ISPARTA UYGULAMALI BİLİMLER ÜNİVERSİTESİ

Turkish Journal of Forestry | Türkiye Ormancılık Dergisi
2024, 25(4): 540-545 | Research article (Araştırma makalesi)

Tree inventory and ecosystem service assessment using web-based geographic information system (GIS) tools: Case study in Edirne

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Abstract: In addition to covering essential human needs, such as food, fuel, and timber, trees have been providing numerous health, aesthetic, and recreational benefits throughout history. Trees in urban areas provide significant ecosystem services, particularly in relation to air quality regulation via particulate matter (PM) entrapment and greenhouse gas absorption. This study was aimed to elucidate the regulatory ecosystem service capacity of trees in the Selimiye Campus of Trakya University, Edirne, Türkiye. We compiled a tree inventory and a method for assessing regulatory ecosystem services using web-based geographic information system (GIS) tools, namely Google Earth, Google My Maps, and MyTree. The results showed that the Selimiye Campus has 197 trees of 22 species. These trees remove 330 kg of pollutants and sequester 5851.09 kg of carbon annually. Despite its limited tree capacity, the Selimiye Campus holds significant potential for regulatory ecosystem services. Overall, this study emphasises the importance of compiling tree inventories using web-based tools to guide landscape planning and decision-making processes. It also highlights that campuses are essential components of urban green spaces, contributing to green area development and providing regulatory ecosystem services.
Keywords: Tree inventory, Ecosystem services, Google My Maps, Google Earth, MyTree

Web tabanlı coğrafi bilgi sistemleri (CBS) araçları ile ağaç envanteri oluşturmak ve ekosistem hizmetlerinin ölçülmesi: Edirne örneği

Öz: Gıda, yakıt ve kereste gibi temel insan ihtiyaçlarını karşılamanın yanı sıra, ağaçlar tarih boyunca birçok sağlık, estetik ve rekreasyonel fayda sağlamıştır. Kent ağaçları, özellikle partikül madde (PM) tutma ve sera gazı emilimi yoluyla hava kalitesinin düzenlenmesi açısından önemli ekosistem hizmetleri sunmaktadır. Bu çalışmanın amacı Trakya Üniversitesi Selimiye Kampüsü'ndeki ağaçların düzenleyici ekosistem hizmetleri kapasitesini ölçmektir. Ağaç envanteri oluşturmak ve düzenleyici ekosistem hizmetlerini ölçmek için Google Earth, Google My Maps ve MyTree gibi web tabanlı açık kaynaklı Coğrafi Bilgi Sistemi (CBS) araçları kullanılmıştır. Bulgular Trakya Üniversitesi Selimiye Kampüsü'nde 22 türe ait 197 ağaç bulunduğunu; bu ağaçların yılda 330 kg kirletici maddeyi temizlemekte ve 5851,09 kg karbonu depolamakta olduğunu göstermiştir. Sınırlı ağaç kapasitesine rağmen Selimiye Kampüsü, önemli bir düzenleyici ekosistem hizmeti potansiyeline sahiptir. Çalışma, peyzaj planlama ve karar alma süreçlerine rehberlik etmek amacıyla web tabanlı ve açık kaynaklı uygulamalar ile ağaç envanteri oluşturmanın önemini vurgulamakta ayrıca kampüslerin kentlerin yeşil alan ihtiyacını karşılayan ve düzenleyici ekosistem hizmetlerine katkı sunan bileşenler olduğunu göstermektedir.
Anahtar kelimeler: Ağaç envanteri, Ekosistem hizmetleri, Google My Maps, Google Earth, MyTree

1. Introduction

Throughout history, trees have not only been covering basic human needs, such as food, fodder, fuel, and timber, but have also been providing health, aesthetic, and recreational benefits (Tyrväinen et al., 2005). Trees are significant elements in urban areas, offering a range of benefits and functions, from psychological and aesthetic improvements to various ecosystem services (Aerts and Honnay, 2011; Roy et al., 2012).

One of the most important ecosystem services of trees is their influence on air quality (Smith, 1990). Owing to their physiological characteristics, trees can store, filter, and convert pollutants (Nowak et al., 2018a), as well as sequester and filter significant amounts of carbon, particulate matter (PM), nitrogen dioxide, and sulfur dioxide annually (Nowak et al., 2014). Trees improve air quality by trapping PM, absorbing greenhouse gases, regulating climate, and improving air quality (Nowak et al., 2014).

