass equations for urban trees [42,43]. Annual carbon sequestration, the net increase of tree biomass, was calculated with tree species-specific growth curves and biomass equations [42,43]. Carbon dioxide (CO_2) released from decomposition and maintenance activities was calculated based on the decomposition rate and amount of gasoline and diesel fuel consumed in the reference city and i-Tree Streets default values. Reduced CO_2 emissions by energy savings were calculated by energy saving benefits and CO_2 emission factors. We used $150 per ton of carbon as the value of CO_2 reduction [30].

2.5.3. Air Pollutants Removal

Street trees can absorb gaseous pollutants (NO_2, O_3, and SO_2) [44] and intercept particulate matters (PM_{10}) [45] through leaf surfaces. Air pollutant removal by street trees was calculated by deposition velocity, meteorological data, and pollutant concentrations of NO_2, SO_2, volatile organic compounds (VOCs), PM_{10} and O_3 to trees [46,47]. The deposition velocity, meteorological data, and pollutant concentrations used in our study were the i-Tree Streets default values.

Energy savings have an indirect effect in reducing air pollutant emissions (NO_2, PM_{10}, VOCs and SO_2). Reduced emissions of air pollutants resulting from energy savings were calculated using the i-Tree Streets default values.

Conversely, biogenic volatile organic compounds (BVOCs) released from trees affect ozone formation [48], thereby negatively affecting the air quality. The emission of BVOCs was calculated by the adjusted factors of emission and leaf biomass [21,49]. Air pollutant removal benefits were calculated using the default values provided for New York as follows: NO_2 = $10.10/kg, PM_{10} = $18.28/kg, SO_2 = $7.66/kg, VOC = $5.09/kg, and BVOCs = $5.09/kg, values for O_3 were equal to the NO_2 [31].

2.5.4. Storm Water Runoff Reduction

The reduction of annual stormwater runoff by street trees was calculated by a numerical interception model of i-Tree Streets [50]. The crown projection area and leaf area calculated according to field inventory in Dalian were applied in this model. Furthermore, the water depth on canopy surfaces, hourly meteorological data, and annual precipitation were i-Tree Streets default values. The value of intercepted storm water was calculated using the annual control cost for New York ($2.11/$m^3$) [33].

2.5.5. Property Value

Street trees can provide a host of intangible benefits such as improving the scenic quality [51], providing refuge for urban wildlife as well as increasing the public willingness to payment [52]. However, it is difficult to quantify these intangible benefits in monetary terms. Previous studies have found that street trees could increase property values in neighborhoods where they were planted [39,53–55]. Thus, the value of these intangible benefits was estimated by the differences in the sale prices of houses. Property value benefits were best modeled by multiplying 0.88% by the city's median home sale price [56]. In our analysis, property value benefits were calculated by the distribution of the street trees, size, land use and growth rates. Data were collected from the field inventory, except the growth rates of trees which were from the reference city. The median home price of $172,246 in Dalian was used in the model.

2.6. Expenditure

Street trees expenditure includes planting, maintenance (irrigation, pruning, crown thinning and removal) and management. However, Dalian lacks information on municipal tree program expenditure, and thus the management costs of street trees were estimated with an empirical value [31,57]: $20 for a small tree (0–15 cm), $27 for a medium tree (15–60 cm), $34 for a large tree (>60 cm), and $23 for a conifer, respectively [31].

3. Results

3.1. Structure

3.1.1. Tree Numbers, Species Composition and Importance Values

There are 57,699 street trees in Dalian, with street trees per capita of 0.04, i.e., one street tree for every 25 people. In this study, twenty-eight different species were identified (Table 1). The predominant street tree species were *G. biloba* (28.7%), *P. acerifolia* (25.7%) and *S. japonica* (9.7%). The top ten occurring species comprised 93.7% of the total tree numbers.

Table 1. Species, tree numbers, and importance values of street trees in Dalian.

