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Research Article

Assessment of Plant Contributions to Air Quality within the Ecosystem Services Framework: The case of Halk Bahçesi in Çanakkale, Türkiye

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Abstract

Urban open green spaces are essential components that provide opportunities to mitigate negative impacts on quality of life. These areas deliver vital ecosystem services such as pollutant removal, cooling, reduction of the heat island effect, and carbon storage. Çanakkale faces air quality challenges due to thermal power plants in Çan and Biga, with additional plants planned. Halk Bahçesi, a historic park in Çanakkale's city center, was selected as the study area. This study aims to evaluate the contribution of urban plant species to air quality through ecosystem services and analyze differences among species. To assess the structural characteristics of plants and their environmental functions, climate and pollution data were used, employing the i-Tree Eco model developed in the USA. According to the findings, *Ulmus minor, Laurus nobilis, Cupressus sempervirens, Pinus brutia*, and *Acer negundo* were identified as the species that most significantly contributed to air quality. These results provide insights into the current situation and recommend more suitable plant species for improving air quality in Çanakkale and similar regions. This research establishes a valuable database for future plant selection in urban green spaces
Keywords: Air quality, Ecosystem services, i-Tree Eco, Urban green spaces, Halk Bahçesi, Çanakkale

Ekosistem Hizmetleri Çerçevesinde Bitkilerin Hava Kalitesine Katkılarının Değerlendirilmesi: Halk Bahçesi Örneği (Çanakkale, Türkiye)

Öz

Kentsel açık yeşil alanlar, yaşam kalitesi üzerindeki olumsuz etkileri azaltmak için fırsatlar sağlayan temel bileşenlerdir. Bu alanlar, kirleticilerin giderilmesi, soğutma, ısı adası etkisinin azaltılması ve karbon depolama gibi hayati ekosistem hizmetleri sunar. Çanakkale, Çan ve Biga'daki termik santraller nedeniyle hava kalitesi zorluklarıyla karşı karşıyadır ve ek santraller planlanmaktadır. Çanakkale şehir merkezinde bulunan tarihi bir park olan Halk Bahçesi, çalışma alanı olarak seçilmiştir. Bu çalışma, i-Tree Eco modeli kullanarak ekosistem hizmetleri aracılığıyla kentsel bitki türlerinin hava kalitesine katkısını değerlendirmeyi amaçlamaktadır. Bulgulara göre bu parkta, *Ulmus minor, Laurus nobilis, Cupressus sempervirens, Pinus brutia* ve *Acer negundo* hava kalitesine en önemli katkıda bulunan türler olarak belirlenmiştir. Bu sonuçlar, mevcut durum hakkında fikir vermekte ve Çanakkale ve benzer bölgelerde hava kalitesini iyileştirmek için daha uygun bitki türleri önermektedir. Bu araştırma, kentsel yeşil alanlarda gelecekteki bitki seçimi için değerli bir veri tabanı oluşturmaktadır.
Keywords: Hava kalitesi, Ekosistem servisleri, i-Tree Eco, Kentsel açık yeşil alanlar, Halk Bahçesi, Çanakkale

Introduction

Ecosystem services (ES) are defined as all the benefits that humanity derives directly or indirectly from ecosystem functions (Alcamo and Bennett, 2004; Costanza et al., 1998). The main message of the ecosystem services concept is that human life on Earth depends on ecosystems (Geneletti, Cortinovis, Zardo and Esmail, 2020). However, continuous population growth and the associated increase in resource consumption are leading to an imbalance between production and consumption on our planet (Novák, 2021). Under the influence of human well-being and growing consumer demand, ecosystems are deteriorating on a global scale, so that the services provided to humans are rapidly declining (Avcıoğlu Çokçalışkan, 2016). As the ability of ecosystems to provide essential services to society is already under stress, the additional pressures from climate change will pose an extraordinary threat to humanity in the coming years (Mooney et al., 2009). The 'regulating services' provided by ecosystems play an important role in reducing the impacts of climate change in cities and increasing the resilience of cities to these impacts (Coşkun Hepcan, 2019).

'Regulating services' are benefits that result from the natural processes of ecosystems, such as regulating air quality and climate, controlling water flow and erosion, treating water and waste, preventing epidemics, controlling pests, regulating pollination, and protecting against natural disasters (Alcamo and Bennett, 2004)

The green infrastructure network is one of the most important suppliers of ES in urban environments (Banzhaf, de la Barrera and Reyes-Paecke, 2019). In addition, many research papers show that it is of great importance for reducing the impacts caused by global climate change (Coşkun Hepcan, 2019; Gill et al., 2007; Sturiale and Scuderi, 2019). Benedict and McMahon (2006) define green infrastructure as an interconnected network of green spaces that preserves thevalues and functions of natural ecosystems, maintains clean air and water, and provides a wide range of benefits for people and wildlife. In this context, a green infrastructure network offers many benefits for cities vulnerable to the effects of climate change, such as reducing the heat island effect, capturingand storing carbon, cleaning the air by removing pollutants, reducingsurface water runoff, and regulating precipitation (Benedict and McMahon, 2006; Coşkun Hepcan, 2019; Önder and Dursun, 2010).

More than half of the world's population lives in urban areas (“OECD”, 2020), and one of the biggest problems that most cities face is also air pollution (Özdemir, 2013). Air pollution causes millions of premature deaths every year (Anonymous, 2020) and is accordingly one of the biggest environmental threats that countries in the globalized world face. Global warming, climate change and high and increasing air pollution threaten the future and life of humanity. Therefore, sustainable urban planning is of great importance to improve the quality of life and maintain the integrity of natural ecosystems (Pace, Biber, Pretzsch and Grote, 2018). An ES based planning and site management approach will help to understand the interactions and create positive connections between human and natural ecosystems in areas with high ecological value and under pressure from anthropogenic threats (Albayrak, 2012). The presence of natural spaces is becoming increasingly important for the quality of life in cities (Chiesura, 2004). Urban parks and other urban green spaces are an important part of the complex urban ecosystem network and have a crucial role in improving the urban environment and the quality of life in the city (Dunnett et al., 2002; Loures et al., 2007). The main objective of this study is to determine the extent to which plant species in an urban park contribute to urban air quality in terms of ES and to quantify the variation in these contributions by species.

