The Contribution of Street Trees to Climate Resilient Cities in the Context of Ecosystem Services: The Case of Bahçelievler, Ankara

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1. Introduction

Climate change threatens the sustainability of ecosystems. It increases the frequency of excessive rainfall and scorching heat waves, lead the intensity of nature's destructiveness. As the intensity rises, the ecological balance enabling the sustainability of life on the planet becomes increasingly fragile (Eren, 2019). Sustainable urban planning plays a crucial role in mitigating the impacts of climate change, with street trees emerging as a key element in creating resilient cities.

As climate change accelerates, urban areas face increased threats from extreme weather events, heatwaves, and deteriorating air quality, necessitating innovative planning approaches that prioritize sustainability. Climate-resilient cities play an important role in reducing the impacts of climate change and enabling communities to adapt to these changes. Urban greenery, particularly street trees, offers multiple ecosystem services that contribute to climate resilience by improving air quality, reducing urban heat island effects, and managing stormwater runoff. Research highlights that street trees act as natural carbon sinks sequestering carbon dioxide and regulating temperatures through shading and evapotranspiration processes (Livesley et al., 2016). Furthermore, they provide social and psychological benefits by enhancing the aesthetic appeal of urban spaces and promoting well-being, which are critical components of sustainable, liveable cities. Sustainable urban planning that integrates street trees not only addresses immediate climate challenges but also fosters long-term resilience by enhancing biodiversity, improving local microclimates, and supporting urban infrastructure against environmental stressors (Gill et al., 2007). Such integration is increasingly seen as vital for cities aiming to balance urban growth with environmental sustainability, ensuring they can adapt to and withstand the multifaceted impacts of climate change.

The ecosystem approach to ensure sustainability is defined as a strategy for managing natural resources in a holistic manner that considers the balance of protection and use (Keleş, 2013). The assessment of ecosystem services and the ecosystem approach are closely related to the aim of ensuring the sustainable use and management of natural resources. By assessing ecosystem services, managers can gain a deeper understanding of the benefits an ecosystem may provide. This deeper understanding, in turn, supports developing and implementing holistic, adaptive, and sustainable management strategies inherent in the ecosystem approach. The ecosystem approach promotes the integrated management of land, water, and living resources to achieve sustainability (Yao et al., 2022; Gedikli, 2022).

In the same vein, Costanza et al. (1997) define ecosystem services as one that emphasizes the interdependence of human well-being and the health of ecosystems. Recognizing these services highlights the importance of conserving and managing ecosystems sustainably and contributing to livability. In other words, ecosystem services are the benefits that humans receive from ecosystems. These services are broadly categorized into four main types (Costanza et al., 1997):

Provisioning Services: These products are obtained from ecosystems, such as food, fresh water, timber, fiber, and genetic resources.

Regulating Services: These are the benefits of regulating ecosystem processes, such as climate regulation, disease control, water purification, and pollination.

Cultural Services: These include non-material benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.

Supporting Services: These are the services that are necessary for the production of all other ecosystem services, such as soil formation, nutrient cycling, and primary production.

There are also benefits from ecosystems within urban areas. In their study, Bolund and Hunhammar (1999) defined seven different urban ecosystems: Street trees, lawns/parks, urban forests, cultivated areas, wetlands, lakes/seas, and streams.

Street trees play a vital role in enhancing the resilience of urban environments, particularly in the face of climate change. As cities grow and face increasing environmental challenges, the integration of natural elements such as trees becomes crucial for sustainable development. Street trees contribute to climate-resilient cities by providing a wide range of ecosystem services, including the regulation of urban temperatures, improvement of air quality, stormwater management, and the enhancement of biodiversity. These green infrastructures act as natural buffers, mitigating the effects of urban heat islands and reducing the energy demands of surrounding buildings. In addition, street trees enhance the aesthetic value of urban spaces, promoting mental well-being and fostering social cohesion. However, their role goes beyond environmental benefits; they are integral to urban planning strategies aimed at adapting to and mitigating climate-related risks.

This paper explores the multifaceted contributions of street trees to climate resilience in urban areas, with a focus on the ecosystem services they provide. By exploring their ecological, social, and economic impacts, we aim to demonstrate how urban Street trees can be a cornerstone of future city planning, enabling cities to become more adaptable and resilient in the face of climate change.

Street trees provide a wide range of benefits to people and the environment, from regulatory services to supporting services, from provisioning services to cultural services. Recognizing these services, the protection and management of street trees is critical to maintaining ecological balance and improving the quality of urban life. As the global urban population continues to rise, cities face increasing challenges related to climate change, including higher temperatures, extreme weather events, and deteriorating air quality. In this context, the concept of climate resilience—referring to the ability of urban areas to adapt and recover from climate-related disturbances—has gained significant attention in urban planning. A key component in building climate-resilient cities is the integration of nature-based solutions, particularly street trees, which provide a wide range of ecosystem services. These services, including carbon sequestration, air purification, temperature regulation, and stormwater management, are crucial in mitigating the adverse effects of climate change and improving the overall livability of cities.

Street trees offer critical ecosystem services that significantly enhance urban environmental quality and human well-being. These services include improving air quality by filtering pollutants such as particulate matter and nitrogen dioxide, thus improving urban residents' respiratory health. Additionally, street trees play a vital role in climate regulation through carbon sequestration, helping mitigate climate change's effects by absorbing carbon dioxide and releasing oxygen. Their presence reduces the urban heat island effect, lowering temperatures in city areas by providing shade and releasing moisture into the air through transpiration, enhancing thermal comfort for pedestrians. Furthermore, street trees help manage stormwater by reducing runoff, thus preventing flooding and reducing the burden on urban drainage systems. They also support biodiversity by providing habitats and food for urban wildlife, promoting a more balanced urban ecosystem (i-Tree, 2021).

