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Urban ecosystems assessment: An integrated approach to maintenance of habitats and their biodiversity

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ABSTRACT

Natural habitats and their biodiversity are usually associated with protected areas, incompatible with direct anthropogenic influence. Is there a biodiversity in urban environment, what is the role of peri-urban areas to the provision of species richness and is their potential being properly utilized? These are current issues that deserve the attention of decision-makers because the human's need of natural environment in cities is expressed more intensely than in any previous period in history. Green and blue infrastructure elements, being part of the larger system of urban ecosystems, provide an essential and proven benefits to the city dwellers, like health improvement, opportunities for nature-based daily outdoor recreation, strengthening sense of place etc. The main objective of this research is to assess this part of the landscape elements in urban and peri-urban environment, which are most supportive to the maintenance of habitats and their biodiversity. Selected Functional urban area with center city of Burgas is choosen for a case study. The urban ecosystems are assessed in GIS environment with unified indicator (based on City Biodiversity Index approach) according to 5 criteria: hemeroby index, share of protected areas, fragmentation index, presence of water and species richness. The assessment is performed on two spatial levels: within Functional urban area by Urban Atlas spatial units and within urban core – by grid cells (local climate zones). The final higher scores identify areas that provide the greatest extent the maintenance of habitats and their biodiversity. The results could support the urban planning and help to optimize the link between the natural elements within the Functional urban areas, providing ecological, economic and social benefits to the regions through the enhancement of the urban ecosystem's functions and their services.

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1. Introduction

Global urbanization includes both urban sprawl and growing density of existing urban areas. Along with temperature anomalies, floods and droughts related to climate change, urbanization is a challenge for our cities and thus for the geographical concentrations, where about 60% of the world's population will soon live (Haase 2021). These problems lead to changes in the structure and functions of urban ecosystems, and therefore in the societal benefits and ecosystem services they provide. Precisely the protection and maintenance of urban ecosystems and especially its natural elements - green and blue infrastructure, is crucial for the health and well-being of urban population.

Climate change is a global phenomenon that greatly affects urban life. Rising global temperatures causes the raising ocean/sea levels, increasing the number of extreme weather events such as floods, droughts and storms, and increasing the spread of tropical diseases. All this has a costly impact on basic services in cities, infrastructure, housing, food and human health. At the same time, cities are making a significant contribution to increasing the global temperatures, as urban areas are the main sources of greenhouse gas emissions. It is therefore essential that cities become an integral part of the solution to the fight against climate change (https://www.unenvironment.

org/explore-topics/resource-efficiency/what-we-do/cities/cities-and-climate-change). In many regions of the world, climate change is expected to increase heat waves, including rising air temperatures in cities (Genelletti et al., 2020), which further enhances the effect of urban heat islands. Among the natural disasters that occur in Europe, temperature anomalies (manifesting as heat waves in cities) cause the most fatalities among the population (Genelletti et al., 2020). All these processes (temperature anomalies - heat waves, floods, droughts, etc.), in combination with the anthropogenic factor, lead to changes (with a negative effect) in the structure and functions of urban ecosystems.

With the increase of the standard of living and the awareness of the big city dwellers, the population has higher requirements for the quality of life. It is important to raise the attention about the problems of our urban environment, which are largely caused by inappropriate management of natural capital. The topic is directly related to current European strategic documents, projects and initiatives (European Biodiversity Strategies, European Climate Action and Green Deal, European Strategy on Green Infrastructure, etc.), which strive to meet the challenges and work together for the development of sustainability and flexibility of contemporary territories, including returning the nature in cities. For instance, with regard to the implementation of the new Biodiversity Strategy for 2030, the European Commission recommends expanding protected areas and Natura 2000 zones, establishing ecological corridors, investing in green and blue infrastructure, creating green plans for cities with more than 20,000 inhabitants etc. (https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm).

The study of urban ecosystem services has become a focus of ecosystem services research in recent years (Rocha, 2015). The inclusion of ecosystem services in urban plans is considered a testament to their quality, and on this basis is an indicator of the ability to take strategic action towards more sustainable cities (Genelletti et al., 2020). Over the last year, we have witnessed innovative concepts integrating urban green infrastructure, ecosystem services and nature-based solutions for sustainable and flexible urban governance (Almenar, 2021; Haase, 2021).