Materials and Methods

Study Area and Its History

The primary focus of the study is Halk Bahçesi situated in the city center of Çanakkale. This park was selected as the study area because it is one of the largest and oldest parks in Çanakkale's city center, holds significant importance for the residents of Çanakkale, and features the oldest trees in the region. The research involved analyzing maps and zoning plans acquired from the Çanakkale Municipality, measurement data from the National Air Quality Monitoring Network, climate records from the General Directorate of Meteorology, and news articles published in both print and visual media. Additionally, notes, measurements, and photographs collected from observations and examinations conducted in the study area were also assessed.

The study area was located in the centre of Çanakkale (Figure 1), which is in north-western Turkey. Çanakkale, which was called Hellespontos and Dardanelles in ancient times, has lands on both sides of Europe and Asia. The city has always been of strategic importance as it connects the Dardanelles with the Sea of Marmara and the Aegean Sea. Çanakkale has an area of 9,933 km^2 on the Biga and Gallipoli peninsulas, between longitudes 25° 37'–27° 45' east and 39° 40'–40° 45' north.

Halk Bahçesi is one of the largest parks in Çanakkale and has been offering the city's residents’ various recreational opportunities for many years. The park, also known as Calvert Garden or English Garden, bears traces of the 19th century, which makes the area important for the history of the city (Kalfa, 2020). The Calvert family, who served as British and American commercial attachés, settled in

Çanakkale from Malta and built a large mansion on the coast of Çanakkale in 1852 (Baytop, 2011; Kaplan, 2009; Kalfa, 2020). It is known that the backyard of this large building, known as the Calvert Villa and Consulate Building, covered a large area in Çanakkale at the time (Kalfa, 2020). Halk Bahçesi, which contains many plant species that were carefully cultivated and protected at the time of the Calvert family, is a small piece of forest in the city and is still home to many of the centuries-old trees (Erbeşler Ayaşlıgil, 2019). After a fire and wars in 1932, the Calvert family's garden was expropriated in 1938 and its former boundaries were reduced to its present form with an area of 36,500 m^2 (Erduran and Kabaş, 2010; Kalfa, 2020).

Figure 1.Study Area (a. "Printable map of world", 2024; b. "vemaps TR", 2024; c., d. "Google Earth",2024, e. Original, 2020)

Halk Bahçesi reached its present state with the renovation works in 2018 and is still the green space in the centre of the city. The park is accessible from five different points; walking paths, jogging tracks, children's playgrounds, amphitheatre, sports equipment, dog park, seating areas, social facilities and the ornamental pool, which preserved after Calverts, are still present, although their original form has been damaged (Figure 2) (Engin, 2022; Engin and KaptanAyhan, 2021).

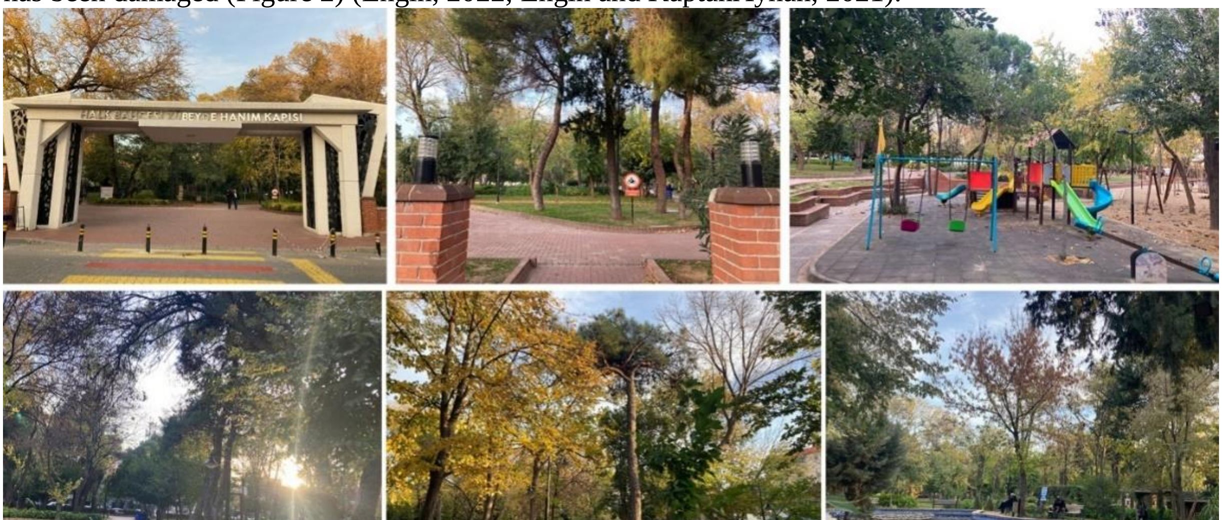

Figure 2. Halk Bahçesi(Original, 2020)

Method: I-Tree Eco Model Application

The importance of the contributions of urban green infrastructure to the city in thecontext of ES has been examined in many studies, but studies conducted by calculating ecosystem services with measurable mathematical methods provide more concrete data (Coşkun Hepcan and Hepcan, 2017). i-Tree Eco (UFORE (The Urban Forest Effects)), one of the software models developed in this context, is used to determine and measure the structural characteristics of plants in urban green areas and the functions they provide to the environment using the city's climate and pollution data. This model, which is the method of research, was developed in the United States in 2006 and is actively used in many countries (Forest Service, 2021)

Within the framework of the model, a vegetation tissue inventory is prepared based on the data collected about the research area and on-site observations. For this purpose, various detailed data such as tree height, branch-less trunk height, trunk chest diameter, top crown width, number of trunks, percentage of crown death, degree of light exposure to the crown, percentage of crown cover loss, tree health status, and tree defects are recorded according to species. With this database created within the scope of the I-Tree Eco software model, analysis results such as annual and average carbon retention amounts of plant species, air filtration and oxygen production values, and the extent of surface runoff prevention can be obtained.