Street trees offer environmental, social, and economic benefits in terms of ecosystem services for people. Many studies in the literature emphasize the benefits of street trees. However, these studies have generally evaluated street trees from an anthropocentric perspective. Street trees enable natural processes to interact and ensure the continuity of nature's functioning by creating a continuous canopy that forms a green network.

By supporting a diverse range of organisms, street trees help sustain urban ecosystems and enhance their resilience to environmental changes. Thus, when assessing the value of street trees, it is essential to consider their broader ecological significance beyond human-centered benefits, recognizing their role in fostering biodiversity and maintaining the integrity of urban ecosystems.

1.1. The Crucial Role of Street Trees in Combating and Adapting to Climate Change as Urban Guardians

Street trees are crucial in sustaining ecosystem services in urban areas and developing approaches to climate change adaptation. They provide many direct and indirect benefits for neighborhood residents and the city. Street trees reduce the adverse effects of climate change by strengthening the connection with nature. The canopy continuity provided by street trees creates connections between independent green areas and creates a green corridor. Thus, it allows the continuation of ecosystem services. The shade cover of street trees provides climatic comfort in hot weather and alleviates heat-related health problems (İnci & Görer Tamer, 2022).

Also, street trees play a significant role in climate change mitigation through various ecological processes that reduce greenhouse gases and adapt urban environments to changing climates. One of the primary ways street trees mitigate climate change is through carbon sequestration. Trees absorb carbon dioxide (CO2) from the atmosphere during photosynthesis, storing carbon in their biomass (stems, branches, leaves, and roots), reducing atmospheric CO2 levels. This long-term carbon storage is designed for extended periods, as trees act as natural carbon sinks. Street trees significantly contribute to carbon storage and sequestration, which is crucial for mitigating climate change. For instance, in Kyoto, Japan, street trees provide an annual value of $41.34 per tree for carbon storage and sequestration (Tan et al., 2021). Similarly, in Szeged, Hungary, urban trees have been evaluated for their capacity to sequester carbon, significantly impacting urban planning processes (Kiss et al., 2015).

Additionally, street trees help moderate urban temperatures provide cooling benefits, and reduce the effects of urban heat islands. Trees can significantly lower ambient temperatures by providing shade and releasing moisture through transpiration, decreasing the demand for air conditioning in nearby buildings. This reduced energy consumption translates to lower fossil fuel use and fewer carbon emissions from power plants. In Kyoto, Japan, the energy savings provided by street trees were valued at $1.67 per tree annually (Tan et al., 2021). In Germany, urban trees were found to reduce direct and thermal radiation by up to 58%, demonstrating their critical role in temperature regulation (Scholz et al., 2018). Similarly, in Shenyang, China, the total ecological benefit value of street trees was estimated at $163,965.62, with an additional combined thermal comfort benefit of $233,533.48, totaling $397,499.10 in one year (Sui et al., 2023).

Regarding air quality, street trees play a vital role by removing particulate matter and nitrogen dioxide pollutants. In Dalian, China, for example, street trees provide air quality improvement services valued at $381,088 annually (Wang et al., 2018). Likewise, street trees are instrumental in removing air pollutants in Berlin, Germany, highlighting their importance in urban ecosystem services (Döhren & Haase, 2019).

Street trees also enhance local climate resilience by improving stormwater management. Street trees mitigate stormwater runoff, reducing the risk of flooding in urban areas. Their root systems increase soil permeability, which helps absorb rainwater and reduces surface runoff by mitigating the risk of urban flooding during extreme weather events. This can prevent infrastructure damage and reduce the energy required for pumping and treating stormwater (Marando et al., 2019; Nowak, 2000). In Taipei, Taiwan, street trees contribute to runoff avoidance with an estimated economic value of $5.6 million (Cheng & Wei, 2020).

Street trees provide critical ecosystem services in urban environments, contributing to environmental sustainability, human health, and urban aesthetics. These trees are significant in carbon sequestration, air quality improvement, stormwater management, and temperature regulation, among other benefits.

Understanding and quantifying these services is essential for urban planning and policy-making to enhance cities' livability. So, the density of tree placement and street trees can be an essential tool for urban planners and designers in developing resilient and resourceful cities in an era of climatic change (Salmond et al., 2016).

The study emphasizes that urban trees serve as a critical defense system for climate-resilient settlements, highlighting the need for proactive steps to protect and develop existing trees. In Ankara’s Bahçelievler District, street trees play a particularly important role in fostering climate-resilient urban environments. To successfully implement street afforestation plans, it is essential to establish a comprehensive mapped database of existing trees within cities. This database will provide the necessary foundation for effective management and expansion of urban greenery.

1.2. The Role of i-Tree Ecosystem Application in Estimating Ecosystem Service Values of Street Trees

Inventories are considered a critical tool in protecting and improving urban ecosystems. Understanding street trees' structural characteristics and ecosystem services allows city planners and managers to make more informed decisions. Street tree inventories are vital for the sustainability and improvement of urban environments. These studies provide the necessary data to optimize cities' ecosystem services and contribute to preserving long-term environmental benefits.

Tree inventory is a process that identifies and records the number, species, size, and health of trees within a given area. A tree inventory is vital for monitoring the health of ecosystems, sustainable management of natural resources, and combating climate change. In particular, the status of trees within cities is essential for planning and protecting green areas in urban planning and green space management. Such studies ensure that the services provided by street trees are comprehensively assessed and that these services are managed sustainably (Gedikli, 2022).

The prominent application in tree inventory is i-Tree. i-Tree is a set of tools and software packages for tree inventory creation and urban forest management. The i-Tree program allows for a holistic assessment of environmental, economic, and social benefits in tree inventory creation and management. For this reason, it is considered a critical tool in urban planning and environmental management. The ecosystem services of trees can be evaluated scientifically, and their benefits can be expressed in monetary terms. The created inventory is an essential source of information for municipalities, urban planners, and environmental managers, guiding them in decision-making processes and directing afforestation strategies. It provides input for scientific research and public awareness studies to examine the long-term effects of trees, combat climate change, and promote sustainable urban planning (Eren, 2021).