Species	Total Tree Numbers	% of Total Tree Numbers	% of Total Leaf Area	% of Total Canopy Cover	Importance Value
Platanus acerifolia	14,836	25.7	33.8	36.8	32.1
Ginkgo biloba	16,537	28.7	9.3	14.2	17.4
Sophora japonica	5579	9.7	10.4	7.2	9.1
Populus canadensis	2026	3.5	11.4	9.3	8.1
Platanus occidentalis	3608	6.3	7.3	8.0	7.2
Robinia pseudoacacia	2710	4.7	8.1	7.4	6.7
Salix babylonica	2659	4.6	6.0	4.4	5.0
Fraxinus chinensis	2490	4.3	4.3	4.1	4.2
Sabina chinensis	2607	4.5	1.3	1.0	2.3
Salix matsudana	986	1.7	2.9	2.2	2.3
Acer negundo	840	1.5	1.4	1.2	1.3
Cedrus deodara	418	0.7	0.9	1.0	0.9
Eucommia ulmoides	407	0.7	0.7	0.7	0.7
Populus alba	276	0.5	0.7	0.7	0.6
Sabina chinensis K.	535	0.9	0.2	0.3	0.5
Koelreuteria paniculata	226	0.4	0.1	0.2	0.3
Acer truncatum	188	0.3	0.2	0.2	0.2
Liriodendron chinense	129	0.2	0.2	0.2	0.2
Paulownia tomentosa	47	0.1	0.2	0.2	0.1
Cerasus serrulata	108	0.2	0.1	0.1	0.1
Pyrus ussuriensis	57	0.1	0.1	0.1	0.1
Morus alba	70	0.1	0.1	0.1	0.1
Diospyros lotus	73	0.1	0.1	0.1	0.1
Platycladus orientalis	96	0.2	0.0	0.0	0.1
Ailanthus altissima	50	0.1	0.1	0.1	0.1
Albizzia julibrissin	64	0.1	0.0	0.1	0.1
Evodia daniellii	64	0.1	0.0	0.1	0.1
Armeniaca sibirica	13	0.0	0.0	0.0	0.0
Total trees	57,699	100.0	100.0	100.0	100.0

The predominant street tree species in Dalian represented 93.7% of the total tree numbers, 94.9% of the total leaf area, and 94.6% of the total canopy cover. The total importance values (IVs) of these predominant street trees was 94.4 (Table 1). Of these species, Dalian relied most on *P. acerifolia*, with the highest IV of 32.1. This made *P. acerifolia* twice as significant as *G. biloba* (IV = 17.4), and three times more significant than *S. japonica* (IV = 9.1). The importance values of young trees and small-stature trees were relatively lower due to their relatively small leaf area and canopy cover such as *S. chinensis* (IV = 2.3).

3.1.2. Age Structure

The age structure of street trees in Dalian was distributed somewhat unevenly, with 18% of young trees (0–15 cm), 56% of maturing trees (15–30 cm), 25% of mature trees (30–60 cm), and 1% of old trees (>60 cm) (Figure 1). Of the ten dominant tree species, only *S. chinensis* exceeded the 40% ideal in the young trees (65%) but had inadequate representation in the mature trees (Figure 1). *G. biloba*, *P. acerifolia*, *S. japonica*, *P. occidentalis*, and *P. canadensis* dominated in the maturing and mature trees and had inadequate representation in the young trees.