In Bulgaria, research on the quality of the environment in urban conditions is also increasing: the intensity of the urban heat island (Popov et al., 2019, Dimitrov et al., 2021), the state of the green system (Sarafova, 2021), and the urban ecosystem services spectrum are being studied (Zhiyanski et al., 2017; Nedkov et al., 2019 et al., Zhelev, 2020). Projects related to measures for mitigation and adaptation to climate change are also being developed, an example of which are current developments on the territory of Sofia and Burgas Municipalities.

The urban environment is not isolated in space, but is connected to the adjacent ecosystems in a complex natural-social system. Therefore, research is needed on urban areas not only within narrow limits, in their built-up area, but it is important to consider the surrounding areas. The European Commission's working group on Mapping and Assessment of Ecosystems and Their Services (MAES) outlines several scales and boundaries that are important for the assessment of urban ecosystem services, one of which is the Functional Urban Areas (FUA). Such an approach promotes the validation of nature-based solutions for environmental assets and the integration of ecosystem services assessment as a planning and management tool in urban areas (La Notte and Zulian 2021).

The concept of integrating the ecosystem approach into urban planning, aimed at maintaining and improving the functions of urban ecosystems, can be easily promoted through the benefits of ecosystem goods and services. For example, in an urban environment, the ecosystem services' main source is the green infrastructure - it purifies the air, reduces noise, regulates water flow, provides a cooling effect, habitats for organisms and an environment for recreation and improving the quality of life of the urban population (Fig.1). Improving the urban environment will also meet people's expectations - with the increase in living standards and awareness of residents of larger cities, the population has higher requirements for quality of life in urban areas.
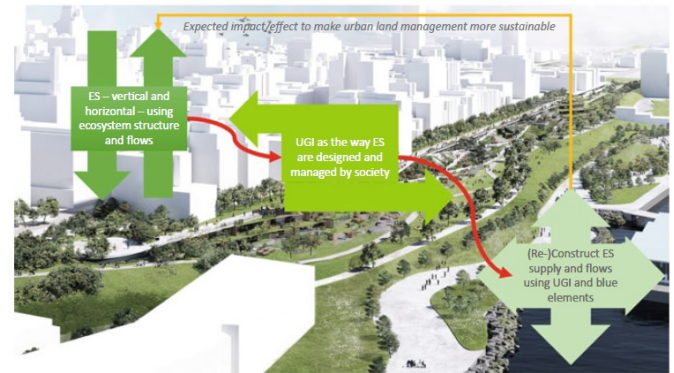

Figure 1. Green Infrastructure benefits (Haase et al., 2021).

For significant part of the population, green spaces in urban environments are their only encounter with nature and their notions of biodiversity are limited to this contact. They are also crucial for human health and comfort (Trzyna et al., 2014).

The latest study on the assessment of ecosystems at European level, conducted by the Joint Research Center at the EC (https://publications.jrc.ec.europa.eu/repository/handle/JRC120383), notes that in the future it is necessary to complete gaps in the availability of detailed spatial data for the monitoring of Natura 2000 sites within the FUAs, as well as for accurate and detailed data on urban biodiversity.

Urban biodiversity has its own distinctive features given the characteristics of urban ecosystems and the quality of their habitats. It includes a variety of inherited natural fragments of the primary landscape, landscape architectural green spaces, ornamental plants, a concentration of flowering species (favorable environment for pollinators), a specific diversity of avifauna and more. The topic is permanently in the attention of researchers, both in terms of adaptation of species in urban habitats (McDonnell and Hahs 2015), and in terms of overall management of socio-ecological systems and the need for ecosystem services derived from green infrastructure (Oliveira et al 2014; Elmquist et al 2015; Knapp et al 2021). The focus on urban biodiversity and ecosystem services can substantially help to rethink the essential relationship between humans and nature and can be helpful to planners or policy makers in creating sustainable cities (Zari 2018). Strong efforts have focused on analyzing how urban biodiversity associates with spatial differences in the physical and anthropogenic environment (Li et al., 2019).

