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Assessment of ecosystem services provided by street trees: Burdur (Türkiye) city center

Yol ağaçlarının sağladığı ekosistem hizmetlerinin değerlendirilmesi: Burdur (Türkiye) kent merkezi

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ABSTRACT

Objective: The objective of this study was to reveal at which level urban street trees in Burdur city center can accomplish ecosystem services (ES) regulation.

Material and Methods: In this study, ecosystem benefits in physical terms are quantified by using a software called i-Tree Eco model developed by the USDA Forest Service. Besides tree characteristics and urban forest cover, air pollution reduction, carbon storage and sequestration, oxygen production, and avoided runoff are four regulating ES selected and studied.

Results: As a result of the measurements made it was estimated that trees in Burdur city center remove 66.79 kilograms of air pollution per year and the gross sequestration of street trees was about 12.92 metric tons of carbon per year.

Conclusion: Considering the data obtained as a result of this study, it can be stated that the species to t provide an advantage in terms of ecosystem services-pollution removal, carbon sequestration and storage, oxygen production, stormwater avoided-should be preferred to determine the tree species to be used in urban street afforestation.

Keywords: Street trees, ecosystem services, i-Tree Eco, Burdur (Türkiye)

ÖZ

Amaç: Bu çalışmanın amacı, Burdur il merkezindeki kentsel yol ağaçlarının ekosistem hizmetleri (ES) düzenlemesini ne düzeyde gerçekleştirebileceğini ortaya koymaktır.

Materyal ve Yöntem: Bu çalışmada, USDA Forest Service tarafından geliştirilen i-Tree Eco modeli adı verilen bir yazılım kullanılarak ekosistemin fiziksel faydaları araştırılmıştır. Ağaç özellikleri ve kentsel orman örtüsünün yanı sıra, hava kirliliğini azaltma, karbon depolama ve ayırma, oksijen üretimi ve önlenen akış, seçilen ve incelenen dört düzenleyici ES'dir.

Araştırma Bulguları: Yapılan ölçümler sonucunda Burdur il merkezindeki ağaçların yılda 66,79 kilogram hava kirliliğini ortadan kaldırdığı ve yol ağaçlarının brüt olarak yılda yaklaşık 12,92 metrik ton karbon tuttuğu belirlenmiştir.

Sonuç: Bu araştırma sonucunda elde edilen veriler dikkate alındığında, kent içi yol ağaçlandırmasında kullanılacak ağaç türlerinin belirlenmesinde ekosistem hizmetleri açısından avantaj sağlayan türlerin (kirlilik giderme, karbon tutma ve depolama, oksijen üretimi, yağmur sularından kaçınma) tercih edilmesi gerektiği anlaşılmıştır.

Anahtar sözcükler: Yol ağaçları, ekosistem hizmetleri, i-Tree Eco, Burdur (Türkiye)

INTRODUCTION

Ecosystem services (ES) are defined, as the benefits acquired by people from ecosystems (Millennium Ecosystem Assessment, 2005). The Economics of Ecosystems and Biodiversity (TEEB, 2011) provides a refined definition of ES as the direct and indirect contributions of ecosystems to human well-being. These benefits and services include supply services such as water, food, fiber and timber; regulatory services that affect disease, floods, climate, water quality and waste; cultural services that provide spiritual benefits, entertainment and aesthetics; and supporting services such as photosynthesis, soil formation and nutrient cycling (Millennium Ecosystem Assessment, 2005).

Human well-being strongly relies on the conservation of natural resources that provide the services that humans require to sustain their lives. However, humans have significantly affected regulating services such as climate regulation by altering the ecosystems and exceeding ecosystems' ability to provide different ecosystem services (Myers et al., 2013). For instance, changes in land use are putting these service resources under risk (Foley et al., 2005). The transformation of ecosystems can lead irreversible results, especially in the Mediterranean region, where the effects of climate change are severely felt. In geographies where hot climates are felt, city centers with less tree cover than necessary are places that are difficult to live in if the population concentrated in the city centers is taken into account (Aurelle et al., 2022). These urban centers, where the need for potable water resources and usable water resources for the continuation of life increases, stand out as climate sensitive hot spots (Pörtner et al., 2022). Urban centers, which were previously agricultural areas, forest areas, maquis areas or low-density settlement areas, have changed the character of land cover with the demand for dense living. In these places with denser residential areas, especially in developing countries, air pollution is also exposed. These land use and ecosystem changes also cause changes in ecosystem services provided by green areas.

