Open access • Journal Article • DOI:10.1134/S1064229318100137

The Ecological Functions and Ecosystem Services of Urban and Technogenic Soils: from Theory to Practice (A Review) — Source link

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Published on: 16 Oct 2018 - Eurasian Soil Science (Pleiades Publishing)

Topics: Ecosystem services, Soil functions, Urban planning and Urbanization

The Ecological Functions and Ecosystem Services of Urban and Technogenic Soils: from Theory to Practice (A Review)[1]

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Translated by D. Konyushkov

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Received: November 23, 2017.

Abstract—A review of Russian and foreign approaches to analyze and assess the ecological and socioeconomic role of urban and technogenic soils is made in the context of the two popular concepts: the ecological functions of soils and ecosystem services. The modern definitions, classification, and evaluation of ecosystem services and their relationships with soil functions are considered both in general and in relation to urban and technogenic soils. Despite some methodological differences, the work shows that the concepts are closely related, and their joint use is highly promising. Three practical examples for the cities of Moscow, Hangzhou, and Hong Kong show a consistent transition from the analysis of soil properties and functions to the assessment of ecosystem services and decision making in engineering, urban improvement, and sustainable urban development.

Keywords: urbanization, ecologic and economic assessment, decision-making support, sustainable development of cities

INTRODUCTION

Urbanization is one of the key trends in modern land-use change[87]. The extent of urban areas on the planet increased fourfold in 1970–2000 [98]. By 2050, more than 70% of the nine billion people of the Earth will live in cities

[1]Materials of the 9th Congress "Soils of Urban, Industrial, Traffic, Mining and Military Areas, SUITMA."

[60]. Against the background of the increasing urbanization rate, the quality of life in urban environments and sustainability of urboecosystems attract special attention of the scientific community and policy institutions [28, 58, 47]. Urban and technogenic soils (**UTSs**, as analogous to Soils of urban, industrial, traffic, mining, and military areas (SUITMA)) are a key component of urboecosystems. Being the link between the atmosphere, green plantations, and groundwater, these soils greatly affect the state of the environment and human health in the cities [82, 105]. High vulnerability of these soils to anthropogenic loads (pollution, salinization, sealing, compaction, etc.) necessitates their ecological monitoring, assessment, and norming. A wide range of practical sectors (environmental planning, environmental impact assessment, urban planning, landscaping) specify a growing demand for high-quality objective data on the environmental state of the UTSs. The problem and adequate interpretation of soil information in a language understood by the end users—environmental engineers, land surveyors, or politicians—is very acute [93]. The following criteria for information on the UTSs necessary for solving various applied tasks of urban development can be suggested: (1) information integrity (maximum information with a minimum of indicators), (2) objectivity (adequate characterization of various soil processes and functions), and (3) informativeness (understandability to the consumer).

A traditional analysis of the physical and chemical properties of soils, as well as the application of classical agroecological indices [15, 41] and sanitary and hygienic standards [7, 29, 26], does not fully satisfy the proposed criteria [102]. Thus, the practice of environmental monitoring is based on a limited list of static indicators (usually, data on the acidity and on the contents of nutrients and pollutants in the upper layers of urban soils) [14]. Sanitary and hygienic norms are focused on monitoring the effect of soil on human health and underestimate the participation of soils in global ecological processes: biodiversity preservation, water balance regulation, carbon sequestration, etc.

[54]. Integral approaches to assess soil quality [72] or soil health [55], which characterize the soil through a combination of diverse processes and functions, rather than individual indicators, have become an alternative to the existing practice of environmental assessment and norming [4, 83]. The concept of soil ecological functions seems to be more promising for the assessment of the role of soils for humans and for the environment. There is a large number of publications on the classification, diagnostics, and evaluation of soil ecological functions both in Russia [9, 10, 13, 18] and abroad [38, 43]. Nevertheless, a significant difference in the existing approaches to the classification of ecological functions, insufficient substantiation of the particular indicators for their evaluation, and the lack of evident links with management decision-making limits the practical application of knowledge about the environmental functions of soils, especially in complex and heterogeneous systems, such as urban systems.

To the contrary, the concept of ecosystem services was initially focused on establishing clear relationships between environmental information and decision-making practices. In Russian literature, along with the original term (ecosystem services), its Russian equivalent—*ekosistemnye uslugi* (ecosystem favors)—is often used; it became popular after the Russian translation of the *Millennium Ecosystem Assessment* report [78]. From our point of view, the Russian term somewhat narrows the initial meaning of the term *ecosystem services*. In further discussion, we use the latter term. Although soil ecosystem services represent a relatively small part of ecosystem services [46, 78], the high potential of this approach for an integral assessment of the role of soils for humans and the environment is obvious; adequate interpretation and adaptation of the results of soil studies can be helpful for solving a wide range of practical tasks [53]. The concepts of the ecological functions and ecosystem services of soils are closely interrelated. Thus, *The Economics of Ecosystems and Biodiversity* (TEEB) project suggests that soil functions can be considered as the basis for evaluation of some ecosystem services [98]. At the same time, the differences in the objects, methods, and tasks addressed by these approaches, as well as different levels of their perception and authenticity, especially in the Russian scientific community and political institutions, limit practical application of the concepts of ecosystem services and soil ecological functions in urban planning, environmental assessment, and environmental protection.

The purpose of this review is to summarize the theoretical basis of both concepts and to evaluate their applicability for solving various problems of the assessment, ecological norming, and management of UTSs.

COMPARISON OF THE CONCEPTS OF ECOLOGICAL SOIL FUNCTIONS AND ECOSYSTEM SERVICES: PURPOSES, OBJECTS, CLASSIFICATION, AND DIAGNOSTICS

Soil ecological functions. The term soil functions, or, more specifically, soil ecological functions has been used since the early 1970s (Table 1), when the traditional perception of the role of soils for the agricultural production was complemented by a better understanding of the global role of soils in the biosphere [8, 16, 17, 74]. At the early stages, the ecological functions of soils were mainly identified and analyzed at the global level, e.g., the function of sustaining life on the planet, or the function of ensuring the continuous interaction between the large geological and the small biological cycles of matter [19]. A significant growth of the number of investigations into this subject at the turn of the 20th century led to the appearance of new definitions and more detailed classifications of soil ecological functions. The approaches to classification of soil ecological functions developed in Russia differed significantly from those developed in Europe and the United States. The classical Russian theory of soil ecological functions [9, 11–13] defines them as the functions of soils and soil processes in ecosystems contributing to their preservation and development. Moreover, relying on the approaches of classical genetic pedology, the ecological functions of soils can be interpreted as the reverse impact of soils on soil-forming factors [13]. The approaches developed in Europe and in the United States have a more applied character; the ecological functions of soils are considered as the impact of soil processes on the environment and human beings [83, 59]. The analysis of soil functions is actively applied for land assessment and land management planning [71, 105], whereas in Russia, the concept of soil ecological functions is often applied for the purposes of environmental protection; in particular, the concept is taken into consideration for the creation of the Red Data books of soils [1, 9, 35]. The differences between the Russian, European, and American approaches become even evident if we analyze the proposed classifications of the ecological functions of soils. These classifications differ both in the number of identified functions and in their categories. Apparently, the most detailed classification existing at the moment is the Russian classification, which includes 32 functions, including 16 global and 16 biogeocenotic functions [13] (Table 2). In European and American classifications, six and seven soil functions are usually separated, respectively; as a rule, they are subdivided into ecological and non-ecological functions [43], or into natural and "useful to humans" functions [42]. Most of the functions offered by the European and American classifications have obvious analogues in the Russian classification (Table 3), although it is difficult to fine exact analogues for some functions. The latter concerns "non-ecological" [43] and "useful for human" [42] functions, since the main attention in the Russian classification is paid to the interactions between soil and landscape (at the biogeocenotic level) or soil and environment (globally) rather than to interactions between soil and humans, as in the case of European and American classifications. An additional reason for the discrepancies between Russian and foreign classifications is a clear terminological division between soil as a natural body and land as a spatial base in Russian scientific and legal practices [22]. In this regard, such functions as "the basis for infrastructure" or "the source of minerals and building materials," proposed by foreign classifications are not directly reflected in the Russian variant.