Information systems are important for collecting, storing, generating, and distributing information that can support management functions; ultimately, they enable the public to readily access and efficiently use geographic information (Dragićević and Balram, 2004). Web-based geographic information system (GIS) tools for environmental assessment, resource management, and decision making are popular, as they allow for efficient and systematic use of data (Shim et al., 2002); they enable compiling inventories and conducting assessments of the regulatory ecosystem services of vegetation through storage, analysis, and use of various plant-related data (Tasoulas et al., 2013).

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✓ **Received** (Geliş tarihi): 04.09.2024, **Accepted** (Kabul tarihi): 30.10.2024

Citation (Atıf)**:** Malkoç, E., 2024. Web tabanlı coğrafi bilgi sistemleri (CBS) araçları ile ağaç envanteri oluşturmak ve ekosistem hizmetlerinin ölçülmesi: Edirne örneği. Turkish Journal of Forestry, 25(4): 540-545.
DOI: 10.18182/tjf.1543353

The use of web-based GIS tools was popularized through the introduction of Google Earth in 2005 and Google My Maps in 2007 as free mapping tools enabling the creation and sharing of location-based maps on the web (Google Inc., 2007). Another web-based GIS tool, namely MyTree, is a rapid, practical, and free ecosystem service assessment tool developed by the United States Department of Agriculture i-Tree program (Nowak, 2021b); it has been used in tree inventory studies conducted in many cities across the USA, Canada, and Mexico, as well as in European cities, such as Barcelona, London, Madrid, and Zurich (Nowak et al., 2018b).

Trees in urban areas are the most important and dominant natural resources, significantly contributing to the ecological, social, cultural, economic, and aesthetic aspects of cities. Numerous studies involving tree inventories and regulatory ecosystem service assessments have been conducted worldwide; their purposes vary, from regional and municipal scales to campuses, according to the individual needs at different scales (Csurgó and Smith, 2021; Veerkamp et al., 2021). Municipalities in North America have primarily conducted economic assessments of trees in cities; however, in Northern Europe, environmental management issues, such as monitoring tree health and canopy dynamics of tree stands, have been assessed using the i-Tree program (Östberg et al., 2018).

University campuses constitute main components of urban areas and include varieties of trees (Wang et al., 2021). A total of 6159 trees were inventoried on the Yale University campus in the city of New Haven, Connecticut, USA (Yale University, 2020). Hepcan and Hepcan (2017) examined the tree cover in the Lojmanlar Campus of Ege University, İzmir, Türkiye, and assessed the ability of the trees to remove harmful pollutants from the atmosphere. Several studies have used the web-based i-Tree Canopy—a fast and practical assessment tool—for assessing regulatory ecosystem services (Qian et al., 2019; Ghorbankhani et al., 2024). i-Tree Canopy uses the average coefficients for conducting regulatory ecosystem service calculations; these coefficients are derived from USA data and are not based on tree species. Ma et al. (2021) emphasized tree species and trunk diameter as the most commonly used parameters in comprehensive assessments of regulatory ecosystem services. MyTree is a tool that uses tree species, trunk size, and crown size information for assessing PM absorption, carbon sequestration, NO_2, and O_3, as well as the equivalent monetary values, providing comprehensive results for small-scale studies (Nowak, 2021).

Considering the 21st century climate variability and climate regulation needs, compiling tree inventories for cities and assessing the ability of trees to regulate air quality have emerged as key procedures (Loughner et al., 2012; Nowak et al., 2014). Our enhanced understanding of the importance of trees in urban areas has highlighted also the importance of obtaining detailed information on trees and their regulatory ecosystem services. In Türkiye, assessments of the regulatory ecosystem services of trees on university campuses are limited. The aim of this study was to compile a tree inventory and assess the regulatory ecosystem services of the trees on the Selimiye Campus of Trakya University, Edirne, Türkiye. Furthermore, we aimed to develop an assessment method using various web-based information system tools that are becoming increasingly popular owing to technological advancements, consistent with the information needs of societies.

