Cost–Benefit Assessment for Maintenance of Urban Green Infrastructure at the University Campus in Moscow : Application of GreenSpaces and TreeTalker Technologies to Regulating Ecosystem Services

Smart and Sustainable Urban Ecosystems: Challenges and Solutions

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Chapter 22
Cost–Benefit Assessment for Maintenance of Urban Green Infrastructure at the University Campus in Moscow: Application of GreenSpaces and TreeTalker Technologies to Regulating Ecosystem Services

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Abstract Trees are a key element of urban green infrastructure (UGI). They supply a wide range of benefits—ecosystem services—from air purification to places for recreation. UGI is also an expenditure item in the budget due to the investments required for its establishment and maintenance. Accounting for ecosystem services in monetary terms allows considering direct and indirect benefits of green spaces together with costs, has not only implications for decision-making but also could be instrumental in changing landowners' perceptions of UGI and its importance. In this paper, we used the data from advanced tree monitoring technologies to compare monetary values of regulating ecosystem services to maintenance costs for the case of campus of the People's Friendship University of Russia (RUDN) in Moscow, Russia. Inventories of UGI elements were conducted by means of a field survey and remote sensing, that resulted in GIS project in GreenSpaces software. The same program was used to keep track of costs of the different types of maintenance work based on information from Greening Department of RUDN. Biophysical parameters of tree functioning were obtained from more than 60 TreeTalker sensors installed on the major species during the two years. The monetary value of four major regulating

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ecosystem services (air purification, climate regulation, water transpiration, carbon sequestration) of the trees was then assessed, allowing a comparison of the costs for maintenance and some of the benefits derived. The results show that even when considering just monetary value from regulating services, it outweighs the costs for maintenance of the UGI in the amount of 1.5 million rubles or about a quarter of the costs.

Keywords Ecosystem services · Value · TreeTalker · R3GIS · Green area maintenance

22.1 Introduction

Urban green infrastructure (UGI) plays a crucial role in ensuring good quality of life and human well-being, as well as in the sustainable development and functioning of urban environment (Gómez-Baggethun and Barton 2013; Haase et al. 2014; Kondo et al. 2018), especially at the times of crisis (Fagerholm et al. 2022). One of the most substantial components of UGI are trees, growing on roadsides, in backyards, as well as in the parks, gardens and urban forests and are even included in vertical greening. Urban trees provide a wide range of benefits, referred to as ecosystem services (ES), such as supporting, regulating, provisioning and cultural (Burkhard et al. 2018; Klimanova and Illarionova 2020). Carbon sequestration as part of climate mitigation, provision of shade and cooling effect, aesthetic and recreational values, habitat for birds and other species is the most widely studied ecosystem services provided by urban trees. Many of these services fall under the category of so-called non-market services (e.g., recreation in a park), i.e., not traded on markets and often they are also not easy to quantify / determine value both in biophysical and socio-economic terms (Small et al. 2017). This is also partly linked to the challenge of stakeholders often not realizing the full range of services and values provided by the UGI and its components.

At the same time, having trees in cities coincide with costs that include not only those for planting and maintenance, but also a long list of potential indirect costs, such as damage to buildings and pavements by tree roots, damage and injury from falling trees, disruption to traffic during maintenance, carbon emissions through operating machinery, blockage of drains by leaf litter and air pollution by volatile organic compounds emitted by foliage, to name but a few (Vogt et al. 2015). Calculation of costs is also not a straight-forward exercise, as it involves specific rates for labor and other components, technologies and materials to be used, all set by the official documents.

This complex balance of understanding and valuation of UGI's benefits and costs is the reason why planting trees in the cities can be and often is a controversial issue, involving many stakeholders with different interests and preferences, as well as more importantly with differences in awareness of the entirety of the costs and benefits associated with urban trees. Therefore, in order to support decision-making, it is paramount to investigate benefits and costs and explore ways to better quantify them. In recent years, a number of studies devoted to the question have emerged (Bolund and Hunhammar 1999; Russo et al. 2017), including reviews (e.g., Song et al. 2018). Many of them have quantified the benefits, while the costs have received less attention. Suggesting that understanding of the balance between costs and benefits (namely, which way it lies) remains poor.

