I. ТЕОРЕТИКО-МЕТОДОЛОГІЧНІ ДОСЛІДЖЕННЯ

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INDICATORS AND CALCULATION PARAMETERS IN THE ASSESSMENT OF ECOSYSTEM SERVICES FOR BIODIVERSITY CONSERVATION

Background. *The concept of ecosystem services (ES) is closely related to the concept of biodiversity conservation. Urban green spaces (UGS) are areas of importance for urban biodiversity conservation. UGSs can effectively provide biodiversity services if they form an ecological network. The issue of assessing ecosystem services for biodiversity conservation in cities, where the assessment of ES is based on the "ecological network" approach, is currently not sufficiently covered. The development of a set of assessment indicators, calculation parameters, and a methodology for assessing ecosystem services for biodiversity conservation in the city has become the goal of this work.*

Methods. *In this paper, we have developed an assessment methodology based on determining the effectiveness of the UGSs performance of "eco-network" functions. Differences in the indicators of biodiversity conservation are caused by a number of factors. The natural factors include the presence of rare and endangered species within the UGS; landscape diversity; metric and qualitative characteristics of green spaces. Anthropogenic factors include the degree of landscape transformation.*

Results. *Accordingly, these factors have become indicators for assessing: biopopulation, landscape diversity, nature conservation, territorial, phase-anthropisation and phase-ethological sustainability. The calculated parameters are: biopopulation potential indicator, integral indicator of landscape diversity, indicator of conservation status, sufficient dimensionality, phase-anthropisation sustainability index, etc. These parameters make it possible to implement the assessment methodology at two territorial levels (citywide and local) and determine the effectiveness of the urban blue-green infrastructure (BGI) or a particular UGS in performing the biodiversity conservation function. The effectiveness of UGS s is determined depending on their condition. At the city-wide level, the effectiveness is determined through the interconnectedness of the elements of the GIS.*

Conclusions. *Effectiveness indicators, based on the Harrington's desirability function, allow to establish the scope of biodiversity conservation ES. The assessment based on this methodology can be a useful tool in urban planning decision-making, as it allows identifying green spaces that require priority action to create conditions for biodiversity conservation.*

Keywords: *Urban green spaces, ecosystem services, biodiversity conservation.*

Background

According to the Convention on Biological Diversity (CBD), biodiversity loss is currently recognised as one of the most pressing global environmental problems (The Convention on Biological Diversity, 2011). The concept of ecosystem services (ES) is closely related to the concept of biodiversity conservation. The Global Biodiversity and Ecosystem Services Assessment Report concludes that, despite insufficient action, it is not too late for biodiversity conservation, but transformative action at all levels is needed (Brondizio et al., 2019). Accordingly, EU Member States have insisted on focusing on the proper functioning of ecosystems and the role of biodiversity in maintaining ecosystem services (Maes et al., 2016). According to the Edinburgh Declaration, city and local governments recognized that biodiversity loss is ongoing and expressed deep concern about the significant impacts of urban biodiversity loss on societal well-being (Edinburgh Declaration..., 2020).Areas of importance for the conservation of urban biodiversity include areas with remnants of natural vegetation, parks and gardens, small gardens, etc. i.e. urban green spaces (UGS) (Urbanization..., 2013). On the one hand, biodiversity plays a key role in the ecosystems of urban green spaces in providing ecosystem services (Maes et al., 2016). For example, urban biodiversity is important for providing cultural ecosystem services, such as restoring the physical and psychological health and well-being of citizens. Loss of biodiversity reduces the resilience of urban ecosystems and reduces the amount of, for example, cooling services (mitigation of the urban heat island) (Zari, 2018). On the other hand, green urban spaces, among other ES, create opportunities for biodiversity conservation. Urban green spaces are actually centers of biodiversity and provide ecosystem services for its conservation. After all, they are the totality of ecosystems that provide natural or artificial habitats for plants, animals, fungi and microorganisms in urban areas (Martens et al., 2022). *Given the degree of disruption of the ecological balance due to anthropogenic impact, one of the priorities for the sustainable development of cities and surrounding areas is to address the issue of biodiversity conservation. In this regard, UGSs are the objects that require special attention of scientists and city planners in terms of supporting their capacity to conserve biodiversity in general and urban biodiversity in particular. Therefore, the assessment of urban green spaces in terms of their biodiversity conservation services is currently one of the most pressing issues in the framework of CBD implementation and sustainable urban development.*

