Urban Biodiversity Performance Determining Model (UrBioPDeM): The Case of Isparta, Türkiye

Mert Çakır * and Atila Gül

Identifying, protecting, and developing biodiversity in urban environments contributes to ecosystem integrity. Although there are studies addressing biodiversity in natural areas in Türkiye, there has been no study specifically measuring the biodiversity of city centers. Adapting existing methods for measuring city biodiversity to Turkish cities is challenging due to their unique local dynamics. Therefore, there is a need to identify indicators that can be used to monitor and evaluate biodiversity performance for the protection and sustainability of urban areas in Türkiye and to develop a feasible, reliable, and measurable biodiversity performance assessment approach. The developed UrBioPDeM has 4 main factors and 32 sub-factors. Indicators for the assessment and management of urban biodiversity performance in Isparta, Türkiye, were identified and analyzed, and it was found that Isparta's urban biodiversity has low potential. Therefore, suggestions were made to increase the urban biodiversity of Isparta. The developed approach is an appropriate and effective biodiversity performance model that can be applied in Turkish cities. The factors and sub-factors used in this method can be adjusted and revised according to the potential biodiversity characteristics of a city.

DOI: 10.15376/biores.19.4.9285-9309

Keywords: Isparta; City ecosystems; Urban Biodiversity; Environmental sustainability; Ecological balance; Urban green spaces; UrBioPDeM

*Contact information: Department of Landscape Architecture, Faculty of Architecture, Süleyman Demirel University, 32260, Merkez/Isparta, Türkiye; * Corresponding author: pmmertcakir@gmail.com*

INTRODUCTION

The biological diversity (biodiversity) of life on Earth is the foundation for human existence and welfare. Biodiversity is essential for all living things and sustainable life. It encompasses the diversity, quantity, and distribution of life's components, including species, ecosystems, and genes. The Rio Declaration (1991) articulated the importance of biodiversity on a global scale. According to the Convention on Biological Diversity (1992), "biological diversity" means the variability among living organisms from all sources, including, *inter alia*, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species, and of ecosystems. The areas where biodiversity is most affected are those where human activities and urbanization are most intense. Urban areas and their surrounding natural habitats are valuable for the protection and development of biodiversity (Alvey 2006). Biodiversity can be seen as a system of structured relationships connecting plant and animal species and humans in each biotope. Therefore, urban areas can be considered as environments for biodiversity and ecosystems, just like any other. Biodiversity in urban areas extends beyond parks and managed green spaces. Animal and plant species can be

found in a variety of urban environments, including cemeteries, sports fields, parking lots, roads and railroads, pavement and wall cracks, barren lands, and waterways.

The benefits provided by urban biodiversity are important for the continuation of life. Biodiversity itself is a tool for regulating species and establishing relationships between specific species. Biomass absorbs and recycles carbon dioxide emitted in excess by domestic and industrial facilities, urban traffic, and other greenhouse gases. Biodiversity improves the urban microclimate, provides an aesthetic appearance, establishes a relationship between man and nature, facilitates recreation, relaxation, and play through various arrangements that combine living elements in certain grasslands, forests, and aquatic biotopes. This has a calming and relaxing psychological effect on urban people, increases people's awareness of nature/environmental protection, assumes an educational function in urban areas, recycles some residual elements through compost as a nutritious substrate, and gas absorption through water retention. It also helps reduce the ecological footprint of the city, contributes to urban food production, cycles nitrogen in the urban environment, increases water supply and capacity, and biodiversity areas provide opportunities for recreational and cultural activities for citizens. However, biodiversity is declining, and many of the world's most important biodiversity hotspots are located in countries struggling with poverty, food insecurity, and accelerating climate change.