Ecosystem services. The concept of ecosystem services appeared in the late 1960s in the works of American economists [73, 65] and became widely used after publication of the article "The value of the world's ecosystem services and natural capital" in *Nature* [49]. Noting the obvious underestimation of natural capital and environmental values in comparison with economic ones, the authors singled out 17 groups of ecosystem services and estimated their total value for the planet's territory at $33 trillion per year (with the total GDP of $18 trillion per year). The work had significant impact, not just by the total value of the natural wealth of the planet but by the very idea of the maximally utilitarian, economic approach to the assessment of natural capital. Within the framework of this approach, the term ecosystem service is considered as economic benefits that people directly or indirectly obtain from ecosystem functions [49, 52]. The use of this term in Russian publications started at the beginning of the XXI century, and predominantly in economic geography [2, 24, 32]. In recent years, the assessment of ecosystem services has been applied to land assessment issues or to the assessment of damage from soil degradation [25, 23]. The classification of ecosystem services has somewhat changed in the past 20 years. However, the main classification schemes [52, 78, 98] separate four categories: production/supply, regulation, life-supporting/sustaining (habitat), and cultural/information services [69]. The last version of the International Classification of Ecosystem Services (CICES), prepared by the European Environmental Agency [64], excludes life-supporting/sustaining services, which was the reason for criticizing the approach for a clear ecological bias to the detriment of socioeconomic factors [96]. In Russia, as a rule, the classification suggested in the *Millennium Ecosystem Assessment* is used [78]. According to the reviews of studies devoted to ecosystem services [63, 95, 101], this concept is usually applied for the assessment and mapping of natural resources [50, 80] and for the analysis of alternative land use scenarios [79, 106]. Among the most well-known cases of the use of this concept in the international environmental, economic, and political practices is the litigation for compensation of damage from an oil spill in the Gulf of Mexico [48].

SOIL ECOSYSTEM SERVICES

The role of soils in the provision of ecosystem services remained underestimated for a long time. The concepts of ecological functions of soils and ecosystem services were developed independently from one another. Practical application of the concept of ecosystem services, as well as the growing understanding of the role of soil as a key component of natural capital [61, 92], showed the importance of soil properties and functions for the assessment of ecosystem services and led to a discussion about the need for a deeper integration of these concepts [46]. As a result, the number of studies on the role of soils in the provision/maintenance of ecosystem services increased, and the term "soil-based ecosystem services" was introduced [45, 54]. Despite a large number of particular examples of the relationships between the ecological functions of soils and ecosystem services [70, 86, 107], an integral scheme combining both concepts has not been developed so far. The main reason is the complexity and diversity of soil functions, each of which is associated with several ecosystem services of different levels. Thus, the comparison of the ecological functions [13, 43] and ecosystem services [100] shows the presence of about four linkages for each of the functions, and of about eight linkages for each of the services (Fig. 1). Among the general schemes, the most interesting ones are the scheme suggested by Dominati with coauthors [54] (Fig. 2) and the "flower" scheme [37] (Fig. 3). Among Russian publications, the approach proposed by Bondarenko [3], which combines the functions of soils and ecosystem services at the biogeocenotic and global levels, is particularly interesting. All the proposed schemes allow us to correlate the soil functions and the corresponding services, though there is no unified approach to their analysis and assessment. The most suitable for these purposes is the cascade model, which integrates the properties, functions, and ecosystem services of soils and opens possibilities for the practical application of assessment results (Fig. 4).

ECOSYSTEM SERVICES OF UTSs

As a rule, investigations into the role of soils in the provision of ecosystem services are focused on soils of natural and agroecosystems; UTSs have virtually escaped the attention of researchers. This is due to the traditional perception of UTSs as highly degraded (contaminated, over-compacted, with low microbiological activity) soils [21, 81]. However, modern concepts of sustainable urban development (for example, "ecologically sustainable city" [88] or "city of minimum emissions" [91]) emphasize functions and services provided by UTSs [5, 30, 85]. A review of sources from WoS (Web of Science), Scopus, and RSCI (Russian Science Citation Index) shows a predominance of papers devoted to the assessment of soils ecosystem services published by European, American, and Chinese authors (as a rule, with "domestic" objects of their studies) over the papers by Russian scientists, by more than a tenfold. The portion of papers devoted to the UTSs in both cases generally does not exceed 5%, although the number of such papers prepared by American, Chinese, German, and French authors has increased noticeably in the recent years (Fig. 5). The work "*Ecosystem services provided by soils of urban, industrial, traffic, mining, and military areas (SUITMAs)*" [82] was a pioneer study in this field. In this study, 17 ecosystem services are considered, and the potential for their implementation by UTSs of four different categories—quasi-natural, constructed, soils of abandoned territories, and sealed soils—is estimated. Along with the services, the concept of "dis-services" (negative impact on the ecosystem, as in the case of soil sealing or soil contamination) is suggested (Fig. 6). It is noted in this study that the same groups of soils may deliver both services and dis-services in dependence on the character of their use. For example, sealed soils may increase the risk of flooding due to reduced filtration.

However, the organization of surface runoff will facilitate more efficient water disposal and reduce the risks of flooding. The proposed assessment scale (zero, low, high or very high importance of the ecosystem service) seems somewhat simplistic, and the lack of specifications on the nature of the impact (positive or negative) complicates its understanding. Thus, the ecosystem service impact on the global climate is assessed equally as highly significant for the constructed soils and soils of abandoned areas and landfills. At the same time, there is much evidence for the positive effects of constructozems on the climate because of carbon sequestration (e.g., for golf courses [97]), as well as for the negative impact of the soils of landfills on the climate because of the enhanced methane emissions [44]. However, despite the its shortcomings, the presented classification is a unique attempt to organize the information about the UTS ecosystem services.

Much of the subsequent research on the ecosystem services of the UTSs is summarized in two monographs [75, 76]. They focus on one of the most studied services (for example, carbon sequestration [77] or biodiversity conservation [39]) but do not reflect a consistent analysis of soil properties and functions for service assessment and decision-making.

Further in this paper, three examples are offered, which illustrate the sequential analysis of UTS properties, functions, and services and decision making in accordance with the proposed cascade model (Fig. 1). The examples differ in geographical location and bioclimatic conditions, the category of functions and services being analyzed, and the nature of the suggested decisions, which reflects the universality of the proposed cascade model.

EXAMPLES OF UTS ECOSYSTEM SERVICES ASSESSMENT

Planning of green infrastructure objects to reduce the negative impact on the climate. The regulating service to reduce the negative impact on the climate is one of the most well-studied soil services, and frequently used in environmental and economic projects. Soil and green plantations play a decisive role in carbon sequestration thus reducing the greenhouse effect. At the same time, soils are the major source of CO_2 emission into the atmosphere [66]. Carbon pools in urban soils are comparable with or exceed those in natural soils [90, 103], but a significant portion of these pools is represented by easily mineralizable carbon compounds [99]. The relationship between carbon stocks and CO_2 emissions in UTSs varies for different land uses and types of surfaces (urban lawns, parks, forest parks, specially protected areas) [94]. A comparative analysis of CO_2 emissions from the soils of urban lawns in the Northern administrative district of Moscow [36] and the adjacent background territories (the Petrovsko-Razumovskoe nature reserve) [6, 31] indicates that the average CO_2 emission from the urban lawns is more than two times higher than that from the background territories: 7.3 and 3.1 t C-CO_2/ha, respectively. Taking the potential price of 1 t C-CO_2 at $15 [27], the economic regression of the regulating service of urban lawns in comparison with the soils of urban forests and forest parks should comprise $63/ha. These results may be used for the ecological and economic substantiation of urban gardening strategies. In particular, it is feasible to reduce the portion of fragmented areas of urban lawns in favor of extended areas of tree and shrub plantations. The implementation of the cascade model in this case allows us to move from the estimation of the carbon stock (property) and respiration (function) of the UTSs to the estimation of emissions and their negative effects on the climate (service) that should be taken into account in decision-making aimed at sustainable development of urban green areas (Fig. 7).