At the same time, advanced GIS-based technologies for monitoring tree health and greenery maintenance allow considering these costs and aim to minimize them. One of such systems is GreenSpaces, developed by R3GIS company (https://www.r3gis.com/greenspaces). Its main tasks include inventory of current state and changes of main elements of UGI, management and control of maintenance activities. The company is also developing features for valuation of ES integrated in the app along with TreeTalker integration (Valentini et al. 2019; Matasov et al. 2020). This company entered the Russian market relatively recently and thus the app is still undergoing the process of adaptation to the institutional, biophysical, climatic and economic conditions of Russian cities.

Aim of this study was to determine whether the costs of maintaining urban trees outweigh the benefits they provide in order to support decision- and policy-makers. Benefits were represented through four main regulating ecosystem services measured in real time with TreeTalkers. Data on costs for their establishment and maintenance of trees have been collected from the authorities managing the site—the campus of the Peoples' Friendship University of Russian (RUDN) in Moscow, Russian Federation.

22.2 Materials and Methods

22.2.1 Study Site

Founded in 1960, the RUDN University campus (No 1 in Russia and No 42 in World University Green Metrics Ranking) (GreenMetric 2023) is situated in southwestern Moscow, in the Konkovo and Obruchevsky districts. The southwest of Moscow is located within the Teplostan upland, making the territory much higher than the rest of the city (Fig. 22.1). That, together with the prevailing western winds, an abundance of greenery, and a lack of big industrial areas, makes the territory one of the most favorable places to live in the capital. The campus occupies 0.34 km^2 of land and includes 20 teaching blocks and 14 dormitories.

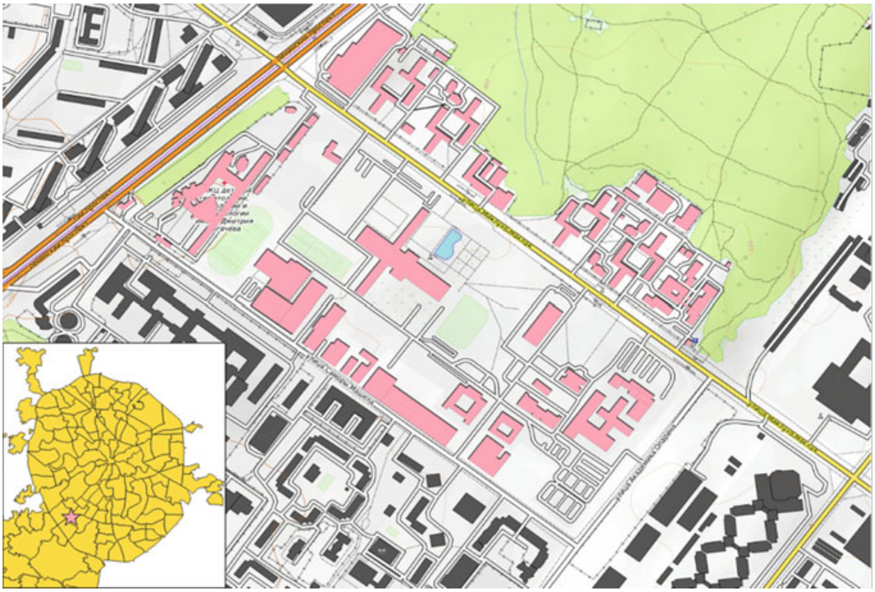

Fig. 22.1 Location of the study site (in Moscow)

22.2.2 Assessment of Costs and Benefits

Our study was conducted in three steps:

(1) We carried out inventory on campus and identified the structure of green infrastructure as well as the number of trees and their parameters.
(2) We gathered data on costs for establishment and maintenance of the trees using several calculation methods and primal information from RUDN Greenery Department, which were then compared to the benefits.
(3) Based on findings from the previous steps and using TreeTalker data, we have calculated the value of regulating ecosystem services provided by the trees on campus.

22.2.2.1 Inventory of Green Infrastructure

We used basic classification of green spaces in R3GIS, which is represented by four groups: trees, shrubs, lawns, flower beds. Trees can be a linear object or a point object. Shrubs can be designated as a single object, a line (hedge) if work is estimated per meter in length, and a polygon (shaped/unshaped) if work calculations are estimated per square meter. Lawns are polygonal objects and are represented by several types (by grass composition and type of care). Flowerbeds represent different variations of mixborders, flowerbeds and modular flowerbeds. Differences in classification are due to the longevity of plants: perennials and annuals. There are also ampelous plants that decorate the front entrances of buildings.