This paper is based on the following studies:

- *development of the concept of ES. This issue has been covered in many publications, in particular, a detailed historical description and analysis of the history of ES development in economic theory and practice is presented in (Gómez-Baggethun et al., 2009).*
- *Study of urban green areas as providers of ES. Since cities are home to a concentration of conditions that have a negative impact on the environment, they are perhaps the most difficult object to assess in terms of ES. Therefore, there is a growing body of work on the assessment of various ES provided by urban green spaces (Korohoda, Kovtoniuk, & Halahan, 2023; Korohoda, & Kupach, 2023; Korohoda, 2023).*
- *Research on biodiversity conservation through the creation of ecological networks. After all, an ecological network is an integral territorial system, the sustainable*

functioning of which naturally leads to the conservation of biological diversity (Conservation and Monitoring..., 2000; Development of the Ecological Network..., 1999).

It is quite obvious that UGSs are able to perform the function of biodiversity conservation and provide relevant ecosystem services most effectively if they form an ecological network of the territory. Risks to the ecological network will fully correspond to the risks of not receiving (losing) the relevant ecosystem services today or in the future. However, despite all of the above, the issue of assessing ecosystem services for biodiversity conservation in cities is currently insufficiently covered in scientific and applied research. In particular, we are currently unaware of any studies that assess ES based on the "ecological network" approach. Thus, the development of a set of indicators on the basis of which the assessment should be carried out and their corresponding calculation parameters, as well as the actual methodology for assessing ecosystem services for biodiversity conservation in UGSs, has become the main task of this paper. The volumes of ES in this assessment are fully consistent with the effectiveness of the UGS's performance of "ecological network" functions. It is also important to focus on a comprehensive assessment of the state of UGS as ecological network objects, taking into account a large number of factors that determine changes in this state, primarily in terms of biodiversity threats.

Methods

The methodology for assessing the volume of ecosystem services is based on determining the effectiveness of UGS in performing the function of biodiversity conservation. This function will be most efficiently performed if the urban BGI facilities form an ecological network. After all, the main purpose of an ecological network is to connect ecologically valuable areas. Such an association will create conditions for the dispersal and migration of species and ensure the survival of populations and the preservation of their habitats. Only in this case will biodiversity conservation ESs be provided in the maximum amount.

The processes that affect the volume of biodiversity conservation ES through self-development and self-preservation also underlie the allocation of the biocentric network landscape territorial structure (LTS). The elements of this LTS are biocentres – territories that play the function of preserving the gene pool in anthropogenic space. This function is only effectively performed if the area of biocentres provides conditions for self-reproduction of populations. At the same time, reducing the likelihood of population extinction, increasing their genetic variability and ability to adapt is only possible if biocentres are connected by corridors along which species and individuals can exchange. Thus, it is obvious that the assessment of the current state and formation of the biocentric network LTS is the methodological step that will allow for a reasonable assessment of ecosystem services for biodiversity conservation. At the same time, it is clear that the connection of biocentres by a system of corridors should be based on the similarity of the edaphic conditions of individual populations, so the assessment of these ecosystem services should also take into account the genetic and morphological LTS (Grodzinsky, 1993). In order to objectively assess the spatial location of the "indicators" that determine the "value" of a particular biodiversity conservation region, it is necessary to cluster the study area and use the "sliding window" method. In previous studies, it was found that hexagonal polygons (hexagons) are the most effective "floating territorial unit" for GIS modelling (Samoylenko, & Korogoda, 2006). They will be used in this paper.