The assessment of additional cost of purification of surface runoff as a result of UTS sealing. Soil sealing is one of the most significant negative consequences of urbanization. The portion of sealed soils (Ekranic Technosols, or ekranozems in Russian literature) in modern cities varies from 10 to 70%, depending on the size, location, and functional use of the territory [57, 103].

Though some works attest to the potential of sealed soils to perform certain ecological functions (e.g., preservation of carbon stocks [89]), a general decrease in the quality of sealed soils is unquestionable. Sealing leads to a fundamental change in the physical properties of soils, including the filtration coefficient and the bulk density. Changes in the physical properties of the surface lead to redistribution of surface and underground runoff, deterioration of the water and air regimes, creation of unfavorable conditions for plant roots and soil microbial community, formation of conditions for methane emissions, and other adverse consequences. An analysis of the negative consequences of soil sealing was performed for Hangzhou in Zhejiang Province of China [68]. It was shown that the average surface runoff in the areas with sealed soils increases by 40% in comparison with that in the urban forest park. Additional surface runoff increases the burden on the waste treatment plant and necessitates the construction of additional purification facilities. The average surface runoff from sealed soils comprised 234 m^3/ha per year compared to 167 m^3/ha per year for the forest park. The additional cost of construction and operation of waste treatment plants was estimated at $3684/ha per year on the average. In this case, the application of the cascade model allows us to use information on soil properties (density, filtration coefficient) for evaluation of the soil function (filtration, surface runoff) and ecosystem service (water balance regulation) to be taken into account in decision making on engineering measures and site preparation.

Energy saving for air conditioning owing to construction of green roofs. The effect of the thermal island is another urgent problem for almost any large city [84]. The considered sealing of soils combined with the increased concentrations of greenhouse gases, decreased transparency of the atmosphere, and air stagnation lead to a significant increase in air temperatures in centers of the cities in comparison with the suburbs. The development of such thermal islands lowers the standard of living conditions [56] and increases the cost of air conditioning. One of the most common solutions to the problem is the creation of green roofs. Soil constructions (constructozems) are the key component of green roofs; these artificial soils control nutrient balance and water and temperature regimes and, ultimately, directly affect the ecosystem service of microclimate formation. An analysis of this service for green roofs on different soil constructions was performed for six green roofs of new buildings in Hong Kong with an area from 350 to 1250 m^2 [67]. It was shown that, in dependence on the type of soil construction and vegetation, the soil temperature at the depth of 10 cm decreases by 2–5°C on the average during the year and by 7–12° during the hottest days in comparison with not greened roofs. The decrease in heat transfer reached 17–42%, which made it possible to reduce energy consumption for room air conditioning by 0.04 kW/day per 1 m^2 of green roof. Taking into account the cost of electricity ($0.18 per 1 kW h, the annual savings amounted to $2.63/$m^2$, or from $920 to $3288 for the studied objects. These results were used in the report of the Department of Green Construction on the implementation of the state program to support the creation of green roofs and vertical gardening. Thus, the application of the cascade model in this case implies the establishment of relationships between the UTS property (temperature), the UTS function (heat flow), the microclimate service (reducing the cost of air conditioning), and the strategies to increase the use of green roofs in the city.

CONCLUSIONS

The importance of urban ecology issues for improving the quality of life and for solving global environmental problems has gained recognition among scientists, politicians, and practitioners. As indicated in the report of the United Nations General Assembly, the challenge is to create smart and sustainable cities; this challenge is already taken into account in the development strategies of many countries and regions. Against the background of growing public and political attention to urboecosystems in general and to urban and technogenic soils, in particular, it is especially important to be able to ensure the solution of the problems of ecological projecting and planning of the cities with due account for the qualitative and comprehensive soil information. The review of the two most common integrated approaches of soil ecology—the concepts of ecological functions of soils and ecosystem services—showed the absence of antagonism between them and emphasized the prospects for their joint use for such a complex and interesting object as urban and technogenic soils. For an expert in the analysis and assessment of ecosystem services (economist, analyst, or manager), data on soil properties and functions form the necessary basis for making justified decisions on the use of the territory. For a soil scientist, the assessment of ecosystem services provides possibility to bring the results of soil studies to a new level of the practical use and to take part in real decision making on the environmental management in urban territories. Examples of a consistent analysis of the properties, functions, and services of the UTSs have shown the efficiency and relevance of this approach for decision making in various fields of urban engineering and in the general improvement, development, and sound management of the urban environment. Further intensification of interdisciplinary investigations into the ecological and socioeconomic role of soils in the urban environment opens up new promising scientific directions and contributes to the practical implementation of sustainable urban development.

ACKNOWLEDGMENTS

The analysis of ecological functions and ecosystem services was supported by the Russian Science Foundation, project no. 17-77-20046. The collection and processing of information on the use of the cascade model for key sites was performed with financial support from the PFUR 5-100 project.

REFERENCES

1. B. F. Aparin, *The Red Data Book of Soils of Leningrad Oblast* (Aeroplan, St. Petersburg, 2007) [in Russian].
2. S. N. Bobylev, S. V. Solov'eva, and K. S. Sitkina, "Indicators of sustainable development of the Ural region," Ekon. Reg., No. 2 (34), 10–17 (2013).
3. E. V. Bondarenko, Candidate's Dissertation in Biology (Moscow, 2016).
4. V. I. Vasenev, Candidate's Dissertation in Biology (Moscow, 2011).
5. V. I. Vasenev, N. D. Ananyeva, and O. A. Makarov, "Specific features of the ecological functioning of urban soils in Moscow and Moscow oblast," Eurasian Soil Sci. **45**, 194–205 (2012).
6. M. M. Vizirskaya, M. V. Tikhonova, A. S. Epikhina, and I. M. Mazirov, "Ecological evaluation of tolerance of podzolic soils of forest ecosystems toward recreational load in Moscow region by the example of the Forest Experimental Station of the Russian State Agrarian University–Moscow Timiryazev Agricultural Academy)," Agroekologiya, No. 2, 14–21 (2014).
7. *GN (Hygienic Normatives) 2.1.7.2511-09: Approximate Permissible Concentration of Chemical Substances in Soil* (Moscow, 2009) [in Russian].
8. G. V. Dobrovol'skii, "Problems in genetic soil science," Pochvovedenie, No. 7, 103–111 (1979).
9. G. V. Dobrovol'skii and E. D. Nikitin, *Conservation of Soils as an Irreplaceable Component of the Biosphere* (Nauka, Moscow, 2000) [in Russian].
10. G. V. Dobrovol'skii and E. D. Nikitin, *Soil Functions in the Biosphere and Ecosystems* (Nauka, Moscow, 1990) [in Russian].
11. G. V. Dobrovol'skii and E. D. Nikitin, *Ecological Functions of Soil* (Moscow State Univ., Moscow, 1986) [in Russian].
12. G. V. Dobrovol'skii and E. D. Nikitin, *Ecology of Soils* (Moscow State Univ., Moscow, 2006) [in Russian].
13. G. V. Dobrovol'skii and E. D. Nikitin, *Ecology of Soils: The Theory about Ecological Functions of Soils* (Moscow State Univ., Moscow, 2012) [in Russian].
14. *A Report on the State of the Environment in Moscow City in 2016*, Ed. by A. O. Kul'bachevskii (Institute of Urban and System Design, Moscow, 2017) [in Russian].
15. I. I. Karmanov and D. S. Budgakov, "Experience in the development of the methods to calculate the value agricultural lands on the basis of soil-ecological approach, in *Role of Soils in the Biosphere*, Tr. Inst. Pochvoved., Mosk. Gos. Univ., Ross. Akad. Nauk (Institute of Soil Science, Moscow State Univ., Moscow, 2003), No. 3, p. 62.
16. V. A. Kovda, "Biosphere, soils, and their use," Pochvovedenie, No. 1, 3 (1975).
17. V. A. Kovda, "Soil cover as a biospheric component," Vestn. Ross. Akad. Nauk, No. 9, 16 (1973).
18. V. A. Kovda, "World soil cover and life," Izv. Akad. Nauk SSSR, Ser. Biol., 181 (1986).
19. V. A. Kovda and B. G. Rozanov, *Soil Science: Soil and Pedogenesis* (Vysshaya Shkola, Moscow, 1988), Part 1.
20. D. E. Konyushkov, "Development of the concept of ecosystem services: a review of foreign literature," Byull. Pochv. Inst. im. V.V. Dokuchaeva, No. 80, 26–49 (2015).
21. A. S. Kurbatova, V. N. Bashkin, Yu. A. Barannikova, S. G. Gerasimova, E. V. Nikiforova, E. V. Reshetina, V. A. Savel'eva, D. S. Savin, A. V. Smagin, and A. L. Stepanov, *Ecological Functions of Urban Soils* (Madzhenta, Smolensk, 2004) [in Russian].
22. O. A. Makarov, *Why Soil Should Be Evaluated?* (Moscow State Univ., Moscow, 2003) [in Russian].