To describe the structure of green spaces, we used field observations with georeferencing using the GPS receiver GarmineTrex 32 and visual description of elements of green infrastructure with fixation of attributes. For trees, we described: species, trunk diameter, canopy diameter and tree height. For shrubs—species, height, length for hedges in addition. Green infrastructure elements with complex shapes were digitized in QGIS using DJI Mavic 2 PRO images (Hasselblad and Mapir DJI Inspire 2 Survey 3 near-infrared (NIR) and visible spectrum (RGB) camera on board, flying altitude 50 m). The images were taken in September 2019. The resulting images (with a resolution of 3–4 cm per pixel) were combined into a single georeferenced image and DEM. We used ForestTools package algorithms in R to obtain a shape file with the exact canopy shapes and georeferencing of each tree (R Core Team 2014).

22.2.2.2 Assessment of Regulating Services and Their Monetary Value

In order to conduct assessment of regulating services and their value, we have chosen four biophysical indicators, which can be measured in real time with TreeTalker (Matasov et al. 2020): carbon sequestration, water transpiration, PM_{10} absorption and energy use for climate regulation. We installed about 60 devices on major species of trees to collect their biophysical functioning data during 3 vegetation seasons in 2019–2021 to make extrapolation possible for the whole number of trees on campus.

To value biophysical flows in terms of money, we made such suggestions. To estimate, carbon deposition was used world prices for CO_2 emissions (40$ per ton—(World Bank 2021). Transpiration was estimated through the cost of drainage in prices of GUP Mosvodostok (https://мосводосток.рф/subscriber-service/rates/—14 rubles/m^3). The energy spent on transpiration was estimated as the work of a climate-conditioning system in rubles at prices of GUP Mosenergosbyt (https://www.mosenergosbyt.ru/individuals/services/pricelist.php—5.5 rubles/kWh). Literature data were used to estimate PM_{10} air purification—$4500/ton (Nowak et al. 2018).

22.2.2.3 Costs for Green Infrastructure Maintenance

The documents of RUDN Greenery Department for 2019 and 2020, job descriptions of the gardener and florist, the calendar of work on the maintenance of green areas were used to determine the costs of maintaining green areas. The data on the costs of planting material, its quantity and types of plants, garden tools and consumables were also obtained from the documents and interviews.

To compare real costs of the maintenance in RUDN campus with norms of maintenance for the Moscow City, we used Government Regulation No. 743-PP dated September 10, 2002 “On Approval of the Rules of Creation, Maintenance and Protection of Green Plantations and Natural Communities of the City of Moscow” (Decree of the Moscow City Government No 2002). We used information on the number of necessary «man working hours» and «machine working hours» for different types of work dedicated to trees and lawns care processes. Thus, the total amount of working hours per year was calculated in accordance with the regulations. These values were recalculated to cost equivalents based on average market prices and salaries.

22.3 Results

22.3.1 Green Infrastructure Composition of the Study Site

As a result of the inventory, a map of RUDN campus green infrastructure was created (Fig. 22.2), the areas of all existing objects of green infrastructure presented in Table 22.1. Open lawns (33%) and lawns under crowns (13%) dominate the structure of green areas. The share of sealed areas on campus is a bit over 50%. These include parking lots and roadways, 33%, and buildings, 18%.

The RUDN campus has 1707 trees. The four most common species here are *Tilia cordata, Betula pendula, Salix caprea* and *Populus tremula*. They account for 64.7%

Fig. 22.2 RUDN campus green infrastructure

Table 22.1 Share of land cover types and green infrastructure elements

Green elements	Area, sq. m	Share of area, %	Number, pcs
The entire territory	347,314	100	
Sealed:	179,502	51	
Roads and parking slots	116,099	33	
Buildings	63,402	18	
Green area:	167,812	48	
Lawns:	163,235	47	
Open lawns	115,465	33	
Lawns under the canopy	47,770	13	
Bushes:	4100	0.6	260
Artificial shapes	3522	1	
Natural shapes	578	0.16	
Flower beds:	402	0.12	
Annuals	234	0.07	
Perennial	168	0.05	
Trees:			1707
Trunk area	74	0.02	

of all trees. The distribution of tree diameters, heights and canopy areas by species is shown in Annex 1. Rare individuals exceed the height of 20 m, the most typical height is about 10–13 m. Trunk diameters in most cases range from 10 to 30 cm.

