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EFFECTS OF URBAN TREE COVER DECLINE ON CAPACITY OF REGULATING ECOSYSTEM SERVICES IN EDİRNE, TÜRKİYE

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Abstract

Urban trees and forests play a crucial role in providing ecosystem services (ES) that enhance the well-being of urban residents and environmental sustainability. However, studies on the regulating ES of urban trees and their change under the influence of urbanisation in Türkiye are limited. Thus, in this study, we assessed the regulating ES provided by urban trees in the central neighbourhoods of the Merkez District, Edirne, Türkiye, focusing on their ability to remove air pollutants and sequester carbon using web-based i-Tree Canopy. The results revealed a substantial decline in tree cover in the central neighbourhoods, leading to reduced air pollution removal (5,242 kg in 2023 vs 6,976 kg in 2005) and carbon sequestration (181 tonnes/year in 2023 vs 241 tonnes/year in 2005). Contrarily, in the protected area of the Sarayiçi Tavuk Forest, stable tree cover was maintained; this tree cover exhibited a high ES-provision capacity despite its relatively small size. Our novel findings showed that employing web-based tools provides a rapid, easy geospatial solution for assessing regulating ES that can be reproduced in other cities and is useful when comprehensive analysis is limited by insufficient data, time, and resources. Our novel assessment of current and past information on regulating ES establishes a basis for policymakers, urban landscape planners, and researchers to pursue ES-related research, fulfilling the crucial need for climate change adaptation and mitigation strategies in 21st-century cities.

Keywords: Regulating ecosystem services, Urban trees, Air pollution removal, Carbon sequestration, i-Tree Canopy

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Öz

Kent ağaçları ve ormanlar, kent sakinlerinin refahını artıran ve sürdürülebilirliği destekleyen ekosistem hizmetleri sağlamada kritik bir rol oynamaktadır. Ancak, Türkiye'de kent ağaçlarının sağladığı düzenleyici ekosistem hizmetleri ve bu hizmetlerin kentleşmenin etkisi altında nasıl değiştiğine dair yapılan çalışmalar sınırlıdır. Bu çalışmada, Türkiye'nin Edirne ili Merkez İlçesi'ndeki ağaçların sağladığı düzenleyici ekosistem hizmetleri, hava kirleticilerini temizleme ve karbon tutma kapasitelerine odaklanarak i-Tree Canopy aracı kullanılarak hesaplanmıştır. Sonuçlar, çalışma alanındaki ağaç örtüsünde yıllar içinde önemli bir azalma olduğunu, bunun da hava kirliliği temizleme ve karbon tutma kapasitesinde azalmaya yol açtığını göstermektedir. Buna karşılık, koruma altında olan Sarayiçi Tavuk Ormanı'nda 2005-2023 yılları arasında ağaç örtüsü korunmuş olup, sınırlı bir alan olmasına rağmen yüksek bir düzenleyici ekosistem hizmeti sağlama kapasitesi olduğu görülmüştür. Çalışma web tabanlı uygulamaların düzenleyici ekosistem hizmetlerini ölçmek için hızlı ve pratik çözümler sunduğunu; özellikle yetersiz veri, zaman ve maddi kaynak nedeniyle kapsamlı analizlerin sınırlı olduğu durumlarda faydalı olduğunu göstermektedir. 2005-2023 döneminde Edirne'deki kent ağaçlarının sağladığı düzenleyici ekosistem hizmetlerini değerlendiren bu çalışma; peyzaj mimarları, politika yapıcılar, kent plancıları ve araştırmacılar için sürdürülebilirlik ve ekosistem hizmetleri konularında bir temel oluşturarak, 21. yüzyıl şehirlerinde iklim değişikliğine uyum ve azaltım stratejileri konusunda kritik bir ihtiyacı karşılamaktadır.