23. O. A. Makarov, A. S. Yakovlev, E. V. Tsvetnov, E. V. Bondarenko, Ya. R. Ermiyaev, and A. S. Strokov, “Economic evaluation of soils: existing experience and prospects for development,” APK: Ekon., Uprav., No. 7, 58–67 (2017).
24. O. E. Medvedeva, “Methods of valuation of valuable natural territories,” Vestn. Gos. Univ. Uprav., No. 1 (19), 32–41 (2007).
25. O. E. Medvedeva, “Cost evaluation of the harmful environmental impact of degradation and pollution of soils,” Vor. Otsenki, No. 1, 79–90 (2012).
26. *MU-2.1.7.730-99: Methodological Recommendations for Hygienic Evaluation of Urban Soil Quality* (Moscow, 1999) [in Russian].
27. A. Perov, War for climate: how the "carbon tax" will affect utility payments, 2016. https://www.rbc.ru/opinions/society/26/04/2016/571f0dd39a794712caedfdd2.
28. *Resolution of the Government of Moscow No. 394-PP of July 10, 2014 on the New General Ecological Policy of Moscow City until 2030* (Moscow, 2014) [in Russian]
29. *SP-11-102-97: Rules on Engineering-Ecological Surveys for Construction Purposes* (Moscow, 1997) [in Russian]
30. A. V. Smagin, *Theory and Practice of Soil Construction* (Moscow State Univ., Moscow, 2012) [in Russian].
31. M. V. Tikhonova and M. M. Vizirskaya, “Ecological evaluation of spatiotemporal variability of N_2O and CO_2 emissions from soils of the background forest site in the north of Moscow megapolis,” in *Ecological Monitoring, Modeling, and Design of Natural, Urban, and Agricultural Ecosystems*, Ed. by R. M. Valentini (Moscow, 2015), pp. 176–178.
32. A. A. Tishkov, “Biosphere functions and ecosystem services of the steppe landscapes of Russia,” Arid. Ekosist. **16** (41), 5–15 (2010).
33. A. A. Tishkov, *Biospheric Functions of Natural Ecosystems of Russia* (Nauka, Moscow, 2005) [in Russian].
34. V. A. Chernikov, R. M. Aleksakhin, A. V. Golubev, I. G. Gringof, V. M. Ivonin, V. F. Kormilitsyn, V. F. Ladonin, Sh. I. Litvak, N. Z. Milashchenko, N. A. Mosienko, L. V. Mosina, S. A. Murakaeva, V. V. Parakiiin, G. N. Popov, D. A. Postnikov, et al., *Agroecology* (Kolos, Moscow, 2000) [in Russian].
35. O. V. Chernova, “A project of the Red Data Book of Russian soils,” Pochvovedenie, No. 4, 514–519 (1995).
36. A. S. Shchepeleva, Candidate’s Dissertation in Biology (Moscow, 2015).
37. K. Adhikari and A. E. Hartemink, “Linking soils to ecosystem services—a global review,” Geoderma 262, 101–111 (2016).
38. S. S. Andrews, D. L. Karlen, and C. A. Cambardella, “The soil management assessment framework: a quantitative soil quality evaluation method,” Soil Sci. Soc. Am. J. **68**, 1945–1962 (2004).
39. A. Auclerc, “Regulating services provided by urban soils. Biodiversity,” in *Soils within Cities* (Catena-Schweizerbart, Stuttgart, 2017), pp. 213–220.
40. A. Balmford, A. Bruner, P. Cooper, R. Costanza, S. Farber, R. E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, et al., “Ecology—economic reasons for conserving wild nature,” Science **297**, 950–953 (2002).
41. F. Bastida, A. Zsolnay, T. Hernandez, and C. Garcia, “Past, present and future of soil quality indices: a biological perspective,” Geoderma **147**, 159–171 (2008).
42. Federal Soil Protection Act (Bodenschutzgesetz, BBodSchG), Federal Law Gazette, March 17 (1998).
43. W. E. H. Blum, “Functions of soil for society and environment,” Rev. Environ. Sci. Biotechnol. **4**, 75–79 (2005).
44. J. Bogner, K. Spokas, E. Burton, R. Sweeney, and V. Corona, “Landfills as atmospheric methane sources and sinks,” Chemosphere **31** (9), 4119–4130 (1995).

45. J. Bouma, “Soil science contributions towards sustainable development goals and their implementation: linking soil functions with ecosystem services,” J. Plant Nutr. Soil Sci. **177** (2), 111–120 (2014).
46. A. M. Breure, G. B. De Deyn, E. Dominati, T. Eglin, K. Hedlund, J. van Orshoven, and L. Posthuma, “Ecosystem services: a useful concept for soil policy making,” Curr. Opin. Environ. Sustainability **4** (5), 578–585 (2012).
47. E. Cohen-Shacham, G. Walters, C. Janzen, and S. Maginnis, *Nature-Based Solutions to Address Global Societal Challenges* (IUCN Commission on Ecosystem Management, IUCN World Commission on Protected Areas, Geneva, 2016).
48. *An Ecosystem Services Approach to Assessing the Impacts of the Deepwater Horizon Oil Spill in the Gulf of Mexico* (National Academies Press, Washington, 2013).
49. R. Costanza, R. d'Are, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. S. Raskin, P. Sutton, and M. van den Belt, “The value of the world's ecosystem services and natural capital,” Nature **387**, 253–260 (1997).
50. N. D. Crossman, B. Burkhard, S. Nedkov, L. Willemen, K. Petz, I. Palomo, E. G. Drakou, B. Martín-Lopez, T. McPhearson, K. Boyanova, R. Alkemade, B. Egoh, M. B. Dunbar, and J. Maes, “A blueprint for mapping and modeling ecosystem services,” Ecosyst. Serv. **4**, 4–14 (2013).
51. G. C. Daily, P. A. Matson, and P. M. Vitousek, *Nature’s Services: Societal Dependence on Natural Ecosystems* (Washington, Island Press, 1997), pp. 113–132.
52. R. S. De Groot, M. A. Wilson, and R. M. J. Boumans, “A typology for the classification, description and valuation of ecosystem functions, goods and services,” Ecol. Econ. **41**, 393–408 (2002).
53. E. Dominati, A. Mackay, S. Green, and M. Patterson, “A soil change-based methodology for the quantification and valuation of ecosystem services from agro-ecosystems: a case study of pastoral agriculture in New Zealand,” Ecol. Econ. **100**, 119–129 (2014).
54. E. Dominati, M. Patterson, and A. Mackay, “A framework for classifying and quantifying the natural capital and ecosystem services of soils,” Ecol. Econ. **69**, 1858–1868 (2010).
55. J. W. Doran, “Soil health and global sustainability: translating science into practice,” Ecosyst. Environ. **88**, 119–127 (2002).
56. T. Elmqvist, H. Setala, S. N. Handel, S. van der Ploeg, J. Aronson, J. N. Blignaut, E. Gomez-Baggethun, D. J. Nowak, and K. R. de Groot, “Benefits of restoring ecosystem services in urban areas,” Curr. Opin. Environ. Sustainability **14**, 101–108 (2015).
57. C. D. Elvidge, C. Milesi, J. B. Dietz, B. T. Tuttle, P. C. Sutton, R. Nemani, and J. E. Vogelman, “Paving paradise,” GeoSpatial Solutions **14**, 58 (2004).
58. *LIFE Building up Europe’s Green Infrastructure, Addressing Connectivity and Enhancing Ecosystem Functions* (European Commission, Luxembourg, 2010).
59. *European Soil Strategy, 2006, Thematic Strategy for Soil Protection (SEC(2006)620) (SEC(2006)1165)* (Communication from the Commission to the Council, European Parliament, European Economic and Social Committee and the Committee of the Regions, Brussels, 2006).
60. *How to Feed the World in 2050* (Food and Agriculture Organization, Rome, 2013), Vol. 2050, No. 1.
61. *Status of the World’s Soil Resources, Main Report* (Food and Agriculture Organization, Rome, 2015).
62. J. A. Foley, R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, et al., “Global consequences of land use,” Science **309** (5734), 570–574 (2005).