Green spaces and urban trees in cities are the key elements to maintain ES. Trees in urban areas provide a number of ecosystem services, or direct environmental advantages for people, that are often overlooked. Improving air quality by reducing air pollutants (Nowak et al., 2002; Hewitt et al., 2020), decreasing building cooling costs as a result of shading by trees (McPherson & Simpson, 1999; Moss et al., 2019), reducing stormwater runoff by intercepting precipitation (Maco & McPherson, 2003; Livesley et al., 2014; Rahman, 2019) are some of the numerous advantages of urban trees for people. Micro climate effects, carbon sequestration impact, being a habitat for urban wild life and street animals are some other services provided for people and environment itself by urban trees (Wai et al., 2020; Wood & Esaian, 2020; Shadman et al., 2022).

With the recognition of the positive impacts of street trees on ecosystems, studies aim raising awareness for the improvement of ecosystem services by measuring ecosystem services have become very popular. There are many studies that measure ES using various models. Some of these studies measure ES through models using software (Philips, 2011; Coşkun Hepcan & Hepcan, 2017; Rogers et al., 2018; Selim & Atabey, 2020), while others involve other types of measurements of ES (Coşkun Hepcan & Cangüzel, 2021; Tırnakçı, 2021).

In this study, ecosystem benefits in physical terms are quantified by using a software called i-Tree Eco model developed by the USDA Forest Service. Besides tree characteristics and urban forest cover, air pollution reduction, carbon storage and sequestration, oxygen production, and avoided runoff are four regulating ES selected and studied. Street trees in an urban landscape in Burdur city (Türkiye) center are the main focus of this study and the question needs to be answered will be at which level urban street trees in Burdur city center can accomplish four stated regulating ES?

MATERIALS and METHOD

The study was carried out on six avenues namely Atatürk, Cumhuriyet, Gazi, İstasyon, Kışla, and Mehmet Akif Avenues, which are the most active, most visited main streets of the Burdur (Türkiye) city center. The geographical location of the study area and the route followed during data collection are depicted in Figure 1.

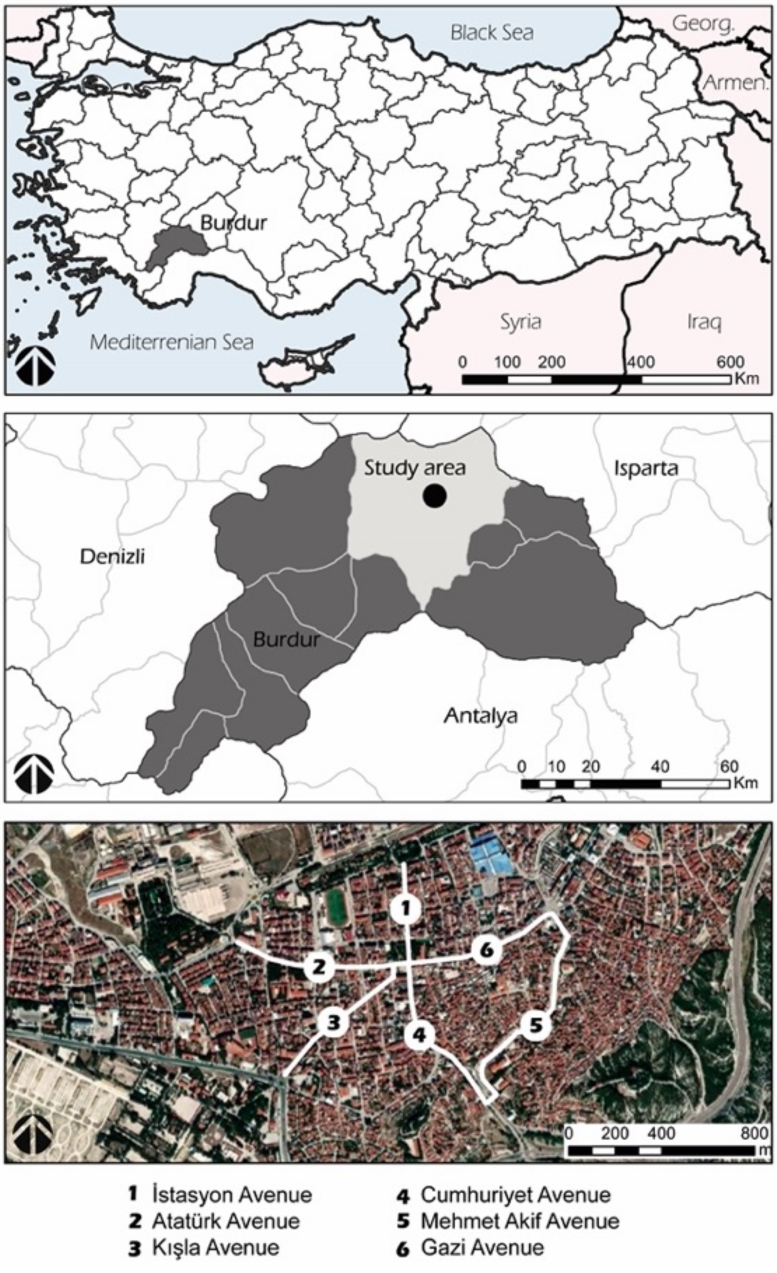

Figure 1 Location of the study area and field data collection route.