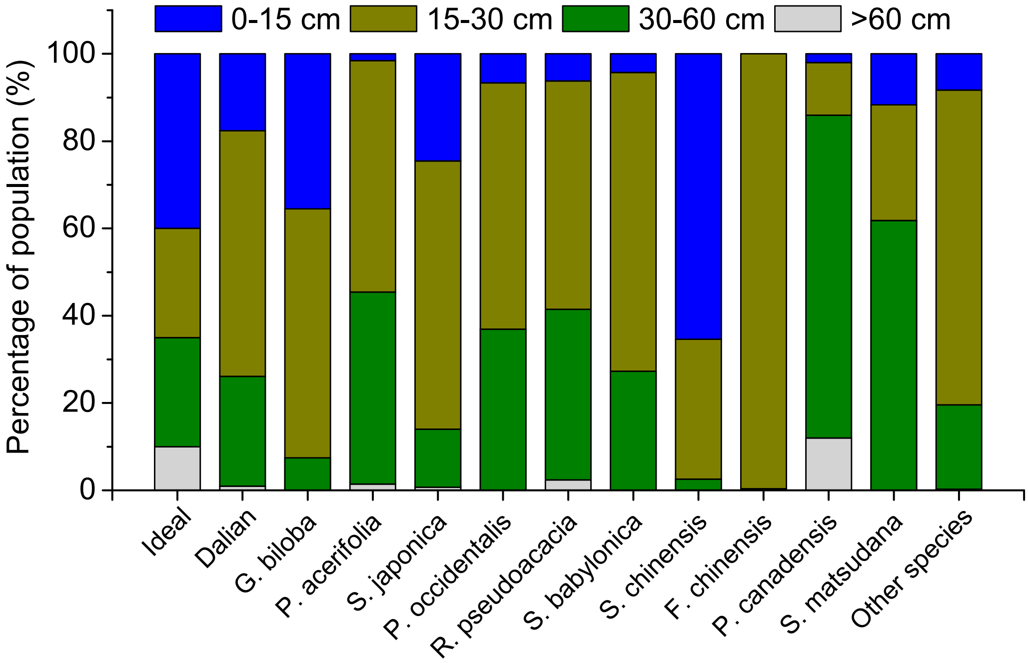

Figure 1. The age structure of predominant street tree species compared to the ideal. Note: "Dalian" represents the total street trees.

3.2. Function and Value

3.2.1. Energy Savings

Annual electricity and natural gas saving by street trees have been valued as 12,339 GJ year^{-1} ($248,176) and 141,011 GJ year^{-1} ($1,436,228), respectively (Table 2). The total energy saving benefits provided by street trees in Dalian were $1.7 million annually, or a citywide average of $29.2/tree. *P. acerifolia* (35.2%), *G. biloba* (15.3%), *R. pseudoacacia* (7.9%), *S. japonica* (7.8%), *P. occidentalis* (7.8%), and *P. canadensis* (7.7%) produced great benefits.

Table 2. Annual energy savings benefits produced by predominant street trees.

Species	Total Electricity (GJ)	Electricity ($)	Total Natural Gas (GJ)	Natural Gas ($)	Total ($)	% of Total $	Avg. $/Tree
G. biloba	1778	35,770	21,804	222,081	257,851	15.3	15.6
P. acerifolia	4496	90,426	49,404	503,188	593,615	35.2	40.0
S. japonica	894	17,976	11,116	113,214	131,191	7.8	23.5
P. occidentalis	980	19,710	10,941	111,441	131,151	7.8	36.3
R. pseudoacacia	1008	20,271	11,147	113,530	133,801	7.9	49.4
S. babylonica	556	11,190	6623	67,460	78,650	4.7	29.6
S. chinensis	117	2353	1438	14,650	17,003	1.0	6.5
F. chinensis	488	9814	6256	63,716	73,530	4.4	29.5
P. canadensis	1018	20,478	10,685	108,832	129,310	7.7	63.8
S. matsudana	280	5636	3101	31,585	37,221	2.2	38.1
Other species	723	14,552	8496	86,531	101,083	6.0	27.6
Total	12,339	248,176	141,011	1,436,228	1,684,404	100.0	29.2

On a per tree basis, large-stature trees produced the greatest benefits such as *P. acerifolia* ($40.0), *R. pseudoacacia* ($49.4), *P. occidentalis* ($36.3), *P. canadensis* ($63.8), and *S. matsudana* ($38.1). Small-stature trees with less leaf area and canopy cover such as *S. chinensis* ($6.5) and *G. biloba* ($15. 6) produced energy saving benefits well below the average value ($29.2).

3.2.2. Carbon Reduction

Dalian's street trees were estimated to store 29,873 t ($4,478,353) of CO_2 that was accumulated in tree biomass (Table 3). *P. acerifolia* (34.6%), *P. canadensis* (14.9%), *G. biloba* (11.2%), *S. japonica* (7.7%), and *R. pseudoacacia* (7.6%) stored the most CO_2.

