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Assessment of ecosystem functions of public green spaces in the city of Berezhany, Ternopil region

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Abstract. Researching the possibilities of using modern approaches and tools for evaluating the ecosystem services of green spaces is relevant and requires theoretical justification and applied research, especially in the context of the importance of ensuring the sustainable development of Ukraine. Therefore, the purpose of this study was to work out the procedure of quantitative and cost evaluation of ecosystem services of green spaces for public use and search for opportunities to present the received information to stakeholders. For this, an inventory of green spaces was carried out with the measurement of their biometric and sanitary indicators. For quantitative and cost assessment of the ecosystem functions of plantations and individual trees, the i-Tree Eco toolkit was used, and the Google My Maps application was used for their visualization. The conducted study helped obtain information about individual ecosystem functions of green spaces (reduction of pollutants, carbon absorption and sequestration, oxygen production volumes and regulation of surface water flows). As part of this utility, the annual ecosystem function for the absorption of 770 kilograms of harmful compounds (ozone, carbon monoxide, nitrogen dioxide, and particles of various sizes) was calculated, which is estimated at UAH 128,648,000 annually; reduction of air pollution by 7.43 metric tonnes of gross carbon sequestration (19 kg per 1 plant), with an estimated cost of UAH 41,028,000 and a reduction of water runoff by 684.9 cubic meters, which is estimated at UAH 47,042 of annual utility. Furthermore, as of the moment of the study, the researched green spaces retain carbon in their tissues, which creates an ecosystem benefit in the amount of UAH 1,493,009 thousand (€36,901). The highest indicators of ecosystem usefulness are inherent in park stands, while the trees and bushes of the central part of the city are more effective in absorbing pollutants. Trees capable of achieving significant biometric indicators in local conditions are characterized by greater

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ecosystem productivity. The conducted study creates conditions for better awareness of the ecosystem value of green spaces, but its popularization is also important. The practical value of the results also lies in the possibility of bringing them to authorities, enterprises, and organizations, activists and other stakeholders, which will create conditions for improving environmental awareness, promoting the security and protection of tree stands, improving management and making informed decisions in the field of green construction

Keywords: monetization; utility; tree and shrub services; i-Tree Eco; urban landscapes; environmental awareness

INTRODUCTION

A promising modern area of scientific research of urban landscapes is the search for new opportunities and approaches to the assessment of ecosystem functions of green spaces. Therefore, the analysis of advanced global practices and the possibilities of using the latest tools in this field, together with the implementation of applied research on obtaining information on the volumes and assessment of ecosystem services of tree-shrub vegetation, is characterized by relevance.

It is common knowledge that urbanization processes in most cases lead to negative changes in the environment (Nyelele *et al.*, 2019). Specifically, according to Wolf *et al.* (2020), simultaneously with the growth and development of settlements, a consequent deterioration of climatic, hydrological, and biotic conditions of the urban environment occurs, which adversely affects the health of residents of settlements. Furthermore, according to other scientists, such as Wong *et al.* (2018), due to built-up density, urban landscapes experience higher levels of pollution, biodiversity loss, and social inequality compared to rural areas. Under such conditions, green spaces become important for cities, which, according to the conclusions of Rötzer *et al.* (2019) can not only mitigate the consequences of this negative impact but improve the condition of urban landscapes and create optimal conditions for human habitation. These properties of tree and shrub plantations, or the benefits they can provide for the environment, are called ecosystem functions or ecosystem benefits of green spaces.

The study of various possibilities and approaches to the quantitative measurement and valuation of the ecosystem functions of trees and shrubs, according to researchers (Bidolakh *et al.*, 2023), is characterized by relevance, as evidenced by the constant increase in the number of scientific publications in this filed (Velasco-Muñoz *et al.*, 2022) and the growing interest of the international community (Yang & Khan, 2021; Esperon-Rodriguez *et al.*, 2022; Gaglio *et al.*, 2023) in the implementation of the results of these studies in the practice of ensuring the sustainable development of settlements. At the same time, in Ukraine, according to the author (Pryshchepa, 2019), this process takes place much more slowly and, according to the conclusions of scientists (Havrylenko & Tsyhanok, 2019), there is an urgent need to develop methodological and applied principles for evaluating the ecosystem functions of green spaces, considering the benefits they produce for the environment and society. Therefore, the study of the possibilities of using modern approaches and tools for evaluating the ecosystem services of urban plantations for the conditions of Ukraine is relevant and requires further theoretical substantiation and applied research.

As the object of this study, the methodology of obtaining information about individual ecosystem functions of green spaces for their quantitative and cost evaluation was chosen. The purpose of this study was to investigate the possibilities of determining the ecosystem benefits of public green spaces using the i-Tree Eco toolkit and the possibility of presenting the obtained information to local authorities, the academic community, public organizations, environmental activists, and other stakeholders. To fulfil this purpose, the main tasks were set as follows: to measure the biometric indicators of the tree-shrub vegetation together with the development of the methodology for the performance of works to determine the quantitative and value indicators of ecosystem functions; performing an analysis of the received information in terms of various ecosystem services, categories of plantations, species composition, and other indicators, as well as working out the possibility and perspectives of presenting the obtained results.

LITERATURE REVIEW

An important requirement today in the context of the balanced development of settlements around the world is their sustainable development. In such operating conditions, according to scientists Wong *et al.* (2018), green infrastructure is the basic concept of using an ecosystem approach to enhance the sustainable development of urban landscapes. According to the research by various authors (Castro-Díez *et al.*, 2019), tree and shrub plantations, as an integral element of urban ecosystems, provide critically important ecosystem functions for the safe existence and well-being of residents, such as improving air quality by removing pollution and reducing noise, protecting and purifying water, protecting and stabilizing the soil, improving and regulating the microclimate, mitigating the consequences of urbanization, improving the biological interchange of the matter, preserving biodiversity, etc. Apart from socio-economic benefits, phytolandscapes, according to Castro-Díez *et al.* (2019) and Nyelele *et al.* (2019), produce intangible benefits, such as cultural

and educational services, aesthetic values; activation of mental processes, awareness of one's own identity, etc.