***Şekil 1** Çalışma alanının konumu ve veri toplama rotası.*

The total length of 6 main streets in the center of Burdur city selected as the study area is 4100 m. Trees are located on sidewalks on both sides of the street. To give an idea of the appearance, physical structure and tree cover of the avenues, photographs taken in 6 main avenues are presented in Figure 2.

Figure 2. Physical structure and tree cover of avenues.

Şekil 2. *Caddelerin fiziki yapısı ve ağaç örtüsü.*

Quantitative information about the streets such as the widths of the streets, widths of the pavements and qualitative information such as paving materials, whether the street is one-way or two-way are tabulated in Table 1.

Table 1. Some quantitative and qualitative information about the study area.

Çizelge 1. *Çalışma alanı ile ilgili nicel ve nitel bazı bilgiler.*

	Quantitative Information		**Qualitative Information**		
	Widths of the Streets (m)	**Widths of the Pavements (m)**	**Planation on One Side / Both Sides**	**Paving Materials**	**One-way Street / Two-way Street**
Atatürk Avenue	15	3-5	Both Sides	Asphalt	One-way Street
Cumhuriyet Avenue	20	3	Both Sides	Asphalt	Two-way Street
Gazi Avenue	15	3-5	Both Sides	Asphalt	Two-way Street
Mehmet Akif Avenue	35	1.5	Both Sides	Asphalt	Two-way Street
İstasyon Avenue	21	3.5	Both Sides	Asphalt	One-way Street
Kışla Avenue	17	2.5	Both Sides	Asphalt	One-way Street

Except for the study area, which is the main material of the study, the other materials of the study are the photographs taken to collect information about the study area, the field observation form used in the inventory study, and the i-Tree Eco software used in the measurement of ecosystem services.

The method of the study consists of 4 main stages (Figure 3). The first stage is the selection of the study area. The location of the streets, the presence of street trees and the suitable conditions for the application of the model used were effective in the selection of the study area. Burdur city center was selected because of its featured characteristics of avenues in urban context. The second stage is measurement of ecosystem services. At this stage, firstly, the evaluation criteria to be used in determining the ecosystem services provided by plants were defined. Along with the geographical locations of the trees, physical characteristics such as plant type (tree/shrub) and name (scientific name), height (m), trunk diameter (DBH) (cm), diameter of crown (m), height of the trunk from the ground (m), coverage ratio (%) and vitality status were determined as evaluation criteria. An inventory form was then prepared to record the observations to be made in the field. Field research was carried out in October 2021. Data on 588 trees identified within the scope of the inventory data collected during the field research were transferred to the i-Tree Eco module. Finally, analysis reports on ecosystem services were obtained. In the third stage, the analysis results presented by the model were evaluated, and in the last stage, conclusions and recommendations were developed.

At the stage of measurement of ecosystem services, the i-Tree Eco model was used to measure the ecosystem services provided by street trees in research area. I-Tree Eco is a software that uses tree measurements and other data to quantify the structure and environmental effects of urban trees in other words to estimate structural characteristics and ecosystem services of the trees developed by the USDA Forest Service (i-Tree, 2020).

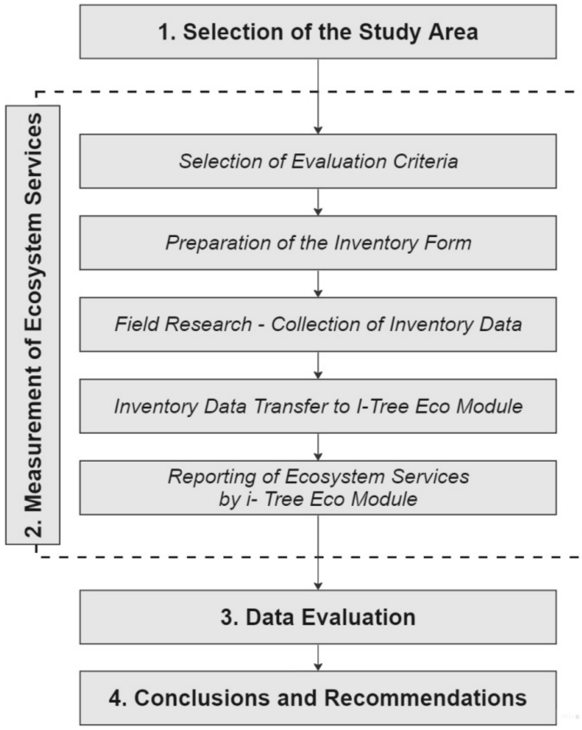

Figure 3. Methodology of the study.