22.3.2 Costs for Maintenance

Actual spending consists of three main categories—employee salaries, supplies for planting, and equipment purchases or repairs (Table 22.2). In 2020, lawn seeds, seedlings for flower beds, soil and fertilizers were purchased for a total of about 1 million rubles, which amounted to 18% of the total cost. Among the equipment used are all kinds of soil drills, lawn mowers, long pruners and other stuff. There were spent on them about 10% of the total amount, i.e., about 0.5 million. Other 72% went on salaries of employees according to their employment by months and types of work (see Annex 2). Thus, the total costs amounted to 5.5 million rubles.

Compared to regulation norms (Decree No. 743-PP) on the man-hours for different types of work care for 1700 trees and an area of 34 hectares, we get the total number of man-hours about 21,035. Based on average salaries and the number of working days in 2020, we get an estimated amount of 213 rubles per working hour of a gardener which in total gives an amount of about 3.5 million rubles.

Table 22.2 Amount and types of the costs

Type	Category	Units	Quantity	Costs, rub	Costs, %
Flower seedling	Consumables	pieces	36,000	829,056.00	17.90
Soil and fertilizers		cubic meter	100	142,800.00	
Grass seeds		kg	60	24,000.00	
Equipment repair	Equipment	-	-	36,000.00	10.74
Petrol brush		pieces	3	192,000.00	
Lawn mower		pieces	2	144,000.00	
Gas shears		pieces	1	67,200.00	
Pole cutter		pieces	1	60,000.00	
Office equipment		pieces	4	14,400.00	
Soil drill echo $d = 12$ cm		pieces	1	10,022.84	
Soil drill echo $d = 20$ cm		pieces	1	10,051.37	
Soil drill echo $d = 25$см		pieces	1	10,517.42	
Soil drill echo EA-410		pieces	1	53,273.42	
Personnel of service jobs	Personnel	person	7	3,823,012.05	71.37
Personnel of planning jobs		person	1	95,333.33	
Personnel of planting jobs		person	1	52,962.96	
			Total	5,564,629.41	100

22.3.3 Benefits Obtained from the Trees: Regulating Ecosystem Services

According to the results of the analysis, we can conclude that the RUDN campus trees produces regulating ecosystem services worth about 7.2 million rubles per year (Table 22.3), with most of it being climate regulation through transpiration (1144 MWh/yr). The second most valuable is air quality regulation (2263 kg/yr), slightly less valuable is rainwater removal through transpiration (11,185 m^3/yr) and carbon deposition (14.8 t/yr) is valued the least.

To sum up, with this estimate, we get that the balance of benefits to the territory due to regulating ecosystem services at the RUDN campus is more than 1.5 million rubles.

Table 22.3 Biophysical volume of ES and their cost estimation

Ecosystem service	Biophysical flow, units	Cash flow, thousand rubles
Tree carbon accumulation	14.8 t/yr	6.2
Energy absorbed	1144 MWh/yr	6292.2
Total transpiration	11,185 m^3/yr	156.6
Total PM absorbed	2263 kg/yr	712.8

22.4 Discussion

Our assessment of costs and benefits associated with the maintenance of trees as part of the UGI concludes that the latter even based on regulating services value only slightly outweighs the former. Similar findings have been reached by Song et al. (2018): these estimates are often within the same range if not the same. Regulating services are the most common to be used in such cost–benefit assessments (Song et al. 2018). Of the differences, it can be noted that several studies have concluded water retention to be more valuable than air purification, which is probably due to the large number of studies conducted in the subtropical climate zone, where there is significantly more precipitation than in Moscow. Carbon sequestration has the least effect most of the time. And microclimate regulation through shading and transpiration turns out to be the most significant of all regulatory services.