Anahtar Kelimeler: Ekosistem hizmetleri, Kent ağaçları, Hava kirliliği temizleme, Karbon tutma, i-Tree Canopy

1. INTRODUCTION

Trees occur in a wide range of contexts, from natural conservation areas to urban streets (Schnell et al., 2015). They provide vital ecosystem services (ES) and benefits to urban areas and improve the well-being of urban residents (Gómez-Baggethun & Barton, 2013; Qian et al., 2019). The Millennium Ecosystem Assessment identifies four categories of ES: supporting, cultural, provisioning, and regulating (MEA, 2005). The regulating ES of trees in urban contexts are crucial for managing the challenges of cities adapting to future climate variability (Cilliers et al., 2013; Tang & Adesina, 2022). Trees improve the microclimate at a local scale and remove pollutants from the atmosphere (Nowak et al., 2018). Trees also absorb CO_2, which otherwise contributes to increased air temperature and exacerbates the heat in urban areas (Beckett et al., 1998).

Urban trees and their ES provide several benefits to urban residents (Eisenman et al., 2019; Nowak et al., 2014). However, a concerning trend of declining tree cover and an increase in impervious surfaces has been observed in several cities globally (Nowak &Greenfield, 2020), including cities in Türkiye (Atasoy, 2020; Ersoy Tonyaloğlu & Atak et al., 2021). Increases in impervious surface areas increase available housing and transport areas for urban residents whereas limiting the growth of urban vegetation, influencing the local climate, and regulating temperature, air pollution, and levels of natural resources for carbon storage and sequestration (Nowak et al., 2013; Nowak et al., 2014). Studies have demonstrated the alteration of regulating ES due to heavy urbanisation (Aguilera et al., 2020; Lu et al., 2022). Although the importance of trees and their regulating ES in urban areas is well established, these services are rarely considered while formulating landscape and urban planning policies (Başak et al., 2022). Furthermore, the insufficient fundamental research on urban trees and the regulating ES in Türkiye often results in landscape and urban planners and policymakers not having the necessary benchmarks to set specific planning goals or expectations.

Geographic information systems and remote sensing (RS) technologies have been extensively used to assess and monitor regulating ES (Aguilera et al., 2020; De Araujo Barbosa et al., 2015; Egoh et al., 2008; Lu et al., 2022). Studies have demonstrated the capacity of traditional RS technologies to process large amounts of data concerning complex environmental interactions (Du et al., 2014; Xie et al., 2008). Conversely, Parmehr et al. (2016) and Richardson and Moskal (2014) have suggested that cost-effective and rapid assessment tools—other than traditional RS techniques—are feasible, considering the rapidly changing cities of the 21st century.

The United States Department of Agriculture Forest Service's i-Tree is a state-of-the-art, peer-reviewed software that enables users, including the public and decision-makers, to rapidly assess tree cover changes, quantify current and past regulating ES, and estimate the benefits of tree cover in urban and rural areas (Nowak, 2021). Since approximately 2006, numerous studies have used the i-Tree platform to categorise and quantify the proportion of various land cover types, map urban tree cover (UTC), and evaluate regulating ES in a defined area in rapidly urbanising regions worldwide by using a random point sampling method (Endreny et al., 2017; Song et al., 2020; Nowak, 2021; Coşkun Hepcan and Canguzel, 2021; Ersoy Tonyaloğlu and Atak, et al., 2021).

Edirne, a city of substantial historical importance, has been a pivotal location at the intersection of Europe and Asia, serving for centuries as a hub for commerce, transport, and cultural exchange. As the capital of the Ottoman Empire for approximately 90 years, Edirne has played a crucial role in the development of various empires, including the Byzantine and Roman empires. In 2021, Edirne joined the New Integrated Covenant of Mayors for Climate and Energy, a European Commission-based agreement for cities that aim to manage climate change via mitigation and adaptation plans. Signatory cities, such as Edirne, have committed to reduce their greenhouse gas emissions by 55% in 2030 and 80% by 2050 and report their annual emissions to international bodies (Edirne Belediyesi, 2023). Notably, one of the main regulating ES of urban trees is carbon storage and sequestration, which helps reduce greenhouse gases (i.e., CO_2 and O_3) from the atmosphere.

The understanding of the importance of urban trees and their regulating ES in cities has improved. However, studies on the regulating ES of urban trees and their change under the influence of urbanisation in Türkiye have been limited. Therefore, assessments of regulating ES and understanding the economic benefits in Edirne have become vital. From this perspective, this study aimed to fill a crucial knowledge gap by investigating two key questions: i) how much air pollution is removed by the existing tree cover in the central district of Edirne, and ii) how have changes in the UTC between 2005 and 2023 changed the provision of regulating ES, particularly air pollution removal and carbon sequestration. To answer these questions, we estimated the regulating ES of past and current tree cover in Edirne over an 18-year period from 2005 to 2023.