Şekil 3. *Çalışmanın Yöntem akış şeması.*

The software calculates, evaluates and reports on ecosystem services such as carbon storage, removal of air pollution and prevention of runoff (Nowak et al., 2008). A deeper understanding of the ecological life support system of urban forests is provided by the economic values of biophysical condition assessment and multiple ecosystem services (Nikodinoska et al., 2018). i-Tree Eco also provides various data estimates of future tree population aggregates, canopy cover, ecosystem services and tree benefits.

According to the working principle of the i-Tree Eco, in this study, tree measurements and field data are introduced to the software by manual data entry. The data obtained in the field, local pre-processed hourly weather and air pollution concentration data obtained from Turkish State Meteorological Service were used during the process.

In this study i-Tree Eco is used to provide estimates of the structure, and pollution reduction capacity of street trees, total carbon stored and net carbon sequestered, avoided runoff by trees.

RESULTS and DISCUSSION

Tree characteristics, urban forest cover and leaf area, air pollution reduction, carbon storage and sequestration, oxygen production, avoided runoff are the parameters evaluated by i-Tree Eco model in this study. Therefore, the results are explained according to these parameters respectively.

According to the data collected to evaluate tree characteristics, an inventory study was carried out with a total of 588 street trees belonging to 32 different species from 15 families. The most common species in the study area were *Fraxinus angustifolia* (20.7%), *Tilia tomentosa* (18.2%), and *Tilia cordata* (10.2%).

When the percent of tree population by diameter class is examined, it is seen that those with DBH values of 45.7-61.0, 121.9 + and 15.2-30.5, respectively, are in the majority (Figure 4).

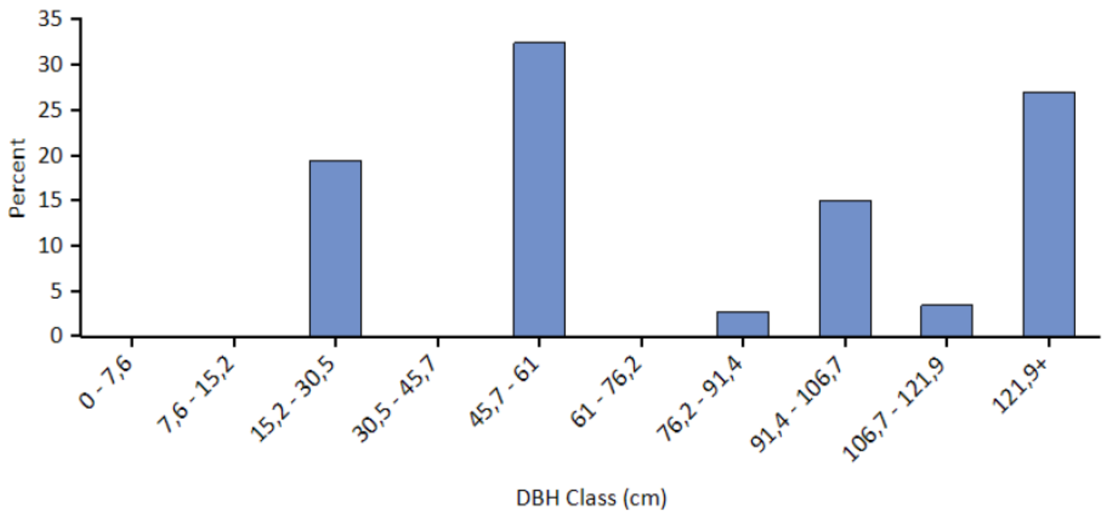

Figure 4. Percent of tree population by diameter class (DBH-trunk diameter at 1.37 meters) of street trees in study area.

Şekil 4. *Çalışma alanındaki yol ağaçlarının çap sınıfına (DBH-gövde çapı 1,37 metre) göre ağaç popülasyon yüzdesi.*

In means of urban forest cover and leaf area, it was determined that street trees in Burdur city center provide 5.25 hectares of leaf area. The most dominant species in terms of leaf area are *Fraxinus angustifolia*, *Pinus nigra*, and *Tilia platphyllos*. The sum of the percent of the population and the leaf area was used to compute importance values (IV). Ten species with the highest importance values in the study area was listed and given in Table 2. .

Table 2. The most important species in the study area according to population percentage and leaf area percentage.

Çizelge 2. *Popülasyon yüzdesi ve yaprak alanı yüzdesine göre çalışma alanındaki en önemli türler.*

Species Name	Percent Population	Percent Leaf Area	IV
Fraxinus angustifolia	20.7	16.7	37.5
Tilia tomentosa	18.2	8.4	26.6
Tilia platyphyllos	8.7	8.9	17.6
Pinus nigra	4.8	9.9	14.6
Tilia cordata	10.2	3.6	13.8
Gleditsia triacanthos	2.9	8.8	11.7
Acer negundo	3.7	6.6	10.3
Fraxinus excelsior	2.9	5.4	8.3
Juglans regia	3.4	4.4	7.8
Cedrus deodara	4.3	3.1	7.3

Air pollution removal by street trees in the study area was estimated using field data and recent available pollution and weather data obtained from Turkish State Meteorological Service. Pollution removal was greatest for ozone (Figure 5). It is estimated that trees remove 66.79 kilograms of air pollution (*ozone* (O_3), *carbon monoxide* (CO), *nitrogen dioxide* (NO_2), *particulate matter less than 2.5 microns* (PM2.5) and *sulphur dioxide* (SO_2) per year.