In Türkiye, open source access to tree information in urban areas is limited.

Some mobile or web-based applications have introduced trees. Some of these applications with different functions are “Doğa Kâşifi,” “Konuşan Ağaç, and “Anıt Ağaç” application. Local platforms focusing on a limited region and the inventory of monumental trees and trees worth protecting share them with a web page and smartphone application in a limited geographical area. The i-tree smart application can collect global inventory and calculate ecosystem service value (2021,06 16). The i-Tree Eco software was first used in Türkiye by Tuğluer & Gül (2018) in their study in Isparta.

Unlike other studies, this study is essential because it makes visible the contribution of a limited number of mature street trees to climate resilience at the neighborhood scale. In this study, street trees will be discussed, focusing on their roles within the urban ecosystem, and the regulatory ecosystem service values they provide in the context of adaptation to climate change.

Street trees growing on public sidewalks or roads provide continuity by creating a green and cool corridor within the city, connecting green areas. Street trees have countless environmental, social and economic benefits and are gradually lost because precautions are not taken. In particular, it is significant for mature and old street trees, which provide more benefits than newly planted young trees, to be protected by both local governments and neighborhood residents to prevent them from facing the danger of extinction. It emphasizes ensuring the sustainability of street trees for a nature-based climate adaptation strategy.

The i-Tree Ecosystem Analysis is a comprehensive suite of tools and software developed by the USDA Forest Service and its partners to assess and quantify the benefits provided by urban trees and forests. These tools help urban planners, foresters, researchers, and community groups understand and maximize the ecological, economic, and social services that trees offer in urban environments. Here is an overview of the i-Tree Ecosystem Analysis and its key components (Nowak et al., 2008).

Quantifying Ecosystem Services: i-Tree tools evaluate a range of ecosystem services trees provide, including carbon sequestration, air pollution removal, stormwater runoff reduction, energy savings, and biodiversity support. By quantifying these services, i-Tree helps demonstrate the tangible benefits urban trees provide to communities.

Economic Valuation: The analysis translates ecological benefits into economic terms, providing estimates of the monetary value of ecosystem services. This information is crucial for justifying investments in urban forestry and making informed management decisions.

Comprehensive Urban Forest Inventory: i-Tree tools facilitate the collection and analysis of data on tree species, size, health, and distribution. This inventory helps cities manage their urban forests effectively, identifying areas for improvement and strategic planting.

Scenario Modeling and Forecasting: i-Tree allows users to model different scenarios and predict the future impact of various management strategies. This capability aids in planning for climate change adaptation, pest outbreaks, and urban development pressures (Nowak, 2021).

Community Engagement and Education: i-Tree provides accessible tools to non-experts, helping communities understand the value of their urban forests and encouraging public participation in tree planting and care initiatives.

Policy Support and Decision-Making: The insights gained from i-Tree analyses can inform policy development, helping governments prioritize urban forestry initiatives and allocate resources efficiently. By demonstrating the return on investment of urban trees, i-Tree supports sustainable urban planning.

Flexible and Adaptable Tools: The i-Tree suite includes various applications tailored to different scales and needs, such as i-Tree Eco for detailed urban forest analysis, i-Tree Canopy for quick assessments of tree cover, and i-Tree Hydro for analyzing stormwater impacts. This flexibility allows users to choose the appropriate tool based on their objectives and resources.

Global Application: While initially developed in the United States, i-Tree tools have been adapted for use in many countries worldwide, incorporating regional data and metrics. This global applicability makes i-Tree a valuable resource for international urban forestry efforts. By providing detailed, data-driven insights into the benefits of urban trees, i-Tree Ecosystem Analysis supports the effective management and enhancement of urban forests, contributing to more sustainable and resilient cities (2021,06 16).

The i-Tree Eco application, developed by the U.S. Department of Agriculture, is used in more than 100 countries to quantify urban trees' multidimensional ecosystem service value (Rogers et al., 2015).

In Turkey, limited studies reveal the ecosystem service values of trees using the i-Tree Eco software. The first study, the i-Tree Eco software application, was carried out with a detailed inventory study of the existing road trees on the most crucial boulevard of Isparta City, “Süleyman Demirel Boulevard” (SDB) (Tuğluer & Gül, 2018). Another application, within the scope of the project titled “Tree Inventory and Ecosystem Services Technical Guide”, was carried out by the Landscape Research Association (PAD) as a mobile application with Turkish support. Within the scope of the “My Tree” application software, an inventory study of the monumental trees located on Kumrular Street in Ankara was carried out (Ağacım, 2023, 02.10). Taking into account the applications stated above, this chapter is based on the thesis entitled “An Approach to Protection of Street Trees As Green Infrastructure Unit At The Neighborhood Level: The Case Of Ankara Bahçelievler District”. The inventory recording of street trees was carried out with the “Nature at My Door” phone application, the content of which was also created within the thesis. Using the i-Tree Eco program revealed the ecosystem service value of the trees on the determined route in the Bahçelievler District (İnci, 2023).

2. Material and Method

The study area is Bahçelievler District, a settlement planned by Hermann Jansen with the garden city model in the Çankaya District of Ankara. Urban transformation gradually leads to decreased street trees in the neighborhood, with 5.5 street trees per 100 people in 2019 (İnci, 2023). Therefore, the study emphasizes the value of trees in terms of the ecosystem services they provide, starting from the importance of street tree presence in terms of climate-resilient settlements.

This study utilized the i-Tree Eco model, a software developed by the US Department of Agriculture and Forest Service (USDA), to assess and visualize the ecosystem services provided by street trees.

The study is based on estimating ecosystem value in the i-Tree Eco program of street tree data generated via the phone application. The phone application is created in collaboration with Başarsoft.