Results

In order to assess the actual scope of ES for biodiversity conservation, both for individual green spaces and for the city's BGI, one should take into account their potential for ES implementation, on the one hand, and their condition and the strength of anthropogenic pressure that limits this potential, on the other. Therefore, the methodological basis for the assessment is to substantiate a set of indicators, according to which it is advisable to develop the estimated parameters of the assessment. The solution to this problem is based on our previous research on geographic information modelling of ecological networks (Samoylenko, & Korogoda, 2006). The first step is to identify the most valuable areas. Such identification takes on its own special features in cities. Firstly, due to the high degree of anthropogenic transformation of urban areas, any area with vegetation close to the natural one can be considered as an ecological network object. However, given their current state and the level of anthropogenic pressure, urban green areas may almost completely lose their potential for providing ES. Thus, the main identification indicators should be chosen (Samoylenko, & Korogoda, 2006):

- biopopulation, which is indicated by the presence of rare, endemic and relict species. This will help identify areas where the most valuable species can be preserved.
- Landscape diversity, according to which there is a significant variation in the choric-typical LTS within the territory (Samoylenko, & Korogoda, 2006). That is, such territories can potentially become habitats for, and therefore conserve, a greater number of biospecies requiring diverse edaphic conditions.
- Nature protection, according to which, in accordance with the current legislation, the green area should be classified as an element of the ecological network.
- Territorial, including: sufficient size of the objects; ecocorridor "gaps" that do not limit the necessary biomigration and dispersal and/or gene exchange functions; typical correspondence – similarity of edaphic conditions or similarity of cores and ecocorridors that connect them.

Those green areas that meet the above indicators can be identified as having the highest potential for providing ES for biodiversity conservation. The condition of the sites and their sustainability in providing ES depends primarily on the surrounding natural and anthropogenic conditions. In this case, the objects should be assessed in accordance with the following indicators: phase-anthropisation sustainability, which will determine the acceptability of the degree of anthropogenisation of territories as a necessary measure of their "residual" ability to self-regulate and will be determined by the degree of anthropogenisation of the region where the green zone is located; phase-ethological sustainability, according to which it is advisable to assess the city's SPI as an ecological network as a whole.

Compliance with these indicators will determine the efficiency of functioning of both individual green areas in providing ES and the entire urban green space, and hence the amount of ecosystem services provided for biodiversity conservation.

Calculations in accordance with the presented indicators should be carried out using the set of calculation parameters proposed by us. In accordance with the indicators indicating the biopopulation value of the territory, it is proposed to choose the indicator of biopopulation potential – the density of all "Red Book" species – as an "input" calculation parameter in the assessment of the potential for the implementation of the EP on biodiversity conservation (Samoylenko, & Korogoda, 2006).

According to the indicators of landscape diversity, taking into account the spatial scale of the study, the most appropriate parameters were chosen: for choric diversity, the number of all geosystems in each hexagon, for typical diversity, the number of geosystem types in each hexagon (Samoylenko, & Korogoda, 2006). They became the basis for the development of the calculated integral indicator of landscape diversity, which is proposed as an "input" parameter.

The next group of calculated indicators takes into account the status, metric and topological characteristics of UGSs that determine their potential for providing ES. Among them is the indicator of environmental protection status, which is included in the assessment in accordance with environmental indicators. The indicator of sufficient size in accordance with territorial indicators. These indicators identify green areas that, by their metric characteristics (sufficient size (Table 1)) and topological characteristics (those located at distances sufficient for effective migration and exchange of genetic material (Table 2)), currently correspond to the elements of the ecological network.

Table 1

Type of natural core of the ecological network by area in urban areas, based on (Shelyag-Sosonko, Grodzinsky, & Romanenko, 2004; Forman, 1995)

Core type	Area (hectares)
Miniature	Less than 0.5
Little	0,5–1
Small	1–5
Medium	5–30
Relatively large	30–100
Large	Over 100

Table 2

Critical distances between natural ecological network cores, based on (Shelyag-Sosonko, Grodzinsky, & Romanenko, 2004; Hoppes, 1988)

Edaphic core type/ method of distribution of seeds	Critical distance (m)
Subhydromorphic / hydrochoric	More than 2000–3000
Hydromorphic / vegetative reproduction	Up to 5000
Subhydromorphic / anemochorous	500–600
Subhydromorphic / zoochoric	200–300
Semixeromorphic and subxeromorphic / anemochorous	300–500

To assess the "real" rather than potential volumes of ES, the indicators should be used, which were introduced in accordance with the indicators of phase-anthropisation sustainability. The "input" calculation parameter in this case is the phase-anthropisation sustainability index. Its value indicates the "individual" efficiency of functioning for each green space, taking into account the nature and strength of anthropogenic pressure. The value of this index is calculated within a hexagon as the inverse of the anthropogenisation index (Samoylenko, & Korogoda, 2006).