2. MATERIALS AND METHODS

2.1. Study area

The selected study areas were within the central district of Edirne in northwestern Türkiye, encompassing the most historical, urbanised, and central neighbourhoods of the Merkez District and Sarayiçi Tavuk Forest (Figure 1). In 2023 the central neighbourhoods (41.676848° N, 26.556194° E) had a dense population of 72,857 individuals within an area of 445.19 ha (Türkiye İstatistik Kurumu, 2023). These neighbourhoods were characterised by several historical buildings, some serving as residential dwellings for local families, and others fulfilling commercial roles, providing goods and services to long-term residents and newcomers. The Sarayiçi Tavuk Forest (41.695542° N, 26.559826° E), 2.5 km from the centre of the central neighbourhoods, is adjacent to the Tunca River and covers 70.62 ha (Figure 1). In 2019, the Sarayiçi Tavuk Forest was designated as a Natural Site-Qualified Natural Conservation Area and a Natural Site-Sustainable Conservation and Controlled Use Area (Ministry of Environment, Urbanization and Climate Change, 2024).

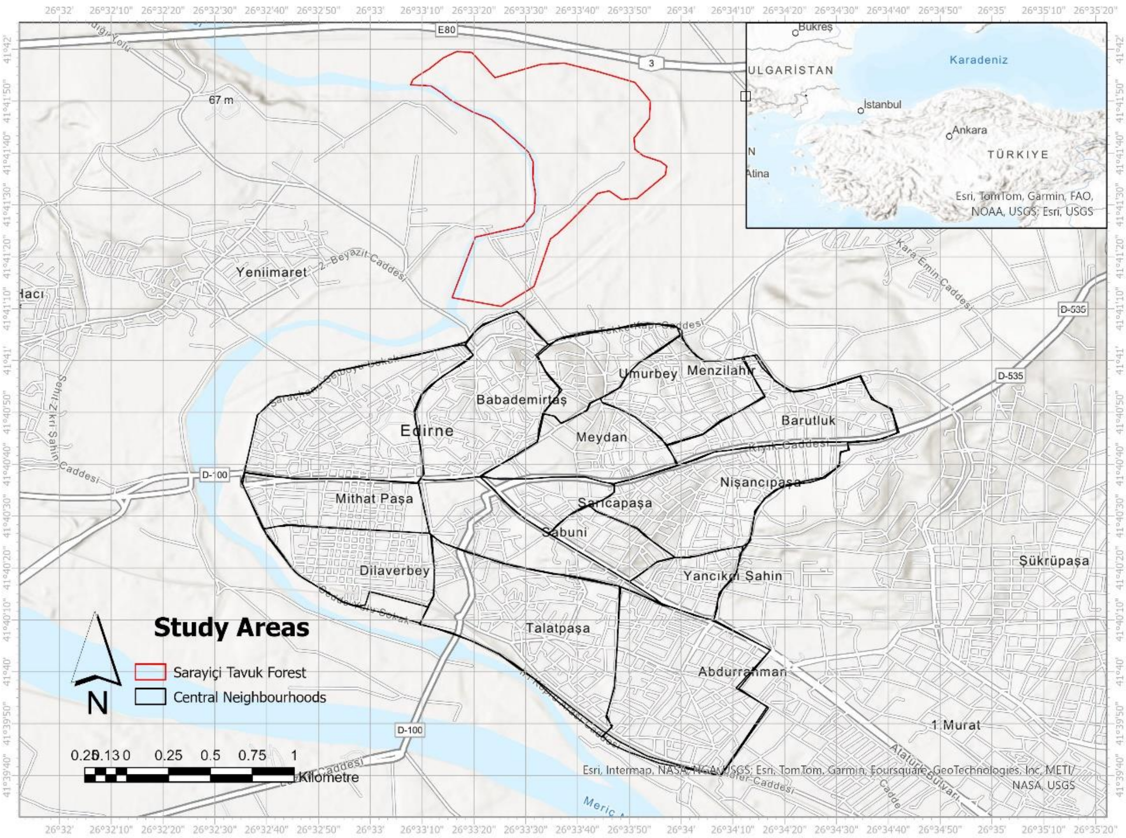

Figure 1- Sarayiçi Tavuk Forest and central neighbourhoods of Merkez District, Edirne