The annual amount of CO_2 sequestered by street trees was 2317 t ($347,358) (Table 3). Meantime, the annual avoided CO_2 emissions from energy savings totaled 4683 t ($702,073). Annual release of CO_2 from tree maintenance activities and decomposition was 762 t, valued $114,226 (Table 3). Therefore, net annual CO_2 removed by street trees totaled 36,111 t. The monetary value associated with CO_2 reduction was $935,205 (Table 3). *P. acerifolia* (35.4%), *G. biloba* (14.8%), *R. pseudoacacia* (8.2%), *P. canadensis* (8.2%), *S. japonica* (7.7%), and *P. occidentalis* (7.7%) produced the greatest net benefits.

On a per tree basis, the carbon reduction benefits were $16.2 on average. *P. canadensis* produced the greatest net carbon reduction benefits, valued at nearly $38/tree. *P. acerifolia* ($22.3) and *R. pseudoacacia* ($28.4) were also important contributors to carbon reduction. *G. biloba* produced net benefits valued at $8.4/tree, well below the average value ($16.2).

3.2.3. Air Pollutants Removal

The annual air pollutants absorbed (NO_2, O_3, and SO_2) or intercepted (small particulate matter PM_{10}) directly by Dalian's street trees totaled 16.3 t, for a value of $193,972 (Table 4). *P. acerifolia* removed the most air pollutants, accounting for 36.1% of the total removing benefits. Due to the largest proportion of the total tree population, *G. biloba* (13.9%) was the next greatest contributors of removing air pollutants.

Indirectly avoided emissions of air pollutants resulted from energy savings that amounted to 21.9 t year^{-1} with an implied value of $209,855 (Table 4). *P. acerifolia*, *P. canadensis*, *G. biloba*, *S. japonica* and *R. pseudoacacia* had the greatest contribution to avoiding air pollutants emissions by reducing energy consumption, accounting for 74.3% of the avoided benefits.

About 4.5 t year^{-1} BVOCs were released by trees, offsetting the total benefits by $22,740 (Table 4). The species that emitted more BVOCs were *P. acerifolia* (62.8%), *P. occidentalis* (13.5%), and *G. biloba* (6.5%).

The net benefits of air pollutant removal were valued at $381,088/year or $6.6/tree (Table 4). *P. acerifolia* (34.4%) and *G. biloba* (14.8%) produced the greatest contribution to air pollutant removal. On a per tree basis, however, *R. pseudoacacia* ($11.5) and *P. canadensis* ($17.1) produced the greatest benefits.

Table 3. Annual carbon reduction benefits produced by predominant street trees.

Species	Total Stored CO_2 (t)	Total Stored ($)	Sequestered (t)	Sequestered ($)	Decomposition Release (t)	Maintenance Release (t)	Total Release ($)	Avoided (t)	Avoided ($)	Net Total (t)	Total ($)	% of Total $	Avg. $/Tree
P. acerifolia	10,334	1,549,168	726	108,774	−158	−64	−33,217	1706	255,810	12,544	331,368	35.4	22.3
G. biloba	3340	500,740	368	55,183	−75	−45	−17,928	675	101,191	4264	138,446	14.8	8.4
R. pseudoacacia	2262	339,043	194	29,115	−51	−12	−9335	383	57,344	2776	77,124	8.2	28.4
P. canadensis	4450	667,104	229	34,327	−88	−13	−15,148	386	57,932	4964	77,111	8.2	38.1
S. japonica	2288	342,973	206	30,817	−49	−17	−9811	339	50,854	2767	71,860	7.7	12.9
P. occidentalis	1990	298,333	153	23,011	−34	−14	−7148	372	55,760	2468	71,622	7.7	19.8
S. babylonica	1501	225,089	118	17,756	−34	−10	−6492	211	31,655	1788	42,918	4.6	16.1
F. chinensis	566	84,821	66	9844	−13	−8	−3063	185	27,763	796	34,544	3.7	13.9
S. matsudana	962	144,169	55	8230	−22	−4	−3902	106	15,943	1097	20,272	2.2	20.8
A. negundo	569	85,354	42	6317	−13	−3	−2344	59	8827	655	12,801	1.4	15.2
Other species	1611	241,558	160	23,985	−27	−11	−5839	260	38,994	1992	57,140	6.1	10.5
Total	29,873	4,478,353	2317	347,358	−561	−201	−114,226	4683	702,073	36,111	935,205	100.0	16.2

Table 4. Annual air pollutants removal benefits produced by predominant street trees.