In the street tree inventory created through the “Nature at My Door” application, ten different parameters based on the physical properties of street trees, including species name, stem diameter, height at which the stem diameter is measured, total tree height, living tree height, crown base height, crown width (north-south), crown width (east-west), crown health, and degree of light intake, were selected according to the titles required for the i-Tree Eco software. The i-Tree Eco model provides detailed insights into various ecosystem services by quantifying metrics such as carbon storage, pollution removal, and runoff avoidance. This data is crucial for urban planners in making informed decisions to optimize urban greenery for both environmental and economic benefits.

Within the scope of the study, six different parameters, including the soil area of the tree above the pavement, the distance from the street corner to the tree, the distance from the measured tree to the unmeasured tree, the pavement width where the tree is located, the number of forks of the tree, and the stem circumference, were evaluated together with experts and added to the physical properties section of the application. The tree information to be recorded with the smartphone application provides comprehensive information with simultaneous tree cadastre and tree relief information compared to other inventories.

The application was utilized on the specified route to gather data about street trees using volunteers, thereby compiling an inventory based on this data. This application, considered within the citizen science framework, facilitates data collection and monitoring by automatically consolidating the user-entered information into a single database. It also contributes to forming an active database by allowing the data to be updated continuously.

The following table summarizes the key steps in the field work.

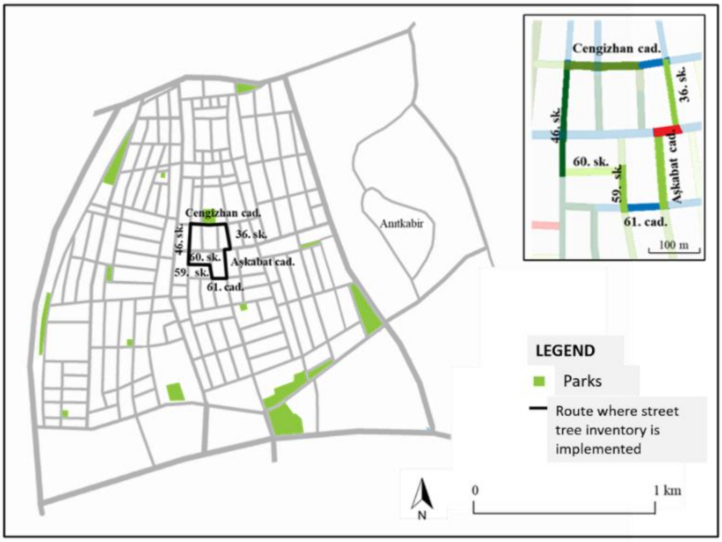
Step	Description
Feature of the study area	Decrease in street trees due to urban transformation (5.5 trees per 100 residents)
Objective	To raise awareness for the protection and dissemination of street trees by revealing their ecosystem service value and their role in planning climate resilience cities and neighborhoods.
Model Used	i-Tree Eco Model developed by the USDA Forest Service
Data Collection Method	Field study using a mobile application (Nature at My Door) developed in collaboration with Başarsoft.
Tree Inventory Parameters	- Species Name - Stem Diameter - Tree Height - Crown Width (north-south, east-west)

Step	Description
	-Crown Health - Permeable Surface Area
Assessment	Data was transferred to the i-Tree Eco program for analysis of ecosystem services provided by 115 street trees.
	Report generated in May 2023 showing ecosystem service values of the Street trees in the Bahçelievler case.

The study reveals the ecosystem service value for 115 street trees along the Route was recorded in the street tree inventory using the phone application called “Nature at My Door” (Map 1).

The route is determined to include six groups of streets (Figure 1) based on the frequency of tree presence in the street vista and canopy criteria.

Figure 1. Trees' Effect on the Street View



Map 1. Study Area and Street Trees Route in the Bahçelievler Neighborhood (Ankara) (İnci, 2023)

Table 1. Distribution of Street Trees and Species along the Route in Bahçelievler (İnci, 2023)

Street Name	Street Tree Species	Number of Trees	(%)
60. St.	*Platanus orientalis*- Oriental Plane Tree	1	0.87
59. St.	*Acer negundo* – Boxelder	3	2.61
	Acer pseudoplatanus -Mountain maple	2	1.74
	Alianthus altissima – Tree of Heaven	1	0.87
	Cupressocyparis leylandii – Hybrid Cypress	1	0.87
	Cupressus arizonica – Arizona Cypress	1	0.87
	Sophora japonica – Sophora	1	0.87
	Pinus brutia – Red Pine	1	0.87
61. St.	*Acer negundo* – Boxelder	2	1.74
	Fraxinus excelsior-European ash	2	1.74
	Alianthus altissima- Tree of Heaven	1	0.87
	Prunus mahaleb	1	0.87
Aşkabat St.	*Fraxinus excelsior* - European ash	11	9.57
	Fraxinus americana – White Ash	4	3.48
	Tilia tomentosa – Silver Linden	1	0.87
36. St.	*Aesculus hippocastanum* - Horse Chestnut	4	3.48
	Koelreuteria paniculata – Golden raintree	2	1.74

	Acer negundo - Boxelder	1	0.87
	Fraxinus excelsior - European ash	1	0.87
	Robinia pseudoacacia - Water locust	1	0.87
Cengizhan St.	*Aesculus hippocastanum* - Horse Chestnut	12	10.43
	Platanus orientalis - Oriental Plane Tree	8	6.95
	Acer negundo - Boxelder	4	3.47
	Tilia tomentosa – Silver Linden	3	2.61
	Quercus robur – English Oak	1	0.87
	Sophora japonica – Sofora	1	0.87
46. St.	*Platanus orientalis* - Oriental Plane Tree	42	36.52
	Acer negundo - Boxelder	1	0.87
	Aesculus hippocastanum - Horse Chestnut	1	0.87
Total number of street trees on the route		115	100.00

There are 16 different tree species within the study area. The distribution of these trees in terms of species and numbers on the streets of the route is given in Table 1. As can be seen in the study area, the three most common species are 32.9% Oriental Plane Tree (Platanus orientalis), 10.97% Horse Chestnut (Aesculus hippocastanum), and 9.03% European Ash (Fraxinus excelsior). In addition, the dominant tree species on each street differs (Table 1).