Some Data Collection Methods and Factors to Consider

DBH measurements were conducted according to measurement standards at 1.30 m breast height using a tape measure, focusing on trees with a trunk diameter greater than 5 cm. For trees growing vertically on flat ground, measurements are taken perpendicular to the ground, while for those on a slope, they are taken parallel to the tree from the top of the slope. For trees leaning on the slope, the 1.30 m height is measured parallel to the tree, and for trees with trunk deformation at chest level, it is measured above the defect. In cases of forked trunks, chest height is measured separately if above the fork, and as a single measurement if below it, adjusting the height as needed for trunk width or root elevation. The measurement method is illustrated in Figure 3.

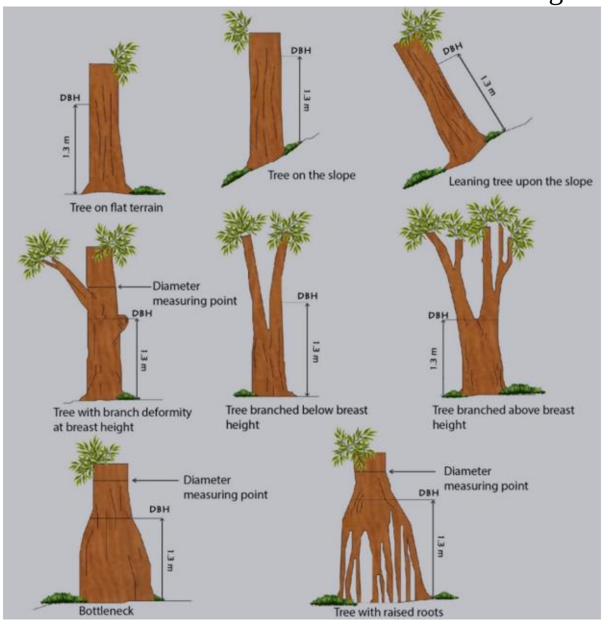

Figure 3. DBH Measurement (Revised from, Huy, 2013)

Crown health was assessed visually. In these evaluations, the percentage of crowns deemed missing for each tree was determined based on Figure 4.

When analysing the crown's exposure to light in field studies, it is crucial to considerthe number of surfaces from which the crown receives light. Each tree is assigned a number between 0 and 5 and processed into data formats (Forest Service, 2021). The degrees of light exposure for the crown are detailed in Table 1 and Figure 5, referencing the i-Tree Eco v6.0 user manual.

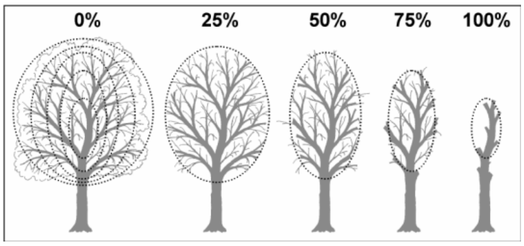

Figure 4. Crown die back (Meilby and Puri, 2007)

Table 1. Crown light exposure (Forest Service, 2021)

Number of sides	Description
0	The tree receives no full light because it is shaded by trees, vines, or other vegetation
1	The tree receives full light from the top or 1 side.
2	The tree receives full light from the top and 1 side (or 2 sides without the top).
3 4	The tree receives full light from the top and 2 sides (or 3 sides without the top).
4	The tree receives full light from the top and 3 sides.
5	The tree receives full light from the top and 4 sides.

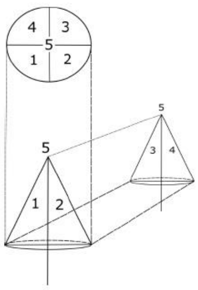

Figure 5. Crown light exposure (Forest Service, 2021)

Collecting Data from the Study Area and Processing it into the Database

As a result of land observation, examination, and inventory studies conducted in the park selected as the study area in Çanakkale city centre, tree inventory data sets were created for the park in question and entered into the database. Based on the data obtained from 925 trees representing 64 species found throughout the Halk Bahçesi during the periods of November/December 2019 and June/July 2020, an inventory assessment was made regarding the structure, function, and value of the trees.

Details on the standard protocol used for data collection were sourced from the i-Tree Eco v6.0 user manual and field guide (Forest Service, 2021). To ensure the program provides the most accurate results based on the data, important parameters beyond the species name and DBH (diameter at breast height; measurement of tree trunk diameter at breast height) include: Land use, Total tree height, Live tree height, Height to the base of the crown, Crown width, Crown loss percentage, Exposure of the crown to light (Table 2) includes the data and definitions that are collected and not collected depending on program requirements.

Table 2. Field data collection table (Forest Service, 2021)

Data Variables		Description		
Species		Identify and record the species and genus names of each tree	REQUIRED	
DBH		Exact measurement or categories of the tree stem diameter at breast height for each tree	REQUIRED	
General site fields			COLLECTED	NOT COLLECTED
Tree address		Street address of tree or notes for locating trees in areas without street addresses	✓	
Land use		Land use type in which tree is located	✓	
Strata		Sub-units by which study area are divided for analysis (e.g., land use, neighborhood)	✓	
Status		Status of tree as planted or self-seeded		x
Street tree/non-street tree		Identify if tree is a street tree or not (Y/N)		x
Map coordinates		Longitude and latitude of tree		x
Public/private		The classification of each tree as city managed (public) or not (private)		x
Tree detail fields			COLLECTED	NOT COLLECTED
Total tree height		Height from the ground to the top (alive or dead) of the tree	✓	
Crown Size	Live tree height	Height from the ground to the live top of tree	✓	
	Height to crown base	Height from the ground to the base of the live crown	✓	
	Crown width	The width of the crown in two directions: north-south and east-west	✓	
Crown health	Dieback	Estimate of the percent of the crown that is composed of death branches	✓	
	Condition	Estimate of the condition of the crown recorded as 100 minus the percent of the crown composed of dieback (i.e, dead branches)	✓	
Crown light exposure		Number of sides of the tree receiving sunlight from above (maximum of 5)	✓	
Energy	Direction	Direction from tree to the closest part of the building		x
	Distance	Shortest distance from tree to the closest part of the building		x