Species	Deposition (kg)	Deposition ($)	Avoided (kg)	Avoided ($)	BVOCs Emissions (kg)	BVOCs Emissions ($)	Total (kg)	Total ($)	% of Total $	Avg. $/Tree
P. acerifolia	5911	70,094	7893	75,444	−2804	−14,280	11,000	131,258	34.4	8.8
G. biloba	2277	26,997	3235	31,010	−288	−1469	5223	56,538	14.8	3.4
P. canadensis	1495	17,730	1763	16,826	0	0	3258	34,556	9.1	17.1
R. pseudoacacia	1190	14,111	1773	16,949	0	0	2963	31,060	8.2	11.5
S. japonica	1177	13,976	1633	15,666	−170	−864	2641	28,778	7.6	5.2
P. occidentalis	1280	15,178	1729	16,534	−603	−3070	2406	28,641	7.5	7.9
S. babylonica	720	8547	1002	9599	−98	−499	1624	17,647	4.6	6.6
F. chinensis	653	7748	901	8649	0	0	1554	16,397	4.3	6.6
S. matsudana	364	4328	493	4713	−46	−236	811	8805	2.3	9.0
A. negundo	209	2473	284	2723	−42	−213	451	4983	1.3	5.9
Other species	1070	12,790	1226	11,742	−414	−2108	1883	22,424	5.9	4.1
Total	16,345	193,972	21,932	209,855	−4465	−22,740	33,812	381,088	100.0	6.6

3.2.4. Stormwater Runoff Reduction

Dalian's street trees intercepts approximately 217,404 m^3 of rainfall annually. The total stormwater runoff reduction benefits to Dalian were $459,457, with an average value of $8.0/tree (Table 5). The most effective species on a per tree basis were *P. acerifolia* ($10.8/tree), *P. canadensis* ($23.0/tree), *R. pseudoacacia* ($12.9/tree), and *S. matsudana* ($12.3/tree). The most important tree species for stormwater interception were *P. acerifolia* (34.9%), *G. biloba* (11.4%), *P. canadensis* (10.2%), *S. japonica* (9.0%), and *R. pseudoacacia* (7.6%), accounting for 73.1% of stormwater runoff reduction benefits.

Table 5. Annual stormwater runoff reduction benefits of predominant street trees.

Species	Total Rainfall Interception (m^3)	Total ($)	% of Total $	Avg. $/Tree
P. acerifolia	75,974	160,561	34.9	10.8
G. biloba	24,776	52,360	11.4	3.2
P. canadensis	22,077	46,657	10.2	23.0
S. japonica	19,611	41,445	9.0	7.4
R. pseudoacacia	16,492	34,853	7.6	12.9
P. occidentalis	16,388	34,633	7.5	9.6
S. babylonica	11,656	24,633	5.4	9.3
F. chinensis	8876	18,758	4.1	7.5
S. matsudana	5693	12,031	2.6	12.3
S. chinensis	3476	7345	1.6	2.8
Other species	12,387	26,179	5.7	7.2
Total	217,404	459,457	100.0	8.0

3.2.5. Property Value

The estimated property value benefits were $1,453,175, for an average of $25.2/tree (Table 6). *P. acerifolia* (27.2%), *G. biloba* (15.7%), *S. japonica* (11.0%), *R. pseudoacacia* (9.9%), and *P. canadensis* (7.9%) produced the highest property value benefits.

Table 6. Property value benefits produced by predominant street trees.