Back in the 1990s, many participants in various international conventions recognized the ever-growing need for international scientific assessment of ecosystems. Therefore, in 2005, scientists and activists developed the international program "Millennium Ecosystem Assessment" (Millennium Ecosystem Assessment, 2005), the purpose of which was to obtain scientifically sound information about changes in ecosystems with the investigation of their impact on people's well-being to develop appropriate measures. The participants of the program determined that currently there are enough opportunities to preserve and even improve the quality of ecosystems, by replacing some services they provide with others, or by ensuring a positive synergistic interaction between them. However, in practice, the ecosystem services of urban landscapes are rarely considered during actual urban design and urban infrastructure planning due to the lack of sufficient fundamental research and recommendations in this area (Song *et al.*, 2020).

In the conditions of the need to ensure the sustainable development of settlements, the awareness of the underestimated role of green spaces in creating a comfortable and safe living environment for their residents should stimulate the implementation of regular measures regarding the caring attitude, protection, qualitative and quantitative reproduction of spaces in urban landscapes (Bidolakh *et al.*, 2023). In turn, to improve the awareness of the usefulness of trees and shrubs for urban ecosystems, it is important to investigate the value of phytolandscapes in this regard and to present the obtained results both to specialists involved in green economy, and to governing bodies and a wide scope of consumers of ecosystem services, which are all residents of settlements (Vallecillo *et al.*, 2019). Under such conditions, in the absence of a direct financial expression of ecosystem services produced by green spaces, degradation and loss of these objects due to their underfinancing is observed (Havrylenko & Tsyhanok, 2019). Many researchers in various parts of the planet (Croci *et al.*, 2022) testify to the constant growth of the demand for the assessment of ecosystem services of green spaces around the world.

Notably, the material part of the utility of plantations, such as wood products, pulp, by-products, leaf mass, etc., according to Castro-Díez *et al.* (2019) is much easier to estimate since many mechanisms have already been developed in this area. While the quantification and evaluation of the environmental benefits and services of green spaces stays a current hot topic, so does its implementation in urban design and planning (Song *et al.*, 2020). Furthermore, as noted by scientists (Steenberg *et al.*, 2017), to ensure constant and regular support of ecosystem services, the process of quantifying them and investigating the vulnerability of green spaces is important. According to other scientists (Wolf *et al.*, 2020), in general, urban planning and management of green spaces should strategically promote the development of trees and shrubs as a social determinant of public health, while quantitative understanding of complex synergies, trade-offs and dependencies on the interaction of different components of urban landscapes, according to Castro-Díez *et al.* (2019), is essential for achieving the sustainable provision of ecosystem services.

According to researchers (Wong *et al.*, 2018), the overall increase in the global sustainability of settlements is only possible if the ecosystem services of green spaces are increased, along with the simultaneous reduction of the environmental load on urban landscapes. In this process, a vital component is the awareness of both the benefits of each individual plant and the plantation as a whole, because each individual tree can affect the microecosystem, and in different plantations, these effects can extend to the neighbouring built environment (Franceschi *et al.*, 2022). The results of research by other scientists (Song *et al.*, 2020) proved that diverse types of urban green spaces are extremely heterogeneous, characterized by different plant groups, structure, and biodiversity, and have different purposes, which is also reflected in their ecosystem functions. In this context, evaluating the usefulness of public plantings, it should be noted that according to the Rules for the maintenance of green areas in populated areas of Ukraine (Order No. 105, 2006), these phytolandscapes are located on the territory of parks and gardens of various locations and purposes, squares, boulevards, on slopes, embankments, and other areas that have free access for recreation. Therefore, this category of plantations should be of maximum benefit to the inhabitants of settlements, who regularly use these ecosystem functions without always comprehending their value.

Evaluating the prospects of current research in the field of evaluating the ecosystem functions of green spaces, one should note the importance of further investigating the processes of introducing ecosystem payments (Gaglio *et al.*, 2023), improving decision-making by stakeholders, mechanisms for returning investments (Roman *et al.*, 2020), optimizing the structure and composition of urban green spaces to maximize the provision of ecosystem services (Song *et al.*, 2020), practical studies on the dependence of ecosystem functions on individual plant species and their biological metric parameters (Wolf *et al.*, 2020). A separate major area of research is the methodological substantiation of the procedure for obtaining and using information about the ecosystem functions of green spaces, including the involvement of modern tools for performing work and presenting the obtained results. In this area, there is a lot of work on improving the procedure for obtaining information about biometric indicators of plants during their inventory, by involving global positioning systems (GPS), methods of remote sensing of the earth (RSE), geographic information systems (GIS), modern mapping

systems and services, electronic maps, geoportals, etc. (Bidolakh & Lakyda, 2019). One of the promising areas of research in this field is also the involvement of a special i-Tree Eco toolkit for investigating certain ecosystem services of green spaces and their replacement cost (Song *et al.*, 2020). However, this toolkit is not widely used to investigate the ecosystem functions of trees and bushes in Ukraine and needs a more detailed approval regarding suitability for the conditions of Ukraine, efficiency and feasibility of use in this area of research.

MATERIALS AND METHODS

As an experimental base of the study, green spaces of public use growing in the territory of the city of Berezhany, Ternopil region, were used. The field collection of materials was performed during June-August 2022 in the territory of the central part of the city of Berezhany (1.64 ha), Pryzamkovyi park (3.6 ha) and the city square on the Ternopilska street (0.6 ha). The total area of the study base was 5.84 ha. Its location can be described by the following values of geographic coordinates: north latitude within 49.445481°–49.447314° and east longitude within 24.937804°–24.946753°. In total, 390 trees and bushes were included in the inventory at this facility.