2.2. Tree cover, tree cover change, and regulating ES assessment

Tree cover and regulating ES were assessed using random points and image interpretation by combining i-Tree Canopy v.7.1. (Nowak, 2021) with Google Earth Pro v.7.3.6. This adaptable, straightforward method comprised five steps: (i) defining the boundaries of the study area, (ii) determining land cover types (i.e., tree/non-tree), (iii) classifying random sample points (same 1000 points) within the study areas, (iv) calculating tree cover change, and (v) estimating regulating ES and their change. Screen digitisation was performed while defining the study areas in i-Tree Canopy v.7.1 using high-resolution Google Earth aerial images. A specific number of sampling points (i.e., 1000) was distributed to ensure the accurate assessment of tree cover, with a confidence level >95% and standard error <1.6% in accordance with the i-Tree Canopy user guide (https://canopy.itreetools.org/). Regulating ES were estimated based on the area covered by the past (i.e. 2005) and current (i.e. 2023) tree canopy and location-specific coefficient values. The ability to remove atmospheric pollutants and sequester and store carbon, along with their corresponding monetary values, was estimated using coefficients from the i-Tree Canopy tool. In estimating the effect of trees, a local standardised removal rate (e.g. kg/m² of tree cover) was multiplied by the local tree cover (m²) obtained from i-Tree Canopy. For air pollution removal, i-Tree Eco uses air pollution and weather data to calculate the average pollution removal effect per unit of tree cover (g/m² or USD/m² of tree cover) for each county in the United States. In this study, air pollutant removal rates and their monetary values were statistically standardised using a unit tree in i-Tree Eco, which was based on data from cases in the United States (Nowak & Greenfield, et al., 2012). Air pollution estimates were based on the following values, measured in kg/ha/year and USD kg/year, which have been rounded: CO, 1.069 kg at USD 1.57; NO_2, 4.227 kg at USD 0.17; O_3, 50.944 kg at USD 0.64; SO_2, 9.119 kg at USD 0.01; PM2.5, 2.660 kg at USD 25.93; and PM10*, 20.428 kg at USD 7.45. Detailed methods for this process are outlined in Hirabayashi and Nowak (2016) and Nowak et al. (2014). The coefficients for carbon estimates were based on the average carbon density per unit of canopy cover in urban environments. These coefficients were derived from national and state data by using the methods of Nowak et al. (2013). The amount sequestered was based on 3.060 tonnes of carbon, or 11.220 tonnes of CO_2, per hectare per year and was rounded. The amount stored was based on 76.848 tonnes of carbon, or 281.776 tonnes of CO_2, per hectare and was also rounded. The value (USD) was calculated using USD 188.00 per tonne of carbon, or USD 51.27 per tonne of CO_2, and was rounded (Nowak et al. 2013).

3. RESULTS

3.1. Tree cover change

Among the central neighbourhoods, tree (N = 133) and non-tree (N = 867) classes covered 13.31% (SE ± 1.07) and 86.70 % (SE ± 0.80), respectively, in 2023. In 2005, tree coverage (N = 177) and non-tree (N = 823) coverage were 17.72% (SE ± 1.21) and 82.28% (SE ± 0.70), respectively (Table 1). The non-tree class was more dominant than the tree class in the study area for both years, comprising 385.92 and 366.31 ha in 2023 and 2005, respectively (Table 1).