Species	Total ($)	% of Total $	Avg. $/Tree
P. acerifolia	395,614	27.2	26.7
G. biloba	227,539	15.7	13.8
S. japonica	159,430	11.0	28.6
R. pseudoacacia	144,095	9.9	53.2
P. canadensis	115,050	7.9	56.8
P. occidentalis	92,522	6.4	25.6
S. babylonica	73,816	5.1	27.8
F. chinensis	72,970	5.0	29.3
S. chinensis	56,390	3.9	21.6
S. matsudana	29,650	2.0	30.4
Other species	86,099	5.9	23.6
Total	1,453,175	100	25.2

3.2.6. Total Annual Benefits and Benefit-Cost Ratio (BCR)

The total benefits of Dalian's street trees were $4,913,328 annually, or $85.2/tree (Table 7). Over half (70%) of the total benefits provided to the city residents were environmental services. Energy savings accounted for 49% of the environmental benefits and 34% of the total benefits. The second largest benefits were property value benefits, accounting for 30% of the total benefits. The reduction of CO_2 accounted for 27% of the environmental benefits and 19% of the total benefits. Air pollutant removal (11%) and stormwater runoff reduction (13%) provided the lowest contribution to the environmental benefits and accounted for 8% and 9% of the total benefits, respectively.

The top 10 occurring species comprised 94.0% of the total annual benefits. *P. acerifolia* was the most valuable to the city (32.8% of total benefits). *G. biloba* (14.9%), *S. japonica* (8.8%), *R. pseudoacacia* (8.6%), *P. canadensis* (8.2%), and *P. occidentalis* (7.3%) also produced significant benefits to Dalian. On a per tree basis, *P. canadensis* ($199), *R. pseudoacacia* ($155), and *P. acerifolia* ($109) produced significant benefits. Additionally, *G. biloba* produced the least benefits at $44/tree.

The management costs of Dalian's street trees are approximately $1.5 million annually or $26.5/tree. Therefore, the annual net benefits were $3.4 million, at an average $58.7/tree (Table 7). City residents received $3.2 in benefits from every $1 invested in tree management, i.e., the benefit-cost ratio was 3.2:1.

Table 7. Benefits and costs for Dalian's street trees.

Benefits	Total ($)	$/Tree	% of Total Benefits
Energy	1,684,404	29.2	34.3
CO_2	935,205	16.2	19.0
Air Quality	381,088	6.6	7.8
Stormwater	459,457	8.0	9.4
Property value	1,453,175	25.2	29.6
Total benefits	4,913,328	85.2	
Total costs	1,526,302	26.5	
Net benefits	3,387,026	58.7	
Benefit-cost ratio	3.2		

3.2.7. Structural Value

The structural value of Dalian's street trees was $130 million (Table S1), which was estimated by the costs of replacing all street trees with trees of the same status. The average structural value per tree was $2250. *P. acerifolia* accounted for nearly 44% of the total structural value, followed by *G. biloba* (20.6%), *S. japonica* (8.4%), *P. occidentalis* (5.9%), *R. pseudoacacia* (5.4%), and *P. canadensis* (3.5%).

4. Discussion

4.1. Structure

Dalian's street trees were estimated to be 57,699 (Table 1). The street trees per capital were 0.04, lower than that in Europe and U.S. cities [10,11,21,41], reflecting the high population density in Dalian. The species abundance of street trees in Dalian (28 species) was approximately the same as other Chinese cities such as Shenyang (23 species), Lhasa (24 species) and Qingdao (43 species) [18,58,59]. However, the species abundance of street trees in these Chinese cities was smaller than other foreign cities (e.g., 105 to 214 species in Californian cities, 78 species in Lisbon, 130 species in Pittsburgh, 108 species in Bangalore, and 61 species in the Eastern Cape) [11,12,15,16,60], indicating that the species configuration lacks rationality in these Chinese cities. In addition, a diversity of street tree species is important to enhance the stability of street trees and protect street trees against the possibility of catastrophic losses [61]. Santamour [55] proposed a widely accepted diversity rule that any street tree species should not account for more than 10% of the total tree numbers, any one genus more than 20%, and any one family more than 30%. This meant that an ideal street tree of one city should not be dominated by a few species. In this study, however, the predominant tree species, *G. biloba* (28.7%) and *P. acerifolia* (25.7%), exceeded the accepted diversity rule. Another robust indicator, the importance value, was used to reflect the importance of tree species [32,33]. The importance values of the top 10 occurring species was 94.4, further indicating that Dalian's street trees were much too dependent on these few species. Overreliance on *G. biloba* and *P. acerifolia* has generated a serious management concern and made street trees vulnerable to catastrophic losses caused by plant diseases, insect pests, or other stressors, highlighting the need to diversify street tree species composition.