Results and Discussion

With the rising air pollution in crowded cities each day, our world is confronting disasters such as climate change and global warming (Rosenzweig, Solecki, Hammer and Mehrotra, 2011). In their study, Alpan and Sekeroglu (2020), observed that the emphasis placed on green spaces and the ecological system in expanding cities with increasing populations is minimal, resulting in cities resembling concrete forests. Consequently, they asserted that tree inventory systems developed using GIS technologies would be highly advantageous for both tree protection and afforestation monitoring. As highlighted in numerous similar studies, tree inventory systems are vital for managing urban tree populations. Many communities plant, maintain, or remove trees without an inventory (Hauer and Peterson, 2017). However, algorithms or models that illustrate the effects of plant species, structural characteristics, locations, and groupings on specific ecosystem services offer guidance on selecting tree species and promoting diversity in urban areas. Moreover, ecosystem modelling assists in making decisions regarding the planting of urban trees (Pace et al., 2018). In this context, the vegetation structure, function, and value of the Halk Bahçesi situated in the city centre of Çanakkale have been analyzed using the i-Tree Eco model.

Distribution and Measurement Results by Type

Based on data from 925 trees representing 64 species found throughout the Halk Bahçesi, the most prevalent tree species in the area are *Ulmus minor*, *Laurus nobilis*, and *Acer negundo*, with species distributions depicted in Figure 6. The other species depicted in Figure 6 comprise a variety of species in the park with DBH measurement results exceeding 5 cm.

There is a notable relationship between tree size and the functional services they provide. Larger trees are more efficient at storing and sequestering carbon due to having more tissue in their roots and trunks. Furthermore, larger trees typically offer more functional services, as removing pollution and intercepting precipitation are generally accomplished through a greater leaf surface area (Anonymous, 2016).

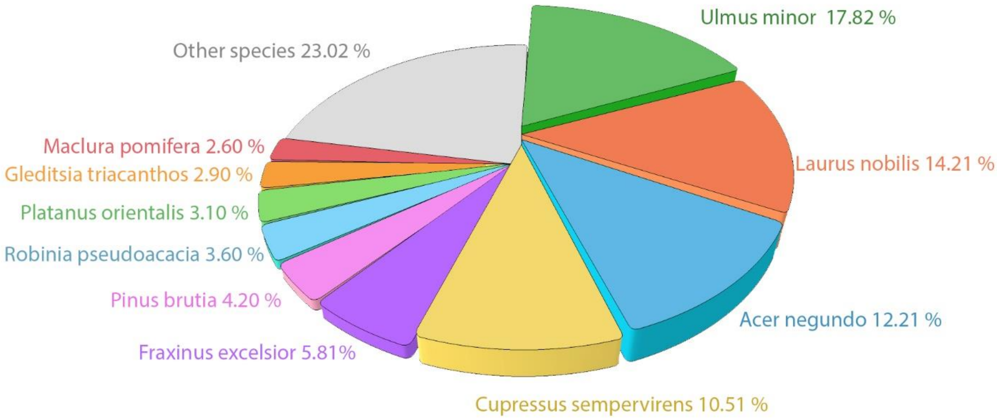

Figure 6. Species distrubition

Ulmus minor, the most dominant species in terms of numbers in the Halk Bahçesi, also has the highest DBH measurements for trunk diameter, with 57.6% of its total number exceeding 122 cm. Among *Pinus brutia*, which constitutes 4.2% of the Halk Bahçesi, 48.7% have DBH measurements greater than 122 cm. The DBH for *Laurus nobilis*, one of the common species in the area, ranges from 7 cm to 91 cm, with the maximum typically between 30 and 45 cm. DBH measurements for 6.2% of *Acer negundo*, another common species with a 12% distribution, exceed 122 cm.

Tree canopy cover in the i-Tree Eco assessment is primarily based on measurements of canopy spread (Anonymous, 2016). The estimated canopy cover for the Halk Bahçesi is 120%. However, it is important to note that the canopies of most trees overlap, and some or all of the smaller trees are situated beneath the canopies of larger trees.

Many tree benefits are directly related to the amount of healthy leaf surface area a plant possesses. While trees may have similar canopy areas, variations in care, pruning, light exposure, and other factors lead to differences in their leaf surface areas (Anonymous, 2016). Based on species measurements and estimates of crown loss percentages, a total of 21 hectares of leaf area was calculated for Halk Bahçesi.

Carbon Benefit Estimates

The plant tissue in open green spaces throughout the city consists of a blend ofnative and exotic tree species, leading to greater tree diversity than that found in natural landscapes. The increase in species diversity underscores the range of benefits offered by various species (Forest Service, 2021). To clarify the results obtained from the analyses, the findings for the 10 most common species were assessed. Carbon benefit estimates for Halk Bahçesi are presented in Table 3.

Table 3.Carbon benefit estimates for 10 most common species in Halk Bahçesi

Species Name	Number	Carbon Storage		CO_2 Equivalent	Carbon Sequestration		CO_2 Equivalent
		ton	$	metric ton^{-1}	tonyear^{-1}	$year^{-1}	metric ton^{-1}
Ulmus minor	165	889.70	88.694,193	3.262,50	6,61	658,553	24,22
Laurus nobilis	131	204.54	20.390,988	750,10	7,93	790,214	29,07
Acer negundo	113	162.14	16.163,473	594,60	5,68	566,280	20,83
Cupressus sempervirens	97	208.63	20.798,194	765,00	0,71	71,028	2,61
Fraxinus excelsior	54	123.80	12.337,990	453,80	3,14	312,865	11,51
Pinus brutia	39	99.80	9.952,491	366,10	0,90	89,829	3,30
Robiniapseudoacacia	33	40.60	9.632,641	148,70	1,68	167,351	6,16
Platanusorientalis	29	62.70	6.246,394	229,80	1,53	152,643	5,61
Gleditsia triacanthos	27	66.08	6.587,391	242,30	0,96	95,216	3,50
Maclurapomifera	24	95.00	9.466,710	348,20	0,06	6,141	0,23