Almost all impacts of climate change have direct or indirect effects on urban ecosystems, biodiversity and the ecosystem services they provide. Urban ecosystems and biodiversity have an important and growing role to play in helping cities adapt and mitigate the effects of changing climate, and their use as adaptation and mitigation solutions will help achieve more sustainable urban living outcomes and urban regions. Ecosystem-based approaches to tackling climate change in cities clearly define the critical role of urban and suburban ecosystems, which require careful management to ensure the sustainable provision of ecosystem goods and services to the people who need them in the next 20 years, 50 and 100 years.

Ecosystem-based planning can strengthen the links between urban, sub-urban and rural ecosystems through planning and stakeholder management and the participation of nature-based solutions at urban and regional scale (McPhearson et al. 2016).

The urban biodiversity is a key topic in the "Methodology for assessment and mapping of urban ecosystems their state and the services that they provide in Bulgaria" (Zhiyanski et al. 2017), as well as in the implemented on its basis national assessment (ExEA – Bulgaria 2018). The country's participation in "Enhancing Resilience of Urban Ecosystems through Green Infrastructure (EnRoute)" stands out among the realized pilot projects (Maes et al. EC JRC 2019). Leading municipalities in the country take initiatives to integrate the ecosystem approach and ecosystem services into spatial urban planning policies and tools: Sofia Municipality (Sofiaplan 2021) and Burgas Municipality (Integrated development plan – Burgas Municipality 2021). Their distinctive features are associated with the proximity of protected areas with urban spaces. In support of the latter, Burgas, the territory in focus of this study, participates in the project for nature-friendly solutions for green cities (Connecting Nature, 2017-2022), aimed at the analysis of good practices and their application. NGOs in the country play an important role in initiating and testing such projects, along with close contact with society to build empathy. In particular: the Bulgarian Biodiversity Foundation, which is at the heart of the process of renovation of the Biosphere parks of Bulgaria as an example of harmonious coexistence between man and nature (https://bbf.biodiversity.bg/bg/Biosferni-parkove.c141).

Increasingly, various organizations are implementing initiatives related to urban dwellers and biodiversity, such as the "Role of Civic Science for Biodiversity Conservation", Park Birding Weekend - Sofia Bird Walks, the creation of mobile applications with information about species in urban areas, etc. (BSPB, https://smartbirds.org/). This is proof that in our country there is a potential to develop the topic of the benefits of the ecosystem services and to raise awareness of the urban population not only in the capital but also in other major cities in the country.

The main objective of this research is to assess this part of the landscape elements in urban and peri-urban environment, which are most supportive to the maintenance of habitats and their biodiversity: in case of Burgas FUA. Focus of the study is the potential for provision of the regulating ecosystem services 'maintaining nursery populations and habitats, including gene pool protection' (according to the ecosystem services classification CICES v5.1, https://cices.eu/) in urban environment. This is one of the selected EU (together with climate regulation at the local level, regulation of water flows, assessment of opportunities for outdoor recreation, etc.), which have been identified as most necessary for the urban population according to a number of studies on the subject (Haase et al. 2014).

One of the sub-goals of the research is the connectivity of urban green infrastructure with green infrastructure at regional scale – i.e. linking the urban green infrastructure elements with the surrounding natural landscapes. Such an upscaling approach provides additional information about the character of the urban landscape mosaic and its ecological functions. It should be borne in mind that not all green areas qualify and manage as elements of the green infrastructure. Important criteria for the identification of green infrastructure are: multifunctionality (provision of diverse ecosystem services) and connectivity (protection of ecological networks) in the territory (Liquete et al. 2015). A well-planned green infrastructure on a regional scale would provide a more natural and diverse environment for organisms, which is directly related to increasing biodiversity in cities and their surroundings.

The results of the study are addressed to all institutions involved in urban planning and management.