63. L. Greiner, A. Keller, A. Grêt-Regamey, and A. Paprit, "Soil function assessment: review of methods for quantifying the contributions of soils to ecosystem services," Land Use Policy **69**, 224–237 (2017).
64. R. H. Haines-Young and M. B. Potschin, *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August–December 2012, Report to the European Environment Agency, EEA Framework Contract No. 866 EEA/IEA/09/003* (European Environment Agency, Brussels, 2013).
65. D. R. Helliwell, "Valuation of wildlife resources," Reg. Stud. **3**, 41–49 (1969).
66. R. A. Houghton, "Why are estimates of the terrestrial C balance so different?" Global Change Biol. **9**, 500–509 (2003).
67. S. Hui, *Study of Thermal and Energy Performance of Green Roof Systems: Final Report* (University of Hong Kong, Hong Kong, 2009).
68. C. Y. Jim and W. Y. Chen, "Ecosystem services and valuation of urban forests in China," Cities **26**, 187–194 (2009).
69. J. Ö. G. Jónsson and B. Davídsdóttir, "Classification and valuation of soil ecosystem services," Agric. Syst. 1452, 24–38 (2016).
70. S. Juarez, N. Nunan, A.-C. Duday, V. Pouteau, S. Schmidt, S. Hapca, R. Falconer, W. Otten, and C. Chenu, "Effects of different soil structures on the decomposition of native and added organic carbon," Eur. J. Soil Biol. **58**, 81–90 (2013).
71. D. L. Karlen, C. A. Ditzler, and S. S. Andrews, "Soil quality: Why and how?" J. Soil Water Conserv. **58** (4), 171–179 (2003).
72. D. L. Karlen, M. J. Mausbach, J. W. Doran, R. G. Cline, R. F. Harris, and G. E. Schuman, "Soil quality: a concept, definition, and framework for evaluation," Soil Sci. Soc. Am. J. **61**, 4–10 (1997).
73. R. T. King, "Wildlife and man," New York Conserv. **20** (6), 8–11 (1966).
74. V. A. Kovda, "Disarmament and preservation of the biosphere," Environ. Conserv. **8** (4), 258–260 (1981).
75. R. Lal and B. A. Stewart, *Advances in Soil Science: Urban Soils* (CRC Press, Boca Raton, 2017).
76. M. J. Levin, K.-H. J. Kim, J. L. Morel, W. Burghardt, P. Charzynski, and R. K. Shaw, *Soils within Cities* (Catena- Schweizerbart, Stuttgart, 2017).
77. K. Lorenz and R. Shaw, "Regulating services provided by urban soils. Carbon storage in urban soils," in *Soils within Cities* (Catena-Schweizerbart, Stuttgart, 2017), pp. 203–213.
78. *MA—Millennium Ecosystem Assessment, Ecosystems and Human Well-Being: A Framework for Assessment* (Island Press, Washington, 2003).
79. J. Maes, B. Egoh, L. Willemen, C. Liquete, P. Vihervaara, J. P. Schägner, B. Grizzetti, E. G. Drakou, A. L. Notte, G. Zulian, F. Bouraoui, M. Luisa Paracchini, L. Braat, and G. Bidoglio, "Mapping ecosystem services for policy support and decision making in the European Union," Ecosyst. Serv. **1** (1), 31–39 (2012).
80. A. Makó, M. Kocsis, G. Barna, and G. Tóth, *Mapping the Storing and Filtering Capacity of European Soils, JRC Technical Report (EUR 28392 EN)* (Publications Office of the European Union, Luxembourg, 2017).
81. M. L. McKinney, "Urbanization as a major cause of biotic homogenization," Biol. Conserv. **127**, 247–260 (2006).
82. J. L. Morel, C. Chenu, and K. Lorenz, "Ecosystem services provided by soils of urban, industrial, traffic, mining, and military areas (SUITMAs)," J. Soils Sediments **15** (8), 1659–1666 (2015).
83. S. Nortcliff, "Standardization of soil quality attributes," Agric., Ecosyst. Environ. **88**, 161–168 (2002).
84. T. R. Oke, *Boundary Layer Climates* (Methuen, London, 1989).