Biodiversity issues are the subject of several international conventions. Such conventions have been signed, mainly for the conservation of specific species and biotopes. Biodiversity conventions seek to establish policies at the national, regional, and global levels to achieve the common goals of conservation and sustainable use. The Convention on Biological Diversity (CBD) was signed in Rio de Janeiro on June 5, 1992, and it entered into force on December 29, 1993. Following the adoption of the Rio Convention, the preparation of legal instruments on biodiversity was initiated. A total of 188 countries that signed the Convention on Biological Diversity committed themselves to take national and international measures to achieve three main objectives: i) the conservation of biological diversity; ii) the sustainable use of the components of biological diversity; and iii) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. In 1994, the Pan-European Strategy for Biological and Landscape Diversity was signed, which was comprehensive but did not include anything about urban biodiversity. In 2003, 51 countries in the Pan-European region signed the Kyiv Resolution on Biodiversity, whose aim was to reduce the loss of biodiversity and set loss reduction targets for 2010. However, no decisions have been taken on other habitats, species, or areas. The European Landscape Convention (2000) has more detail than the Pan-European Strategy and the Kyiv Resolution on Biodiversity, especially recognizing that towns and cities are landscapes like any other. The European Landscape Convention recognizes that landscape is an important part of the quality of life for people everywhere. International conventions and Turkish national legislation emphasize that the protection of biodiversity and sustainability are important and that society and countries should take urgent measures in this regard. It is important to note that there is a broad consensus on the awareness of managers, politicians, and decision-makers about protecting biodiversity and ensuring sustainability. It will not be possible to establish viable and effective policies unless there are measurement tools in the process of monitoring and controlling the sustainability of biodiversity.

Measuring biodiversity is a complex and multifaceted concept. Policy makers must have access to accurate information to make the right decisions about biodiversity conservation. To this end, measurable indicators need to be defined, systematically

measured, or evaluated to monitor and manage urban biodiversity. Several methodologies have been developed to measure urban biodiversity. For example, the "City Biodiversity Index" was developed and adopted as a self-assessment tool for cities in Singapore to assess and monitor the progress of their biodiversity conservation efforts on an individual basis. In this methodology, scoring was quantified using three factors (native biodiversity, ecosystem services, and governance and management of diversity) and twenty-three indicators. Each indicator was given a score between zero and four points, and a total of ninety-two points were scored (Chan *et al.* 2014). The same methodology (three factors and twenty-three indicators) was applied in Sorocaba, Brazil. In the study of de Camargo *et al*. (2022), twenty-three indicators were used in all three categories to determine the Urban Biodiversity Index. The biodiversity factor has ten indicators, the ecosystem services factor has four indicators, and the communication and management factor has nine indicators. Each of the indicators is assigned a value between zero and four, with a total score of ninety-two points. The higher the total score, the higher the level of biodiversity in the city.

Urban biodiversity is too complex to be fully measured holistically across the scales and types involved. However, it is possible to characterize biodiversity using individual measures. Indicators should be used to regularly measure performance in management and monitoring processes for the protection and sustainability of urban biodiversity. Although there are limited publications and studies on urban biodiversity measurement around the world, there is no detailed index study that combines all indicators related to biodiversity in Türkiye. The currently developed methods and indicators (Convention on Biological Diversity 2013; Chan e*t al.* 2014; Ruf *et al.* 2018; de Camargo *et al*. 2022) are not suitable for Turkish cities. When these methods are applied to Turkish cities, they do not reflect the real biodiversity values of the cities. Each country has its own dynamics. There are also important dynamics that need to be taken into consideration, specifically to assess the urban biodiversity of Turkish cities. These dynamics arise from the ecological, social, historical, and economic structures of Turkish cities and therefore require the adaptation of biodiversity performance measurement and management methods specifically for Türkiye. Climatic and geographical conditions, cultural and social factors, economic and industrial activities, social and economic inequalities, natural disasters and risks, laws and policies, local ecosystem dynamics, migration and population mobility, infrastructure and urban planning, biological monitoring, and research activities are among the important dynamics of cities. Türkiye is a geographically diverse country with different climatic zones. Since the existing developed methods are generally designed according to specific geographical and climatic conditions, these methods cannot fully reflect the different ecosystems and biological characteristics in various regions of Türkiye. The unique historical and cultural structures of Turkish cities have a significant impact on biodiversity. Factors such as traditional landscape elements, local agricultural practices, and green space use play a role in shaping biodiversity. These elements are not sufficiently taken into account in existing methods. Many cities in Türkiye are intertwined with agricultural activities. Agricultural activities around urban areas directly affect the biodiversity of cities. The nature of these agricultural activities limits the effectiveness of the methods used because these methods generally focus on dense urban areas and do not sufficiently cover agricultural-urban transition zones. The urban structures, growth models, and planning approaches of Turkish cities are different from cities in different countries. These differences require different strategies for the protection and development of biodiversity. Existing methods do not fully reflect the urban structure in Türkiye and its impact on biodiversity. Factors such as the use