3. Findings and Discussion

Street trees along the Route were examined in two main sections regarding the ecosystem service value they provide. The first is structural and compositional, and the second is functional analysis.

3.1. Structural and Composition Analyses

The street trees on the route consist of native and exotic tree species. 64% of the trees are of European and Asian origin, while approximately 3% are species native to Asia. In terms of leaf area, the most dominant species were determined to be the Oriental Plane Tree (*Platanus orientalis*), Horse Chestnut (*Aesculus hippocastanu*m) and European Ash

(*Fraxinus excelsior*). When the first three street trees providing a total leaf area of 93.01 hectares are examined, the Oriental Plane Tree (*Platanus orientalis*) with 59.2 hectares, the Horse Chestnut (*Aesculus hippocastanum*) with 19.8 hectares and the European Ash (*Fraxinus excelsior*) with 9.2 hectares respectively had the highest value. Species with high values in leaf area do not always mean species that need to be encouraged in the future. Instead, these species determine the dominant species among the trees.

The three most common species are Oriental Plane Tree (44.3%), Horse chestnut (14.8 %), and European ash (12.2 %) (Figure 2). In Bahçelievler, about 3 percent of the trees are species native to Asia. Most trees originate from Europe and Asia (64.0%).

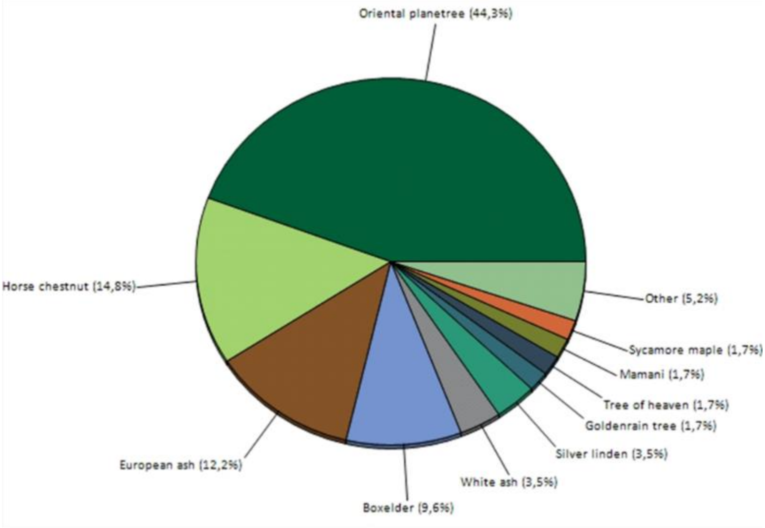


Figure 2. Tree Species Composition along The Route in Bahçelievler (i-Tree Eco, 2023)

Wang et al. (2020) evaluated trees in three classes in terms of stem diameter; less than 20 cm (young trees), trees between 20 cm and 40 cm, and trees greater than 40 cm (mature trees) diameter.

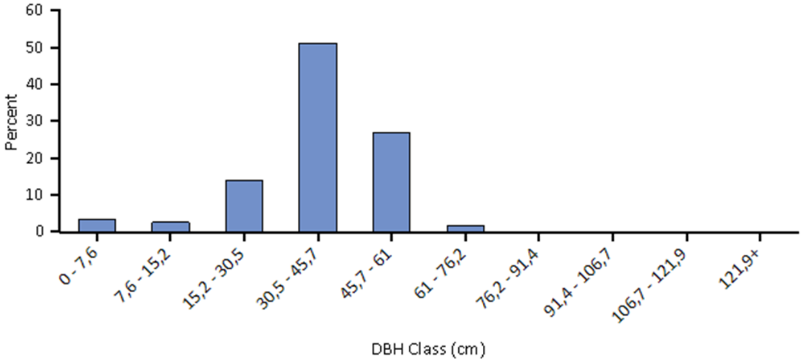


Figure 3. Percent of tree population by stem diameter class (DBH-stem diameter at 1.37 meters) along the Route in Bahçelievler Neighborhood (i-Tree Eco, 2023)

According to the measurements on the physical appearance of street trees, 8.70% of the street trees are smaller than 20 cm in terms of stem diameter; 41.7% are between 20-40 cm; 49.6% are larger than 40 cm. These results revealed that mature trees are predominant in the study area (Figure 3). In particular, mature street trees are seen on Cengizhan Street and 46th Street on the route (Table 2).

Table 2. Stem Diameter Class of Street Trees along the Route in Bahçelievler Neighborhood (İnci, 2023)

Street Name	Stem Diameter Class -DBH (cm)	Number of Trees	(%)
60. St.	20-40	1	0.87
59. St.	< 20	4	3.48
	20-40	5	4.35
	>40	1	0.87
61. St.	< 20	1	0.87
	20-40	5	4.35

Aşkabat St.	< 20	5	4.35
	20-40	7	6.09
	>40	4	3.48
36. St.	20-40	1	0.87
	>40	8	6.96
Cengizhan St.	20-40	16	13.91
	>40	13	11.30
46. St.	20-40	13	11.30
	>40	31	26.96

Analyses on the height of street trees displayed that 2.61% are under 5 meters; 7.83% are between 5-7.9 meters; 46.96% are between 8-15 meters and 42.61% are over 15 meters. In general, it was determined that there are medium-sized street trees in the study area. Newly planted and small trees are pretty rare (Table 3).