Based on these parameters, it is possible to implement an algorithm for assessing the volume of biodiversity conservation ES. The implementation consists in the sequential fulfilment of the following tasks.

1. Identify green spaces with the highest biodiversity conservation potential.
2. Determine the effectiveness of the biodiversity conservation function, depending on the current state of individual green spaces and the entire urban BGI and the strength of anthropogenic pressure.
3. Translate the value of the function's efficiency into the volume of ecosystem services for each UGS and the city's BGI.

The first step is to identify green spaces with the highest potential for biodiversity conservation. Firstly, using the "eco-network approach", the most valuable areas with the highest potential for conservation of rare and endangered species should be identified. This identification should be done by calculating biopopulation potential indicators in the defined polygons. Given the accuracy of the spatial information in the Red Book of Ukraine (Electronic database..., 2023), this indicator should be determined not in individual green spaces, but within hexagonal polygons (hexagons). Polygons with the presence of Red Book species will correspond to biopopulation indicators. Secondly, the highest potential for conservation of the largest number of species, since the most diverse areas in terms of landscape can naturally provide conditions for their existence. This identification should be done through the calculation of an integral indicator of landscape diversity in the designated polygons (Davydchuk et al., 2021). Those polygons with the highest values correspond to landscape diversity indicators. Green areas that fall entirely or more than half of their area within such identified polygons potentially have the best natural properties for biodiversity conservation.

The green areas selected in this way should be supplemented by those with nature conservation status. The determination should be made by overlaying geodata sets of existing green areas (Open Street Map, 2022) and nature reserve fund (NRF) objects (State cadastre..., 2023). Green areas that include NRFs or are NRFs themselves should be included in the ecological network elements.

The green areas of the city identified in this way have the highest potential for biodiversity conservation. However, as noted in (Development of the Ecological Network*..., 1999*), in urban areas, almost any area of sufficient size can be included in the ecological network, so other green areas with appropriate metric and topological characteristics (Tables 1, 2), although not having high potential, play a significant role in biodiversity conservation in a highly fragmented landscape. Therefore, the next step is to "add" to the already identified green areas those that meet the territorial indicators.

Since biodiversity conservation can only take place in the case of a connection between individual green areas, its effectiveness should be assessed at two levels: local (individual effectiveness of the UGS in biodiversity conservation) and city-wide (effectiveness of the BGI). In other words, the second task of the methodology – determining the effectiveness of the biodiversity conservation function – should be based on the assessment of external anthropogenic pressure, on the one hand, and on the sustainability of the green space (or BGI) itself, as a measure of their "residual" ability to self-regulate, on the other.

Thus, the determination of individual effectiveness should consist of the following: first, the degree of anthropogenic transformation of landscapes should be determined in the polygons selected for modelling according to (Havrylenko, 2003). This will allow us to establish the level of compliance of the green zone with the indicators of phase-anthropisation sustainability according to the relevant index. The values of this indicator allow us to determine the effectiveness (in %) of each green area in conserving biodiversity (E_biodiversity(g_a)) (Table 3).

Table 3

Effectiveness of green areas in conserving biodiversity (E_biodiversity(g_a)) based on their ability to self-regulate based on the index of phase-anthropisation sustainability

E_biodiversity(g_a) (%)	Ability to self-regulation
[0–20)	very poor
[20–37)	poor
[37–63)	medium
[63–80)	strong
[80–100]	very strong

*Determination of the effectiveness of the entire BGI functioning at the city-wide level should be carried out in accordance with the criteria of phase-ethological sustainability of ecological network elements (Samoylenko, & Korogoda, 2006). The principle of determining such sustainability is based on the fact that ecological network elements with similar edaphic conditions should be located at such a distance that there are no obstacles to free migration (and settlement). Thus, the identified green areas should be analysed according to the predominant vegetation type for the presence of similarly situated green areas within 300 m (*Forman, 1995*). Those green areas that do not have opportunities for such exchange cannot currently effectively perform the function of biodiversity conservation. The percentage of such green areas will determine the effectiveness of the BGI. The values of the BGI effectiveness (E_biodiversity(BGI)) as a category of the degree of formation of its structure are presented in Table 4.*