The amount of carbon storage can be estimated from aboveground biomass (AGB), defined by the Earth Observation Satellites Committee as the above-ground dry mass of living or dead matter derived from tree or shrub (woody plant) life forms. AGB is quantified through allometric models to estimate the total amount of carbon stored in urban trees, calculated using two dendrometry measures: DBH and tree height (Gülçin and Konijnendijk Van Den Bosch, 2021). As shown in Table 4 for Halk Bahçesi, *Ulmus minor*, which is dominant in both numberand age in the area, also leads in carbon capture and storage. This species stores 889.70 tons ofcarbon, equivalent to 3,262.50 tons of CO_2, with an economic contribution value for the stored carbon calculated at 88.694,193$. When comparing *Laurus nobilis* (131), the most common species after *Ulmus minor*, to *Cupressus sempervirens* (97), which is less numerous, it is evident that *Cupressus sempervirens* stores 4.09 tons more carbon. This difference is calculated to be equivalent to 407,206$ in economic terms. Similarly, when comparing *Maclura pomifer*a (24 specimens) and *Platanus orientalis* (29 specimens), a significant difference of 32.3 tons is observed in their carbon storage amounts. The correlation between carbon storage levels, DBH, and species count is illustrated in Figure 7.

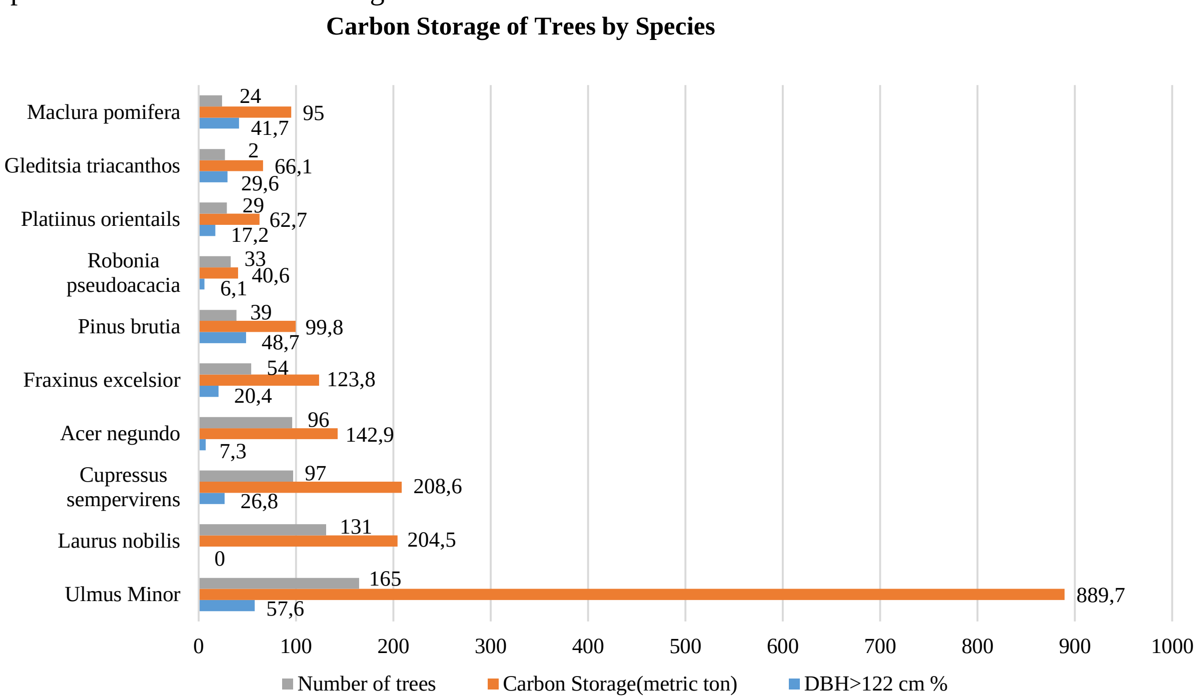

Figure 7. (Carbon Storage of Trees by Species)

Carbon sequestration is a natural process that removes carbon from the atmosphere by storing it in the biosphere. The amount of carbon sequestered by a tree significantly increases throughout its life until it reaches maturity (Chavan and Rasal, 2011). Table 3 presents data on carbon sequestration, estimating the annual carbon captured from the air and stored in various tree species. According to Table 3, the plants with the highest carbon sequestration rates in Halk Bahçesi are *Laurus nobilis* (7.93 tonsyear^{-1}), *Ulmus minor* (6.61 tonsyear^{-1}), and *Acer negundo* (4.74 tonsyear^{-1}), collectively contributing a total value of 2.015,27 $ per year from the carbon they sequester. Halk Bahçesi, covering an important area of 36,500 square meters in the centreof Çanakkale, also features century-old trees that enhance local air quality by sequestering 2,151.99 tons of carbon and capturing an additional 34.28 tons annually. The financial equivalent of this contribution to carbon storage is approximately two hundred thousand dollars (200.270,47 $), while the annual value of the carbon sequestration alone is around threethousand dollars (2.910,12 $).

Oxygen Production Estimates

Although many ecology textbooks indicate that the vast majority of the world's oxygen-producing organisms are aquatic, oxygen production remains one of the most frequently cited benefits of urban trees (D. J. Nowak, Hoehn and Crane, 2007). The net oxygen production of trees is determined by subtracting the oxygen consumed during plant respiration from the oxygen produced during photosynthesis (Salisbury and Ross, 1978). Furthermore, a tree's annual oxygen production is directly linked to the amount of carbon sequestered, which is dependent on the accumulation of tree biomass (Forest Service, 2021). Table 4 displays the production amounts of the 10 species with the highest annual oxygen production in the study area.