At the same time, trees provide other benefits than regulating services, such as cultural services. (Song et al. 2018) In their review demonstrated that benefits from the latter (for example, aesthetics) are often larger than those of water purification and carbon sequestration. Authors of another review of cultural services provided by the UGI have concluded that while parks, gardens and forests have been examined in studies often, more comprehensive assessments of services from other components of UGI (such as trees, tree lines) as well as network as a whole are needed (Cheng et al. 2021). In line with the call to assess various components of UGI is the fact that lawns, while being one of the most common components of open green spaces and UGI, their importance for the human well-being and urban sustainability is still underestimated in many parts of the world, including Russia (Ignatieva et al. 2020). Their transpiration and PM10 removal rates, especially microclimate regulation, could be similar or even higher than trees due to the larger area they occupy. Moreover, as with trees, cultural services of lawns have not been represented in our valuation. Other studies have demonstrated their importance for people as well as a whole range of preferences toward their composition (Ignatieva et al. 2017; Yang et al. 2019).

Methodologically, we tested a combination of hardware and software: TreeTalkers and GreenSpaces. We discovered that while they have potential for application in such assessments, first a few limitations need fixing. For example, R3GIS didn't contain some of the management functions inherent in Moscow climate (like snow drilling in spring) and some of the elements of UGI that are present in Moscow, such as stone flowerbeds. Moreover, it became evident that there is a need for development of similar sensors for lawns (LawnTalker) which will be able to assess the biophysical processes in such important green infrastructure elements and translate them into ecosystem services numbers to be used in the decision support.

22.5 Conclusion

The results show that even when considering just monetary value from regulating services, it outweighs the costs for maintenance of the UGI by about a quarter of the former. Findings from such studies could play a major role in transforming a decision-maker's perspective of an urban tree, as the most typical element of UGI, from a liability on the landowner' balance sheet into an asset. This outcome could add to the current understanding of the value of a tree among decision-makers, that is largely determined by the value of a felling ticket or the value of a cubic meter of its timber, and the necessary costs of its valuation are forced by the need to avoid the risks of damage to someone else's property in the event of a possible fall of a tree. This study presents the foundation for future research, which needs to conduct more comprehensive assessments of UGI and its components. Moreover, as suggested by previous studies, decision-making could benefit largely from findings and process of the transdisciplinary research involving stakeholders (Ignatieva et al. 2017; Willcock et al. 2016). Such close engagement with among other decision-makers would be beneficial for the researchers and their studies in terms of knowledge and navigation of the currently applied procedures for calculation of costs.

22.6 Conflicts of Interest

The authors declare no conflict of interest.

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Annex 1

See Fig. 22.3.

Annex 2

See Table 22.4.