Table 3. Height Class of Street Trees along the Route in Bahçelievler Neighborhood (İnci, 2023)

Street Name	**Tree Height (m)**	**Number of Trees**	**(%)**
60. St.	>15 (tall tree)	1	0.87
59. St.	<5(newly planted tree) (sapling)	3	2.61
	5-7,9 (small tree)	1	0.87
	8-15 (medium sized tree)	3	2.61
	>15 (tall tree)	3	2.61
61. St.	5-7,9 (small tree)	1	0.87
	8-15 (medium sized tree)	5	4.35
Aşkabat St.	5-7,9 (small tree)	5	4.35
	8-15 (medium sized tree)	11	9.57
36. St.	8-15 (medium sized tree)	8	6.96
	>15 (tall tree)	1	0.87
Cengizhan St.	5-7,9 (small tree)	1	0.87
	8-15 (medium sized tree)	26	22.61
	>15 (tall tree)	2	1.74
46. St.	5-7,9 (small tree)	1	0.87
	8-15 (medium sized tree)	1	0.87
	>15 (tall tree)	42	36.52

3.1.1. Street tree cover and leaf area

Many tree benefits equate directly to the plant's healthy leaf surface area. Trees provide 93.01 hectares of leaf area on the route in Bahçelievler.

In Bahçelievler, the most dominant species in terms of leaf area are Oriental Plane Tree, Horse Chestnut, and European Ash. The ten species with the most significant importance values are listed in Table 4. Importance values (IV) are calculated as the sum of the percent population and percent leaf area. High importance values do not mean that these trees should necessarily be encouraged in the future; rather, these species currently dominate the urban forest structure.

Table 4. The Top 10 Species along the Route in Bahçelievler Neighborhood (i-Tree Eco, 2023)

Species Name	**Population (a) %**	**Leaf Area (b) %**	**Importance values (a+b) %**
Oriental planetree	44.3	59.2	103.5
Horse chestnut	14.8	19.8	34.5
European ash	12.2	9.2	21.3
Boxelder	9.6	5.2	14.8
Silver linden	3.5	3.9	7.4
White ash	3.5	0.1	3.5
English oak	0.9	1.6	2.5
Tree of heaven	1.7	0.2	2.0
Goldenrain tree	1.7	0.2	2.0
Sycamore maple	1.7	0.2	1.9

3.2. Functional Analyses

The i-Tree Eco application was reported under five headings as ecosystem service value in the package program transferred as an Excel file. These were evaluated as ecosystem services through air pollution removal, carbon sequestration, and storage, air quality improvement, and avoided runoff rainwater. The i-Tree-Eco report is summarized below.

3.2.1. Air pollution removal by urban trees

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, consequently reducing air pollutant emissions from the power sources. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that increased tree cover reduces ozone formation (Nowak et al., 2000).

Pollution removal by trees in Bahçelievler was estimated using field data and recent pollution and weather data available. Pollution removal was most significant for nitrogen dioxide (Figure 5).

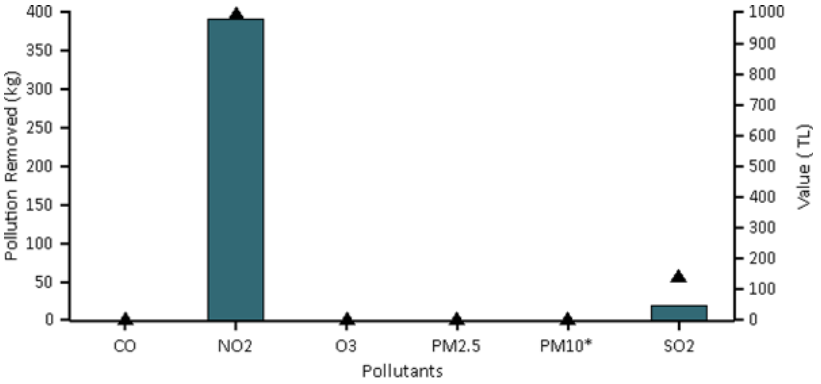


Figure 5. Annual Pollution Removal (points) and Value (bars) by Urban Trees, along the Route Bahçelievler (i-Tree Eco, 2023)

It is estimated that trees remove 452 kilograms of air pollution (ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter less than 2.5 microns (PM2.5), particulate matter less than 10 microns and more significant than 2.5 microns (PM10*)2, and sulfur dioxide (SO_2)) per year with an associated value of TL. 1030 (€ 48) (The average euro exchange rate for May 2023 was taken as reference, May 2023 1Avro=21,5 TL.)

3.2.2. Carbon sequestration and storage

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue, altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel-based power sources (Abdollahi et al., 2000).

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of Bahçelievler trees is about 2 086 metric tons of carbon per year with an associated value of TL. 1860 (77,5 €). The most effective tree is the Oriental Plane Tree, 46.1% of all sequestered carbon (Figure 6).

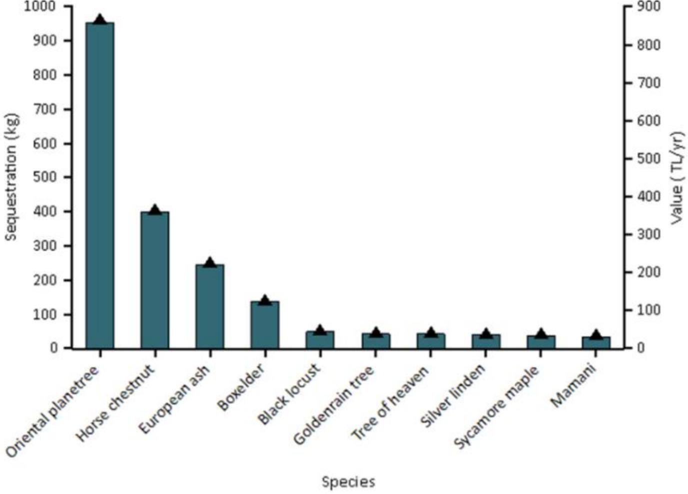


Figure 6. Estimated Annual Gross Carbon Sequestration (point) and Values (bars) for Urban Tree Species with the Greatest Sequestration along The Route in Bahçelievler (i-Tree Eco, 2023)

Carbon storage is another key way trees influence global climate change. As trees grow, they store more carbon in their accumulated biomass. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Thus, carbon storage indicates the amount of carbon that can be released if trees are allowed to die and decompose.