For the researched public green spaces, an inventory was performed during the growing season according to the instructions for the inventory of green spaces in populated areas of Ukraine (Order..., 2014). Simultaneously with the implementation of the recommendations of this instruction, the biometric indicators of trees and shrubs were additionally measured to determine their ecosystem functions per the recommendations of the USDA Forest Service (2021) for their assessment using i-Tree Eco tools. Such indicators include geolocation of each tree and bush; land use category; plant height from the ground surface to the base of the crown and from the beginning of the crown to the top of the plant; the dimensions of the projection of the crown in two mutually perpendicular directions; the percentage value of the lost and dead parts of the crown (if any), as well as the illumination of the plant from four sides and from above.

Species of tree-shrub plants were established according to the definition of Dobrochaeva & Prokudin (1999). The age of the plants was determined by morphological characteristics. The diameters at breast height (DBH) of trees and bushes were measured using an aluminium measuring fork according to the rules of forest inventory, and in some cases a tape measure was used. Plant height was determined with Anuchin's altimeter. Geolocation of trees and bushes was performed using the Garmin GPSMap64s receiver in the geographic coordinate system. USDA Forest Service recommendations (2021) were used to determine the land use category, the percentage value of the lost and dead part of the crown, and the illumination of the crown. Clarifying and correcting the locations of plants, based on the results of their geolocation with a GPS receiver, was performed according to the methodology (Bidolakh & Lakyda, 2019), which helped increase the accuracy of the final coordinates of the park's plants.

After collecting field materials, they were processed according to the recommendations of the USDA Forest Service (2021) and entered into the i-Tree Eco tools software. After processing the information entered into the software, the results of the assessment of individual ecosystem functions of green spaces (reduction of the amount of pollutants, carbon absorption and sequestration, volumes of oxygen production and regulation of surface water flows) of each tree in particular and the plantation as a whole were obtained. These indicators were obtained in quantitative, qualitative, and cost terms and displayed in the form of tables, reports, and graphs. The geoinformation database created in I-Tree Eco tools (combination of the obtained indicators of each tree and bush along with their locations) was exported in KML format to prepare an electronic map of ecosystem services of green spaces. This map was placed in open interactive access on the Google My Maps resource to inform all stakeholders about the ecosystem functions of public green spaces in the city of Berezhany, Ternopil region.

RESULTS AND DISCUSSION

The results of the research of the public green spaces in the territory of the city of Berezhany, Ternopil region, suggested that the examined phytolandscapes are represented by 34 tree and shrub species, among which the most numerous are *Aesculus hippocastanum* L. (share of 14.1% of the total number of plants), *Tilia cordata* Mill. (13.8%), *Acer platanoides* L. (12.8%), and *Fraxinus excelsior* L. (10.0%). The listed tree species together account for more than half of the plants in the plantations by quantitative indicator, while the rest of the tree-shrub species are represented by a share of no more than 6%. Large-sized plants have the greatest influence on the functioning of the landscapes under study (Table 1), most of which are representatives of the green spaces of Pryzamkovyi Park and the square on the Ternopilska street, thanks to a considerable area of nutrition on the largest biometric indicators in the stand composition.

Table 1. *Summary information about plant specimens with the highest biometric indicators*

ID	Botanical name	Latitude, degrees	Longitude, degrees	Landuse	DBH, cm	Crown Dieback, %	Height, m	Base height, m	Top height, m	Crown (NS), m	Crown (EW), m	Mmissing crown, %	Light exposure, category
231	*Quercus robur*	49.4463	24.9438	park	136	48	27	15	12	33	26	38	5

Table 1, Continued

ID	Botanical name	Latitude, degrees	Longitude, degrees	Landuse	DBH, cm	Crown Dieback, %	Height, m	Base height, m	Top height, m	Crown (NS), m	Crown (EW), m	Mmissing crown, %	Light exposure, category
131	*Quercus robur*	49.4458	24.9438	park	107	43	19	5	14	13	16	33	1
155	*Salix alba*	49.4465	24.9429	park	106	48	20	0	20	8.2	7.9	48	3
236	*Quercus robur*	49.4462	24.944	park	106	38	28.5	10	18.5	15	22	18	4
347	*Salix alba*	49.4471	24.9437	park	92	48	16	2	14	16	9	38	4
252	*Fraxinus excelsior*	49.4458	24.9442	park	90	18	33	4	29	14.2	12.9	18	3
381	*Salix alba*	49.447122	24.938562	park	90	3	31	4	27	14	12	3	5

Notes: *light exposure is evaluated according to five criteria. Number of sides of the tree receiving sunlight from above (maximum of five). Top of tree is counted as one side*
Source: *developed by the author of this study based on their own research*

The estimated area of the projection covers of the crowns of trees and bushes (according to I-Tree Eco tools) is 2.743 hectares, which is 47.0% of the total area of the territory under study and, according to the calculations of I-Tree Eco tools, corresponds to 23.89 ha of leaf area. The given information allows determining that, under the given experimental conditions, the leaf area of public green spaces in the city of Berezhany with a canopy density of about 0.5 exceeds the area of such an object by 4.1 times, and the area of projection coverage of tree and shrub crowns by approximately 8.7 times. This information can indicate the efficiency of the use of space by green spaces because their crown develops in horizontal and vertical planes. Therewith, under the given conditions of the study, thanks to the development of the crown of trees and bushes in the vertical plane, the leaf area of phytolandscapes increases almost nine times compared to the area of the horizontal projection cover of plants.

Assessment of the impact of varied species on the production of ecosystem services largely depends on their leaf area. Therefore, to determine the dominant species in relation to the ecosystem functions of the plants under study, we calculated the dominance index, which was calculated as the product of the share of plants in the stand composition and the area of their leaf surface and is presented in the form of a diagram in Figure 1. Notably, this distribution proves only the existing influence of vegetation on the ecosystem services of urban landscapes through its leaf surface. The high values of the dominance indicator are not at all an indicator that these trees are critical for the ecosystem and require special attention in the further green management. However, these tree species currently dominate the structure of public green spaces in the city of Berezhany due to their predominance in composition and larger crown sizes.