Table 4

Effectiveness of the urban BGI (E_biodiversity(BGI)) by signs of its phase-ethological sustainability (connectivity)

E_biodiversity(BGI)	Formation (connectivity) of the territorial structure
[0–20)	poor
[20–37)	unsatisfactory
[37–63)	average
[63–80)	satisfactory
[80–100]	good

The third task – the conversion of function performance values into volumes of ecosystem services for biodiversity conservation – should be performed similarly to other ESs (Korohoda, Kovtoniuk, & Halahan, 2023; Korohoda, & Kupach, 2023; Korohoda, 2023) on the basis of the empirical generalised scale of desirability E. Harrington (1965), which is based on the transformation (normalisation) of all parameters of the object under study (in this case, indicators of the effectiveness of the biodiversity conservation function of individual green areas (E_biodiversity(g_a)) and the effectiveness of the functioning of BGI (E_biodiversity(BGI)) – into dimensionless indicators. In this case, a one-sided increasing function was applied (quality increases with the indicator), where 0 reflects the worst quality of UGSs (BGI) and the minimum volumes of ecosystem services (ES__biodiversity(g_a)) and (ES_biodiversity(BGI)), and 1 reflects the highest (maximum volumes) (Table 5).

Table 5

Ranking of indicators of effectiveness of the function and scope of ecosystem services for biodiversity conservation according to Harrington's desirability function

E_biodiversity(g_a) / E_biodiversity(BGI)	Normalised value on the Harrington desirability scale	Assessment score	Volumes of ESs ES__biodiversity(g_a)) / "ES_biodiversity(BGI)
[80–100]	[0,8–1]	5	Maximum
[63–80)	[0,63–0,8)	4	Above average
[37–63)	[0,37–0,63)	3	Average
[20–37)	[0,2–0,37)	2	Below average
[0–20)	[0–0,2)	1	Minimum

Thus, based on the performance indicators E_biodiversity(g_a) / E_biodiversity(BGI) and Harrington's desirability function, it becomes possible to determine the scope of biodiversity conservation ES provision for the entire urban BGI and each individual green area, which is necessary for the implementation of the methodology.

Discussion and conclusions

In accordance with the aim of the study, we have developed a methodology for assessing ecosystem services for biodiversity conservation in urban green spaces. Such an assessment is based on determining the efficiency of the performance of "ecological network" functions in urban green areas, taking into account natural and anthropogenic factors. In particular, it was determined that differences in the indicators of biodiversity conservation are due to a number of factors. The natural factors include the presence of rare and endangered species within the UGS; landscape diversity; metric and qualitative characteristics of green areas. Anthropogenic factors include the degree of landscape transformation, etc. Accordingly, they were used as the main assessment indicators: biopopulation, landscape diversity, nature protection, territorial, phase-anthropisation and phase-ethological sustainability.

In accordance with the leading factors (indicators), the paper proposes a number of calculated indicators (parameters) for the assessment. These include the biopopulation potential indicator, an integral indicator of landscape diversity, an indicator of conservation status, sufficient dimensionality, the phase-anthropisation sustainability index, etc. These indicators are not only effective, but also well mapped, in particular by GIS tools.

These parameters make it possible to implement the assessment methodology. Its peculiarity is that the assessment should be carried out at two territorial levels: citywide and local. This makes it possible to determine the amount of ES that citizens receive from the urban blue-green infrastructure (BGI) and each individual urban green space (UGS). In the process of GIS modelling, the proposed methodology determines the effectiveness of the biodiversity conservation function, depending on the condition of individual green areas (E_biodiversity(g_a)), according to the proposed calculation indicators. At the city-wide level, performance indicators (E_biodiversity(BGI)) were determined, in particular, through the interconnectedness of the elements of the green infrastructure.