Street Trees in Bahçelievler on the route stored 47.25 metric tons (1000 kilos) of carbon, with a total value of TL 42100 (1750 €). Among the sampled species, the tree species with the highest carbon storage amount (approximately 45.8% of the total carbon) was the Oriental Plane Tree (Platanus orientalis), with a total of 21.64 metric tons (Figure 7).

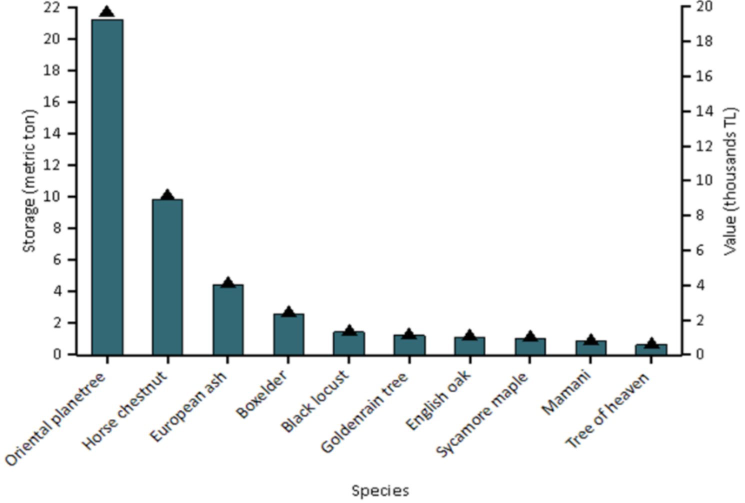


Figure 7. Estimated Carbon Storage (point) and Values (bars) for Urban Tree Species with the Greatest Storage along The Route in Bahçelievler (i-Tree Eco, 2023)

3.2.3. Air quality improvement

Oxygen production is one of the most commonly cited benefits of urban trees. The annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass.

Trees in Bahçelievler are estimated to produce 5.563 metric tons of oxygen annually. Oriental Plane and Horse Chestnut trees contribute the most to oxygen production species. They are mature trees in stem diameter and leaf area and are the dominant tree species (Table 5).

Table 5. The Top 16 Oxygen Production Species along The Route in Bahçelievler (i-Tree Eco, 2023)

Species	Oxygen (kilogram)	Gross Carbon Sequestration (kilogram/yr)	Number of Trees	Leaf Area (hectare)
Oriental plane Tree	2.563,48	961.31	51	5504
Horse chestnut	1.078,01	404.25	17	18.38
European ash	661.29	247.98	14	8.52
Boxelder	369.83	138.69	11	4.87
Black locust	133.33	50.00	1	0.23
Golden rain tree	114.77	43.04	2	0.21
Tree of heaven	113.16	42.44	2	0.22
Silver linden	110.94	41.60	4	3.66
Sycamore maple	103.09	38.66	2	0.18
Mamani	94.50	35.44	2	0.03
English oak	83.96	31.48	1	1.53
White ash	83.03	31.14	4	0.05
Mahaleb Cherry	40.05	15.02	1	0.04
Cypress spp	6.26	2.35	1	0.00
Arizona cypress	6.26	2.35	1	0.03
Turkish pine	1.45	0.54	1	0.01
Total	*5.563,41*	*2.086,29*	*115*	*93.00*

3.2.4. Avoided runoff rainwater

Surface runoff can cause concern in many urban areas as it can pollute streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion of the precipitation is intercepted by vegetation (trees and shrubs) while the other portion reaches the ground. The portion of the precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff (Hirabayashi, 2012). In urban areas, the large extent of impervious surfaces increases the amount of surface runoff.

Urban trees and shrubs, however, are beneficial in reducing surface runoff. Trees and shrubs intercept precipitation, while their root systems promote infiltration and storage in the soil.

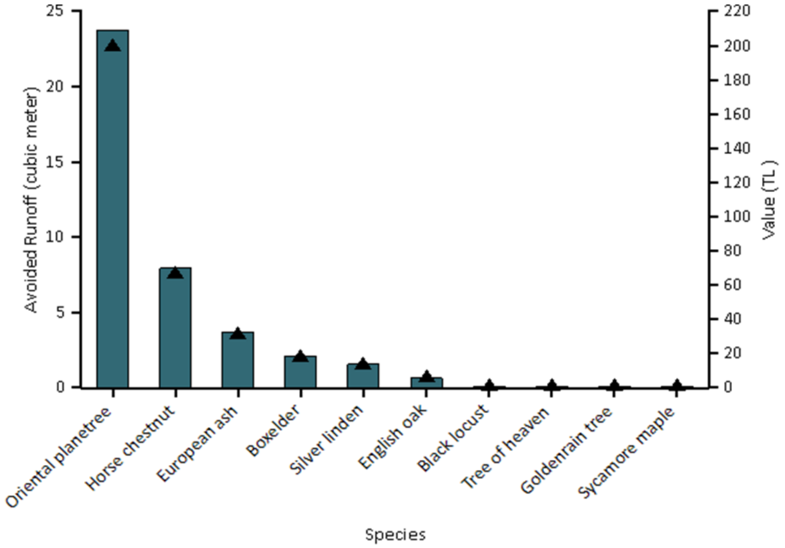


Figure 8. Avoided Runoff (point) and Value (bars) for Species with Greatest Overall Impact on Runoff, along The Route in Bahçelievler (i-Tree Eco, 2023).

The street trees of Bahçelievler help to reduce runoff by an estimated 38.2 cubic meters annually, with an associated value of TL 354 (15 €). Avoided runoff is estimated based on local weather from the user-designated weather station. In Bahçelievler, the total annual precipitation in 2017 was 10.3 centimeters.