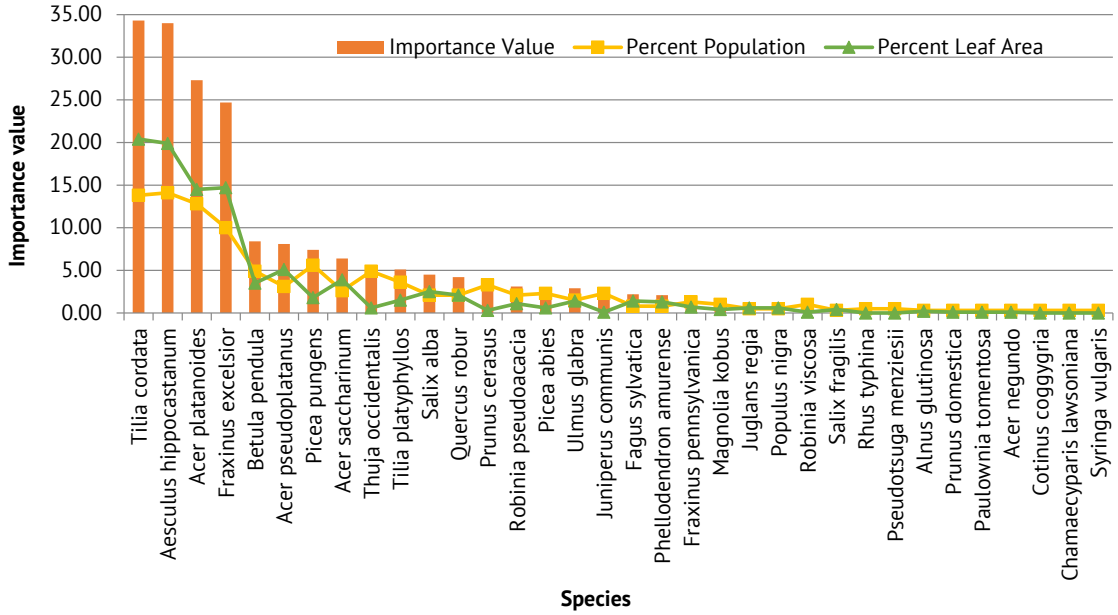

Figure 1. *Importance value by species*
Notes: *the "Importance value" indicator is calculated as the product of the "Population" and "Leaf Area" percentage values*
Source: *developed by the author of this study based on their own research*

Analysing the distribution of the public green spaces under study in the context of DBH classes (Fig. 2), one should note the predominance of middle-aged stands. Therewith, the most numerous DBH classes in terms of the number of trees and bushes were 30.5-45.7 (26.7% of the total number of plants), 15.2-30.5 (25.9%), 7.6-15.2 (16.0%) and 45.7-61 (14.6%). The predominance of large trees with large diameters for such species as *Quercus robur* L., *Salix fragilis* L. and *Aesculus hippocastanum* L. is also of note.

Figure 2. *Species distribution by DBH class*
Source: *developed by the author of this study based on their own research (2022)*

Characterizing the sanitary condition of stands based on the results of the conducted study, there is a difference in the approaches to the assessment of this indicator according to the national methodology of the inventory of green plantations (Order..., 2014) and the recommendations of the USDA Forest Service (2021). Thus, according to the Ukrainian inventory method, the sanitary condition of the public stands under study is characterized by three categories of quality condition, and according to the results of the conducted study, 53% of the plants are classified as good, 41% as satisfactory, and 6% as unsatisfactory. At the same time, the USDA Forest Service (2021) method, after data processing according to the i-Tree Eco tools program, divides trees and shrubs into seven status categories. After data processing, the following results were obtained for assessing the sanitary state of green spaces: Excellent – 3.1%; Good – 49.5%; Fair – 27.9%; Poor – 15.6%; Critical – 2.3%; Dying – 1.5%, Dead – 0%. The given results indicate the importance of taking measures to improve the health of 47.4% of the stands under study, of which 3.8% require immediate measures to treat trees. Analysing the species distribution of the sanitary state of plants, the worst indicators are typical for coniferous species, and specifically for *Picea abies* L. (22.2% in a critical and dying state) and *Thuja occidentalis* L. (10.5% in a dying state).

Based on the results of processing the information entered into the program, data was obtained regarding the assessment of individual ecosystem services of green spaces: reduction of the number of pollutants, absorption and sequestration of carbon, volumes

of oxygen production and regulation of surface water flows of each tree in particular and plantations in general. In this study, the reduction in the number of pollutants was calculated based on the analytical data of the i-Tree Eco tools program regarding the absorption by trees and bushes of sulphur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), as well as particles with a size of less than 2.5 μm (PM2.5) and 2.5-10 μm (PM10). Analysing the obtained data (Fig. 3), the largest volumes of absorption and the highest value of the ecosystem service are inherent in sulphur dioxide (SO_2).