Table 4.Annual oxygen production amounts for 10 most common species in Halk Bahçesi

Species Name	Number	Leaf Area (ha)	Oxygen production (ton year^{-1})	Annual Gross Carbon Sequestration (ton year^{-1})
Laurus nobilis	131	1.14	21.14	7.93
Ulmus minor	165	5.70	17.62	6.61
Acer negundo	113	3.06	15,15	5.68
Fraxinus excelsior	54	2.50	8.37	3.14
Robiniapseudoacacia	33	0.64	4.48	1.68
Platanusorientalis	29	1.40	4.08	1.53
Gleditsia triacanthos	27	0.77	2.55	0.96
Pinus brutia	39	1.13	2.40	0.90
Cupressus sempervirens	97	1.57	1.90	0.71
Ligustrum lucidum	20	0.16	1.46	0.55

When examining the table, the relationship between annual gross carbon sequestrationand oxygen production becomes evident. The highest oxygen production in Halk Bahçesi is atributed to *Laurus nobilis*, contributing 21.14 tons of oxygen per year (Table 4). *Ulmus minor* follows with 17.62 tons, while *Acer negundo* produces 15.15 tons, making them the leading oxygen-producing species in Halk Bahçesi. It is estimated that the trees in Halk Bahçesi collectively produce a total of 87.93 tons of oxygen annually.

Elimination of Air Pollution

Air pollution is an increasing environmental threat, with rising global emissions jeopardizing ecosystems and human health (Riondato, Pilla, Sarkar Basu and Basu, 2020). Poor air quality in urban areas is an unavoidable reality, given the high concentrations of pollutant sources such as vehicle exhaust emissions, industrial processes, domestic heating, and solvent use. Deteriorating air quality is the leading cause of premature death and disease, as well as posing significant challenges to the functioning of ecosystems, infrastructure, and environmental systems. Urban vegetation plays a vital role in both the direct and indirect improvement of air quality (Anonymous, 2016). Plants reduce pollutant levels by absorbing gaseous pollutants through leaf stomata and capturing and retaining airborne particles on their surfaces (Morani, Nowak, Hirabayashi and Calfapietra, 2011). In the i-Tree Eco evaluation of air pollution reduction, Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Ozone (O_3), Particulate Matter ($PM_{2.5}$), and Sulphur Dioxide (SO_2) are identified as criterion air pollutants by the United States

Environmental Protection Agency. The program utilizes land data, current pollution, and weather data for pollution predictions (i-Tree Eco, 2021). According to the analysis results, it is estimated that 279 kilograms of pollutants will be removed annually from Halk Bahçesi, with a total associated value of 395$. Upon examining the relevant estimates, it is clear that the highest amount of ozone gas (O_3) is removed from the atmosphere (Figure 8). The removal of 217.46 kg of ozone gas per year corresponds to a financial value of approximately two thousand liras.While sulphur dioxide (SO_2) is noted as the second most removed pollutant after ozone (31.67 kg), the estimated figure for particulate matter ($PM_{2.5}$) is significantly higher when considering the associated value ($) equivalents. In addition to these values, the total amount of air pollutants removed was normalized by the surface area of the park and expressed in terms of spatial purification efficiency (g m^{-2} $year^{-1}$). Accordingly, the annual removal of 279 kg of pollutants across an area of 36,500 m² corresponds to approximately 7.64 g m^{-2} $year^{-1}$. This result highlights the meaningful spatial contribution of the vegetation in Halk Bahçesi to urban air quality improvement.

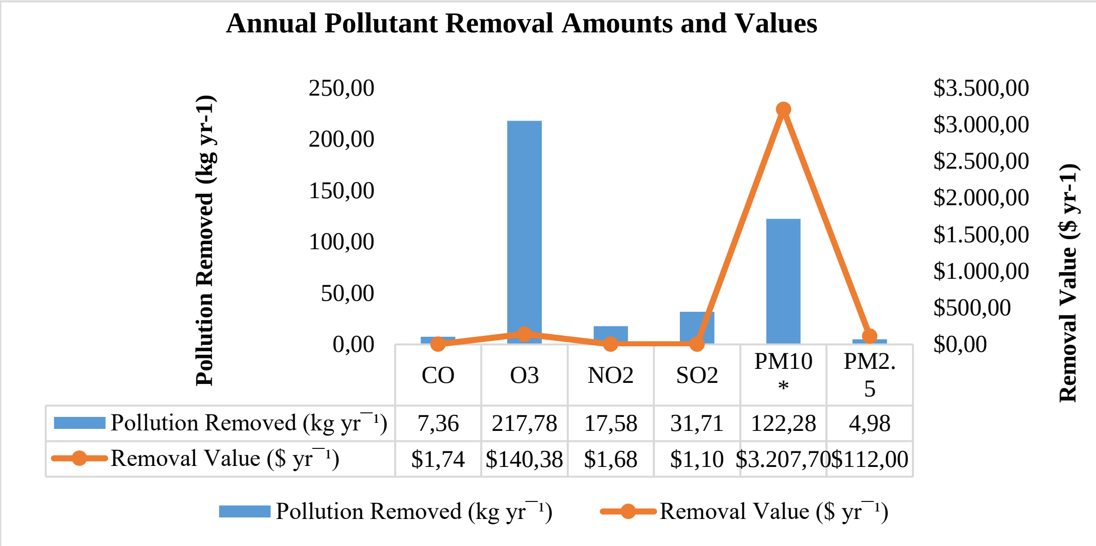

Figure 8. Halk Bahçesi annual pollutant removal amounts and values

Pollution removal values for each pollutant will vary monthly due to factors such as canopy density, pollution concentration, length of the leafy season, rainfall, and other meteorological variables that affect transpiration and sedimentation rates. These factors collectively influence the total pollutant removal and the standard rate of pollutant removal per unit of canopy (D. J. Nowak, Crane and Stevens, 2006). The monthly amounts of pollutants removed are depicted in Figure 9. The graph shows that ozone gas removal peaks during the summer months when vegetation is abundant, and temperatures—and consequently transpiration—are high.