2.Materials and methods

2.1.Case study

Selected Functional urban area with center city of Burgas is chosen for a case study (Fig.2). Five municipalities with a total area of 2 947 sq. km, or 3.8% of the country's territory, are included. The area is the second largest (after the metropolitan area - Sofia) and the fourth most populous among the other FUAs in the country (NSI 2016). The city of Burgas is characterized by complex urban morphology - high density of residential, industrial and public spaces, located among a system of coastal lakes (lagoons, estuaries and their wetlands) and Burgas Bay (at the Black sea west coast).
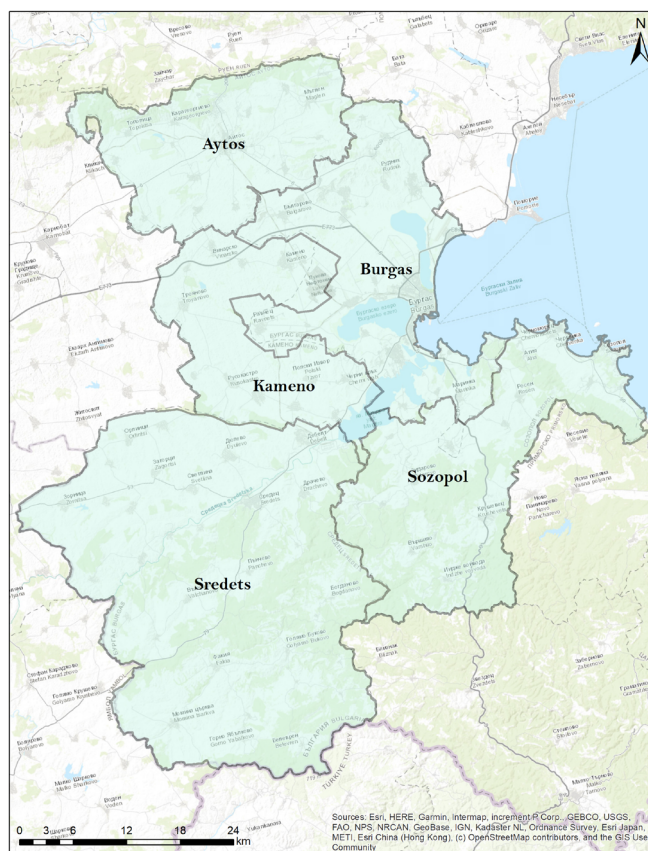

Figure 2. Functional urban area with center Burgas city.

The region is characterized by representative biodiversity from Bulgarian Natural Heritage. In direct contact with the city are a series of protected sites, united under the name "Burgas Wetlands" - a significant fragment of the migration route of the avifauna - Via Pontica (Fig.3). According to the long-term climate scenarios (https://www.moew.government.bg/static/media/ups/articles/attachments/obshta_chast5ea57b35e2e39fef724cd5e98a2514dd.pdf), under the influence of the peculiarities of the Mediterranean climate, the urban area is expected to be exposed to a greater risk of permanent droughts, fires and floods.

2.2. Urban ecosystem assessment: Spatial scale

A complex indicator has been developed for assessment of the potential of FUA Burgas' ecosystems to provide the specified ecosystem service. It reflects the best scientific knowledge. It focuses on the assessment at predefined spatial levels, which aims