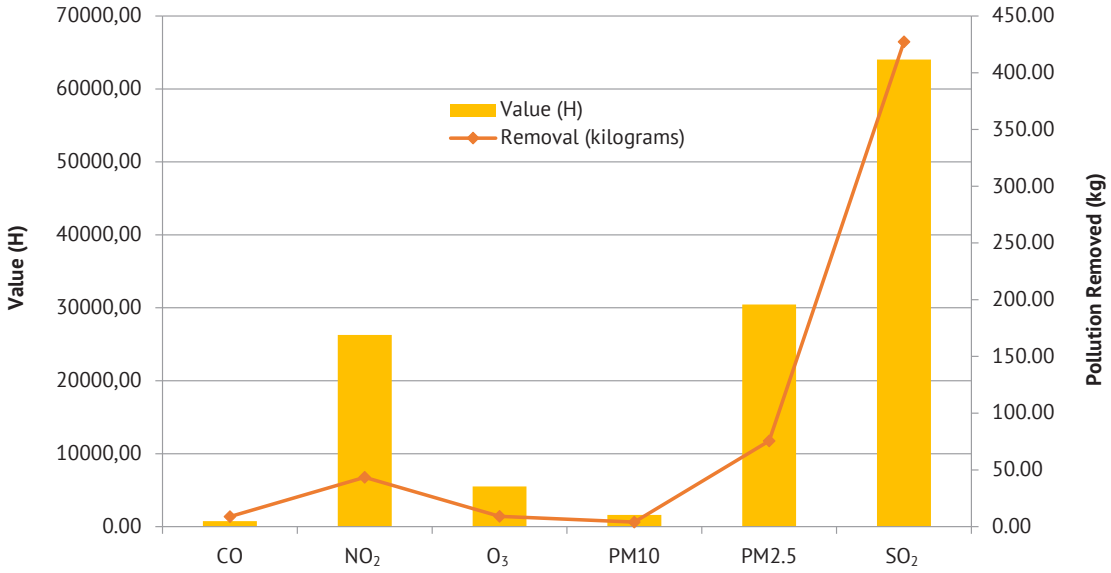

Figure 3. *Quantitative and cost assessment of the annual absorption of pollutants for public green spaces in the territory of the city of Berezhany, Ternopil region*

Notes: *on the diagram, the graph shows the annual amounts of absorption of pollutants, and the bars show the same indicators in value terms*

Source: *developed by the author of this study based on their own research (2022)*

In general, according to the data of the I-Tree Eco Tools program, it was established that the researched public green spaces can absorb 770 kilograms of harmful compounds (ozone, carbon monoxide, nitrogen dioxide, and particles of different sizes) annually in their biomass, and accordingly reduce air pollution. According to the methodology of the USDA Forest Service (2021), the investigated public green spaces in the city of Berezhany perform an ecosystem service to reduce air pollution in the amount of UAH 128,648 thousand annually in terms of the indicators under study.

Evaluating other annual ecosystem functions of public green spaces in the city of Berezhany (Table 2), the phytolandscapes under study can absorb and *sequester carbon*. This service becomes increasingly useful in the face of global climate change, where green spaces can sequester carbon from carbon dioxide in their tissues, thereby creating conditions for mitigating these changes. The results of data processing proved that the green spaces under study can annually provide 7.43 metric tonnes of gross carbon sequestration, with the estimated cost of this service for the urban ecosystem in the amount of UAH 41,028,000 (€1010.5). Notably, per plant, this indicator is 19 kg of annual carbon sequestration with the associated utility of UAH 105.2 (€2.6).

Table 2. *Summarized information on the ecosystem benefits of public green spaces in the territory of the city of Berezhany, Ternopil region*

Category	Trees (pcs.)	Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Carbon Storage	
		(metric t/yr)	(H/yr)	(m^3/yr)	(H/yr)	(metric t/yr)	(H/yr)	(metric ton)	(H)
Pryzamkovyi park									
Total by object	228	4.89	26,993.56	480.01	32,969.44	0.48	72,537.08	208.99	1,154,804.84
Recalculation for 1 plant	1	0.021	118.39	2.105	144.60	0.0021	318.15	0.917	5,064.93

Table 2, Continued

Category	Trees (pcs.)	Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Carbon Storage	
		(metric t/yr)	(H/yr)	(m^3/yr)	(H/yr)	(metric t/yr)	(H/yr)	(metric ton)	(H)
Square on Ternopilska street									
Total by object	43	0.92	5,077.12	81.09	5,569.48	0.07	11,936.41	21.02	116,130.71
Recalculation for 1 plant	1	0.021	118.07	1.886	129.52	0.0016	277.59	0.489	2,700.71
Green spaces in the central part of the city									
Total by object	119	1.62	8,957.56	123.80	8,503	0.22	44,174.35	40.19	222,074.26
Recalculation for 1 plant	1	0.014	75.27	1.040	71.45	0.0018	371.21	0.338	1866.17
Aggregated data on public green spaces									
Total by public green spaces	390	7.43	41,028.24	684.90	4,7041.92	0.77	128,647.84	270.20	1,493,009.81
Recalculation for 1 plant	1	0.019	105.20	1.756	120.62	0.0020	329.87	0.693	3,828.23

Notes: *the table shows the annual utility data for the indicators "Gross Carbon Sequestration", "Avoided Runoff" and "Pollution Removal" and the cumulative utility as of 2023 for the indicator "Carbon Storage"*
Source: *developed by the author of this study based on their own research by processing them in the i-Tree Eco tools program*

The analysis of the provision of this ecosystem service in terms of different stands (Fig. 4) showed a considerable predominance of park stands due to the greater number of trees and better sanitary conditions. At the same time, the green spaces of the square along the Ternopilska street can provide annual carbon sequestration volumes almost comparable to the stands in the central part of the city with almost half the number of plants, which is explained by the larger number of large trees growing in the square. That is, the volumes of carbon sequestration depend to a considerable extent on the biomass and sanitary condition of plants and increase during the growth and development of trees and bushes, which is also confirmed by the results of analogous studies (Lin *et al.*, 2020).