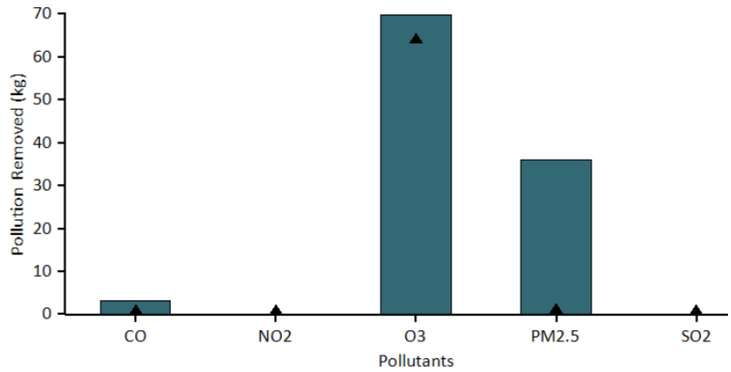

Figure 5. Annual pollution removal of street trees in the study area.

Şekil 5. *Çalışma alanındaki yol ağaçları tarafından tutulan yıllık kirlilik miktarı.*

As Atkinson & Arey (2003) stated that vegetation is the main producer of volatile organic compounds (VOC). In 2022, street trees in Burdur city center emmitted an estimated 25.34 kilograms of volatile organic compounds (VOCs). Emissions vary among species based on species characteristics and leaf biomass. Moreover, the seasonality of vegetation, namely its phenological and developmental stages, has an impact on the emission of volatile organic compounds (VOCs) (Bracho-Nunez et al., 2013). It has been determined that the street trees in the study area emitted an estimated 25.34 kilograms of volatile organic compounds (VOCs), and 44% of the street tree's VOC emissions were from *Pinus nigra* and *Sophora japonica*.

Urban trees sequester atmospheric carbon (from carbon dioxide) in tissue. As a result, they can contribute to mitigating climate change by changing carbon dioxide emissions from fossil fuel-based power sources (Abdollahi et al., 2000; Safford et al., 2013). Trees sequester carbon in new growth each year, reducing the amount of carbon in the atmosphere. The amount of carbon captured annually increases with the health and size of trees. Within the light of this information, the gross sequestration of street trees in the study area is approximately 12.92 metric tons of carbon per year. (Figure 6).

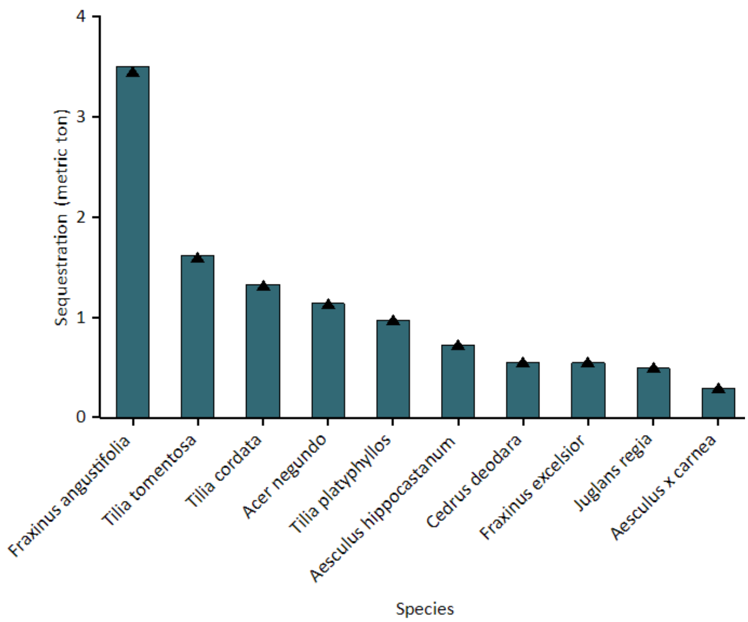

Figure 6. Estimated annual gross carbon sequestration for tree species with the greatest sequestration of street trees in study area.