Figure 3. "Poda" protected area. birds observation point in the nature conservation centre (the only place on the Bulgarian Black Sea coast where you can find a mixed colony of spoonbill, glossy ibis, pygmy cormorant, night heron, red heron, squacco heron, little and great egret, bspb.org).
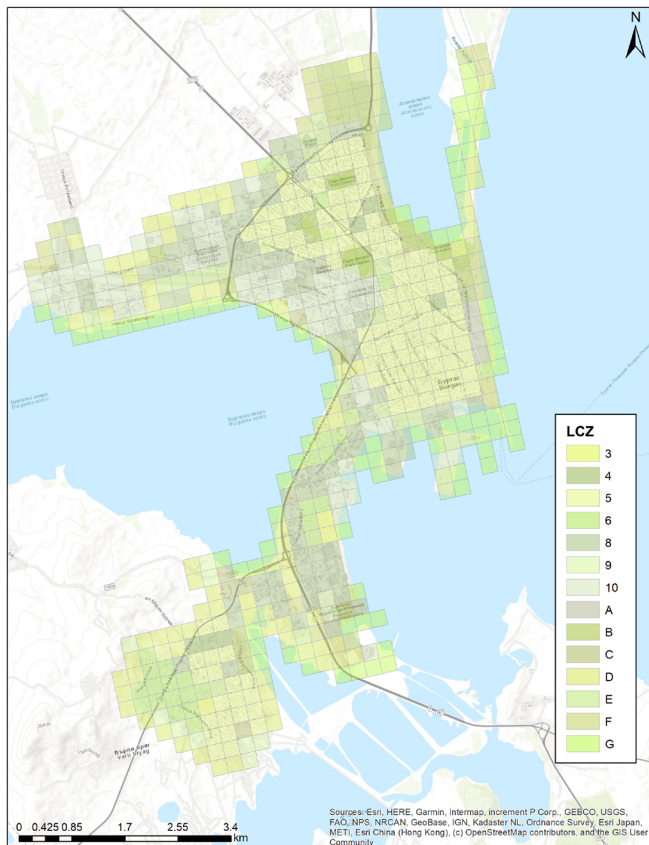

Figure 4. Identified local climate zones within the FUA-Burgas urban core.

to adequately address current issues related to the planning and management of green infrastructure in support of urban biodiversity. The assessment procedure was carried out in a GIS environment – Arc GIS Desktop 10.6 Esri inc.

Local level: within FUA urban core – The assessment is applied within the basic spatial units (grid cells 250 x 250 m), which here have the meaning of 'local climate zones' (LCZ, according to the methodology for climate classification of urban areas of Oke and Stewart, 2012). The identification of LCZ includes analysis of the orthophoto imagery and recent data from survey with the application of an unmanned aerial system (July 2021 - paper in preparation). Field verification of representative 'local climate zones', including the distinctive for Burgas types (open arrangements of: midrise and low-rise buildings, low plant areas, wetlands etc.) was carried out (Semerdzhieva et al. 2021). The application of the methodology for LCZ aims to provide the maximum amount of information on urban planning in the context of socio-ecological hybrid urban systems (Qian et al., 2020) for: structure (considering the land cover of the territory with information on abiotic and biotic elements of natural environment) and functionality (taking into account the functions of the territory) (Fig. 4).

Regional level: within municipalities in FUA. The assessment is applied within the Urban Atlas' spatial units as representative for analyses in the indicated spatial scale (https://land.copernicus. eu/local/urban-atlas). The focus here is only on those units of the above nomenclature that bear the attributes of 'green infrastructure'. This assessment should answer the question 'How do the natural landscape elements in the FUA support urban ecosystems for 'maintaining nursery populations and habitats, including gene pool protection'? The proportion of green and built infrastructure varies between urban cores and larger urban areas, and a significant proportion of total GI is in the non-core area: this zone is therefore important for the provision of urban ecosystem services, which should be considered when planning urban growth and climate adaptation strategies (Kourdounouli and Jönsson 2019).

2.3. Urban ecosystem assessment: Composed indicator

'Habitat maintenance and biodiversity' sub-indicators were selected after a literature review on the topic, including Ziter (2015), Schwarz et al (2017), and Uchida et al. (2021), as well as publications related to the results of research projects in recent years, such as GREEN Surge (2017) and URBES (Kremer et al 2016). The focus of this review is on two aspects of urban biodiversity analysis: the urban structure as an environment with distinctive conditions for habitat management, and green infrastructure as a source of ecosystem services which potential is determined by the general characteristics of the urban ecosystem. Some of sub-indicators are adopted from the most common methodological framework for assessing biodiversity in urban environments - Singapore Index on Cities' Biodiversity (https://www.cbd.int/subnational/partners-and-initiatives/city-biodiversity-index): a methodological tool for assessing cities that identifies and monitors progress and efforts to conserve biodiversity against the city's own resources. It's methodological scheme of evaluation consists of two parts: i) City profile - provides basic information about the city; and ii) 23 indicators that assess local biodiversity, ecosystem services provided by biodiversity and biodiversity management. Each indicator is assigned a scoring range between zero and four points, with a total possible maximum score of 92 points.