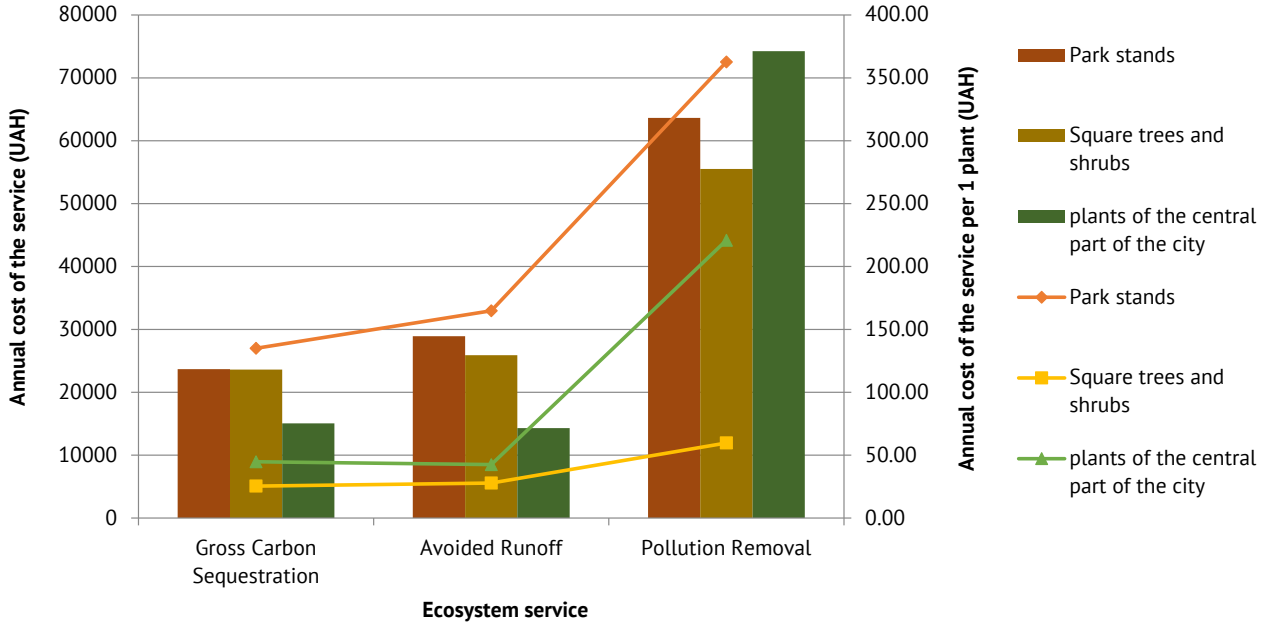

Figure 4. *Summarized data on the annual ecosystem benefits of public green spaces in the territory of the city of Berezhany, Ternopil region*
Notes: *the graph shows the annual costs of ecosystem services for different types of stands, and the columns show the same indicators per 1 plant*
Source: *developed by the author of this study based on their own research (2022)*

Another ecosystem function investigated in this study was *the ability of green spaces to regulate water flow*. This service is valuable to the urban environment as trees and shrubs reduce and improve surface water runoff. Specifically, green spaces perform protective, anti-erosion, and water-regulating functions. Investigated public tree and shrub stands in the territory of the city of Berezhany, Ternopil region, can reduce water flow by 684.9 m^3 annually (Table 2). Such an ecosystem service in monetary terms, according to the results of data processing in I-Tree Eco Tools, is estimated at the amount of UAH 47,042 (€1158.7) of annual utility. Analysing the features of water flow regulation in the section of the studied urban landscapes, the highest volumes of performance of this ecosystem service are inherent in park stands (Fig. 4). The average plant in the shared areas of the central part of the city fulfils this ecosystem function by about 50% in smaller volumes compared to trees and shrubs that grow in parks and squares. In this case, according to the conclusions of scientists who performed analogous studies (Mosyaftiani *et al.*, 2022), higher indicators of biometric parameters, which, in this study, are inherent in plants growing in parks and squares, have the greatest impact on water flow regulation.

Apart from the above-examined ecosystem services that can be evaluated in annual terms, there are the benefits of trees and shrubs that they produce during their life cycle. One of these functions is the ability of plants to accumulate and store carbon in their tissues during their growth and development. According to the results of the I-Tree Eco Tools evaluation, the public green spaces under study have already accumulated 270.2 metric tonnes of carbon in their tissues, which corresponds to 1,008.4 metric tonnes of carbon dioxide. This ecosystem usefulness is estimated by the program in the amount of UAH 1,493.01 thousand. (€36.9 thousand). The analysis of the productivity of carbon absorption in the species distribution (Fig. 5) proved that the most effective in this regard are *Aesculus hippocastanum* L. (retains in its tissues 29.8% of the total amount of absorbed carbon in the section of the experimental study base), *Fraxinus excelsior* L. (14.0%), *Tilia cordata* Mill. (11.2%) and *Acer platanoides* L. (12.8%). The listed species are also the most numerous in the stand composition and have high biometric indicators, which can serve as an explanation for their maximum efficiency in relation to this ecosystem service. This statement is also consistent with the results of other researchers who investigated this issue (Nowak, 2017).

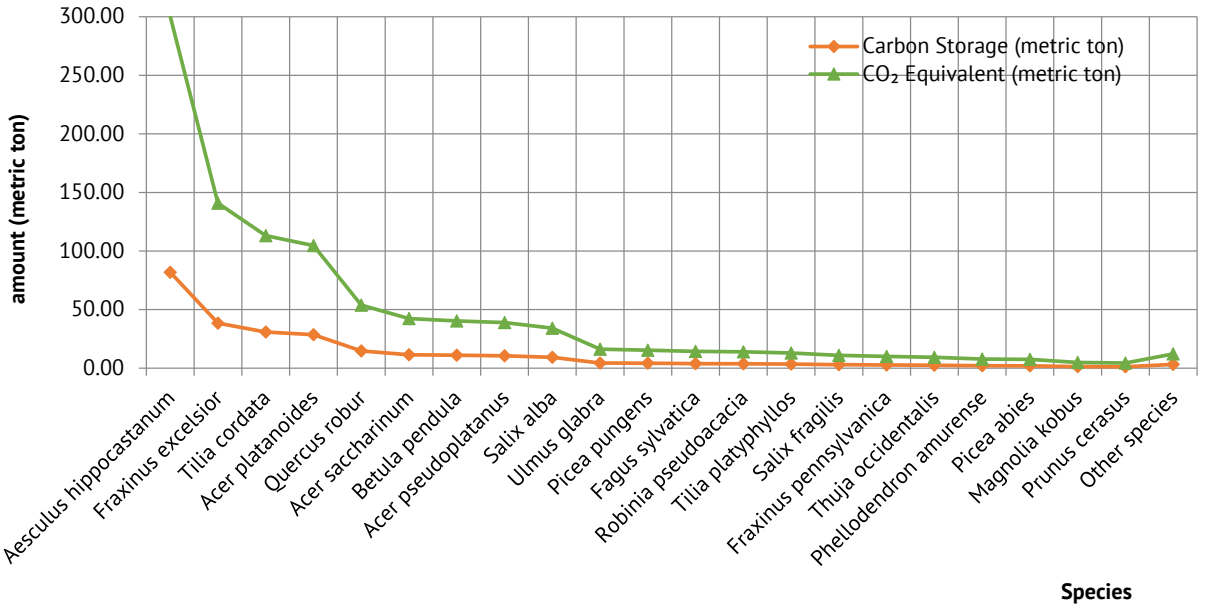

Figure 5. *Volumes of absorbed carbon and CO_2 equivalent in the section of tree-shrub species by plantations of public use in the territory of the city of Berezhany, Ternopil region*

