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Algorithm for assessment and modeling of some ecosystem services in urban areas (Plovdiv, Bulgaria)

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Abstract. In recent years, ecosystem services have been increasingly recognized as a recommended tool for environmental management. The concept of ecosystem services integrates ecological, social and economic principles. Society has long been aware of its dependence on the products and services provided by nature such as food, water, herbs, fuels, etc. Recently, the importance of some indirect services, such as climate regulation, water filtration, soil fertility, as well as some cultural services, has become increasingly evident. In addition to the in-depth understanding of human dependence on natural processes at different temporal and spatial scales, there is also the need to measure the value of these ecosystem services according to economic and management criteria and indicators. Accordingly, in this study we aimed to propose an algorithm for assessment and modeling of some ecosystem services in urban areas, which was developed and validated based on our studies in the city of Plovdiv, Bulgaria). The proposed methodological framework includes several steps, representing a scientifically basis for such research, which, combined with a farsighted policy, professional and financial resources, will promote the sustainable development of urban ecosystems in the future.

Key words: provisioning services, regulating services, supporting services, cultural services.

Introduction

Global urbanization is intensifying, with around 54% of the world's population currently living in cities, and by 2050, the proportion of the urban population is expected to rise to around 68% (6.7 billion inhabitants) (UN, 2015). Data from satellite observations confirm that the area of urban areas increased by 580000 km^2 between 1970 and 2000 (Seto et al., 2011). If current trends continue, there will be three times the size of urbanized areas by 2030 (1.2 million km^2) and an additional 2.5 billion new urban residents by 2050 (Elmqvist et al., 2013; Seto et al., 2011).

Urban population in Europe is about 75% of the total world population. Although the urbanization trends are currently slower than in other parts of the world, by 2030 around 80% of Europe's population is expected to live in cities. This trend necessitates rethinking the organization, functioning and management of urban territories (Elmqvist et al., 2013; Seto et al., 2011).

The Millennium Ecosystem Assessment (MA, 2005) for the first time focused on assessing the state and trends of change in ecosystems and the services they provide. This assessment divides ecosystem services into the four categories – provisioning, regulating, supporting and cultural. Material (provisioning) services include food, water, raw materials, genetic resources, medicinal plants, herbs, etc., provided by both natural and anthropogenic ecosystems. Regulating services reflect the ability of ecosystems to mitigate important global processes such as: air purification, climate change, prevention against natural disasters, water quality and quantity (purification), waste processing, erosion, maintenance of soil fertility, pollination, control of biological processes. Cultural services are interpreted as all intangible benefits of ecosystems - cultural, aesthetic and recreational value of the landscape, places for rest and recreation, spiritual and religious values. Supporting services contribute to providing conditions for all vital processes as photosynthesis, soil formation, genetic diversity, etc. The impact of supporting services on people is indirect and slow, and this is the main difference between them and the first three categories, which have a relatively direct impact that can be felt within a short period of time (MA, 2005).

Societies are embedded in ecosystems, dependent on and influencing the ecosystem services they produce. Ecosystem characteristics, such as species composition, green cover or growth conditions, modulate the type and magnitude of ecosystem services. The governance regime, modern technologies and regulation mechanisms of the ecosystem itself affect the benefits of services to society (Baro, 2016; Petrova et al., 2014; Petrova et al., 2022; Petrova & Nikolov, 2023).

In other words, ecosystem services result from the interaction between ecosystems and societies, which both form a socio-ecological system. In this regard, the ecosystem services of urban green systems are understood as synergized by nature and man, at the boundary between complex ecological and social processes (Andersson et al., 2007; Andersson et al., 2014; Jansson & Polasky, 2010). Traditionally focused on ecosystems themselves, the ecosystem services assessment approach now needs the integration of urban ecosystem services into urban policy and management (Kabisch, 2015; Primmer et al., 2012). Urban ecosystems are considered as areas where a larger proportion of the human population lives, but also as an ecosystem type that significantly influences and affects the functioning of other ecosystem types (Maes et al., 2013). Urbanized ecosystems represent mainly human habitats, which usually also include significant areas for synanthropic species associated with urbanized habitats.