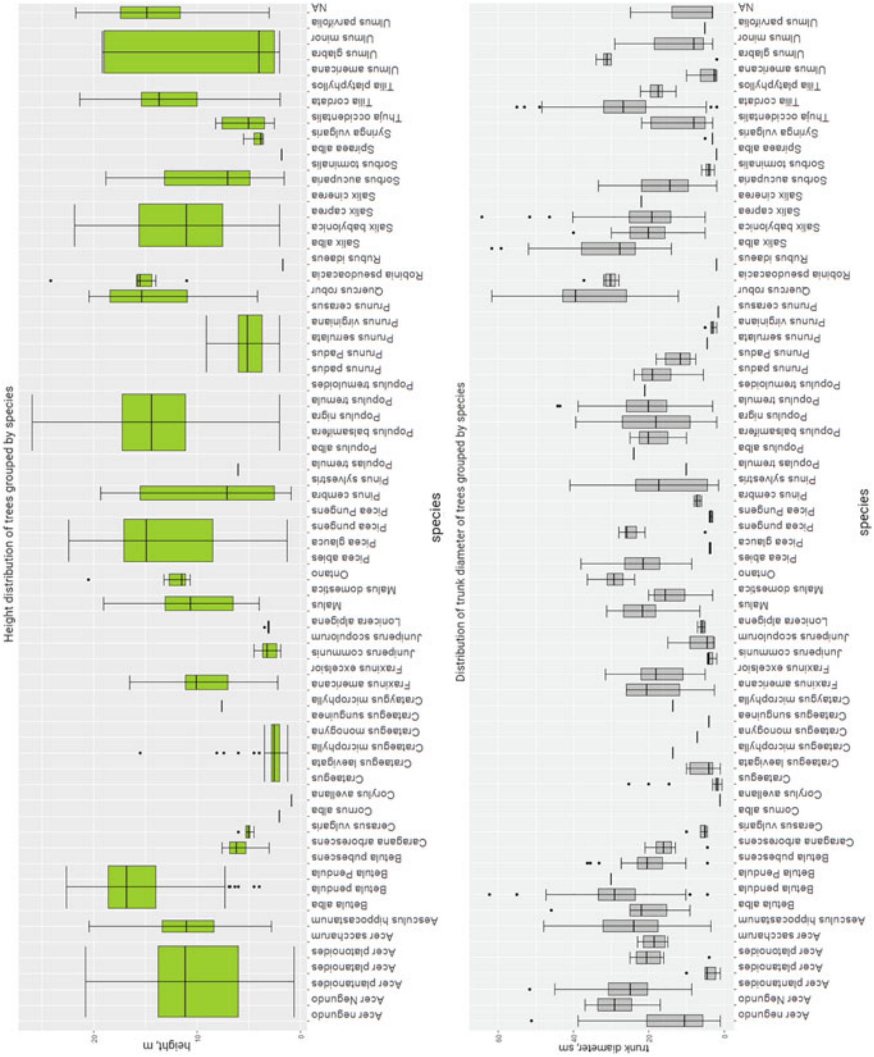

Fig. 22.3 Distribution of tree characteristics by species: height (**a**), diameter at breast height (**b**), canopy area (**c**)

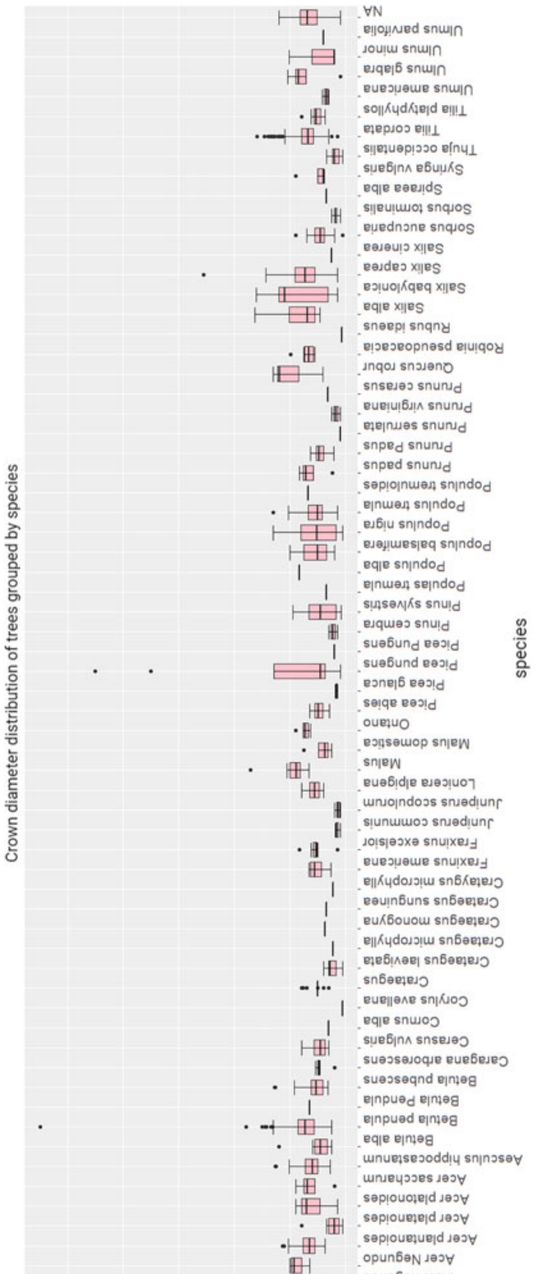

Fig. 22.3 (continued)

Table 22.4 Distribution of different work types across seasons and their working hours assessment

Type of jobs	Job category	Man-hours/ year	January	February	March	April	May	June	July	August	September	October	November	December
Snow removal	Service	2800	700	700	350								350	700
Equipment repair	Service	9			9									
Pruning trees and shrubs	Service	280			140	140								
Cleaning after winter	Service	240				240								
Addition of mineral fertilizers	Service	200				40	40	40	40	40				
Chemical protection of trees from pests and diseases	Service	120			20	20	20	20	20	20				
Chemical protection of shrubs from pests and diseases	Service	720			120	120	120	120	120	120				
Hedge trimming	Service	420						140	140	140				

(continued)

Table 22.4 (continued)