The five criteria of the current composed indicator (with relevant evaluation parameters) as mentioned above, are selected according to the data availability for this territory and are listed below for each spatial unit (land cover types and grid cells/LCZ) at regional

and local level - Degree of naturalness/ Hemeroby index; Share of protected areas and representativeness of the natural heritage elements; Fragmentation degree of green areas/ Remoteness of green infrastructure elements from the urban core; Presence of water and Share of key biological species (Table 1). The assessment is quantitative, influenced by the guidelines and methodology provided in the Singapore Cities Biodiversity Index (https://www.cbd.int/ subnational/partners-and-initiatives/city-biodiversity-index).

Table 1. Urban ecosystem assessment: Composed indicator' criteria and parameters.

Criteria	Parameter	Applicability local/regional level
Hemeroby index	Scores from 1 to 6	Both
Share of protected areas and representativeness of natural heritage elements	Presence/absence of protected areas in a given spatial unit	Both
Fragmentation degree	Spacing of <100 m of green areas (between each other) in a given spatial unit	Local
Remoteness of green infrastructure elements from the urban core	Distance of 2, 10 or more km from the urban core	Regional
Presence of water	Presence/absence of water bodies in a given spatial unit	Both
Share of key biological species	Presence/absence of key biological species in a given spatial unit	Both

3. Results

The first step of the analysis focuses on the results of the combined indicator on regional level – within the FUA' municipalities. The final assessment (Fig.5) is composed by the sum of the five criteria scores and represents the potential of FUA Burgas' ecosystems to provide the ecosystem service 'maintaining nursery populations and habitats, including gene pool protection'. The final values range between 1 and 14 and as a final step are reclassified as follows (Table 2).

Table 2. Reclassification of the final scores – regional scale.

Very low	Low	Rather low	Medium	Rather high	High
1-2	3-4	5-6	7-9	10-12	13-14

The results show that the most common areas are those assessed as medium and rather low potential, following those with low and very low potential (mainly urbanized areas). With the lowest percentage of the FUA's territory is covered by areas with rather high and high potential and they are mainly along the coastline and the wetlands/water bodies.

The second step of the analysis focuses on the results of the combined indicator on local level – within the urban core. The final assessment (Fig.6) is composed by the sum of the five criteria scores and represents the potential of Burgas' urban ecosystems to provide the ecosystem service 'maintaining nursery populations and habitats, including gene pool protection'. The final values range between 1 and 12 and as a final step are reclassified as follows (Table 3).
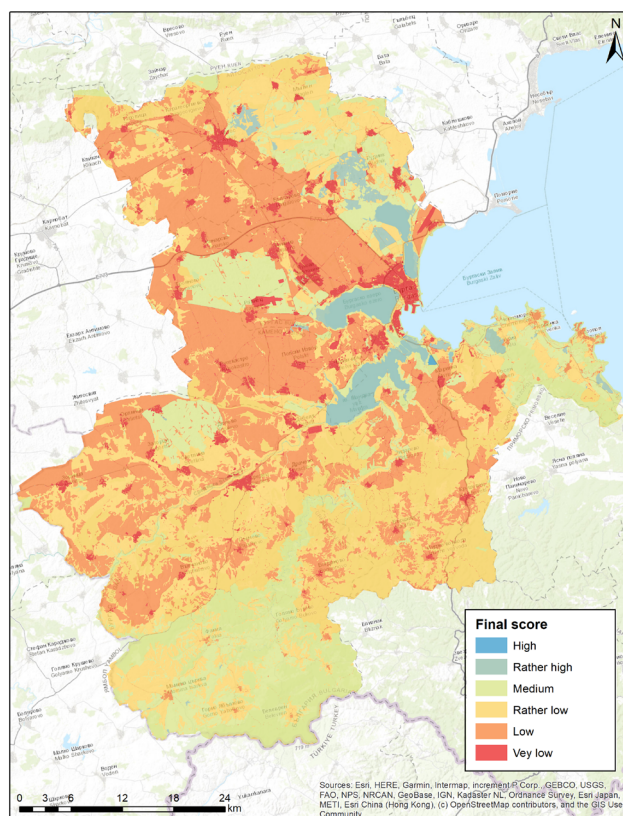