Table 1- Area and percentage of tree and non-tree cover classes in the central neighbourhoods of Merkez District in 2005 and 2023

	Points (N)		% Cover ± SE		Area (ha) ± SE	
Cover class	**2005**	**2023**	**2005**	**2023**	**2005**	**2023**
Tree	177	133	17.72 ± 1.21	13.31 ± 1.07	78.88 ± 5.38	59.27 ± 4.78
Non-tree	823	867	82.28 ± 0.70	86.70 ± 0.80	366.31 ± 4.01	385.92 ± 3.78
Total	1,000	1,000	100.00	100.00	445.19	445.19

In 2005, trees covered 59.27 ha of the study area and were primarily located in residential and school gardens, streets, and river areas (Figure 2). From 2005 to 2023, 4.41% of the tree cover was transformed into non-tree cover, primarily consisting of impervious buildings, roads, and other infrastructure. This shift occurred as single-story homes with gardens were replaced by multi-story buildings, diminishing the importance of gardens and trees. Primary and secondary school gardens underwent a similar change from green areas to sealed, impervious surfaces. Additionally, in 2005, open green areas, namely riparian corridors and meadows with trees and shrubs, were transformed into sealed surfaces, namely asphalt, rubber, and interlocking concrete pavers in industrial zones, school gardens, and playgrounds (Malkoç, 2024).

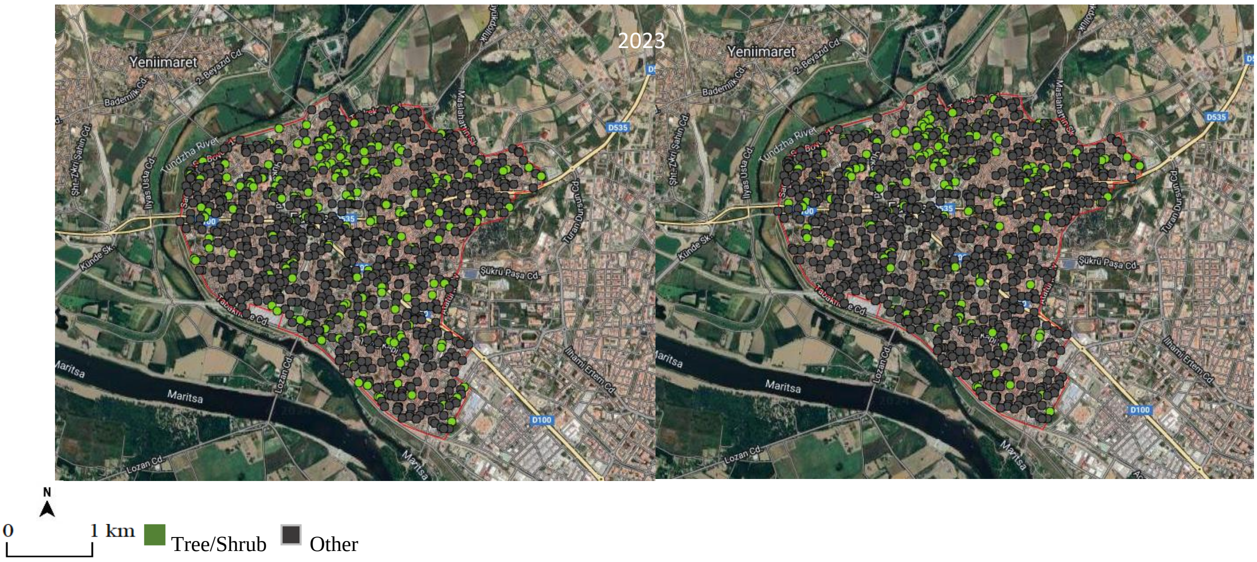

Figure 2- Distribution of random sample points in the central neighbourhoods of Merkez District (N = 1,000) in 2005 and 2023.

3.2. Air quality and carbon storage change

The quantities of atmospheric pollutants and particulates removed in the central neighbourhoods of the Merkez District in 2005 and 2023 are shown in Table 2 and the amount of carbon sequestered and stored by the tree cover is shown in Table 3. In 2005, 6,976.43 kg of pollutant gases and particles were removed from the air by tree cover in the study area, a substantial decrease compared with the 5,242.18 kg removed in 2023 (Table 2). Moreover, annual carbon sequestration by tree cover in 2005 and 2023 was estimated to be 241.37 and 181.36 tonnes/year, with total carbon storage reaching 6,061.58 and 4,554.75 tonnes, respectively (Table 3). The annual economic value of sequestered carbon in trees was estimated to be USD 45,377 and 34,097 in 2005 and 2023, respectively, with monetary values across the life cycle of trees estimated to be USD 1,139,578 and 856,293, respectively.