Notes: *on the diagram, tree-shrub species that have an absorption volume of less than one metric tonne are grouped under the "Other species" group*

Source: *developed by the author of this study based on their own research (2022)*

A comparative analysis of the ecosystem productivity of green spaces in the section of the investigated objects proved that the most effective in this regard are park stands, which can create ecosystem services in the amount of UAH 132.5 thousand (€3275) annually, which is UAH 581 (€14.4) averaged per plant. The annual averaged ecosystem productivity of the considered tree-shrub stands in the park is higher than that of individuals growing in the square and in the central part of the city by 8.1% and 12.2%, respectively. Furthermore, park stands can absorb and store carbon in their tissues during their lifetime, which in terms of

value is estimated, as of today (2023), in the amount of UAH 1,154.8 thousand (€28,542). According to this indicator, the average ecosystem productivity of park plants substantially exceeds analogous values of plants growing in the square and the central part of the city by 83.2% and 171.4%, respectively.

The conducted study offers a better insight into the part of the ecosystem services of public green spaces. However, for a wide scope of users to get acquainted with this information, the stage of its presentation and delivery to stakeholders is also important. As evidenced by the results of many scientists (Nedkov *et al.*, 2017; Bidolakh *et al.*, 2023), assessment and mapping of ecosystem services provide valuable spatial information to support decision-making, planning activities, ensuring the sustainable development of urban ecosystems, climate regulation, and increasing environmental awareness of society. Displaying information about the ecosystem services of each tree and bush of the researched stands in the form of an electronic map using the application (Google MyMaps, 2023), according to the methodology described above, made it possible to provide open access for everyone and create conditions for a better understanding of the value of each plant and the volume of its individual ecosystem productivity (Fig. 6). Another approach to promote the ecosystem services of trees and shrubs at the local level could be to attach information plates to plants and create special information stands with information on the ecosystem services of green spaces in both quantitative and monetized terms.

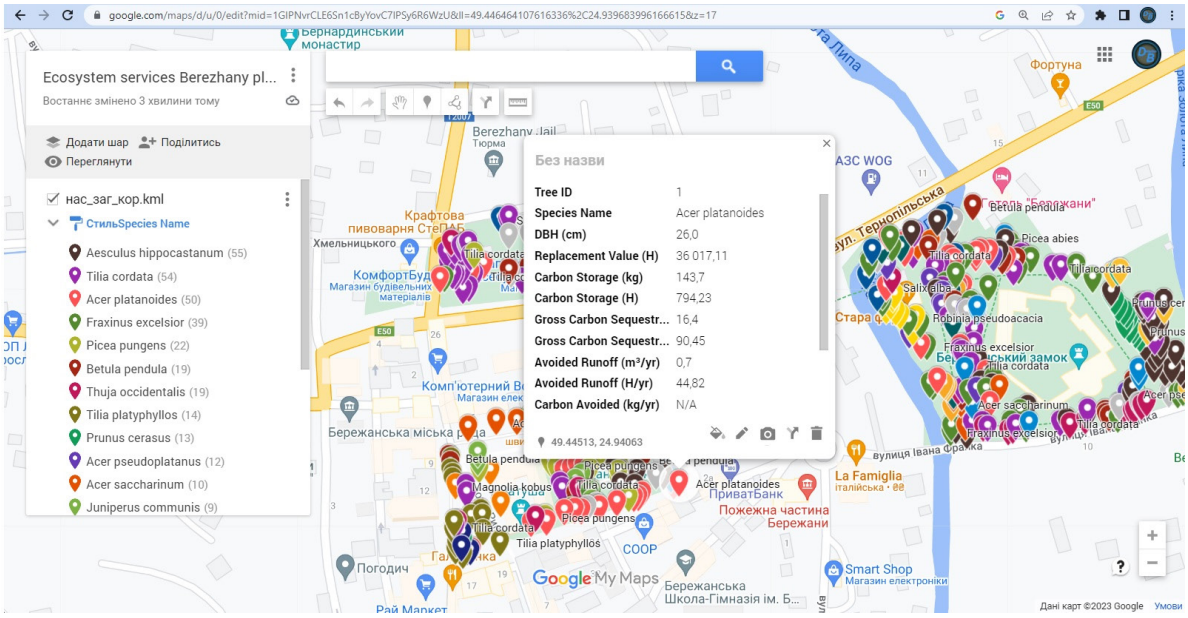

Figure 6. *Interactive map of the amount and cost of ecosystem services of public green spaces in the territory of the city of Berezhany, Ternopil region*

Source: *developed by the authors of this study based on (USDA Forest Service, 2021; Google MyMaps, 2023)*

In general, the conducted study helped determine in quantitative and cost terms part of the ecosystem services of public green spaces (reduction in the amount of pollutants, absorption and sequestration of carbon, volumes of oxygen production, and regulation of surface water flows) and display them in the form of an interactive map. This approach, according to (Burkhard & Maes, 2017), improves the decision-making process in the field of environmental protection activities and creates conditions for improving the environmental awareness of the population.