Figure 5. Potential of FUA Burgas' ecosystems to provide the ecosystem service 'maintaining nursery populations and habitats, including gene pool protection'
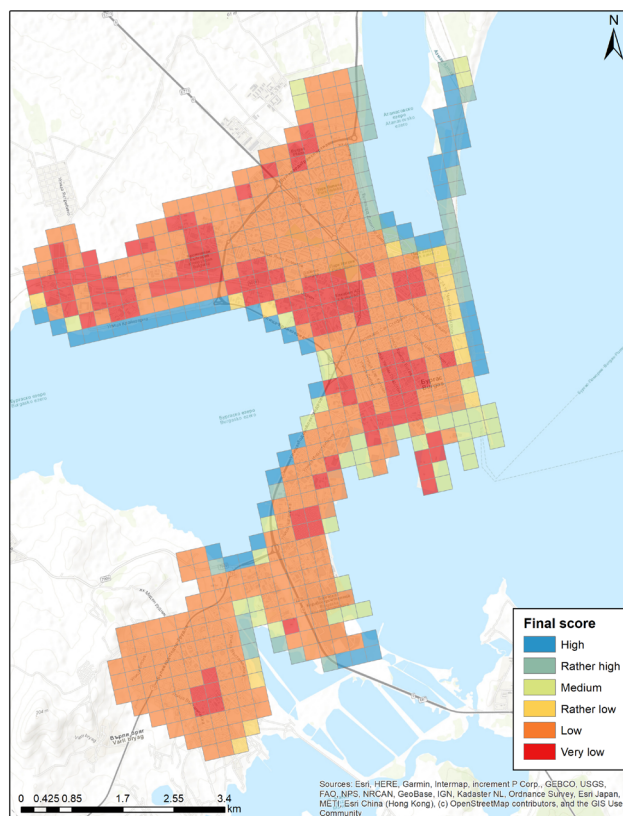

Figure 6. Potential of Burgas' urban ecosystems to provide the ecosystem service 'maintaining nursery populations and habitats, including gene pool protection'.

Table 3. Reclassification of the final scores – local scale.

Very low	Low	Rather low	Medium	Rather high	High
1-2	3-4	5-6	7-8	9-10	11-12

The most common areas are those assessed as low potential, following those with very low potential (urban city center). With the lowest percentage of the FUA's territory is covered by areas with medium to rather high and high potential and they are mainly along the coastline and the wetlands/water bodies.

4. Discussion

The analysis in the urban environment of Burgas is presented in a form suitable for integration into urban governance and environmental planning. The results of the composite indicator identify:

highest values: the areas that provide the highest habitat maintenance and biodiversity service. As expected, these are the coastal/ lakeside areas that fall within the periphery of the protected areas and are characterized by the highest degree of naturalness of the environment;

lowest values: the areas that provide the least habitat maintenance service and their biodiversity. As expected, these are the most built-up areas in the city center. By the fragmentation criteria, there is identified vulnerable zones for the green infrastructure connectivity network - mainly in the central part of the city center and less in the commercial and industrial zones.

The identified zones with the highest value are key areas of the green infrastructure in and around the urban environment (key in terms of biodiversity conservation, landscape identity, etc.) and can be used for proposals for projects to build a unified network from green and blue infrastructure, connecting the natural heritage on the territory of FUA - urban cores with the surrounding area, which will be in favor of:

- supporting urban planning to tackle the problems of the urban environment and improve the quality of life of the population - by improving ecosystem services - regulating urban temperature and air purification, reducing noise, regulating floods, recreation, etc.;
- engaging the local community on the topic;
- promoting nature-based solutions (especially within the areas that provide the least habitat maintenance service and their biodiversity).