In recent years, ecosystem services have been increasingly recognized as a recommendded tool for environmental management (Lyubenova & Peteva, 2016). The emphasis in the concept of ecosystem services is placed not only on the relationships between ecological variables and components, but also on the human presence, without which the functionnality of the entire system in its entirety could not be explained (Andersson et al., 2014). The relationship between man and the natural environment is a key prerequisite for ecosystem services. The concept of ecosystem services integrates ecological, social and economic principles (Maes et al., 2013; Maes et al., 2020). Society has long been aware of its dependence on the products and services provided by nature such as food, water, herbs, fuels, etc. Recently, the importance of some indirect services, such as climate regulation, water filtration, soil fertility, as well as some cultural services, has become increasingly evident (Ates & Erinsel Önder, 2021; Petrova & Nikolov, 2023). In addition to the in-depth understandding of human dependence on natural processes at different temporal and spatial scales, there is also the need to measure the value of these ecosystem services according to economic and management criteria and indicators (Brzoska et al., 2021).

Accordingly, in this study we aim to propose an algorithm for assessment and modeling of some ecosystem services in urban areas, which was developed and validated based on our studies in the city of Plovdiv, Bulgaria).

Materials and Methods

Urban ecosystems correspond to the first and second level classes, defined in MAES (Maes et al., 2013), and include urbanized, industrial, commercial and transport areas, parks, mines, landfills and artificial water bodies.

Following the main aim, two groups of indicators have been selected - the first group allows evaluation of the status of urban ecosystems, and the second group allows evaluation of the ecosystem services provided by the urban ecosystems.

The proposed indicators from the first group assess the status of urban ecosystems – their structure and processes (Chapin et al., 2002; Maes et al., 2020). The set of indicators has been selected so that the provision of ecosystem services by urbanized ecosystems can be effectively assessed and experts have the opportunity to determine their applicability to each specific subtype of urbanized ecosystem. Algorithm follows the methodologies and recommendations of the Guide for Monitoring the State and Development of Ecosystems and Ecosystem Services. Part D., published by Chipev et al. (2017).

The selection and definition of indicators for the assessment of ecosystem services provided by urban ecosystems are based on the methodological framework, presented in the second MAES report (Maes et al., 2014) as well as the guidelines in the "Methodology for assessing and mapping the status of urbanized ecosystems and their services in Bulgaria. Part B1", published by Zhianski et al. (2017).

Results and Discussion

The design of the algorithm for assessment and modeling of some ecosystem services in urban areas is presented on Fig. 1. It includes two phases and each of them comprises five steps.

First phase activities are related to the assessment of the status of urban ecosystems in the area of interest. In this aspect, data of biodiversity, abiotic heterogeneity, energy flow, geochemical cycle, water cycle, should be provided using the selected indicators from the first group. Among the 20 specific indicators proposed in the literature (18 main and 2 optional), we have chosen 16 that are recommended for assessing the status of urban ecosystems. Each of the selected indicators is informative enough and can be assessed based on parameters according to a relevant scale. The range defined in this scale is specific to describe the status of urban ecosystems for each subtype and requires the work of experts in a wide range of qualifications, supported by professional experience and expertise.

Each indicator can be evaluated with parameters that are complex or individual. For parameters without available data (and in need of further studies), appropriate models may be used (if applicable) and/or in-situ verification can be performed if expert opinion requires such activity. These parameters are optional and/or recommended and can be included in the overall assessment of a selected indicator, as well as for additional monitoring. Statistical analysis can be performed to determine the values when evaluating data for indicators/parameters, characterized by spatial variability (Zhyanski et al., 2018).

Second phase activities are dedicated to the assessment of the set of ecosystem services, provided by urban ecosystems. For an ecosystem service to be valued, it is mandatory to be measurable or quantifiable. For this purpose, previously developed indicators are applied, which are measured with a single parameter and presented in metric values. The selection and definition of indicators in this area are following the methodological framework from the second MAES report (Maes et al., 2014). The set of indicators has been selected so that the ecosystem services deliverable can be effectively assessed, allowing to the experts an opportunity to determine their applicability to each specific urban ecosystem subtype. To provide the necessary information, own field studies and field descriptions are recommended, in accordance with the Guide for monitoring the state and development of ecosystems and ecosystem services (Chipev et al., 2017).

The evaluation scale of indicators consists of six grades - from 0 to 5. A score of 0 indicates that there is no capacity to provide a certain service, and a score of 5 indicates the highest capacity to provide this service. One or more indicators are used to determine the capacity of an ecosystem to provide a specific service. The expert assessment of each ecosystem service providing benefits is quantified on a five-point scale (from 1 to 5).