Table 2- Removal of atmospheric pollutants and particulates in the central neighbourhoods of Merkez District in 2005 and 2023

	Amount (kg) ± SE		Value (USD) ± SE	
	2005	**2023**	**2005**	**2023**
CO	84.35 ± 5.75	63.38 ± 5.12	132 ± 9	99 ± 8
NO_2	333.38 ± 22.73	250.51 ± 20.22	58 ± 4	43 ± 4
O_3	4,018.31 ± 273.97	3,019.41 ± 243.77	2,584 ± 176	1,941 ± 157
SO_2	719.31 ± 49.04	540.50 ± 43.64	9 ± 1	6 ± 1
$PM_{2.5}$	209.80 ± 14.30	157.64 ± 12.73	5,439 ± 371	4,087 ± 330
PM_{10}*	1,611.28 ± 109.86	1,210.73 ± 97.75	12,007 ± 819	9,022 ± 728
Total	6,976.43 ± 475.66	5,242.18 ± 423.22	20,228 ± 1,379	15,200 ± 1,227

Table 3- Estimated carbon ecosystem services in the central neighbourhoods of Merkez District in 2005 and 2023

	Amount (tonne) ± SE		CO_2 Equiv. (tonne) ± SE		Value (USD) ± SE	
	2005	**2023**	**2005**	**2023**	**2005**	**2023**
Annual C sequestered by trees	241.37 ± 16.46	181.36 ± 14.64	885.01 ± 60.34	665.00 ± 53.69	45,377 ± 3,094	34,097 ± 2,753
Estimated C stored in trees	6,061.58 ± 413.29	4,554.75 ± 367.72	22,225.81 ± 1,515.39	16,700.75 ± 1,348.30	1,139,578 ± 77,698	856,293 ± 69,131

3.3. Tree cover, air quality, and carbon storage of Sarayiçi Tavuk Forest

Due to its designation as a Natural Protected Area, the Sarayiçi Tavuk Forest maintained a consistent tree cover from 2005 to 2023. Figure 3 and Table 4 provide detailed information on the tree and non-tree cover classes, namely the number of random points, percentage cover and area for each class, standard error rates, and distribution of random sampling points.

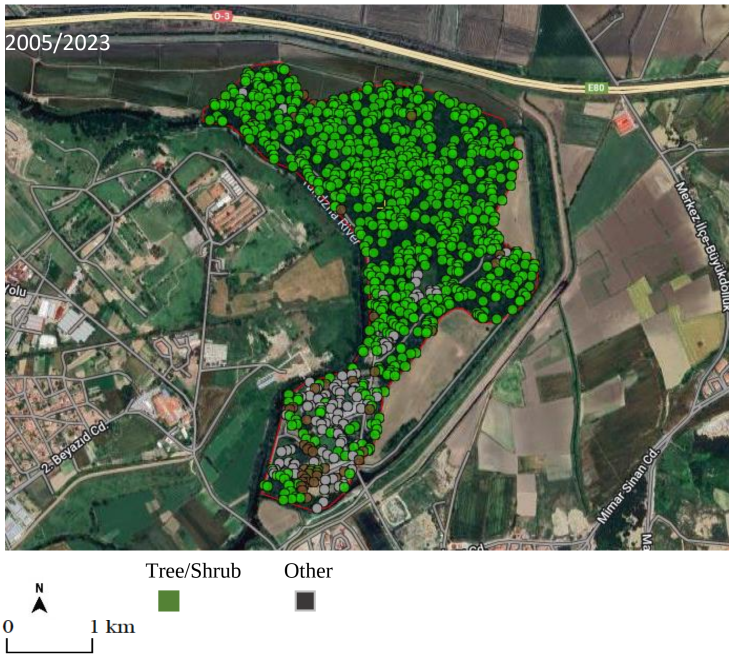

Figure 3- Distribution of random sample points (N = 1,000) in Sarayiçi Tavuk Forest in 2005 and 2023.