2. Materials and methods

2.1 Study area

The Selimiye Campus of Trakya University is located within the boundaries of the Merkez district of Edirne in the Trakya region of Türkiye (41° 40′ 49.75′ N, 26° 33′ 37.52′ E). The campus has a north–south orientation, covering a total area of 23,888.17 m² (Figure 1). The entire campus, including the Harbiye Barracks Building, is registered as a "Protected Monument" (number 294) by the Edirne Cultural Heritage Preservation Board; it lies within the impact and transition zone of the Selimiye Mosque and Complex, which is included in the UNESCO World Heritage List (MoCaT, 2011). Since 2012, the Selimiye Campus of Trakya University has been hosting the Faculty of Architecture.

2.2 Methods

Our method for compiling a tree inventory and conducting regulatory ecosystem service assessment using web-based GIS tools involved five steps. First, the boundaries of the research area were defined using a web-based interactive application that displays the development status of the Urban Planning and Housing Department of Edirne Municipality (MoE, 2024). Subsequently, the attribute information of the trees in the study area (family, Latin name, trunk diameter, crown height, and crown diameter) were determined on site, and their locations and relevant attribute information were marked with ground control points using Google Earth and saved in KML format. The KML file was transferred to Google Maps, represented by visualization symbols depending on the tree species, and made publicly available on the web for use by the community. The regulatory ecosystem services of trees in the Selimiye Campus were calculated using MyTree based on the species, trunk size, health status, and sun exposure of trees. This method was used to calculate and report the annual total regulatory ecosystem services of all trees on campus, including the removal of air pollutants (ozone [O_3], carbon monoxide [CO], nitrogen dioxide [NO_2], PM smaller than 2.5 μm [$PM_{2.5}$], sulfur dioxide [SO_2]), carbon sequestration, and equivalent monetary values. The results obtained were evaluated, and a report was generated using MyTree. All web-based tools used in this study are publicly available and free of charge.