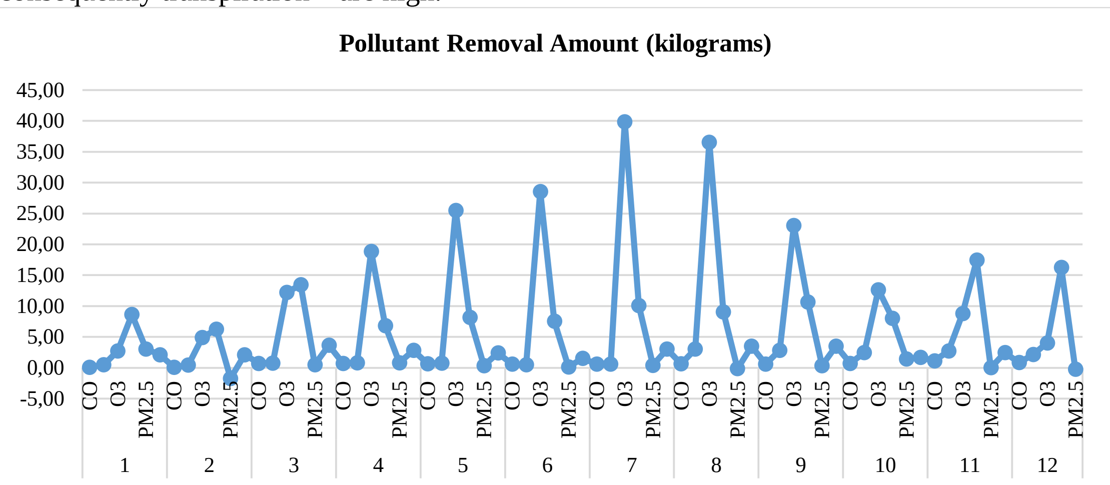

Figure 9. Amounts of pollutants removed by month in Halk Bahçesi

Urban trees play a crucial role in mitigating climate change and delivering diverse ecosystem services. They remove tons of air pollutants annually, influencing local air quality in various ways. Their impacts include capturing atmospheric particles, trapping gaseous pollutants, altering air currents, and providing shade while reducing temperatures through transpiration (Gülçin and Konijnendijk Van Den Bosch, 2021; D. J. Nowak et al., 2006). Consequently, their effects on environmental quality and human health are significant.

There is growing evidence of the devastating effects of air pollution on human health, recognized as a serious environmental issue ("WHO", 2020), leading to millions of premature deaths annually. Simultaneously, over half of the global population now resides in urban areas, many of which have air quality that fails to meet the World Health Organization's healthy living guidelines (Hewitt, Ashworth and MacKenzie, 2020)

According to the findings, it can be stated that the existing trees in Halk Bahçesi are significant environmental assets in the urban landscape, having a considerable impact on improving air quality and providing important benefits to the well-being of the citizens of Çanakkale. Moreover, although the numerical values of certain ES provided by the trees in this area may initially seem low, they are crucial for reducing carbon emissions over the long term, ensuring local biodiversity, and mitigating urban heat island effects. Additionally, these services are essential for adapting to climate change, ultimately leading to significant improvements in human health.

In recent years, efforts to combat air pollution and climate change, such as reducing carbon emissions and promoting public transportation, have been overlooked in favour of individual transportation methods following the COVID-19 pandemic (Özdede et al., 2021). Consequently, vehicle exhaust emissions are rising in cities. However, the green infrastructure approach, which can comprehensively provide ES in urban areas, serves as a crucial element in sustainable urban planning, enhancing air quality, and fostering adaptation and resilience to climate change impacts (Votsis, 2017). Vegetation in urban open green spaces aid in reducing air pollution by directly eliminating pollutants and lowering air temperatures and building energy consumption (D. Nowak and Heisler, 2010). Nevertheless, due to increasing demand and usage pressures, particularly from the uncontrollable population growth in cities, ecosystems are rapidly deteriorating, and the services they offer are beginning to decline. Therefore, to ensure the sustainability of ES and protect the ecosystems that generate these services, their significance must be recognized and embraced by societies (Avcıoğlu Çokçalışkan, 2016).

The findings concerning the numerical expressions of ES examined in this research is anticipated to effectively alleviate pressure on urban open green areas. Disseminating such studies will enhance the understanding of ecosystems and the services they provide. Furthermore, integrating ES into the landscape planning process is crucial for ensuring sustainability. Therefore, when making conservation decisions in plans designed to preserve sensitive areas of ecological significance for future generations, the ES approach, which aids in comprehending ecological processes, should also be incorporated during the planning stages.