Table 4- Area and percentage of tree and non-tree cover classes in Sarayiçi Tavuk Forest in 2005 and 2023

Cover Class	Points (N)	% Cover ± SE	Area (ha) ± SE
Tree	847	84.72 ± 0.90	59.83 ± 0.80
Non-Tree	153	15.28 ± 1.00	10.69 ± 0.60
Total	1,000	100.00	70.62

The Sarayiçi Tavuk Forest primarily consisted of trees, accounting for 84.72% of the land cover in 2005 and 2023 (59.83 ha). The standard error values were equal to or less than 1, indicating that the point distributions across land cover classes in the study area were equally weighted. As shown in Table 5, the Sarayiçi Tavuk Forest was estimated to remove a total of 5,014.68 kg of polluting gases and particulates from the air and sequester 183.03 tonnes of carbon annually. Additionally, the total carbon storage provided by the forest was estimated to be 4,596,680 tonnes (Table 6).

Table 5- Atmospheric pollutants and particulates removed from the air in Sarayiçi Tavuk Forest in 2005 and 2023

	Amount (kg) ± SE	Value (USD) ± SE
CO	60.00 ± 0.81	14 ± 0
NO_2	311.07 ± 4.18	2 ± 0
O_3	3,248.79 ± 43.66	160 ± 2
SO_2	262.96 ± 3.53	1 ± 0
$PM_{2.5}$	159.17 ± 2.14	330 ±4
PM_{10}*	1,131.80 ± 15.21	1,391 ± 19
Total	5,173.78 ± 69.54	1,897 ± 26

Table 6- Estimated carbon ecosystem services in Sarayiçi Tavuk Forest in 2005 and 2023

	Amount (tonne) ± SE	CO_2 Equiv. (tonne) ± SE	Value (USD) ± SE
Annual C sequestered in trees	183.03 ± 2.46	671.13 ± 9.02	$34,410 ± 462
Estimated C stored in trees	4,596.68 ± 61.78	16,854.51 ± 226.53	$864,177 ± 11,615

During the 18-year study period, trees were estimated to sequester 671.13 tonnes of carbon annually, with total carbon storage estimated to be 16,854.51 tonnes (CO_2 equivalent). The economic value of carbon stored via canopy cover was approximately USD 864,177 and the annual value of carbon sequestered in trees was estimated to be approximately USD 34,410. The total tree cover, air pollution removal potential, and stored carbon showed no significant changes over the study period.

4. DISCUSSION

The major contribution of this study is that it fills the knowledge gap regarding the regulating ES of trees in the central neighbourhoods of the Merkez District and Sarayiçi Tavuk Forest in Edirne in the long term. The results demonstrate a significant decrease in the regulating ES-provision capacity in Edirne. During the 18-year study period, the total amount of pollutants removed from the atmosphere decreased by 1,734 kg, with an estimated value equivalent to USD 5,000. Additionally, the sequestered carbon in trees decreased by 60 tonnes, with an estimated value equivalent to USD 11,280. The results are comparable to those of cities that experienced a loss of UTC in Türkiye (Ersoy Tonyaloğlu & Atak, 2021) and worldwide (Aguilera et al., 2020; Lu et al., 2022). Notably, the regulating ES of trees in cities across the United States, Canada, and Europe vary based on the size of the areas and the status of the forests (i.e. protected areas and maintained forests) (Anaya-Romero et al., 2016; Nowak et al., 2014); thus, drawing direct comparisons among studies is difficult because their scopes and scales differ.

Moreover, this study assessed the current air pollution removal capacity of the UTC in the central area of Merkez District (5,242.18 kg) and compared it with (5,173.78 kg) that in the Sarayiçi Tavuk Forest. Notably, the Sarayiçi Tavuk Forest, which is 6.5 times smaller in size, however, has six times greater tree cover than the central neighbourhoods of the Merkez District, removes almost the same amount of air pollutants. The Sarayiçi Tavuk Forest also sequesters almost the same amount of carbon as the trees in the central neighbourhoods of the Merkez District.