85. D. E. Pataki, M. M. Carreiro, J. Cherrier, N. E. Grulke, V. Jennings, S. Pincetl, R. V. Pouyat, T. H. Whitlow, and W. C. Zipperer, “Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions,” Front. Ecol. Environ. **9**, 27–36 (2011).
86. E. Paul and F. Clark, “Soil as a habitat for organisms and their reactions,” in *Soil Microbiology and Biochemistry*, Ed. by E. Paul (Academic, New York, 1996), pp. 12–32.
87. S. T. A. Pickett, M. L. Cadenasso, J. M. Grove, C. G. Boone, P. M. Groffman, E. Irwin, and P. Warren, “Urban ecological systems: scientific foundations and a decade of progress,” J. Environ. Manage. **92**, 331–362 (2011).
88. S. T. A. Pickett, M. L. Cadenasso, J. M. Grove, P. M. Groffman, L. E. Band, C. G. Boone, and M. A. Wilson, “Beyond urban legends: an emerging framework of urban ecology, as illustrated by the Baltimore Ecosystem Study,” BioScience **58**, 139–150 (2008).
89. A. Piotrowska-Długosz and P. Charzyński, “The impact of the soil sealing degree on microbial biomass, enzymatic activity, and physicochemical properties in the ekranic technosols of Toruń (Poland),” J. Soils Sediments **15** (1), 47–59 (2015).
90. R. V. Pouyat, I. D. Yesilonis, M. Dombos, K. Szlavecz, H. Setälä, S. Cilliers, and S. Yarwood, “A global comparison of surface soil characteristics across five cities: a test of the urban ecosystem convergence hypothesis,” Soil Sci. **180** (4–5), 136–145 (2015).
91. S. Raciti, P. Groffman, J. Jenkins, R. Pouyat, T. Fahey, S. Pickett, and M. Cadenasso, “Accumulation of carbon and nitrogen in residential soils with different land use histories,” Ecosystems **14**, 287–297 (2011).
92. D. A. Robinson, N. Hockley, D. M. Cooper, B. A. Emmett, A. M. Keith, Lebron I., B. Reynolds, E. Tipping, A. M. Tye, C. W. Watts, W. R. Whalley, H. I. J. Black, G. P. Warren, and J. S. Robinson, “Natural capital and ecosystem services, developing an appropriate soils framework as a basis for valuation,” Soil Biol. Biochem. **57**, 1023–1033 (2013).
93. D. G. Rossiter, J. Liu, S. Carlisle, and A.-X. Zhu, “Can citizen science assist digital soil mapping?” Geoderma **259–260**, 71–80 (2015).
94. D. A. Sarzhanov, V. I. Vasenev, I. I. Vasenev, Y. L. Sotnikova, O. V. Ryzhkov, and T. Morin, “Carbon stocks and CO_2 emissions of urban and natural soils in Central Chernozemic region of Russia,” Catena **158**, 131–140 (2017).
95. D. Schröter, W. Cramer, R. Leemans, I. C. Prentice, M. B. Araújo, N. W. Arnell, A. Bondea, H. Bugmann, T. R. Carter, C. A. Gracia, A. C. De La Vega-Leinert, M. Erhard, F. Ewert, M. Glendining, J. I. House, et al., “Ecology: ecosystem service supply and vulnerability to global change in Europe,” Science **310** (5752), 1333–1337 (2005).
96. G. Schwilch, L. Bernet, L. Fleskens, E. Giannakis, J. Leventon, T. Marañón, J. Mills, C. Short, J. Stolte, H. van Delden, and S. Verzandvoort, “Operationalizing ecosystem services for the mitigation of soil threats: a proposed framework,” Ecol. Indic. **67**, 586–597 (2016).
97. A. L. Selhorst and R. Lal, “Net carbon sequestration potential and emission in home lawn turfgrasses of the United States,” Environ. Manage. **51**, 198–208 (2013).
98. K. C. Seto, M. Fragkias, B. Güneralp, and M. K. Reilly, “A meta-analysis of global urban land expansion,” PLoS One **6**, e23777 (2011).
99. A. S. Shchepeleva, V. I. Vasenev, I. M. Mazirov, I. I. Vasenev, I. S. Prokhorov, and D. D. Gosse, “Changes of soil organic carbon stocks and CO_2 emissions at the early stages of urban turf grasses’ development,” Urban Ecosyst. **20** (2), 309–321 (2017).
100. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions, and Recommendations of TEEB* (Progress Press, Malta, 2010).
101. A. P. E. van Oudenhoven, K. Petz, R. Alkemade, L. Hein, and R. S. De Groot, “Framework for systematic indicator selection to assess effects of land management on ecosystem services,” Ecol. Indic. **21**, 110–122 (2012).

102. V. I. Vasenev, A. V. Smagin, N. D. Ananyeva, K. V. Ivashchenko, E. G. Gavrilenko, T. V. Prokofeva, A. Patlseva, J. J. Stoorvogel, D. D. Gosse, and R. Valentini, “Urban soil’s functions: monitoring assessment and management,” in *Adaptive Soil Management: From Theory to Practices* (Springer Nature, Singapore, 2017), pp. 359–409.
103. V. I. Vasenev, J. J. Stoorvogel, and I. I. Vasenev, “Urban soil organic carbon and its spatial heterogeneity in comparison with natural and agricultural areas in the Moscow region,” Catena **107**, 96–102 (2013).
104. P. M. Vitousek, J. D. Aber, R. W. Howarth, G. E. Likens, P. A. Matson, D. W. Schindler, W. H. Schlesinger, and D. G. Tilman, “Human alteration of the global nitrogen cycle: sources and consequences,” Ecol. Appl. **7** (3), 737–750 (1997).
105. B. Vrscaj, L. Poggio, and F. A. Marsan, “A method for soil environmental quality evaluation for management and planning in urban areas,” Landscape Urban Plan. **88**, 81–94 (2008).
106. L. Willemen, N. D. Crossman, S. Quatrini, B. Egoh, F. K. Kalaba, B. Mbilinyi, and R. De Groot, “Identifying ecosystem service hotspots for targeting land degradation neutrality investments in south-eastern Africa,” J. Arid Environ. (in press).
107. B. Zhao, F. Xu, and Q. Zhao, “Influences of soil physical properties on water-supplying capacity,” Pedosphere **7** (4), 367–374 (1997).

TABLES

Table 1. Soil functions and ecosystem services in scientific literature[1] (according to www.elibrary.ru[2]/ www.scopus.com)

Parameter	Soil functions	Ecological soil functions	Ecosystem services	Soil ecosystem services
First mentioning	1989/ 1976	1991/ 1976	1993/ 1971	2014/ 1994
Total number of publications	125647/56721	46297/ 10151	258/ 29678	9/4295
Most cited publication (number of citations)	Chernikov et al. [34] (973) / Vitousek et al. [104] (2956)	Chernikov et al. [34] (973) / Vitousek et al. [104] (2956)	Tishkov [33] (188)/ Costanza et al. [49] (7532)	Konyushkov [20] (5)/ Foley et al. [62] (3838)

[1] Data actual on November 1, 2017.

[2] Search in elibrary.ru is limited to 1991 as the earliest year.

Table 2. Russian classification of the ecological soil functions (according to [12])

1. Biogeocenotic functions			
1.1. Physical	1.2. Chemical and physicochemical	1.3. Informational	1.4. Holistic
1.1.1. Living space	1.2.1. Source of nutrients	1.3.1. Signal for a range of seasonal and other biological processes	1.4.1. Accumulation and transformation of matter and energy
1.1.2. Habitat and shelter	1.2.2. Stimulator and inhibitor of biochemical and other processes	1.3.2. Regulation of the population density, composition, and structure of biocenoses	1.4.2. Sanitary function
1.1.3. Mechanical support	1.2.3. Storage of water, nutrients, and energy	1.3.3. Trigger of some successions	1.4.3. Buffer and protective biogeocenotic screen
1.1.4. Storage of seeds	1.2.4. Sorption of	1.3.4. “The memory” of	1.4.4. Conditions for the

and other germs	matter and microorganisms	biogeocenosis	existence and evolution of organisms
2. Global functions			
2.1. Lithospheric	2.2. Hydrospheric	2.3. Atmospheric	2.4. Bioethnospheric
2.1.1. Biochemical transformation of the upper layers of the lithosphere	2.2.1. Transformation of surface water into groundwater	2.3.1. Absorption and reflection of solar radiation	2.4.1. Habitat; accumulator and source
2.1.2. Source of matter for the formation of minerals, rocks, and ores	2.2.2. Participation in the formation of river flow	2.3.2. Regulation of atmospheric water circulation	2.4.2. Link between the biological and geological cycles; planetary membrane
2.1.3. Transfer of accumulated solar energy into deep parts of the lithosphere	2.2.3. Factor of bioproductivity of water reservoirs at the expense of transported soil compounds	2.3.3. Source of solid matter and microorganisms entering the atmosphere	2.4.3. Protective barrier and the condition of the normal biosphere, ethnosphere, and sociosphere functioning
2.1.4. Protection of the lithosphere from excessive erosion and the prerequisite for its normal development	2.2.4. Sorption barrier protecting water bodies from contamination	2.3.4. Absorption and retention of certain gases from escape to outer space; regulation of the gas regime of the atmosphere	2.4.4. Factor of biological evolution, ethnogenesis, and evolution of society

Table 3. Soil functions in Russian classification as related to foreign classification schemes

Blum [43]	BBodSchG [42]	Andrews et al. [38]	Corresponding functions from the Russian Classification[1]
Ecological functions:	Natural Functions		
	participation in the cycles of water and nutrients	Nutrient cycle	1.2.1, 1.4.1, 2.1.2, 2.2.2, 2.3.1, 2.3.4
protection of humans and the environment		Water cycle	
	balance regulation and protection of groundwater	Filtering and buffering	1.2.4, 1.4.2, 1.4.3, 2.1.1, 2.2.1, 2.2.4, 2.3.2, 2.4.2
		Resistance and sustainability	
biomass production	the basis of life and habitat of people, animals, plants, and soil organisms	Biological diversity and habitat	1.1.1, 1.1.2, 1.1.3, 1.2.3, 1.3.1, 1.3.2, 1.3.3, 2.2.3, 2.4.1
total reserve			1.1.4, 1.2.2, 1.4.4, 2.3.3, 2.4.3, 2.4.4
Nonecological functions:	Functions useful to humans		
the physical basis of human activity	land areas for settlements and recreation; agricultural and forestry land plots	Providing physical stability and a mechanical support	
source of raw materials	source of building materials and raw materials; land plots for other types of economic and public use, transport, as well as for supply,		2.1.3, 2.1.4

	provision and disposal		
cultural heritage	accumulation and preservation of artifacts		1.3.4

[1] Numbers of functions were taken from Table 2.