Type of jobs	Job category	Man-hours/year	January	February	March	April	May	June	July	August	September	October	November	December
Removing overgrowth on trees	Service	50					10	10	10	10	10			
Overseeding of lawn grasses	Service	120				60	60							
Flower garden care: watering	Service	3000					600	600	600	600	600			
Flower garden care: weeding	Service	600					120	120	120	120	120			
Lawn mowing	Service	3750					750	750	750	750	750			
Cleaning of flower beds and flower beds before winter	Service	175										175		
Removal of the territory from fallen leaves	Service	385									192.5	192.5		

(continued)

Table 22.4 (continued)

Type of jobs	Job category	Man-hours/ year	January	February	March	April	May	June	July	August	September	October	November	December
Lawn reclamation (locally)	Service	0			1день/ 100 кв.м - 2 человека									
personnel management of service work	Service	1582	131.833	169.5	169.5	169.5	169.5	169.5	169.5	169.5	169.5	169.5	169.5	169.5
conclusion of contracts	Planning	9			9									
Planting design development	Planning	63			31.5	31.5								
Planning new lawns	Planning	45				9	9	9	9	9				
Purchase of soil	Planning	9			9									
Purchase of perennial and annual plants	Planning	54					54							
Planting annual flower seedlings	Planting	125					125							

(continued)

Table 22.4 (continued)

Type of jobs	Job category	Man-hours/year	January	February	March	April	May	June	July	August	September	October	November	December
Planting annual perennial flowers	Planting	25					25							
Planting shrubs and trees	Planting	50					50							
		Total man-hours/year	January	February	March	April	May	June	July	August	September	October	November	December
Total		14,756	831.833	869.5	858	830	2152.5	1978.5	1978.5	1978.5	1842	537	519.5	869.5

References

Bolund P, Hunhammar S (1999) Ecosystem services in urban areas. Ecol Econ 29:293–301. https://doi.org/10.1016/S0921-8009(99)00013-0

Burkhard B, Maes J, Potschin-Young M, Santos-Martín F, Geneletti D, Stoev P, Kopperoinen L, Adamescu C, Adem Esmail B, Arany I, Arnell A, Balzan M, Barton DN, van Beukering P, Bicking S, Borges P, Borisova B, Braat L, M Brander L, Bratanova-Doncheva S, Broekx S, Brown C, Cazacu C, Crossman N, Czúcz B, Daněk J, de Groot R, Depellegrin D, Dimopoulos P, Elvinger N, Erhard M, Fagerholm N, Frélichová J, Grêt-Regamey A, Grudova M, Haines-Young R, Inghe O, Kallay T, Kirin T, Klug H, Kokkoris I, Konovska I, Kruse M, Kuzmova I, Lange M, Liekens I, Lotan A, Lowicki D, Luque S, Marta-Pedroso C, Mizgajski A, Mononen L, Mulder S, Müller F, Nedkov S, Nikolova M, Östergård H, Penev L, Pereira P, Pitkänen K, Plieninger T, Rabe S-E, Reichel S, Roche P, Rusch G, Ruskule A, Sapundzhieva A, Sepp K, Sieber I, Šmid Hribar M, Stašová S, Steinhoff-Knopp B, Stępniewska M, Teller A, Vackar D, van Weelden M, Veidemane K, Vejre H, Vihervaara P, Viinikka A, Villoslada M, Weibel B, Zulian G (2018) Mapping and assessing ecosystem services in the EU—lessons learned from the ESMERALDA approach of integration. One Ecosyst 3. https://doi.org/10.3897/oneeco.3.e29153

Cheng X, Van Damme S, Uyttenhove P (2021) A review of empirical studies of cultural ecosystem services in urban green infrastructure. J Environ Manage 293:112895. https://doi.org/10.1016/j.jenvman.2021.112895

Decree of the Moscow City Government No. 743-PP (2002) On approving the rules for creation, maintenance and protection of green areas and natural communities in the City of Moscow. Dated September 10, 2002

Fagerholm N, Samuelsson K, Eilola S, Giusti M, Hasanzadeh K, Kajosaari A, Koch D, Korpilo S, Kyttä M, Legeby A, Liu Y, Præstholm S, Raymond C, Rinne T, Stahl Olafsson A, Barthel S (2022) Analysis of pandemic outdoor recreation and green infrastructure in Nordic cities to enhance urban resilience. NPJ Urban Sustain 2:25. https://doi.org/10.1038/s42949-022-00068-8