of green areas in cities, the lifestyle of local people, park and garden culture, and social awareness of biodiversity are important dynamics affecting biodiversity. Legal regulations and practices regarding environmental protection and biodiversity in Türkiye differ from international standards in some cases. This legal framework affects the methods used for the protection and measurement of biodiversity. Research and data on biodiversity in Türkiye are not as comprehensive as in some countries. This situation causes difficulties in adapting the currently developed methods to Türkiye because the lack of local data affects the accuracy and reliability of the method. These local dynamics make the need for biodiversity measurement methods specifically developed for cities in Türkiye even more evident. Taking local dynamics into account can provide a more accurate assessment of biodiversity and the integration of this assessment into sustainable urban planning processes. For these reasons, developing a unique biodiversity measurement method for Türkiye requires taking into account local ecosystems, species, and urban structures.

The aim of this study was to identify indicators that can be used to monitor and evaluate biodiversity performance for conservation, sustainability, and ecosystem services in urban areas. This will allow the presentation of an applicable, reliable, and measurable approach to assess biodiversity performance. Furthermore, this study was conducted to identify and analyze indicators for assessing and managing urban biodiversity performance in Isparta, Türkiye.

EXPERIMENTAL

Assumptions

In this work it was assumed, for the sake of discussion, that an increased biodiversity within city centers of Türkiye will have an intrinsic benefit. The focus here on a specific city center is not meant to imply that such a focus is the only or even the most important aspect in future efforts to maintain biodiversity in general. For example, it can be argued that limited resources should be prioritized to protecting the most biologically rich regions. The present work takes a contrasting approach, with the realization that there is potential for inhabitants of city centers can become more engaged with these issues if at least part of the focus of discussion is on the biodiversity within the urban centers themselves.

Study Area

In Fig. 1, the black line shows the provincial border of Isparta. There are 13 districts within the provincial border of Isparta. One of these districts is the Central district, which is bordered by the blue line. The city center of Isparta, bordered by the red dashed line, was chosen as the study area. Isparta city plan is given in Fig 2. The study area is located in the Mediterranean region of Türkiye, one of the 36 recognized biodiversity hotspots in the world (Birben 2020; Karataş *et al.* 2021). The averages of the last 33 years of climatic data were obtained from the General Directorate of Meteorology (2024). According to these data; the average temperature of Isparta is 12.5 °C. The annual average highest temperature in Isparta is 19.0 °C and the annual average lowest temperature is 6.4 °C. The hottest months in Isparta are July and August, while the coldest months are January and February. The average annual total precipitation in Isparta is 568 mm and the average annual number of rainy days is 99.

Isparta is also located at the intersection of the Mediterranean and Irano-Turanian phytogeographic regions. For this reason, Isparta has a rich biodiversity and a high rate of endemism. Isparta is located north of the Mediterranean region and is part of the Lakes Region. The average altitude of Isparta city center is 1049 meters. The general population of Isparta is 449,777 and the population of the city center is 271,396 (Urban Population, 2023). The size of active green areas (parks, playgrounds, and recreational areas) in four districts of Isparta city center is 1,452,506 m^2. The amount of green area per person in Isparta city center is 5.87 m^2. According to Gül *et al*. (2015), the total number of trees planted in public green areas (43 neighborhood parks, 4 boulevards, 2 city parks, and 1 recreation area) in Isparta city center is 46,254. About 11% of these trees consist of exotic plant species. 83 tree species have been used in the city center of Isparta. The crown area of existing trees is about 6.69% of the urban area. According to Carbonify (2023), a tree absorbs an average of 22 kg of carbon dioxide per year for 40 years. During its lifetime, each tree will absorb one metric ton of CO_2, but not all trees will reach their full carbon sequestration capacity because as they grow, they compete for resources, and some may die or be destroyed. Therefore, five trees should be planted to ensure that at least one will live for forty years, or that their combined sequestration will be one metric ton.