Assessing urban ecosystems is much more difficult than natural or semi-natural ones. This is exactly what necessitates the modeling of some of the evaluation parameters (Manes et al., 2014). For example, for the assessment of a regulating ecosystem service such as ambient air quality, one of the main indicators is CO_2 and the presence of fine particulate matter PM_{10} (Harmens, 2013). Modeling in this case is possible through another ecosystem service, namely photosynthesis. Thanks to the method of Manes et al. (2014), it is possible to link several groups of ecosystem services that work synergistically:

1) Regulatory services - storage of carbon (C, incl. CO_2) and the release of oxygen (O_2) from tree species, gas balance; regulating the temperature island in the city and the microclimate; enhancing the quality of ambient air;

2) Supporting services - purification of pollutants (mainly PM_{10}) through accumulation in the vegetation (trees, bushes, grasses) and soils on the city's territory (Petrova, 2020; Petrova & Nikolov, 2023); maintaining the gas balance - carbon dioxide / oxygen in the air;

3) Provisioning services – healthcare for the urban population (Aerts & Van Nieuwenhuyse, 2018; Petrova & Nikolov, 2023).

4) Cultural services - holidays and events on the territory of the green park spaces; tourism, recreation and spiritual value.

Economic methods are also increasingly widespread and effective in analyzing and valuing ecosystem services. The economic valuation of ecosystem services offers a comparison of the various benefits associated with ecosystems by expressing them in a monetary value. Like many other types of services, ecosystem services have value, but as a result of the fact that most of them (with the exception of tangible ones) are not traded in the market, difficulties arise in valuation.

To solve this problem, economists value ecosystem services in terms of their overall contribution to the well-being of human society, a term they coin "total economic value" (TEV) (Pearce & Warford, 1993). The basic framework of TEV differs among different authors, but in most cases it consists of use values (direct, indirect and potential) and values not associated with the use of natural resources (non-use values), such as the desire to preserve those natural resources for future generations or the satisfaction that ecosystems exist and function normally (Pascual et al., 2010).

Direct value (direct use value) refers to natural resources that are used directly by humans (Pagiola et al., 2004). This includes material services or the products obtained from nature such as food, timber, building materials, medicines, hunting animals, etc. These ecosystem services are easy to value and are measured at market prices as a result of supply and demand factors (Dai et al., 2022).

Indirect value (indirect use value) refers to ecosystems and their services related to the maintenance and protection they provide to the economic activity of people. These values are used for ecosystem services that provide benefits beyond the ecosystems themselves (Pagiola et al., 2004) - for example, the regulating and supporting services of ecosystems. They are much more difficult to measure and value.

Costantza et al. (1997) estimate the annual value of ecosystem services for the entire biosphere at between 16 and 54 trillion USD and an average value of 33 trillion USD. The evaluation was carried out on the basis of published studies and original calculations using different methods, the main one being "the willingness of citizens to pay for the relevant ecosystem service". Despite the many criticisms of this publication that it overestimates the value of natural ecosystems, it puts the topic of ecosystem services on the agenda. According to the authors, ecosystem services are not fully "included" in the market and in adequate quantitative conditions that are comparable to economic ones and therefore have too little weight on political decisions. This lack of interest and concern politically compromises human sustainability in the biosphere. Costantza et al. (1997) emphasize that ecosystem services must be valued and that this is of utmost importance to humanity. As an argument, they point out that people are obliged to protect ecosystems, at least for purely moral and aesthetic reasons, and for the realization of this goal, society needs the assessment of ecosystem services.