Şekil 6. *Çalışma alanında yer alan en fazla karbon tutma özelliğine sahip yol ağaçları için tahmini yıllık brüt karbon tutma miktarı.*

Trees act as significant carbon sinks. Their leaves absorb CO_2 from the atmosphere and store it as carbon in the biomass that has accumulated (Aba et al., 2017). A tree stores more carbon as it grows by keeping it in its accumulated tissue. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Healthy trees will continue to store carbon, but maintaining healthy trees can increase carbon emissions (Nowak et al., 2002). Street trees in Burdur city center are estimated to store 1,220 metric tons of carbon. Of the species sampled, *Fraxinus angustifolia* stores and sequesters the most carbon (approximately 30.2% of the total carbon stored and 26.7% of all sequestered carbon.) (Figure 7).

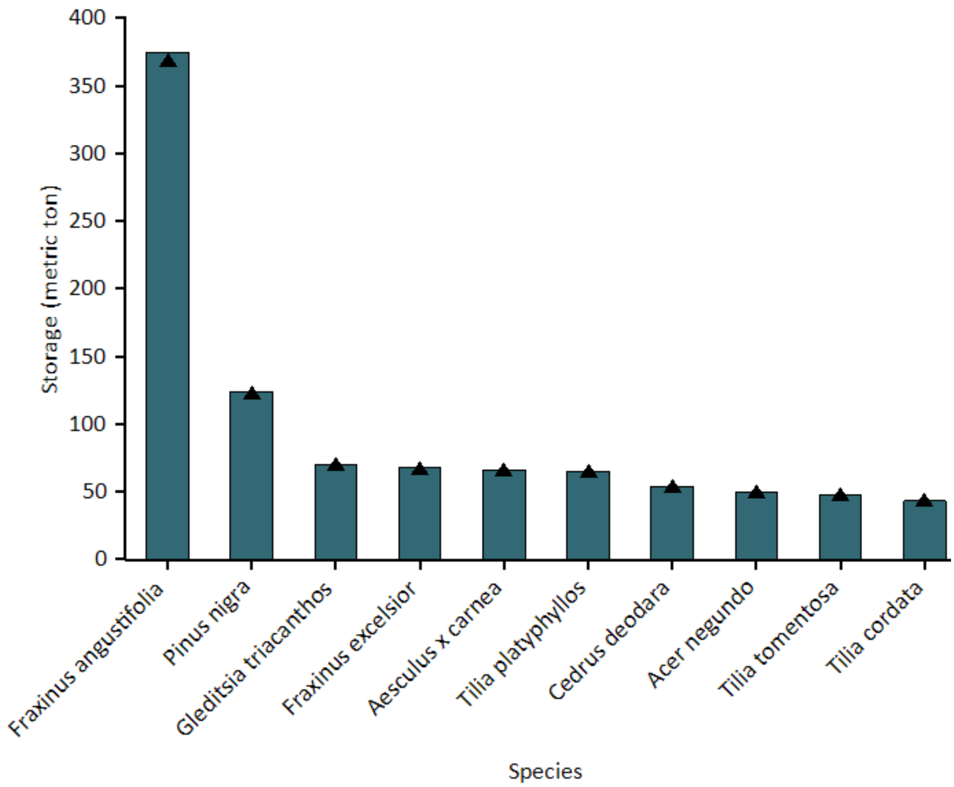

Figure 7. Estimated carbon storage for tree species with the greatest storage of street trees in the study area.

Şekil 7. *Çalışma alanında yer alan, en fazla karbon tutma özelliğine sahip ağaç türleri için tahmini karbon depolama miktarı.*

Oxygen production is one of the most well-known benefits of urban trees. A tree's annual oxygen production is directly related to the amount of carbon retained by the tree, which is dependent on the accumulation of tree biomass (Nowak et al., 2007). It is estimated that street trees in the study area produce 34.44 metric tons of oxygen per year (Table 3).

Another ecosystem service provided by street trees is to reduce runoff. As stated in many studies, trees and shrubs are helpful in reducing surface runoff and improving the quality of runoff water (Scharenbroch et al., 2016; Berland et al., 2017; Turner-Skoff & Cavender, 2019). Based on local weather data from the user-designated weather station, avoided runoff is estimated. In Burdur, the total annual precipitation in 2015 was 19.6 centimeters. The trees and shrubs in the study area help to reduce runoff by an estimated 52 cubic meters a year. According to the avoided runoff for species, *Fraxinus angusitfolia* is the most successful species in preventing runoff (Figure 8).

Table 3. The top 20 species that produce oxygen in the study area.