Gómez-Baggethun E, Barton DN (2013) Classifying and valuing ecosystem services for urban planning. Ecol Econ 86:235–245. https://doi.org/10.1016/j.ecolecon.2012.08.019

UI GreenMetric (2023) https://greenmetric.ui.ac.id/profile/rudn.ru. Accessed 16 Jan 2023

Haase D, Larondelle N, Andersson E, Artmann M, Borgström S, Breuste J, Gomez-Baggethun E, Gren Å, Hamstead Z, Hansen R, Kabisch N, Kremer P, Langemeyer J, Rall EL, McPhearson T, Pauleit S, Qureshi S, Schwarz N, Voigt A, Wurster D, Elmqvist T (2014) A quantitative review of urban ecosystem service assessments: concepts, models, and implementation. Ambio 43:413–433. https://doi.org/10.1007/s13280-014-0504-0

Ignatieva M, Eriksson F, Eriksson T, Berg P, Hedblom M (2017) The lawn as a social and cultural phenomenon in Sweden. Urban for Urban Greening 21:213–223. https://doi.org/10.1016/j.ufug.2016.12.006

Ignatieva M, Haase D, Dushkova D, Haase A (2020) Lawns in cities: from a globalised urban green space phenomenon to sustainable nature-based solutions. Land 9:73. https://doi.org/10.3390/land9030073

Klimanova OA, Illarionova OI (2020) Green infrastructure indicators for urban planning: applying the integrated approach for Russian largest cities. GES 13:251–259. https://doi.org/10.24057/2071-9388-2019-123

Kondo M, Fluehr J, McKeon T, Branas C (2018) Urban green space and its impact on human health. IJERPH 15:445. https://doi.org/10.3390/ijerph15030445

Matasov V, Belelli Marchesini L, Yaroslavtsev A, Sala G, Fareeva O, Seregin I, Castaldi S, Vasenev V, Valentini R (2020) IoT monitoring of urban tree ecosystem services: possibilities and challenges. Forests 11:775. https://doi.org/10.3390/f11070775

Nowak DJ, Hirabayashi S, Doyle M, McGovern M, Pasher J (2018) Air pollution removal by urban forests in Canada and its effect on air quality and human health. Urban for Urban Greening 29:40–48. https://doi.org/10.1016/j.ufug.2017.10.019

R Core Team (2014) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria

Russo A, Escobedo FJ, Cirella GT, Zerbe S (2017) Edible green infrastructure: an approach and review of provisioning ecosystem services and disservices in urban environments. Agric Ecosyst Environ 242:53–66. https://doi.org/10.1016/j.agee.2017.03.026

Small N, Munday M, Durance I (2017) The challenge of valuing ecosystem services that have no material benefits. Glob Environ Chang 44:57–67. https://doi.org/10.1016/j.gloenvcha.2017.03.005

Song XP, Tan PY, Edwards P, Richards D (2018) The economic benefits and costs of trees in urban forest stewardship: a systematic review. Urban for Urban Green 29:162–170. https://doi.org/10.1016/j.ufug.2017.11.017

Valentini R, Belelli Marchesini L, Gianelle D, Sala G, Yarovslavtsev A, Vasenev V, Castaldi S (2019) New tree monitoring systems: from Industry 4.0 to Nature 4.0. Ann Silvicult Res 43. https://doi.org/10.12899/asr-1847

Vogt J, Hauer RJ, Fischer BC (2015) The costs of maintaining and not maintaining the urban forest: a review of the urban forestry and arboriculture literature. 41(6): 293–323

Willcock S, Hooftman D, Sitas N, O'Farrell P, Hudson MD, Reyers B, Eigenbrod F, Bullock JM (2016) Do ecosystem service maps and models meet stakeholders' needs? A preliminary survey across sub-Saharan Africa. Ecosyst Serv 18:110–117. https://doi.org/10.1016/j.ecoser.2016.02.038

World Bank (2021) State and trends of carbon pricing 2021. The World Bank

Yang F, Ignatieva M, Larsson A, Zhang S, Ni N (2019) Public perceptions and preferences regarding lawns and their alternatives in China: a case study of Xi'an. Urban for Urban Greening 46:126478. https://doi.org/10.1016/j.ufug.2019.126478