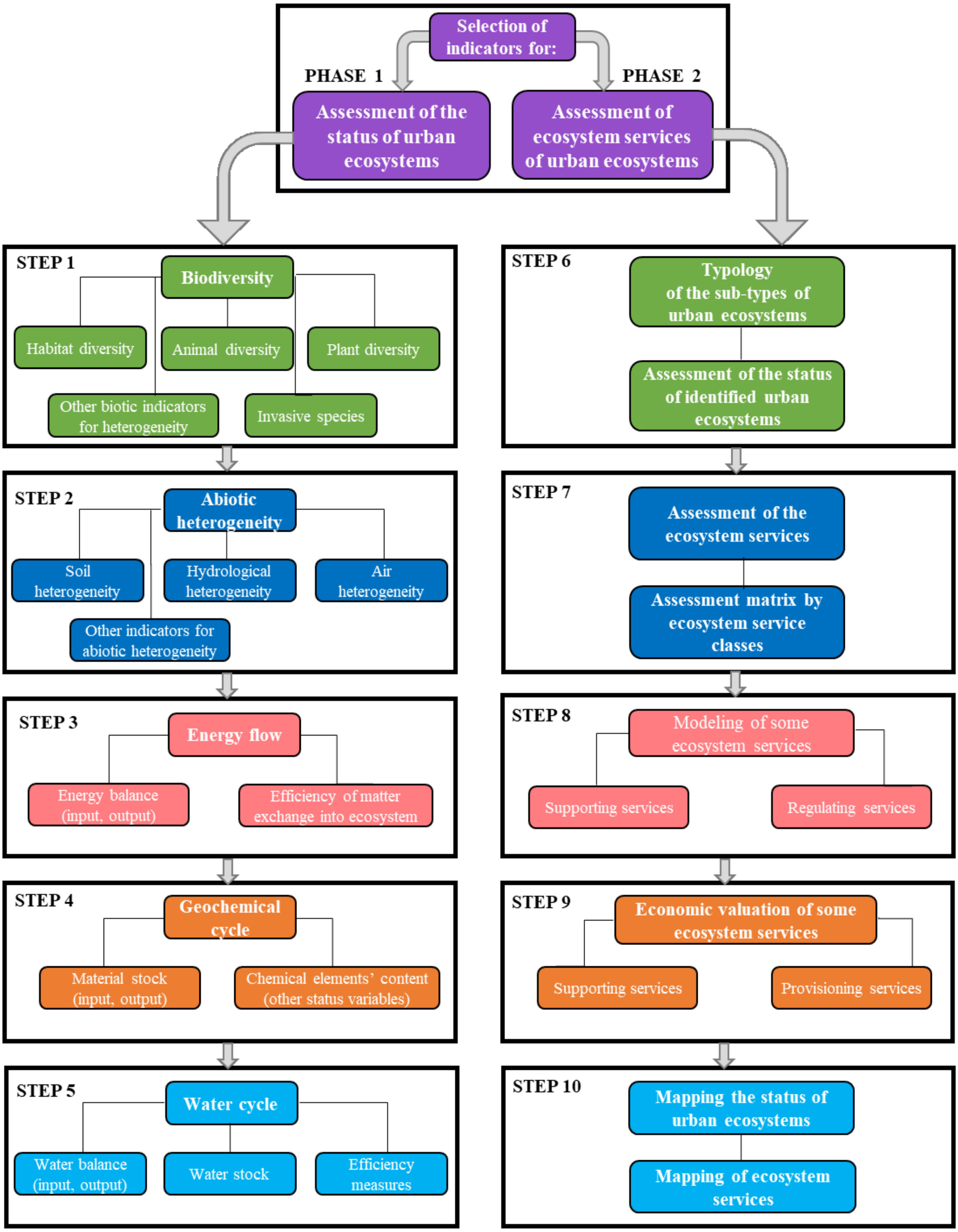

Fig. 1. Algorithm for assessment and modeling of ecosystem services some ecosystem services in urban areas – a methodological framework.

Conclusions

The development of our society has reached a stage where valuation of the nature's benefits to people is necessary, because the importance of ecosystem services can only be understood if they are expressed financially. The main goal in the concept of ecosystem services is the public use and conservation of natural resources in a way that does not harm the environment and protects the interests of future generations. Psychologically, people are wired to keep anything that has a price or that they pay for. Therefore, the assessment of the capacity and valuation of ecosystem services should become a priority for the environmental policies at national and regional level.

The proposed methodological framework includes several steps, representing a scientifically basis for such research, which, combined with a farsighted policy, professional and financial resources, will promote the sustainable development of urban ecosystems in the future.

Data obtained can be applied to solve a wide range of management tasks such as: programming measures for sustainable management of urban ecosystems, evaluation of projects, integrated management plans, landscaping activities, as it can allow the selection of plant species with a higher potential to provide ecosystem services, to increase the efficiency of the green system, and hence the quality of life in the urban areas.

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