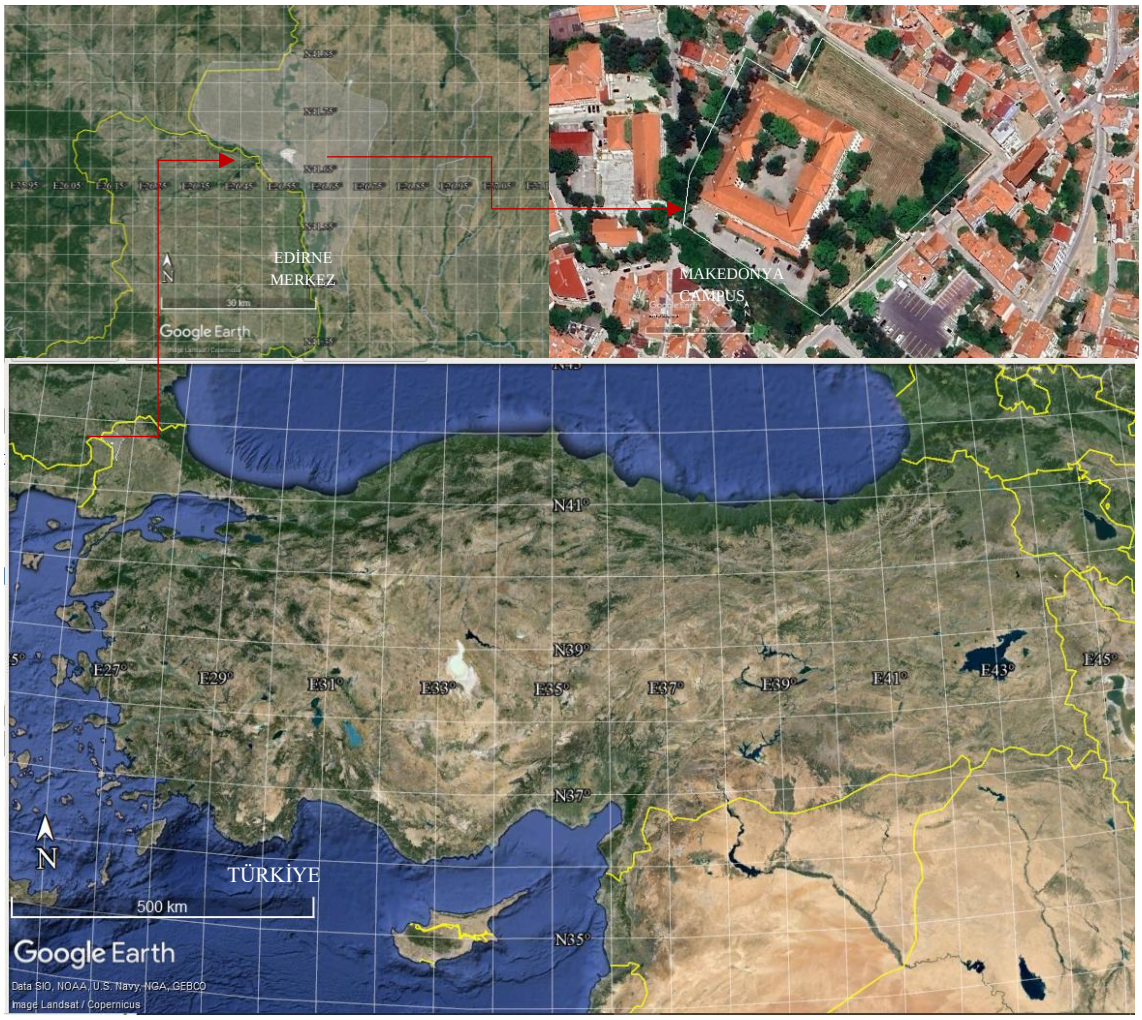

Figure 1. Map of the Selimiye Campus of Trakya University, Edirne, Türkiye

3. Results and discussion

The campus contained 12 families, 22 species, and 197 trees. The individual tree species and numbers in the study area included *Abies nordmanniana* (1), *Acer negundo* (47), *Ailanthus altissima* (11), *Cedrus atlantica* (9), *Cedrus deodara* (1), *Cercis siliquastrum* (2), *Chamaecyparis lawsoniana* (14), *Cupressus macrocarpa* Goldcrest (1), *Cupressus sempervirens* (24), *Gleditsia triacanthos* (1), *Juglans nigra* (seven), *Lagerstromia indica* (3), *Morus alba* (1), *Pinus brutia* (5), *Pinus nigra* (27), *Platycladus orientalis* (2), *Prunus cerasifera* (5), *Prunus cerasus* (1), *Prunus domestica* (3), *Prunus mahaleb* (5), *Robinia* sp. (15), *Sambucus nigra* L. (2), and *Tilia tomentosa* (1). *A. negundo* and *P. nigra* were the most dominant species in terms of their populations in the study area. The distributions as well as the trunk sizes, crown heights, crown widths, statuses, and annual air pollution removal and carbon sequestration values of all species on campus are listed in Table 1. The trunk sizes of the trees on campus ranged from 10 to 100 cm, and the regulatory benefits provided by trees to the ecosystem increased proportionally with increasing trunk size (Table 1). Although *Robinia* sp. and *G. triacanthos* exhibited the highest carbon sequestration capacities, *A. negundo* and *C. atlantica* showed the highest potentials for removing atmospheric pollutants compared to other species.

The results obtained using MyTree provided the annual estimates of air pollution removal, carbon sequestration, CO_2 equivalents, and equivalent monetary values (Table 2). The trees on the Selimiye Campus capture a total of 330 kg of pollutants and particles annually, corresponding to an air pollution removal value of $198.16. The annual amount of carbon sequestered by the trees was estimated at 5851.09 kg, corresponding to a CO_2 equivalent of 21454.01 kg. The amounts of CO and NO_2 removed from the air were estimated at 5276.42 and 15447.77 g/year, respectively. The amount of O_3 removed was estimated at 180517.74 g/year. The amount of SO_2 removed was estimated at 112286.83 g/year. The amount of $PM_{2.5}$ removed by the trees was estimated at 16937.78 g.