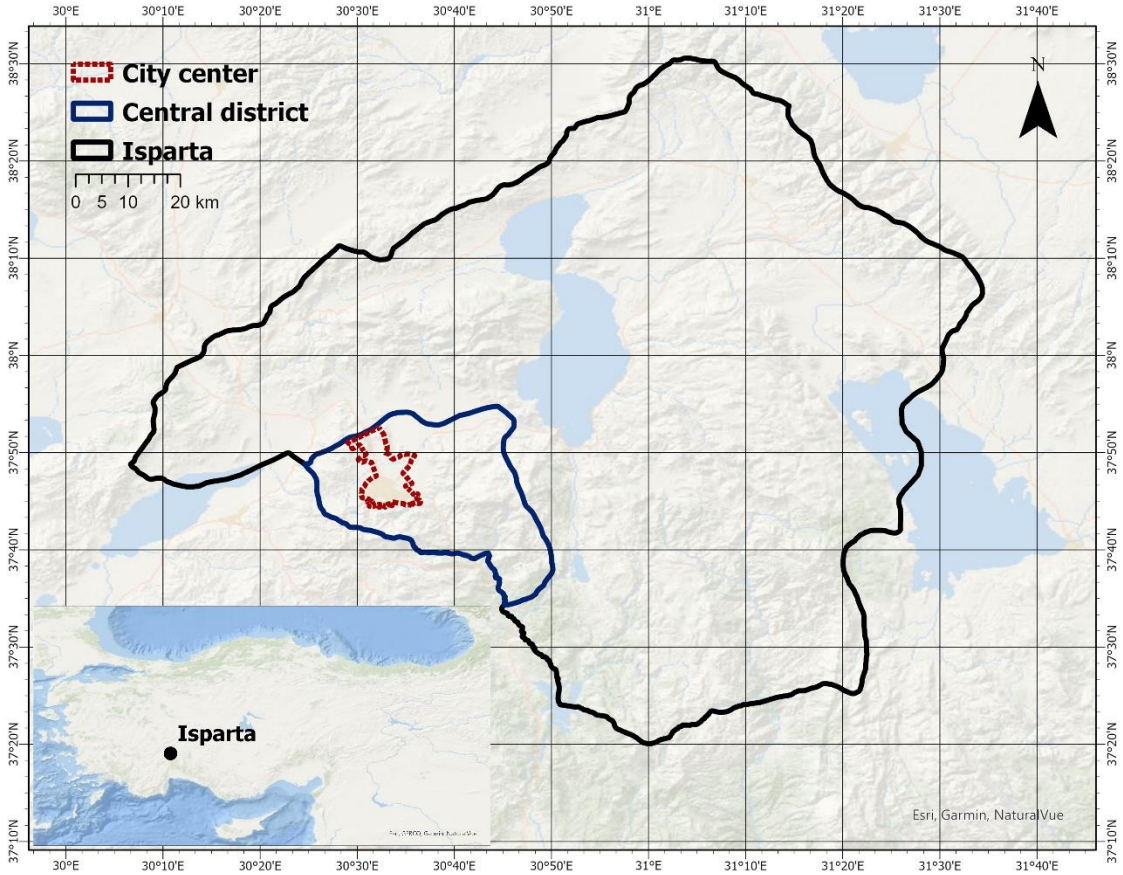

Fig. 1. Study area

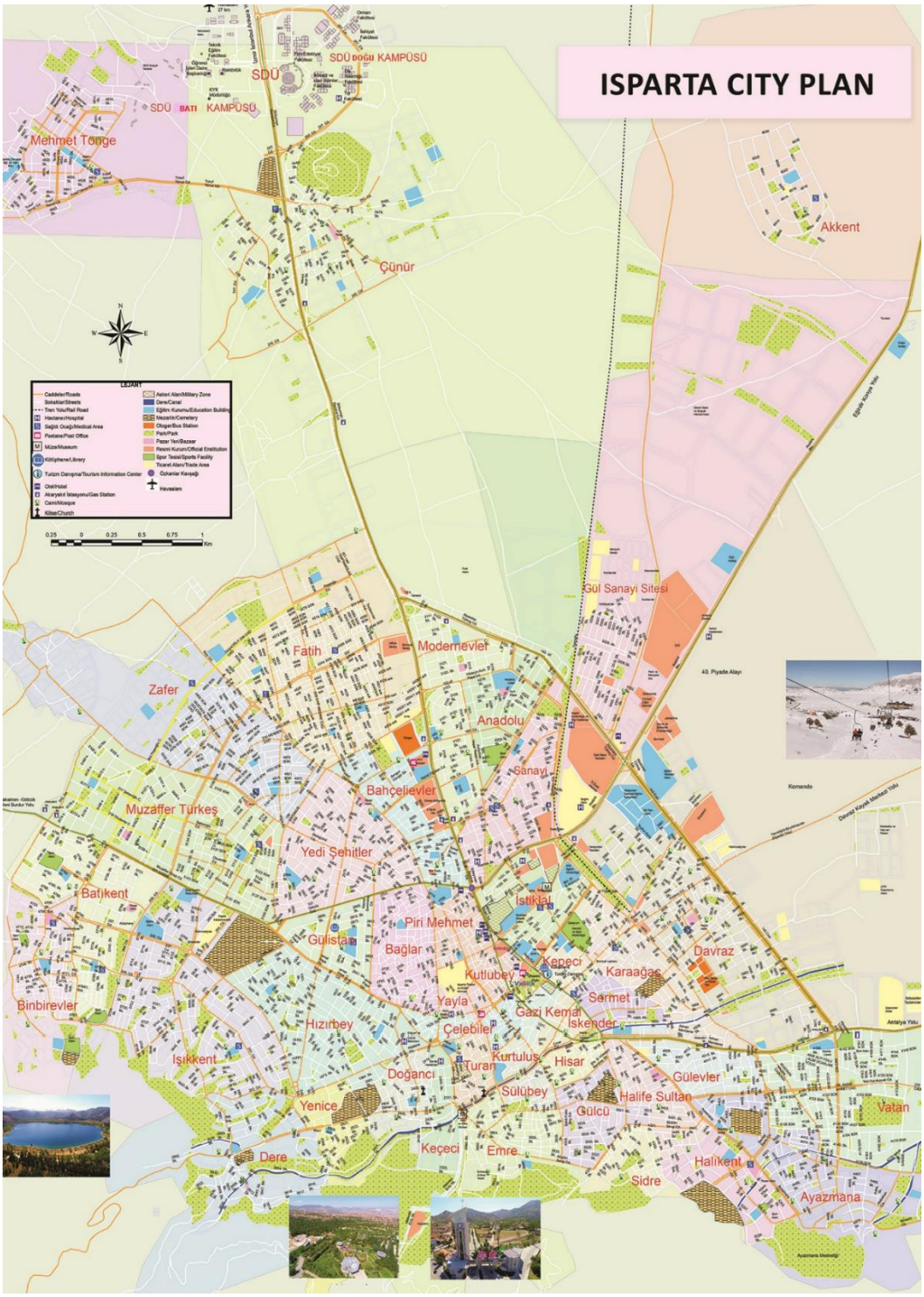

Fig. 2. Isparta city plan (Ministry of Culture and Tourism, 2024)

Methodology

There are some tools available to help cities manage biodiversity. These tools are not suitable for global use, as they are location-specific and have different sub-components in different geographical regions. For this reason, there was a need for a self-assessment tool that would encourage Turkish cities to monitor and evaluate their progress in managing

and increasing biodiversity. The Urban Biodiversity Performance Determination Method (UrBioPDeM) developed for cities is a tool that allows cities to monitor and evaluate their development and performance in terms of protecting and enhancing biodiversity and ecosystem services. This method has been developed by the authors of this article using various sources (Convention on Biological Diversity 2013; Chan *et al.* 2014; de Camargo *et al*. 2022).