The application of nature-based solutions (solutions to social challenges that are inspired and maintained by nature / natural elements) is recommended in the lowest rated areas. The result of nature-based solutions is the provision of side effects, such as improving the attractiveness of territories, health and quality of life of the population and the creation of green jobs (Raymond et al., 2017).

A limitation of the approach is that there is some other factor that reflects on the maintenance of the habitats and their biodiversity, such as natural (climate conditions – temperature changes as well as frequent extreme weather events etc.) and human interventions (transport infrastructure and other facilities, illegal hunting etc.), which are not incorporated in the current research. The lack of comprehensive biological species data as a prove for the existing biodiversity of the territory could also be noted as a limitation and difficulty with the study implementation.

The study uses different spatial units to assess the core and periphery of the FUA, which helps to highlight the contribution of these areas, but the information can only be interpreted at the relevant spatial levels. At the same time, for urban systems planning purposes, it is very important to clearly trace the relationship between urban green infrastructure and regional green elements. A unified spatial approach is essential. Developing a spatial unit that adequately reflects important attributes of urban and adjacent ecosystems is a promising topic for subsequent interdisciplinary research. Such spatial issues also open up the debate on the usefulness of integrating established indicators in European monitoring and information exchange, such as landscape condition and landscape fragmentation. Optimizing the relationship between urban and rural areas would enhance the multifunctionality of landscapes around urban areas - a key issue in defining modern positions for sustainable development of a territory (Borissova, 2013).

An important focus of such research are the urban dwellers and their daily work trips within the FUA build a permanent link between the urban population and biodiversity. An interesting question to investigate is the relationship between population density in terms of the location and area of green infrastructure, the mode of daily commuting, and their complex influence on habitat quality and the distinctive biodiversity within them. Such a study could also contain an additional aspect: how public attitudes towards green elements in residential environments (e.g. private gardens, green balconies, etc.) impact biodiversity.

In the future, research can be deepened by looking for dependencies between, demand, consumption and interaction (synergies and trade-offs) of ecosystem services, as today the natural environment cannot be considered separately from human needs. It is also important to consider in detail the factors of the environment that provides the ecosystem services - the structure, functions, and condition of the urban ecosystems, as the urban environment does not provide the necessary amount and number of ecosystem services for the population, but depends on the surrounding landscape, carrying almost all material and regulating urban ecosystem services, necessary for human well-being. Often an ecosystem service in a city is provided outside its territory, and consumption itself is within its limits. Cortinovis and Geneletti (2018) note the need to follow the entire ecosystem services 'production chain', from urban environmental structures and functions to ecosystem benefits. The ecosystem service 'maintaining nursery populations and habitats, including gene pool protection' can be a very important indicator of the sustainability of this chain. It is the path to the development of sustainable and flexible cities through the combination of the three concepts (green infrastructure, ecosystem services and nature-based solutions), which provides a different perspective for sustainable management of urban areas (Haase, 2021).

5. Conclusion

In conclusion, it should be summarized that Burgas' urban ecosystems have a medium potential to provide the ecosystem service 'maintaining nursery populations and habitats, including gene pool protection'. The relationship between the urban core and the FUA periphery is sufficient to support interactions of ecosystem services. The urban core has a good connectivity of green areas, which sets favorable conditions for habitat maintenance service and their biodiversity. Natural water bodies and the coastline are of major importance. Preserving the conditions that maintain their naturalness is a guarantee for ensuring habitat functions and biodiversity in the urban environment. In the rest of the FUA, the enduring sources of the ecological functions sought are the natural and semi-natural areas, presented by forests habitats in the south and south-eastern part of the territory.

The methodology used in the study is transparent and flexible - it can be applied in any urban area, but it is important to properly

prioritize the indicators depending on the specific purpose of the study, because otherwise it may irrelevant results are obtained.

Only free public databases from national and international registers (Copernicus Land Monitoring Program - Urban Atlas 2018, CORINE Land Cover 2018, BSPB, etc.) were used for the assessment.

By raising the awareness and knowledge of the local population for the urban biodiversity importance and taking collective ecosystem-based actions, society can counteract the negative anthropogenic impacts and adapt to the changes that occur as a result of climate change.

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