Table 1. Tree inventory and regulatory ecosystem services of tree species on the Selimiye Campus

Nr	Family	Latin name	Trunk size (cm)	Crown height (m)	Crown width (m)	Status	Air pollution removal (per yr)	Carbon sequestration (per yr)
1	Pinaceae	*Abies nordmanniana*	75	25	15	Healthy	935 g	21 kg
47	Sapindaceae	*Acer negundo*	100	15	20	Healthy	3900 g	22 kg
11	Simaroubaceae	*Ailanthus altissima*	30	20	10	Healthy	575 g	40 kg
9	Pinaceae	*Cedrus atlantica*	100	25	12	Healthy	1400 g	51 kg
1	Pinaceae	*Cedrus deodara*	65	25	10	Healthy	950 g	50 kg
2	Fabaceae	*Cercis siliquastrum*	60	10	5	Healthy	1120 g	2 kg
14	Cupressaceae	*Chamaecyparis lawsoniana*	35	10	6	Healthy	320 g	20 kg
1	Cupressaceae	*Cupressus macrocarpa* Goldcrest	25	10	3	Healthy	205 g	16 kg
24	Cupressaceae	*Cupressus sempervirens*	60	20	5	Healthy	600 g	1 kg
1	Fabaceae	*Gleditsia triacanthos*	75	12	7	Healthy	1250 g	100 kg
7	Juglandaceae	*Juglans nigra*	15	15	8	Healthy	220 g	7 kg
3	Lythraceae	*Lagerstroemia indica*	20	6	3	Healthy	150 g	13 kg
1	Moraceae	*Morus alba*	55	10	7	Healthy	900 g	62 kg
5	Pinaceae	*Pinus brutia*	95	15	10	Healthy	1300 g	60 kg
27	Pinaceae	*Pinus nigra*	70	25	20	Healthy	800 g	30 kg
2	Cupressaceae	*Platycladus orientalis*	10	5	4	Healthy	70 g	6 kg
5	Rosaceae	*Prunus cerasifera*	40	5	3	Healthy	700 g	17 kg
1	Rosaceae	*Prunus cerasus*	40	12	10	Healthy	750 g	20 kg
6	Rosaceae	*Prunus mahaleb*	70	10	5	Healthy	1200 g	2 kg
15	Fabaceae	*Robinia sp.*	80	20	8	Healthy	1340 g	122 kg
2	Adoxaceae	*Sambucus nigra L.*	75	7	4	Healthy	530 g	1 kg
1	Malvaceae	*Tilia tomentosa*	50	6	3	Healthy	850 g	25 kg

Table 2. Total regulatory ecosystem services of all trees on the Selimiye Campus.

Air pollution removal (per year)	$ 198.16
Carbon monoxide (CO) (per year)	5276.42 g
Ozone (O_3) (per year)	180517.74 g
Nitrogen dioxide (NO_2) (per year)	15447.77 g
Sulfur dioxide (SO_2) (per year)	112286.83 g
$PM_{2.5}$ (per year)	16937.78 g
Total (per year)	330 kg
CO_2 uptake (per year)	$174.81
Carbon sequestration (per year)	5851.09 kg
CO_2 equivalent (per year)	21454.01 kg

By comparing the values estimated in this study with those of other studies, we found that both the number of trees on the Selimiye Campus and the regulatory ecosystem services that they could provide were limited. For example, in a study conducted on the Yale University campus in the city of New Haven, Connecticut, USA, trees had annual carbon sequestration and air pollution removal values of 56,83 and 1,29 t, respectively, with the campus containing approximately 6159 trees and 11 different tree species (Yale University, 2020). The annual NO_2 removal and CO_2 sequestration of the trees on the Oregon State University campus, which contains more than 4000 trees, were approximately 100 times greater than those estimated for the Selimiye Campus (Phillips et. al., 2013). In addition, the regulatory ecosystem services at the Lojmanlar Campus of Ege University and Tandoğan Campus of Ankara University were significantly higher than those at the Selimiye Campus in terms of tree cover, carbon sequestration (Dilaver et al., 2017; Hepcan and Hepcan, 2017). At the former, existing tree cover is 48%, with 2 dominant tree species: *Pinus pinea* (24 ha) and *Olea europea* (10 ha) storing 321.57 ton C per year; whereas at the latter, existing tree cover is 42%, with 5813 trees storing 465.59 ton C per year. The most dominant tree species in Tandoğan Campus of Ankara University are *Pinus nigra* L., *Ailanthus altissima* (Mill.) Swingle and *Sophora japonica* L. In Selimiye Campus dominant tree species are *A. negundo*, *C. sempervirens*, and *P. nigra*. those have almost same amount of carbon sequestration capacity in relation to *Pinus pinea*, *Olea europea*, *Pinus nigra* L. however, the number of trees in Ege University Lojmanlar Campus and Tandoğan Campus are higher than Selimiye Campus. Whereas *Robinia sp.* and *G. triacanthos* which sequester high amount of carbon in relation to *A. negundo*, *C. sempervirens*, and *P. nigra* but exist in limited numbers in Selimiye Campus. Although the sizes of campuses as well as the ages, species, and numbers of existing trees influence these results, the regulatory ecosystem services of trees exhibit notable differences among university campuses in Türkiye, as well as between campuses in Türkiye and campuses in USA.