This study shows that assigning protected status to the Sarayiçi Tavuk Forest would ensure long-term tree cover and maintain its capacity for regulating ES. Over the 18-year study period, the loss of UTC resulted in a scattered spatial distribution of trees in the Merkez District. The high demand for diverse land uses in urban areas, combined with the limited availability of new green and open spaces, highlights potential environmental challenges (Nowak & Greenfield, 2012). The decrease in UTC has also been observed in other cities in Türkiye, which is attributed to a development policy that has favoured urban development (i.e. urban expansion into formerly green areas), soil sealing (i.e. replacing permeable surfaces with impermeable materials, e.g. concrete), and the failure to protect (or to reinstate) trees in development areas since the early 2000s (Başak et al., 2022). Thus, Edirne should prioritise the long-term sustainability and protection of healthy, mature trees and shrubs in urban areas and adjacent forests, namely the Sarayiçi Tavuk Forest.

The assessment approach can be applied at various scales, from the city level to the country level. From this perspective, the results of this study are complementary to the national and international reporting requirements of cities (i.e. 'New Integrated Covenant of Mayors for Climate and Energy') with carbon targets to fulfil climate regulation requirements.

Using random sampling and aerial imagery is a more rapid and cost-effective estimation of the regulating ES of trees in Edirne in the 18-year studied period than traditional RS techniques. The standard error rates for the UTC assessment (%), air pollution removal, and their monetary values were achieved between ±0.7–1.21 and ±5.75–109.86, respectively, which are comparable with those achieved in other studies, as reviewed by Nowak (2021). However, i-Tree Canopy (v.7.1) is tailored to the United States and incorporates characteristic coefficients specific to that region. Conducting additional studies in Türkiye could lead to the integration of Mediterranean or

Turkish standards into the i-Tree Canopy tool, leading to the integration of improved results with regard to the provision of information for landscape and urban planners and city decision-makers.

The i-Tree Canopy tool typically employs average coefficient values for air pollution removal and carbon estimations, which are independent of species and age information. Notably, different tree and shrub species with diverse compositions and age structures have varying abilities to provide regulating ES (Beckett et al., 1998; McPherson and Rowntree, 1989). The i-Tree Canopy tool used in this study has limitations due to plant species, structure, and age information being unavailable; thus, moderate standard error rates are associated with the estimation of air pollution removal capacity, CO_2 sequestration, and monetary values. Nevertheless, the standard error rates associated with these parameters align with those described in an existing study (Nowak, 2021). To overcome these limitations, further research should focus on incorporating relevant detailed information into the assessment. Additionally, expanding the scope of this research to the entire Edirne Province could provide a more comprehensive understanding of the change in tree cover on a larger scale than that in this study.

We posit that the availability and application of rapid and cost-effective assessments of regulating ES, such as those used in this paper, will provide sufficient fundamental information and stimulate the integration of regulating ES while aiding the formulation of landscape and urban planning policies at the local, national, and international levels, filling a crucial information gap on the adaptation of cities to, and mitigation of, climate change while considering the rapidly changing cities in the 21st century.

5. CONCLUSION

In this study, we assessed the regulating ES of urban trees in Edirne, Türkiye, over an 18-year period, including substantial changes in UTC. The findings have crucial implications for informing decision-makers and urban residents. Because of the New Integrated Covenant of Mayors for Climate and Energy declared by the Edirne Municipality in 2023, our study provides detailed information regarding the capacity of UTC to absorb greenhouse gases (i.e., CO_2 and O_3) and will facilitate the process of reporting these data to international bodies.

Our findings illustrate that employing i-Tree Canopy and Google Earth Pro provides a rapid, easy geospatial solution for assessing regulating ES. Owing to the thorough explanation of this straightforward assessment method, it can be reproduced in other cities and is particularly useful in cases where comprehensive analysis is limited by insufficient data, time, and resources.

Beyond filling the extensive knowledge gap regarding the decline in regulating ES of trees in Edirne, this study is a continuation of the web-based UTC assessment conducted by Malkoç (2024). This study has also demonstrated the substantial potential of utilising freely accessible online data and tools (i.e. i-Tree Canopy) to effectively assess and monitor UTC and its regulating ES continuously in the long term. Our assessment of current and past information on regulating ES establishes a basis for policymakers, urban landscape planners, and researchers to pursue ES-related research, fulfilling the crucial need for climate change adaptation and mitigation strategies in 21st-century cities.

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Finansal Destek / *funding conditions*	Yazar(lar) bu çalışma için finansal destek almadıklarını beyan etmiştir. *The authors declared that this study has received no financial support*

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