Finally, the total street tree replacement value was determined as TL 1.42 million (59.166 €). The replacement value of a tree defines the cost of replacing a tree with a similar tree. This value tends to increase with the number and size of healthy trees. The ecosystem service values of street trees can be increased by protecting and managing them (i-Tree Eco, 2023) To summarize the ecosystem value of 115 street trees on the route in the Bahçelievler case study, they have stored 47.25 metric tons of carbon during their lifetime and sequestered 2.09 tons of carbon per year. It was determined that the street trees on the route produced 5.56 metric tons of oxygen annually and eliminated a total of 452 kg of air pollution. In addition, the street trees on the route delay 38.24m^3 of rainwater runoff annually. The tree with the highest ecosystem service value among the street trees along the route was the Eastern Plane Tree (Platanus Orientalis). In this context, the protection of street trees, such as old Plane Trees (Platanus orientalis), which form canopy continuity on 46th Street, is essential to maximizing the value of street trees in terms of ecosystem services.

With this study, the number of research projects focusing on street trees using the i-Tree-Eco software in Turkey is steadily increasing. These studies play a crucial role in highlighting the ecosystem services provided by street trees, paving the way for further exploration and analysis. The following examples illustrate the growing body of work in this field.

One of these works was implemented within the project titled “Tree Inventory and Ecosystem Services Technical Guide” conducted by the Landscape Research Association (PAD). Kumrular Street in Ankara city center, 71 trees were recorded with the “My Tree” application. The total replacement value of the trees on Kumrular Street was 137,585.00 €, and their carbon storage value was 1,114.00 €. The average functional values of each tree were calculated as follows: carbon storage 0.10 €, surface runoff prevention 28.50 €, and pollution prevention value 3.65 € (Ağacım, 2023, 02 10).

A similar study conducted in Isparta City observed that similar types of trees have superior carbon retention properties. Biomass and carbon storage values were obtained from the inventory data of 1498 trees on Süleyman Demirel Boulevard. According to these results, it was determined that the trees on this Boulevard held a total of 197.566 kg of carbon throughout their lifespan. It was observed that the tree species with the highest carbon storage amount was Platanus Orientalis, with an average of 564 kg per tree. The annual carbon storage amounts of the trees were also calculated, and it was determined that all trees stored 21.839 kg of carbon per year. When examined on a species basis, it was determined that Platanus orientalis had the highest annual carbon storage average of 45.8 kilograms (Tuğluer & Gül, 2018, p. 301).

In a similar study handed out using i-tree eco reporting to research by Selim & Atabey (2023), 388 trees in Antalya Atatürk Boulevard have annual carbon storage of 48.5 metric tons.

Another i-Tree Ecosystem reporting was conducted on 588 trees in Burdur city center. In this study, it was seen that street trees produced an ecosystem service value of 66.79 kg of pollution removal, 12.92 metric tons per year of carbon sequestration, 34.44 metric tons per year of oxygen production, and 52 cubic meters per year of stormwater runoff avoided (Kaçmaz Akkurt et al., 2023).

Based on the findings of the above studies, street trees' environmental service values in terms of carbon storage and sequestration come to the fore. This study highlights how important street trees, especially mature ones, are in terms of the diversity and value of the services they provide within a limited area. The findings highlight the significant role of street trees in improving urban environments. For instance, the economic valuation of pollution removal and carbon storage by trees like the Oriental Plane Tree provides strong evidence for including street trees in future urban planning efforts.

The studies mentioned above provided numerical data that revealed the ecological and economic importance of street trees. Street trees play a crucial role in the protection and sustainable management of urban areas by delaying rainwater runoff and providing various ecosystem services. This is particularly important in mitigating the harmful effects of climate change. It is essential to plant new trees to maintain canopy continuity, increase tree shade coverage in cities, and protect existing trees to maximize their ecosystem service values.

4. Conclusion and Suggestions

Street trees provide essential ecosystem services that greatly contribute to urban sustainability and quality of life. Some of the primary benefits of street trees include carbon capture and storage, air quality improvement, stormwater management, and temperature regulation. Additionally, they offer cultural, aesthetic, and biodiversity-related benefits.

For instance, in London, the i-Tree Eco program is used to assess the physical properties of trees and the ecological benefits they provide throughout the year. Similarly, in Washington, the i-Tree application is employed to evaluate the amount of carbon storage, stormwater runoff prevented by trees, and their impact on air quality. Similar analyses conducted in major cities around the world assess the ecosystem services provided by street trees as a tool for climate-resilient urban planning.

Urban tree inventory studies also offer opportunities for citizen participation in environmental management. Urban planners, policymakers, and managers should prioritize the preservation and expansion of street tree populations to maximize the benefits they offer. Ongoing studies are essential to comprehensively understand and optimize the advantages that street trees can provide within the frameworks of urban planning and development. To maximize the ecosystem services provided by street trees, local governments, and urban planners must develop comprehensive afforestation strategies, ensure the preservation of mature trees, and integrate street trees more effectively into urban planning frameworks.

Recognizing the ecosystem service values provided by street trees is vital for informing urban climate action plans and guiding planning initiatives. The effective application of tools like i-Tree requires integrating them into broader urban planning and management strategies. This can be complex due to the need for coordination between various departments and alignment with other urban initiatives. Therefore, it is imperative to acknowledge and safeguard the value of street trees as critical assets that benefit both humans and all living organisms.

In the context of designing resilient cities to combat climate change, attention must be given to the ecosystem services offered by street trees. Cities must prioritize their adaptation to climate change while also focusing on the preservation of urban ecosystems. City planners and policymakers must understand and evaluate these aspects to foster sustainable urban environments. Ultimately, the continued investment in and protection of street trees will be a cornerstone in creating climate-resilient cities, ensuring a sustainable future for urban populations.

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