Previous studies have highlighted the importance of age structure in sustaining the stability and flow of benefits of street trees by offsetting the planting-related and age-related mortality [32,33,35]. However, Dalian's street trees failed to approach this ideal age distribution, with 18% of young trees, 56% of maturing trees, 25% of mature trees, and 1% of old trees (Figure 1). Millward and Sabir [57] suggested that large trees were responsible for the most of the benefits provided by street trees. Thus, the benefits provided by street trees may be approaching the peak or have peaked in the current age structure. However, given the concerning fact when comparing the ideal proportion of younger trees (40%) to that of the current population (18%), this indicates that the age structure of street trees in Dalian will develop towards the mature size classes without an inadequate number of young trees. With regard to more old trees, the urban planner will face greater management costs in order to sustain the high and sustained flow of benefits.

4.2. Function and Value

Street trees are a valuable green infrastructure and provide city residents with benefits in the form of functional value, i.e., energy savings, carbon reduction, air pollutants removal, storm water runoff reduction, and property value [11,12,21]. Numerous studies have demonstrated the monetary values of street trees [10–12,21]. Most Chinese cities, however, lack corresponding policies and management practices for street trees due to their unknown monetary values. Using i-Tree Streets, the total annual benefits provided to the city residents were estimated at $4,913,328 (Table 7), presenting the ecological and economic values of street trees to the urban planner and city residents of Dalian. In addition, of the total annual benefits, over half (70%) were environmental services in Dalian, which were different with other foreign cities with the most important benefit of property value (accounting for 43–83% of the total benefits) [10–12,21,33,60,62]. The most important environmental services were energy saving and carbon reduction, which might be attributed to the rapid urbanization and economic development of China. Nevertheless, the property value benefits still accounted for 30% of the total benefits. It is no doubt that street trees would increase sale prices when urban planners and city residents realize the monetary value of ecosystem services provided by street trees.

Management practices for street trees are costly to sustain the flow of benefits [11,12,21]. The management costs of street trees were $1.5 million in Dalian. As shown in our results, however, a benefit–cost ratio of 3.2 for Dalian demonstrated that the collective benefits produced by street trees were worth the costs of management. Compared to other cities, Dalian's BCR of 3.2 was greater than Modesto Santa (1.8), Monica (1.5), and Pittsburgh (2.9), but less than Lisbon (4.5), New York City (5.6), and Indianapolis (6.1) [10,12,33,60,62]. However, one fact that should be considered is that the age structure of street trees in Dalian will develop towards the mature size classes. Furthermore, 94.0% of total annual benefits were produced by the top ten street tree species in Dalian, and nine out of ten predominant street tree species were dominated by mature trees. The removal and replacement of old trees would reduce the net benefits and the benefit-cost ratio.

4.3. Management Implications

Dalian's street trees provide substantial benefits to the city residents and improve the quality of life. Additionally, the investment in the management of these public assets yields a large return economically, environmentally, and socially. However, Dalian still faces management challenges to optimize the structure of street trees to maximize and sustain the flow of benefits.

First, the distribution of Dalian's street trees was skewed towards a few species. Overreliance on *G. biloba* and *P. acerifolia* will remain a management concern due to the potential for catastrophic losses caused by plant diseases, insect pests, or other stressors. In addition, *G. biloba* produces less benefit at $44 per tree (Table S2). Large-stature trees such as *S. matsudana* ($111/tree) and *P. alba* ($140/tree), are good choices as alternatives to *Ginkgo biloba* and *Platanus acerifolia* (Table S2). These results highlight the need to diversify the species composition through new tree plantings to reduce dependence on *G. biloba* and *P. acerifolia* and to protect against catastrophic losses. Second, the age structure of Dalian's street trees is non-ideal as it lacks young trees (18%). In particular, of the five dominant tree species, all species (*G. biloba*, *P. acerifolia*, *S. japonica*, *P. occidentalis* and *P. canadensis*) exceeded the 50% ideal in the maturing and mature trees (15–60 cm). Although the current age structure of street trees tends to produce more benefits, more mature trees face greater maintenance costs. In addition, without planting young trees planting, the total benefits produced by street trees are vulnerable to fluctuations caused by the death and decline of old trees [34]. Thus, the municipality of Dalian needs to build an ideal age structure of street trees through new tree plantings to ensure a sustainable street tree structure.