Comparing the conclusions obtained in this study with the results obtained by other scientists, it is worth noting the unanimity of scientists from different countries (Croci *et al.*, 2022; Včeláková *et al.*, 2023) regarding the importance of conducting analogous applied studies of the maximum possible number of ecosystem services for various types of green spaces in all corners of the world. Many experts (Mosyaftiani *et al.*, 2022) also recommend using modern tools for this process, including i-Tree Eco Tools for researching ecosystem services of green spaces. Therewith, the obtained study results are interpreted by various authors (Yang & Khan, 2021) in the plane of the most effective delivery of information about the ecosystem functions of green spaces to users of ecosystem services, authorities and scientists, including similarly to the findings this study obtained by visualizing them on maps (Bidolakh & Lakyda, 2019). Ultimately, according to researchers (Cimburova & Barton, 2020; Stoeckl *et al.*, 2023), such studies should contribute to the overall greening of social development and the improvement of environmental awareness of residents of settlements, which is also relevant for ensuring the sustainable development of urban landscapes of Ukraine.

CONCLUSIONS

The conducted study helped work out the procedure for obtaining and evaluating quantitative and value indicators of ecosystem services using the i-Tree Eco tool, using the example of public green spaces in the city of Berezhany, Ternopil region. The findings created conditions for demonstrating the value of green spaces for urban ecosystems and the importance of conducting analogous studies to ensure the sustainable development of ecosystems.

The obtained results proved that the ecosystem usefulness of the researched green spaces in monetized terms amounts to UAH 216,718 thousand (€5356) annually in terms of the investigated indicators (reduction of the number of pollutants, absorption and sequestration of carbon, volumes of oxygen production, and regulation of surface water flows). Therewith, the average value of the annual cost of ecosystem services of each tree-shrub plant in terms of the above-mentioned indicators is UAH 557 (€13.8). Furthermore, evaluating the ability of the investigated green spaces to absorb and store carbon in their tissues during their lifetime, the value assessment of this ecosystem utility as of today (2023) is UAH 1,493,009,000 (€36901).

The results of the analysis of the ecosystem productivity of different plant stands (park, square, and green spaces in the central part of the city) showed the highest indicators for park stands given the higher values of their biometric indicators. Tree and shrub plants of the square on the Ternopilska street in the city of Berezhany is slightly inferior to the investigated park stands in terms of their indicators. Green spaces in the central part of the city, even with lower average biometric indicators, are more effective in absorbing pollutants. In terms of species, trees that can achieve considerable biometric indicators in local conditions of urbanized landscapes are characterized by greater ecosystem productivity. For the city of Berezhany, Ternopil region, such trees should include *Quercus robur* L., *Aesculus hippocastanum* L., *Fraxinus excelsior* L., *Tilia cordata* Mill., and *Acer platanoides* L.

To familiarize more people and popularize the ecosystem value of trees and bushes, we have proposed the creation of electronic interactive maps with unrestricted access for all stakeholders, as well as the installation of information boards and stands with information about the ecosystem services of green spaces. The practical value of the results of this and analogous studies also lies in the possibility of presenting the obtained results to local authorities, enterprises, and organizations related to green management, scientific and public organizations, activists, and other stakeholders. Such an approach will create conditions for improving the awareness of the value of green spaces to ensure the sustainable development of urban ecosystems and society, improving their security and protection, improving management and creating conditions for making informed decisions in the field of green construction, improving the environmental awareness of residents of settlements and achieving other ecologically oriented results.

Notably, the chosen topic has considerable prospects for further research in the context of obtaining information about the ecosystem services of other plant stands, expanding the list of ecosystem functions for research and evaluation, researching the possibilities of involving innovative tools for performing analogous works, expanding the scope of applications and improving the methods of presenting the obtained results to popularize the usefulness of green plantations for urban ecosystems.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Оцінювання екосистемних функцій зелених насаджень загального користування у м. Бережани Тернопільської області

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Анотація. Дослідження можливостей використання сучасних підходів та інструментарію для оцінювання екосистемних послуг зелених насаджень вирізняється актуальністю та потребує теоретичного обґрунтування та прикладних досліджень, особливо в умовах важливості забезпечення сталого розвитку України. Тому метою цієї роботи є опрацювання процесу кількісного та вартісного оцінювання екосистемних послуг зелених насаджень загального користування та пошук можливостей представлення отриманої інформації для зацікавлених осіб. Для цього проведено інвентаризацію зелених насаджень з вимірюванням їх біометричних та санітарних показників. З метою кількісного та вартісного оцінювання екосистемних функцій насаджень та окремих дерев використано інструментарій i-Tree Eco, а для їх візуалізації додаток Google My Maps. Виконані дослідження дали змогу отримати інформацію про окремі екосистемні функції зелених насаджень (зменшення кількості забруднюючих речовин, поглинання та секвестрація вуглецю, обсяги продукування кисню та регулювання поверхневих водних стоків). У складі цієї корисності обчислено щорічну екосистемну функцію щодо поглинання 770 кілограм шкідливих сполук (озон, оксид вуглецю, діоксид азоту та частки різного розміру речовин), що оцінюється на суму 128,648 тис. грн щорічно; зменшення забруднення повітря на 7,43 метричних тони валового обсягу секвестрації вуглецю (19 кг у перерахунку на 1 рослину), із оціненою вартістю у розмірі 41,028 тис. грн та зменшення водного стоку на 684,9 м. куб, що оцінюється на суму 47,042 грн щорічної корисності. Окрім того, досліджені зелені насадження станом на момент дослідження утримують у своїх тканинах вуглець, що створює екосистемну корисність на суму 1493,009 тис. грн (€ 36901). Найвищі показники екосистемної корисності характерні для паркових насаджень, а дерева та кущі центральної частини міста є ефективнішими у відношенню поглинання забруднюючих речовин. Більшою екосистемною продуктивністю характеризуються дерева, які здатні досягати значних біометричних показників в місцевих умовах. Проведені дослідження створюють умови для кращого усвідомлення екосистемної цінності зелених насаджень, проте важлива також її популяризація. Практична цінність результатів полягає також у можливості їх доведення до органів влади, підприємств та організацій, активістів та інших зацікавлених осіб, що створить умови для покращення екологічної свідомості, сприяння захисту та охороні насаджень, удосконаленню менеджменту та прийняття обґрунтованих рішень у сфері зеленого будівництва

Ключові слова: монетизація; корисність; послуги дерев та кущів; i-Tree Eco; урболандшафти; екологічна свідомість