Effectiveness indicators, based on the Harrington's desirability function, allow determining the volume of biodiversity conservation ESs at both territorial levels (ES__biodiversity(g_a)) and (ES_ biodiversity(BGI)).

The assessment based on this methodology can be a useful tool in urban planning decision-making, as it allows identifying green areas that require priority action to identify green areas that require priority action when combined into an ecological network to create conditions for biodiversity conservation.

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ІНДИКАТОРИ ТА РОЗРАХУНКОВІ ПАРАМЕТРИ В ОЦІНЦІ ЕКОСИСТЕМНИХ ПОСЛУГ ЗІ ЗБЕРЕЖЕННЯ БІОРІЗНОМАНІТТЯ

В с т у п . ***Втрата біорізноманіття є однією з найгостріших глобальних екологічних проблем. Концепція екосистемних послуг (ЕП) тісно пов'язана з концепцією збереження біорізноманіття. Враховуючи міру порушення екологічної рівноваги внаслідок антропогенного впливу, одним зі шляхів стійкого розвитку міст є розв'язання проблеми збереження міського біорізноманіття. Міські зелені зони (МЗЗ) є територіями, що мають значення для збереження міського біорізноманіття. МЗЗ здатні найефективніше виконувати функцію збереження біорізноманіття та надавати відповідні екосистемні послуги у тому випадку, якщо утворюватимуть екомережу. Ризики ж для екомережі є ризиками недоотримання (втрати) відповідних екосистемних послуг. Питання оцінювання екосистемних послуг зі збереження біорізноманіття в містах, де б оцінка ЕП базувалась на "екомережному" підході, наразі висвітлено недостатньо.***

М е т о д и . ***Розробка набору індикаторів, на основі яких має проводитись оцінювання, та відповідних їм розрахункових параметрів, а також власне методики оцінки екосистемних послуг зі збереження біорізноманіття у містах, стала завданням даної роботи. Було розроблено методику такого оцінювання. Вона базується на визначенні ефективності виконання МЗЗ "екомережних" функцій. Відмінності в показниках ЕП зі збереження біорізноманіття обумовлено низкою чинників. Серед природних факторів: наявність рідких і зникаючих видів у межах МЗЗ; ландшафтне різноманіття; метричні та якісні характеристики зелених зон. Серед антропогенних – ступінь перетвореності ландшафтів тощо.***

Р е з у л ь т а т и . ***Названі чинники стали індикаторами оцінки (біопопуляційними, ландшафтного різноманіття, природоохоронними, територіальними, фазово-антропізаційної та фазово-етологічної стійкості). Адекватно до провідних факторів (індикаторів) запропоновано низку параметрів для проведення оцінювання. Серед них: показник біопопуляційного потенціалу, інтегральний показник ландшафтного різноманіття, показник природоохоронного статусу, достатньої розмірності, індекс фазово-антропізаційної стійкості тощо.***

В и с н о в к и . ***Ці параметри дозволяють реалізувати методику оцінювання на двох територіальних рівнях (загальноміському й локальному) і визначити ефективність міської синьо-зеленої інфраструктури (СЗІ) або окремої МЗЗ у виконанні функції збереження біорізноманіття. На локальному рівні за запропонованими розрахунковими показниками ефективність виконання функції в МЗЗ (*** $E\_biodiversity_{(g\_a)}$ ***) визначається в процесі ГІС-моделювання залежно від їхнього стану. На загальноміському рівні показники ефективності (*** $E\_biodiversity_{(BGI)}$ ***) визначаються через зв'язаність між собою елементів СЗІ. Показники ефективності, на основі функції бажаності Харрінгтона, дозволяють визначити обсяги ЕП зі збереження біорізноманіття на обох територіальних рівнях (*** $ES\_\_biodiversity_{(g\_a)}$ ***) та (*** $ES\_ biodiversity_{(BGI)}$ ***). Оцінка, що відбувається за такою методикою, може стати корисним інструментом у прийнятті містопланувальних рішень, адже дозволяє ідентифікувати зелені зони, що потребують першочергових дій при об'єднанні їх у екомережу для створення умов збереження біорізноманіття.***

К л ю ч о в і с л о в а : ***Міські зелені простори, екосистемні послуги, збереження біорізноманіття.***

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