The UrBioPDeM consists of 4 main factors and 32 sub-factors and indicators. The factors and sub-factors were determined based on a comprehensive literature review. In the literature review, the most common indicators that affect biodiversity and were used to evaluate the biodiversity performance of cities were examined (Kohsaka *et al.* 2013; Chan *et al.* 2014; Ruf *et al.* 2018; de Camargo *et al.* 2022). In this process, factors and sub-factors that could be suitable for the local dynamics of cities in Türkiye were determined based on indicators that have been proven to be effective in different geographies and urban contexts. In the process of determining the factors and sub-factors, interviews with experts in the field of biodiversity were used. These interviews make it possible to evaluate the applicability of the selected indicators in the Turkish cities context. In addition, field studies conducted in specific cities such as Isparta and feedback from local governments provided valuable insights into the validity and applicability of the indicators. The reason for choosing certain factors and sub-factors used in the UrBioPDeM model is that they have the potential to best reflect local biodiversity in different cities of Türkiye. These factors, sub-factors, and indicators not only ensure that biodiversity conservation targets are achieved, but also have the feature of being compatible with the current environmental policies of local governments. In this context, these data sets were created in light of data obtained from both scientific literature and local practices.

The factor weights of each main factor, *i.e.*, the degree of impact, were determined by group decisions due to the surveys conducted by a total of 20 field experts. The experts include 5 landscape architects, 5 botanists, 5 forest engineers, and 5 agricultural engineers. These experts were professionals, academicians, and local administrators experienced in the field of biodiversity and urban ecology. The surveys were designed to assess the influence of the factors on urban biodiversity and were used to determine the degree of importance of each factor. The experts evaluated the contributions and importance of the factors to biodiversity. As a result of these evaluations, the weights of the factors were determined. The measurement scales used in the surveys enabled experts to express the impact levels of the factors objectively. The survey results were analyzed by group decisions and consensus. The scores provided by the experts were combined and the degree of influence of each factor was determined using various calculation methods (*e.g.* mean, median, weighted score). This process aimed to objectively and systematically evaluate the contribution of the factors to biodiversity performance. This approach increased the validity and reliability of the model and allowed it to reflect the effects of the factors more accurately. As a result of the expert survey, it was determined that the abiotic factors of the ecosystem had a degree of impact of 0.35, the species (plant or animal) factors had a degree of impact of 0.30, the habitat type factors had a degree of impact of 0.20, and the governance and management factors had a degree of impact of 0.15. The indicators were prioritized based on factors that have a direct impact on biodiversity. Practical criteria such as the measurability of the selected indicators, their ability to be evaluated based on data, and their ability to be integrated into the strategic planning processes of local governments were taken into consideration. The performance score of each factor was determined by scoring 1 (the lowest score) or 4 (the highest score) according to the indicators in the

province, and the total performance score (PS) was obtained by multiplying the weighted scores. The data needed to calculate the urban biodiversity performance value in Isparta city center were obtained from literature, institutions, organizations, reports, and personal observations and measurements. The minimum and maximum scores are shown in Table 1.

Table 1. Minimum Scores, Maximum Scores, and Effect Levels of the 4 Main Factors

Main Factors	Minimum Scores	Maximum Scores	The Effect Level	Minimum Scores × The Effect Level	Maximum Scores × The Effect Level
Habitat Type Factors	5	20	0.20	1	4
Species (Plant/Animal) Factors	12	48	0.30	3,6	14.4
Ecosystem Abiotic Factors	4	16	0.35	1,4	5.6
Governance and Management Factors	11	44	0.15	1,65	6.6
TOTAL	32	128	1	7.65	30.6

The total score can range from a minimum of 7.65 to a maximum of 30.6. Based on this scoring system:

- A score range from 7.65 to 15.30 is classified as **low potential.**
- A score range from 15.31 to 22.95 is classified as **medium potential.**
- A score range from 22.96 to 30.60 is classified as **high potential.**

Strategic actions were determined by analyzing the cumulative score across various biodiversity performance aspects of the city. These categories enable the regular assessment of biodiversity performance over an expected monitoring period of five to ten years. The factors contributing to city-specific biodiversity are categorized into four main groups, as detailed below:

A. Habitat-Type Factors

These factors assess the types and extents of habitats within the urban landscape, which are critical to biodiversity preservation and enhancement:

1. **Percentage of protected natural areas in the urban area:** Represents the extent of legally protected zones dedicated to conservation efforts.
2. **Percentage of urban agricultural land in the urban area:** Reflects the contribution of agricultural land to urban biodiversity and sustainable food systems.
3. **Percentage of forest areas in the urban area:** Highlights the role of forested areas in providing habitat and ecosystem services.
4. **Percentage of urban green areas (active and passive):** Accounts for parks, recreation areas, and other green spaces vital to both human well-being and species diversity.
5. **Percentage of water surface areas:** Includes marshes, wetlands, lakes, and reservoirs, which are essential habitats for aquatic species and vital for hydrological balance.