The most dominant tree species on the Selimiye Campus are *A. negundo*, *C. sempervirens*, and *P. nigra*. *Robinia sp.* and *G. triacanthos* exhibit the highest carbon sequestration values, and *A. negundo* and *C. deodora* exhibit the highest air pollution removal capacities. MyTree distinguishes among species and calculates the air quality on the basis of each individual tree and its species (Ma et al., 2021; Nowak, 2021). Conversely, other tools, such as i-Tree Canopy, calculate air quality based on the tree cover without considering tree species. Obtaining information on tree species in relation to determining regulatory ecosystem services and economic returns may be challenging. Small-scale studies, such as those conducted on university campuses, facilitated by web-based tree inventories are crucial for developing in-depth and case-by-case knowledge on each tree and subsequently on the entire study areas.

Understanding urban components, such as university campuses, and their economic values, along with the regulatory ecosystem services they provide, is essential for both citizens and local authorities. The annual economic values of regulatory ecosystem services offered by 197 trees (Table 1) for air pollution removal and CO_2 uptake estimated in this study amount to approximately 197.16 and 174.81 USD, respectively (Table 2). Approximately half of the aforementioned values originate from the annual carbon sequestration of the trees within the study area.

Various studies have assessed the economic role of urban trees in relation to air quality enhancement. For example, Nowak et al. (2018a) estimated that the value of ecosystem services from green spaces in Canada is in the range of

millions of dollars. Similarly, Hepcan and Hepcan (2017) estimated that the economic contribution of trees on the Lojmanlar Campus of Ege University is 112481 USD. Similar research worldwide highlights the significant annual economic benefits of regulatory ecosystem services; they vary according to the scales and whether the forested areas are urban or rural. Given these findings, campus trees play a vital role in the urban economy, even if their primary contribution is limited to improving air quality.

4. Conclusions

Trees in urban areas, including campus trees, are important natural resources that provide ecosystem services to both the city and its residents. Green spaces on university campuses provide regulatory ecosystem services, while also providing shelter for education, teaching, research, and development for students and academics. Regarding the Selimiye Campus of Trakya University, compiling a comprehensive tree inventory and conducting an assessment of regulatory ecosystem services are key procedures for determining the current status and ensuring the long-term management of tree resources.

To the best of our knowledge, this is the first study to assess the regulatory ecosystem services of the trees on the Selimiye Campus and the associated monetary values. The impact of campus trees on the environment and their associated economic contributions to the city and its residents are becoming increasingly important, considering the 21st century climate variability.

Overall, there were 197 trees from 22 different species on campus, removing a total of 330 kg of gas and particulate pollutants from the air and capturing 5851.09 kg of carbon annually. The total economic values of these services were estimated to be $198.16, and $174.81, respectively. Based on these findings, the Selimiye Campus has a limited capacity for regulatory ecosystem services compared to those of other campuses, such as the Lojmanlar Campus of Ege University and Tandoğan Campus of Ankara University. The results of this study should be valuable to decision-makers, landscape planners, and designers, highlighting the necessity for planting trees and increasing species diversity to increase the regulatory ecosystem service capacity of the Selimiye Campus.

This study was conducted at a university campus scale; however, as the methodology and procedure were explained in detail, further studies can be conducted for other public green spaces in Edirne, particularly spaces where comprehensive analyses are required. The detailed methodology and the web-based tools used in this study emphasise the possibilities for rapid, practical, and cost-effective solutions in conducting regulatory ecosystem service assessments and the importance of information technologies in relation to conducting landscape planning and environmental assessments.

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