Today, not only urban green areas but also green infrastructure systems at urban, regional, and national levels need to be organized and interconnected holistically. In addition to protecting and planning open green areas, which play a vital role in the urban fabric, it is essential to assess their adequacy. Although there is no universally accepted standard for the amount of green space a city should have (URBAN20, 2020), WHO data suggests that at least 9 m² of green space per person is necessary ("WHO", 2020). However, the per capita amount of green space alone is insufficient to ensure that ES benefit a large number of urban residents. Various factors, such as accessibility and quality, which influence the usability of urban open green spaces, are also significant (URBAN20, 2020). According to the findings of this research, it can be concluded that public garden trees are a vital environmental asset in the urban landscape, significantly improving air quality and providing substantial benefits to the well-being of Çanakkale city residents. Indeed, Erbeşler Ayaşlıgil (2019) also examined the woody vegetation in Halk Bahçesi in her study and, as a result, highlighted the importance of Halk Bahçesi vegetation for the city and the region, offering suggestions for its protection and enhancement. Erduran et al. (2008), on the other hand, identified the types and characteristics of the plants in their study on the existing flora of Halk Bahçesi, detailing the ecological demands, morphological, aesthetic, and functional properties of the species they identified, as well as their suitability for Çanakkale conditions. They also outlined what needs to be done for the sustainable use of green spaces. Ilgar (2022) assessed the perception and awareness of green areas in Çanakkale through survey studies conducted with the residents, revealing the extent to which green areas meet user needs and demands, as well as the necessity for new parks and green spaces. He made the following observations about Halk Bahçesi, which is one of the green areas he addressed in his study: Halk Bahçesi is the most important and centrally located urban park in Çanakkale, featuring the most effective shade in the city. While these earlier studies focused primarily on the botanical, functional, and user-based aspects of Halk Bahçesi, the present research adds a critical ecosystem services perspective by quantitatively evaluating the air pollution removal capacity of the park's vegetation. Based on the i-Tree Eco model outputs, the total annual air pollutant removal of 279 kg corresponds to 7.64 g m^{-2} $year^{-1}$, which is a spatially significant value. When compared with findings from other studies—such as the values ranging between 6.2 and 23.1 g m^{-2} $year^{-1}$ reported by Nowak et al. (2006) for various cities in the United States, the 4.65 g m^{-2} $year^{-1}$ calculated by Coşkun Hepcan and Hepcan (2017) for a university campus in Türkiye, or the 5.3 g m^{-2} $year^{-1}$ identified by Coşkun Hepcan (2019) in the Aşık Veysel Recreation Area in İzmir—the pollutant removal performance of Halk Bahçesi proves to be both effective and meaningful. These results underline the park's dual ecological and social value, highlighting its role not only as a recreational and historical asset but also as a vital green infrastructure component contributing to urban air quality regulation. Incorporating such quantitative ecosystem service assessments can substantially enhance urban green space planning and policy development.

In the case of Çanakkale, regional air quality challenges intensify the importance of such urban green infrastructures. The city is exposed to multiple pollution sources, including traffic emissions, domestic heating, and most significantly, the presence of thermal power plants located in Çan and Biga, with additional facilities planned. A recent study by Menteşe et al. (2020) emphasizes that pollutant concentrations—particularly PM_{10} and SO_2—often approach or exceed threshold levels, raising public health concerns. In this context, urban parks such as Halk Bahçesi are not merely recreational amenities but act as localized mitigation zones, offering measurable reductions in airborne pollutants. Therefore, understanding and maximizing the unit-area contributions of vegetation to air quality regulation becomes a strategic necessity for cities like Çanakkale, where ecological pressure is expected to rise in the coming decades.

Conclusions

It has long been acknowledged that trees in urban areas enhance the character and appeal of a city, helping to create a unique "sense of place." However, with increasing demands for space and resources to accommodate conflicting land uses, it has become challenging to advocate for the protection of trees based primarily on intangible values (Anonymous, 2016). The economic values derived from the research findings reveal species-specific economic values concerning carbon capture, carbon storage, and pollution removal; this study will serve as a significant example to help bridge this gap to some extent.

As outlined in the research findings section, the key criteria for how urban vegetation enhances air quality include tree height, trunk DBH measurements, crown dimensions and quality, as well as factors related to the crown's exposure to light. It is concluded that plants receiving adequate light, exhibiting healthy development and crown structure, and possessing proper forms contribute more significantly to air quality. In this context, special care is essential regarding pruning and maintenance in urban open green areas, which are vital to the city's ecosystem. This consideration becomes even more critical, particularly for Halk Bahçesi, which holds historical significance with its many centuries-old trees. Halk Bahçesi, a historical urban park favored by citizens and characterized by a unique microclimate (Özden Açmaz and Özelkan, 2023), despite its limited physical size, can be considered an important area for the urban population of Çanakkale, offering significant benefits to their well-being, as demonstrated by this and other studies.

In conclusion, this research was conducted to determine the extent to which plant species within the city contribute to urban air quality in terms of ES and how these contributions vary by species. It forms an important basis for the measures to be taken, the policies to be followed, and the decisions to be made to ensure cities are liveable and healthy places. The Çanakkale province is at risk from the effects of thermal power plants as well as known air pollutants from heating and traffic. The presence of thermal power plants, whose potential negative impacts on air quality are frequently discussed in the literature, along with plans for new ones, underscores the importance of a green infrastructure approach and holistic planning. Furthermore, as revealed in this study, air quality must be one of the most critical criteria considered during the design and plant selection stages. The results will not only indicate the extent to which specific plant species contribute to air quality, guiding the selection of plants in areas with similar climatic conditions, but will also illuminate the traces of temporal change by providing comparisons with increasing or decreasing canopy cover rates in future studies. Indeed, this study holds particular significance for the Çanakkale province, which is the primary focus of the research. Moreover, the study emphasizes that some species demonstrated a higher functional contribution to ecosystem services despite their relatively small numbers or limited physical size. For example, *Maclura pomifera* showed high carbon storage per tree, while *Laurus nobilis* had the highest annual oxygen production. *Fraxinus excelsior* and *Robinia pseudoacacia* also stood out with their high oxygen production efficiency, and *Cupressus sempervirens* provided strong benefits in both carbon storage and sequestration. These findings suggest that, especially in public green spaces, selecting such functionally efficient species—and favoring individuals with broader crown diameters and mature age—can significantly enhance the ecological performance of urban vegetation. Thus, aligning plant selection strategies with species-specific ecosystem service capacities will yield more effective outcomes for air quality improvement and long-term urban sustainability. Moreover, while the maintenance costs of old trees may be higher, the ecosystem services they provide—particularly in terms of climate regulation and air purification—clearly outweigh these costs. This emphasizes the need for careful protection of mature trees with large leaf volumes and highlights the importance of making multifaceted decisions regarding the placement of long-lived species. Urban vegetation can directly and indirectly influence both local and regional air quality by shaping the urban atmosphere. In this context, species diversity not only contributes visual and structural richness through varied textures, colors, and forms but also enhances ecosystem resilience by offering different functional values and resistance to species-specific diseases and pests.

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Authors' Contributions

1- Ç.K.A. and F.E. have designed the study. 2- F.E. collected and analyzed the data and visualized the results. 3- Both authors contributed to writing the article.4- Ç.K.A. reviewed the article.

Conflicts of Interest Statement

The authors declare that there is no conflict of interest.

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