Figure Captions

Fig. 1. Relationships between ecological functions of soils and ecosystem services (solid lines indicate direct relationships, and dotted lines indicate indirect relationships).

KEY

Функции почвы --> Soil functions;

Биогеоценотические --> Biogeocenotic;

Физические --> Physical;

Среда обитания --> Habitat;

Жилище и убежище --> Habitat and shelter;

Механическая опора --> Mechanical support;

Депо семян и других зачатков --> Storage of seeds and other germs;

Химические и физико-химические --> Chemical and physicochemical;

Источник элементов питания --> Source of nutrients;

Депо влаги, элементов питания и энергии --> Storage of water, nutrients, and energy;

Стимулятор/ингибитор биохимических и других процессов --> Stimulator/inhibitor of biochemical and other processes

Сорбция веществ и микроорганизмов --> Sorption of matter and microorganisms;

Информационные --> Informational;

Сигнал для сезонных процессов --> Signal for seasonal processes;

Пусковой механизм некоторых сукцессий --> Trigger of some successions;

Регуляция биоценозов --> Regulation of biocenoses;

«Память» биогеоценоза --> “The memory” of biogeocenosis;

Целостные --> Holistic;

Аккумуляция/трансформация вещества и энергии --> Accumulation/transformation of matter and energy;

Санитарная функция --> Sanitary function;

Буферный и защитный экран --> Buffer and protective screen;

Условия существования и эволюции организмов --> Conditions of the existence and evolution of microorganisms;

Экосистемные сервисы --> Ecosystem services;

Обеспечивающие --> Provisioning;

Пища --> Food;

Пресная вода --> Fresh water;

Сырьё --> Raw materials;

Генетические ресурсы --> Genetic resources;

Медицинские ресурсы --> Medical resources;

Декоративные ресурсы --> Decorative resources;

Регулирующие --> Regulating;

Регулирование качества воздуха --> Regulation of air quality;

Регулирование климата --> Climate Regulation;

Сдерживание экстремальных явлений --> Mitigation of extreme events;

Регулирование воды, переработка отходов --> Water regulation, recycling of wastes;

Предотвращение эрозии --> Erosion control;

Поддержание плодородия --> Fertility support;

Среда обитания --> Habitat;

Обеспечение жизненных циклов мигрирующих видов --> Support of the life cycles of migrating species;

Обеспечение генетического разнообразия --> Ensuring genetic diversity;

Культурные --> Cultural;

Эстетические --> Aesthetic;

Рекреация и экотуризм --> Recreation and Ecotourism;

Источники вдохновения --> Sources of inspiration;

Духовные и религиозные --> Spiritual and Religious;

Функции почвы --> Soil functions;

Глобальные --> Global;

Литосферные --> Litospheric

Защита от эрозии и условия нормального развития --> Protection against erosion and conditions for normal development;

Биохимические преобразования верхних слоёв литосферы --> Biochemical transformation of the upper layers of the lithosphere;

Источник для минералов, пород и полезных ископаемых --> Source for minerals, rocks, and ores;

Передача аккумулированной солнечной энергии в глубокие части литосферы --> Transfer of accumulated solar energy into the deep parts of the lithosphere;

Гидросферные --> Hydrospheric;

Трансформация поверхностных вод в грунтовые --> Transformation of surface water into groundwater;

Участие в формирование речного стока --> Participation in the formation of river flow;

Фактор биопродуктивности водоёмов --> Factor of bioproductivity of water reservoirs;

Сорбционный защищающий от загрязнения барьер акваторий --> Sorption barrier protecting water areas;

Атмосферные --> Atmospheric;

Регулирование газового режима атмосферы --> Gas regulation of the atmosphere;

Поглощение и отражение солнечной радиации --> Absorption and reflection of solar radiation;

Источник твёрдого вещества и микроорганизмов, поступающих в атмосферу --> Source of solid matter and microorganisms entering the atmosphere;

Регулирование влагооборота атмосферы --> Regulation of water cycle in the atmosphere;

Биоэтносферные --> Bioethnospheric;

Среда обитания, аккумулятор и источник --> Habitat; accumulator and source;

Планетарная мембрана --> Planetary membrane;

Фактор этногенеза, биологической и социальной эволюции --> Factor of ethnogenesis and biological and social evolution;

Защитный барьер и условие нормального функционирования биосферы, этносферы и социосферы --> Protective barrier and the condition of the normal functioning of the biosphere, ethnosphere, and sociosphere;

Неэкологические функции --> Non-ecological functions;

Физическая основа человеческой деятельности --> Physical base of human activity;

Источник сырья --> Source of raw materials;

Культурное наследие --> Cultural heritage.

Fig. 2. Framework scheme for providing ecosystem services through soil resources (according to [54]).

KEY

Деградация почвы --> Soil degradation;

Процессы деградации --> Degradation processes;

Эрозия --> Erosion;

Запечатывание --> Sealing;

Уплотнение --> Compaction;

Засоление --> Salinization;

Токсификация --> Toxification;

Потеря органического вещества --> Loss of organic matter;

Сокращение биоразнообразия --> Decrease of biodiversity;

Поддерживающие процессы --> Supporting processes

Круговорот питательных веществ --> Nutrient cycles;

Круговорот воды --> Water cycle;

Биологическая активность почвы --> Biological activity of soil;

Почвообразорвание и поддержание --> Soil forming and support;

Природный капитал --> Natural capital;

Неотъемлемые свойства --> Inherent properties;

Склон --> Slope;

Ориентация --> Orientation;

Глубина --> Depth;

Типы глины --> Types of clay;

Гранулометрический состав --> Texture;

Размер частиц подпочвы --> Size of subsoil particles;

Подпочва --> Subsoil;

Влажность подпочвы --> Subsoil moisture;

Управляемые свойства --> Properties under control;

Растворимые фосфаты --> Soluble phosphates;

Минеральный азот --> Mineral nitrogen;

Органическое вещество почвы --> Soil organic matter;

Содержание углерода --> Carbon content;

Температура --> Temperature;

Кислотность --> Acidity;

Напочвенный покров --> Ground cover

Макропористость --> Macroporosity;

Объёмная плотность --> Bulk density;

Плотность верхнего горизонта --> Density of the upper layer;

Размер частиц в верхнем горизонте --> Particle size in the upper horizon;

Внешние механизмы --> External mechanisms;

Природные --> Natural;

Климат --> Climate;

Стихийные бедствия --> Natural disasters;

Геология --> Geology;

Геоморфология --> Geomorphology;

Антропогенные --> Anthropogenic;

Землепользование --> Land use;

Методы ведения сельского хозяйства --> Methods of Agriculture;

Технологии --> Technologies;

Экосистемные сервисы --> Ecosystem services;

Культурные --> Cultural;

Духовность --> Spirituality;

Знание --> Knowledge;

Чувство места --> Sense of place;

Эстетика и т.д. --> Aesthetics, etc.;

Регулирующие --> Regulating;

Смягчение последствий наводнений --> Mitigating the consequences of floods;

Фильтр питательных веществ --> Nutrient filter;

Биологический контроль вредителей и болезней --> Biological control of pests and diseases;

Утилизация отходов и детоксикация --> Waste recycling and detoxification;

Запас углерода и регуляция N_2O и CH_4 --> Carbon pool and N_2O and CH_4 regulation

Обеспечивающие --> Provisioning;

Обеспечение физической опоры --> Providing physical support;

Обеспечение пищей, древесиной и волокнами --> Provision of food, wood, and fibers;

Обеспечение сырьём --> Provision of raw materials;

Человеческие потребности --> Human needs;

Потребность в самореализации --> Need for self-realization;

Потребность в уважении --> Need for respect

Социальные потребности --> Social needs;

Потребность самосохранения и безопасности --> Need for self-preservation and security;

Физиологические потребности --> Physiological needs;

Запасы --> Stores;

Потоки --> Flows;

Процессы --> Processes;

Механизмы --> Mechanisms.