Çizelge 3. *Çalışma alanıda yer alan, en çok oksijen üreten ilk 20 tür.*

Species	*Oxygen (metric ton)*	*Gross Carbon Sequestration (kg/yr)*	*Number of Trees*	*Leaf Area (hectare)*
Fraxinus angustifolia	9.18	3442.67	122	0.88
Tilia tomentosa	4.23	1586.77	107	0.44
Tilia cordata	3.48	1,303.41	60	0.19
Acer negundo	2.98	1119.16	22	0.35
Tilia platyphyllos	2.55	955.44	51	0.47
Aesculus hippocastanum	1.90	712.26	15	0.01
Cedrus deodara	1.45	541.88	25	0.16
Fraxinus excelsior	1.43	537.89	17	0.28
Juglans regia	1.29	482.48	20	0.23
Aesculus x carnea	0.76	285.31	12	0.02
Salix babylonica	0.60	223.91	6	0.04
Pinus nigra	0.59	222.96	28	0.52
Gleditsia triacanthos	0.54	201.20	17	0.46
Pinus pinea	0.50	188.21	9	0.04
Cupressus arizonica	0.42	156.88	3	0.06
Alianthus altissima	0.35	130.29	10	0.21
Fraxinus americana	0.31	117.76	2	0.01
Catalpa bignonioides	0.31	115.82	5	0.04
Pinus brutia	0.23	85.83	7	0.11
Melia azedarach	0.21	77.00	4	0.08

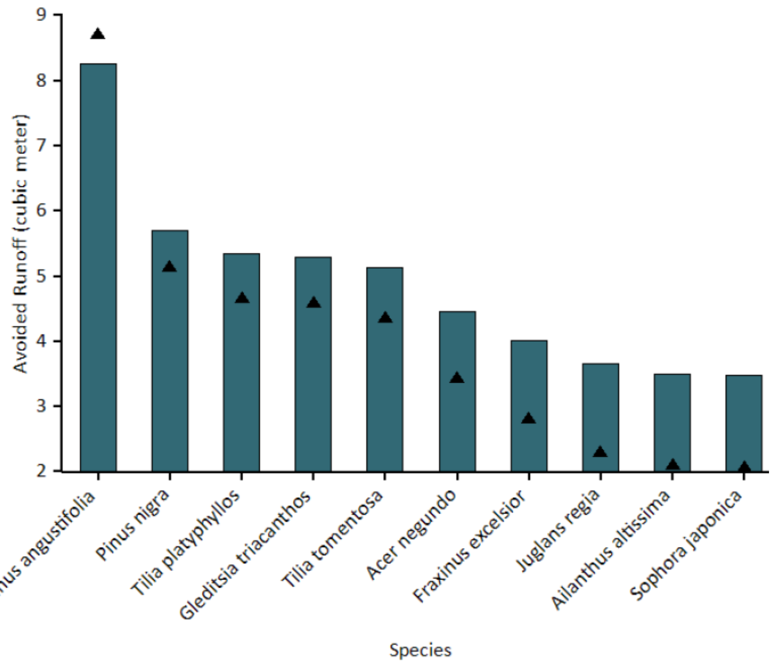

Figure 8. Avoided runoff for species with greatest overall impact on runoff in the study area.

Şekil 8. *Çalışma alanında yer alan, yüzey akışı üzerinde en büyük genel etkiye sahip türlerin önlediği yüzey akış miktarı.*

The ecosystem service values obtained were compared with the results obtained in other studies. Thus, the rationality of the results obtained was revealed. Accordingly, both the results of this study and the results of other related studies have shown that there is a direct connection between the number of street trees and leaf area value (Table 4) As the plant population density size increase, pollution removal capacities, carbon sequestration, oxygen production values, and stormwater runoff avoided increase relatively. In the light of the data in Table 4, the plant diversity in the study area is the highest when compared to other studies (Tuğluer & Gül, 2018; Selim & Atabey, 2020; Coşkun Hepcan & Cangüzel, 2021) according to the number of plants per unit area. However, considering both the length of the study area and the number of plants detected, it has seen that the plant leaf area in the study area is less than the other two studies (Tuğluer and Gül, 2018; Coşkun Hepcan and Cangüzel, 2021). This is thought to be due to the fact that the canopy expansion of the plants in the study area has not yet reached optimum values due to their age.

Table 4. Comparision of ecosystem service parameters from similiar studies with data obtained from the study area.

Çizelge 4. *Benzer çalışmalardaki ekosistem hizmet parametrelerinin çalışma alanı verileri ile karşılaştırılması.*

	Type/Name of the Research Area	Main Avenues in Burdur City Center	Atatürk Boulevard	Bornova University Street	Süleyman Demirel Boulevard
	Location	Burdur, Türkiye	Antalya, Türkiye	İzmir, Türkiye	Isparta, Türkiye
	Reference	(Current study)	*Selim and Atabey, 2020*	*Coşkun Hepcan and Cangüzel, 2021*	*Tuğluer and Gül, 2018*
Comparison Criteria	**Unit**				
Length of the Research Area	m	4100	6276	2500	6120
Number of Plants		588	388	483	1498
Number of Species		32	9	1	24
Number of Families		15	8	1	N/A
Leaf Area	hectares	5.25	0.0065	10.92	21.24
Pollution Removal	kg	66.79	N/A	161.61	N/A
Carbon Sequestration	metric tons per year	12.92	N/A	N/A	N/A
Oxygen Production	metric tons per year	34.44	N/A	N/A	N/A
Stormwater Runoff Avoided	cubic meters a year	52	114.23	N/A	N/A
					N/A: No data available