4.4. Limitations and Uncertainty

In this study, the benefits produced by street trees were calculated on the basis of tree growth curves and other regionally specific data from "best fit" climate zone in the U.S. Thus, the benefits were approximations in this study due to the extrapolation of data from the reference city to Dalian as conducting a reference city analysis cost an estimated $250,000 per city when i-Tree Streets was used outside the U.S. [27]. However, we have done the following works of matching tree species and collecting local data in order to increase the accuracy of our results. First, matching street tree species is a priority as tree benefits are linked to species-specific size variables [27]. Despite the lack of growth curves for Dalian street trees, 63.3% tree species were matched with the reference city we selected. It was noted that the predominant species in Dalian were the species to species match with the reference city, e.g., *P. acerifolia*, *G. biloba*, *S. japonica*. For the remaining species, which were not available matched in species level, a genus to genus match approach was used [27]. Thus, the accuracy of the benefits calculated by i-Tree Streets increased with tree composition matching.

Second, we collected the benefit prices as best as we could including the average electricity [28], natural gas [29], the value of CO_2 reduction [30], and the median home price of Dalian to increase the accuracy of the results. Further study is required to obtain other benefit prices and geographic data to make the results more accurate.

Furthermore, there was an uncertainty in the estimates of the management costs of street trees. In this analysis, the management costs of street trees were estimated by an empirical value [31,57] due to lack of information regarding the municipal tree program expenditures in Dalian. Further precision of the management costs in this study is needed to understand the actual annual cost of maintaining street trees.

5. Conclusions

This study analyzed the structural characteristics of Dalian's street trees and estimated the monetary value of ecosystem services provided to the city residents through using i-Tree Streets. Dalian's street trees comprised a wide range of species; of the 57,699 trees present, 28 species were identified. The most predominant species were *G. biloba*, *P. acerifolia* and *S. japonica*, comprising 64.1% of the total tree numbers. These results indicated that street tree species composition faces a management concern and was vulnerable to catastrophic losses caused by plant diseases, insect pests, or other stressors. In addition, Dalian's street trees were distributed somewhat unevenly with fewer young trees (18%), a large proportion of maturing and mature trees (81%), and a deficit of old trees (1%). Although the current distribution of street trees provides more benefits, street trees with more mature trees will face greater maintenance costs without new plantings taking place.

Dalian's street trees provided substantial structural and functional benefits. The structural value of Dalian's street trees was approximately $130 million, with a value of $4.5 million for carbon storage. The annual functional benefits of Dalian's street trees were $4.9 million ($85/tree). Street trees increased property value with an estimated annual value of $1.5 million ($25/tree). The annual energy saving benefits from all street trees in Dalian was $1.7 million ($29/tree). The net carbon dioxide reduction benefit was valued at $0.9 million ($16/tree). Smaller benefits resulted from air quality ($0.4 million or $7/tree) and stormwater runoff ($0.5 million or $8/tree). However, city managers should also consider the management costs of street trees. The municipality of Dalian spent approximately

$1.5 million ($26/tree) annually on tree management. The annual net benefits were $3.4 million, an average of $59/tree. City residents received $3.2 in benefits from every $1 invested in management costs of street trees. Therefore, our results suggested that the benefits produced by street trees were worth the costs of management. However, the current state of Dalian's street trees is not sustainable due to the unreasonable structure. Managers and policy-makers must realize that street trees are a vulnerable resource and require constant care in order to continuously generate benefits in the future.

Supplementary Materials: The following are available online at www.mdpi.com/2071-1050/10/3/674/s1, Table S1: Structural values of Dalian's street trees, Table S2: Functional values produced by Dalian's street trees.

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Abbreviations

HDDs	Heating degree days
CDDs	Cooling degree days
DBH	Diameter at breast height
BVOCs	Biogenic volatile organic compounds
IV	Importance value
BCR	Benefit-cost ratio

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