Fig. 3. A conceptual scheme of the relationship between soil properties and ecosystem services through soil functions (according to [37]).

KEY

Базовый материал для хорошей жизни --> Basic material for good life;

Хорошие социальные отношения --> Good social relations;

Безопасность, свобода выбора и действий --> Security, freedom of choice and action;

Здоровье --> Health;

Благосостояние людей --> Human well-being;

Поддержание среды обитания человека --> Supporting human habitat;

Обеспечение минерального органического вещества почвы --> Providing minerals and soil organic matter;

Регулирование CO_2 в атмосфере, почвенных системах --> Regulating CO_2 in the atmosphere and soil systems

Поддержание структуры, обеспеченности питательными веществами --> Supporting the structure and nutrient supply;

Ценности культурного наследия (естествознание, история, антропология) --> Cultural heritage values (natural science, history, anthropology);

Поддержание геологического наследия и динамического равновесия --> Supporting geological heritage, maintenance of ecosystem dynamic equilibrium;

Обеспечение пищей, кормом, волокнами и древесиной --> Providing food, feed, fiber, and wood;

Регулирование улавливания углерода --> Regulating carbon sequestration;

Вклад в традиции и духовное вдохновение --> Contributing to traditions, spiritual inspiration;

Поддержание через первичное производство --> Supporting through primary production;

Регулирование доступности воды и питательных веществ --> Regulating water and nutrient availability;

Поддержание экосистемных функций через круговорот воды и веществ --> Supporting ecosystem functions through water and nutrient cycling;

Предоставление фармацевтических и биохимических препаратов --> Providing pharmaceuticals and biochemicals;

Регулирование урожайности, борьбы с вредителями и болезнями --> Regulating crop pollination, pest and disease control;

Содействие научным открытиям --> Contribute to scientific discovery;

Поддержание биоразнообразия --> Supporting biodiversity;

Поддержание среды обитания человека --> Supporting human habitat;

Обеспечение минералогического и органического вещества почвы --> Providing minerals and soil organic matter;

Экосистемные сервисы --> Ecosystem services;

Сохранение геологического и археологического наследия --> Preservation of geological and archeological heritage;

Производство биомассы --> Biomass production;

Хранение, фильтрация и трансформация питательных веществ --> Storage, filtration, and transformation of nutrients;

Источник биоразнообразия --> Hosting biodiversity;

Платформа для человеческой деятельности --> Platform for human activities;

Источник сырья --> Source of raw materials;

Углеродный пул --> Carbon pool;

Функции почвы --> Soil functions;

Свойства почвы --> Soil properties.

Fig. 4. The assessment scheme for the soil properties, soil functions, and ecosystem services for decision making according to cascade model (based on [63, 64]).

KEY

Экосистема --> Ecosystem;

Свойства --> Properties;

Функции --> Functions;

Стратегия менеджмента --> Management strategy;

Воздействия --> Impacts;

Прямое и косвенное воздействие --> Direct and indirect impacts;

Предоставление сервисов --> Providing services;

Экосистемные сервисы --> Ecosystem services;

Общественное мнение --> Public opinion;

Политика и принятие решений --> Policy and decision making;

Выгода --> Profit;

Ценность --> Value;

Восприятие ценности --> Value perception.

Fig. 5. Histogram: changes in the numbers of scientific publications concerning (*1*) soil ecosystem services and (*2*) ecosystem services of UTSs; circular graph:

portion of publications concerning ecosystem services of UTSs in different countries.

KEY:

Количество статей --> Number of articles;

Год выпуска --> Year of publication;

Австралия --> Australia;

Россия --> Russia;

США --> USA;

Китай --> China;

Европа --> Europe.

Fig. 6. The framework classification of services and disservices of UTSs (based on [82])

KEY:

Сервисы --> Services;

Диссервисы --> Disservices;

Обеспечивающие --> Provisioning;

Регулирующие --> Regulating;

Культурные --> Cultural;

Квазиприродные почвы --> Quasi-natural soils;

Сконструированные почвы --> Constructed soils;

Почвы заброшенных территорий --> Soils of the abandoned areas;

Запечатанные почвы --> Sealed soils;

Производство продуктов питания --> Food production;

Производство сырья, древесины и волокон --> Production of raw materials, wood and fiber;

Источник полезных ископаемых --> Source of fossil minerals

Обеспечение пресной водой --> Fresh water provision;

Загрязнение воды --> Water contamination;

Хранение запасов воды --> Water storage;

Контроль стока и затоплений --> Flooding and runoff control;

Повышение риска затоплений --> Increasing flood risks;

Ослабление загрязнения --> Decrease of contamination;

Поддержание глобального климата --> Supporting the global climate;

Поддержание местного климата --> Supporting the local climate;

Повышение эффекта «теплового острова» --> Increase of the “thermal island” effect;

Поддержание биоразнообразия --> Supporting the biodiversity;

Поддержание интродуцентов --> Support of the introduced species;

Очистка воздуха --> Air cleaning;

Контроль уровня шума --> Noise level control;

Выщелачивание токсинов --> Leaching of toxins;

Выбросы парниковых газов --> Greenhouse gases emission;

Рекреация и туризм --> Recreation and tourism;

Архив человеческой истории --> Human history archive;

Ландшафт --> Landscape;

Образование --> Education

Fig. 7. An example of cascade model application for assessing the service of impact on the global climate for UTSs in the cities of Moscow, Hangzhou, and Hong Kong.

KEY:

Свойство --> Properties;

Функция --> Function;

Экосистемный сервис --> Ecosystem service;

Принятие решения --> Decision making;

Запас углерода (содержание углерода, плотность сложения, мощность горизонта) --> Carbon pool (carbon content, bulk density, horizon thickness);

Почвенное дыхание (регулирование газового режима атмосферы) --> Soil respiration (regulating the atmospheric gas regime);

Воздействие на глобальный климат. Депонирование углерода ($/т/га) --> Impact on the global climate. Carbon sequestration ($/t/ha)

Изменение соотношения газонов и кустарниковой растительности в городском озеленении --> Changes in proportion between lawns and shrubs in urban gardening;

Плотность сложения, коэффициент фильтрации --> Bulk density, filtration coefficient;

Фильтрация, напочвенный и подпочвенный сток (трансформация поверхностных вод в грунтовые) --> Filtration, soil and subsoil runoff (transformation of surface water into groundwater);

Регулирование водного баланса. Снижение нагрузки на водоочистные сооружения ($/га/год) --> Regulation of the water balance. Reducing the burden on water treatment facilities ($/ha/year);

Строительство новых водоочистных сооружений. Снижение доли запечатанных территорий --> Construction of new water treatment facilities. The decrease in the percent of sealed areas;

Температура на глубине 10 см --> Temperature at the depth of 10 cm;

Теплопроводность. поток тепла --> Thermal conductivity, heat flux

Формирование микроклимата. Снижение затрат на кондиционирование помещений ($/м^2/год) --> Formation of microclimate. Reducing the cost of air conditioning ($/m^2/year)

Строительство новых зелёных крыш --> Construction of new green roofs;

Москва --> Moscow;

Ханчжоу --> Hangzhou;

Гонконг --> Hong Kong