It has seen that the pollution removal capacity values of the plants in the study area are lower than the values obtained in the study of Coşkun Hepcan & Cangüzel (2021). As Nowak et al. (2018) stated pollution removal is related to the amount of tree cover, pollution concentration, length of in-leaf season, amount of precipitation, percent evergreen leaf area, and other meteorological variables that affect tree transpiration and deposition velocities. Accordingly, the lower pollution removal capacity of the plants in the study area can be explained by the amount of precipitation and pollution concentration of Burdur city, the fact that the majority of the trees are deciduous plants rather than evergreen plants and the amount of tree cover is not high enough. When compared in terms of stormwater runoff avoided (SRA), although the density of plants in the study area of Selim & Atabey (2020) is slightly higher, the performance of the plants in that study in terms of SRA is almost twice the performance of the plants in our study area. As United States Environmental Protection Agency (EPA) (2013) stated trees with their large, dense canopies manage the stormwater better than smaller ones. This means that the street trees in the study area have not yet reached full stature or that the use of broad-crowned tree species has not been prioritized in species selection.

CONCLUSIONS

In this study, ecosystem services were calculated using the i-Tree Eco model by taking an inventory of 588 trees on 6 main avenues in Burdur city center. The main question asked by the study is at which level urban street trees in Burdur city center can accomplish regulating ES. Examinations have shown that trees in Burdur city center are sufficient to provide greatest amounts of ecosystem services provision to the city and mature trees (large size and VGM) provide the largest ecosystem services as Hand et al. (2019) indicated in their study results. On the other hand, when compared to other studies (Tuğluer & Gül, 2018; Selim & Atabey, 2020; Coşkun Hepcan & Cangüzel, 2021) measuring the ecosystem services fulfillment performance of street trees in the same country on a similar scale, it has seen that lower values are calculated in terms of leaf area, pollution removal capacity and stormwater runoff mitigation capabilities. In this context, considering the situation in the 6 main streets of Burdur, the importance of choosing the species to be selected as street tree among the species with high leaf areas and pollution removal capacities has emerged. The species to be selected should also have high oxygen production and carbon sequestration potential and stormwater removal capacity. In order to increase the stormwater removal capacity of these plants, it is necessary to provide the optimum soil width where the roots of the trees can grow and to avoid impervious surfaces directly above the tree. Thus, street trees will reach full status and they will hold more precipitation water.

The street trees in Burdur city center are ecologically important due to their function of connecting green areas throughout the city and serve as green corridors. Considering the data obtained as a result of this study, it can be stated that the species that provide an advantage in terms of ecosystem services like pollution removal, carbon sequestration and storage, oxygen production, stormwater mitigation, should be preferred in determining the tree species to be used in urban street afforestation.

As a well-known fact urban street trees provide multi-faceted services and contributions to the urban ecosystem and urban people, such as increasing air quality, reducing soil erosion, reducing carbon dioxide emissions, reducing the greenhouse effect, reducing the noise level besides stormwater runoff rate, and increasing recreational opportunities (Nowak et al., 2007; EPA, 2013; Shah et al., 2022). In this sense, street trees have vital value for cities capacity of mitigating climate change effects. In addition, determining and interpreting the value of trees by researching is also important in terms of raising awareness about ecosystem services by sharing this information. Today, especially city managers, planners/designers, decision makers and urban people demand to learn concretely the services and contributions of urban trees and urban forests. In this context, software and other manual methods for calculating ecosystem services have become important tools in terms of practice and, functionality use today. It should be mentioned that although the i-Tree Eco module used in the preparation of this study is a software of USA origin, it gives successful results in the calculation of ecosystem services internationally. However, despite the advantages of the i-Tree eco model, there are various uncertainties and limitations in the assumptions and processes carried out in this study that affect the validity of the results. Especially healthy data and monetary values could not be calculated due to lack of data. It is planned to include the analyses of energy savings and health effects, which were not included in the study, in future studies with on-site field studies.

The following conclusions were drawn from the study conducted:

* The choice of tree species, optimum age and crown cover gains importance in the context of ecosystem services, especially in cities located in the Mediterranean basin where the effects of climate change are increasingly felt.

* Mature trees have important cultural and ecological value in providing ecosystem services (Lindenmayer & Laurance, 2017) and it is very important to preserve these trees in cities.

* It would be appropriate to choose street trees in cities by considering their contribution to ecosystem services in the selection of species.

* The presence of street trees in city centers offers many opportunities such as improving the ecosystem in cities, increasing biodiversity, climate change mitigation and is important in this sense.

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