B. Species (Plant and Animal) Factors

These factors measure the diversity of species within the urban area, with a focus on both flora and fauna:

6. **Diversity of animal species:** A broad measure of faunal biodiversity within the city.
7. **Endemic animal species:** The presence of species unique to the area, indicating a high level of biodiversity value.
8. **Rare, threatened, and endangered animal species:** Tracks the conservation status of species at risk of extinction.
9. **Bird species:** Birds serve as important ecological indicators and contribute to biodiversity richness.
10. **Butterfly species:** Butterflies are indicator species that reflect the health of ecosystems.
11. **Stray animals:** A measure of stray populations, which can influence local wildlife dynamics.
12. **Ratio of invasive to native animal species:** Helps evaluate the impact of non-native species on local biodiversity.
13. **Diversity of vascular plant species:** Measures the variety of vascular plants, critical for ecosystem functioning.
14. **Percentage of urban area covered by trees:** Represents tree canopy coverage, an essential component of urban ecosystems.
15. **Endemic plant species:** Identifies plant species that are unique to the urban area.
16. **Rare, threatened, and endangered plant species:** Monitors the status of at-risk plant species.
17. **Ratio of invasive alien plant species to native plant species:** Assesses the influence of non-native plant species on the local flora.

C. Abiotic Factors of the Ecosystem

These factors consider non-living environmental components that significantly impact urban biodiversity:

18. **Quality of urban water resources:** Includes drinking and municipal water quality, a key determinant of habitat health.
19. **Percentage of chemical pesticide use in agriculture:** A measure of the intensity of pesticide use, which can have direct and indirect impacts on biodiversity.
20. **Air pollution index:** Reflects the level of air quality, which influences both human and ecological health.
21. **Amount of carbon capture and storage:** Quantifies the city's capacity to sequester carbon, contributing to climate regulation.

D. Governance and Management Factors

These factors focus on the institutional and managerial efforts toward promoting and preserving urban biodiversity:

22. **Budget allocated to biodiversity initiatives:** Reflects the financial commitment to biodiversity conservation and restoration projects.
23. **Biodiversity projects:** Tracks ongoing and completed projects aimed at enhancing urban biodiversity.

24. **Existence of a local government unit dedicated to biodiversity or ecosystem services:** Demonstrates the governance structure in place for managing urban biodiversity.
25. **Local biodiversity strategy and action plan:** Indicates whether there is a formal strategy for biodiversity management at the municipal level.
26. **Local government agencies involved in biodiversity management:** Evaluates the roles and responsibilities of local institutions in biodiversity initiatives.
27. **Non-governmental organizations (NGOs) in biodiversity efforts:** Highlights the contributions of NGOs to biodiversity conservation.
28. **Outreach and public awareness initiatives:** Assess public engagement and education efforts related to biodiversity.
29. **Percentage of agricultural land used for non-agricultural purposes:** Examines the loss of agricultural land to urbanization and its impacts on biodiversity.
30. **Green areas *per capita*:** Measures the availability of green space for the urban population, an important aspect of human-nature interactions.
31. **Visitors to protected and green areas:** Tracks public use of these areas, which can have both positive and negative effects on biodiversity.
32. **Ecological bridges:** Infrastructure designed to allow wildlife to safely cross urban barriers, promoting habitat connectivity.

RESULTS AND DISCUSSION

Table 2 lists the 4 main factors and 32 sub-factors of the UrBioPDeM model. Table 2 also includes the urban biodiversity performance value for the conservation and management of urban biodiversity in the city center of Isparta.

Data were collected from various sources to score the indicators of the UrBioPDeM in Isparta city center. Accordingly, the total points were calculated as 8, 30, 10, and 23 for the main factors: habitat type factors, species (plant and animal) factors, ecosystem abiotic factors, and governance and management factors, respectively (Table 2). The final assessment scores were calculated by multiplying the total scores of the main factors by the degree of impact of the main factors. As a result of the evaluation, the biodiversity performance score was calculated to be 9.45 points. This shows that urban biodiversity in Isparta city center has a low potential.

The Lakes Region, which includes Isparta, has rich fauna and flora depending on climate, soil, and rock types. The Lakes Region is one of the important plant differentiation centers and biodiversity areas of Türkiye (Özçelik 2017; Aydın 2021). Despite its small surface area of 8946 km^2 (only 1.1% of Türkiye's surface area), Isparta is a province with a very high biodiversity. Within the borders of Isparta province, there are protected areas such as Gölcük Nature Park, Eğirdir Lake, Başpınar Nature Park, Kızıldağ National Park, Kasnak Oak (*Quercus vulcanica* Boiss. & Heldr. ex Kotschy) Nature Protection Area, Kovada Lake National Park, Yazılı Kanyon National Park, which contain various flora, fauna, and landscape features.

Table 2. Factors, Sub-factors, Indicators, Final Evaluation Scores, and the Biodiversity Performance Score of Isparta City Center

Factors	No.	Sub-factors	Indicators	Low Potential (1 Pt)	High Potential (4 Pts)	Evaluation For Isparta City Center	Total Scores of the Main Factors	The Effect Level	Total Scores × The Effect Level
Habitat Type	1	Percentage of protected natural areas in the urban area	(protected natural areas) / (urban area) x 100	× < 5%	5% ≤ x	1	8	0.20	1.6
	2	Percentage of urban agricultural land in the urban area	(urban agricultural areas) / (urban area) x 100	× < 5%	5% ≤ x	1			
	3	Percentage of forest areas in the urban area	(forest areas) / (urban area) x 100	× < 5%	5% ≤ ×	4			
	4	Percentage of urban green areas (active and passive)	(urban green areas) / (urban area) x 100	× < 10%	10% ≤ ×	1			
	5	Percentage of water surface areas	(water surface areas) / urban area) x 100	× < 5%	5% ≤ ×	1			
Species (Plant and Animal) Factors	6	Diversity of animal species	The number of animal species	× < 50	50 ≤ ×	4	30	0.30	0.9
	7	Endemic animal species	The number of endemic animal species	× < 5	5 ≤ ×	1			
	8	Rare, threatened, and endangered animal species	The number of rare, threatened, and endangered animal species	× < 5	5 ≤ ×	1			
	9	Bird species	The number of bird species	× < 5	5 ≤ ×	4			
	10	Butterfly species	The number of butterfly species	× < 5	5 ≤ ×	1			
	11	Stray animals	(number of stray animals) / (number of urban population) x 100	1% < ×	× ≤ 1%	1			
	12	Ratio of invasive to native animal species	(number of invasive animal species) / (number of native animal species) x 100	10% < ×	× ≤ 10%	4			

	13	Diversity of vascular plant species	The number of species of vascular plant diversity	× < 50	50 < ×	**4**			
	14	Percentage of urban area covered by trees	(Number of urban trees) / (number of urban population) x 100	× < 10%	10% < ×	**4**			
	15	Endemic plant species	The number of endemic plant species	× < 5	5 ≤ ×	**4**			
	16	Rare, threatened, and endangered plant species	The number of rare, threatened, and endangered plant species	× < 5	5 ≤ ×	**1**			
	17	Ratio of invasive alien plant species to native plant species	(The number of invasive alien plant species) / (number of native plant species) x 100 5087 / 46254 x 100 = 11%	10% < ×	× ≤ 10%	**1**			
Abiotic Factors of the Ecosystem	**18**	Quality of urban water resources		III and IV Class Water Quality	I and II Class Water Quality	**4**	**10**	**0.35**	**3.5**
	19	Percentage of chemical pesticide use in agriculture	(The amount of chemical pesticide) / (The amount of all pesticides) x 100	1% < ×	× ≤ 1%	**1**			
	20	Air pollution index	The rate of particulate matter in the air (annual average)	10 μg/m^3 < ×	× ≤ 10 μg/m^3	**4**			
	21	Amount of carbon capture and storage	Number of city trees x 25 kg CO_2/per tree in one year/number of urban inhabitants) x 125 kg (5 trees per person x 25 kg) x 100 46254 x 25 kg x 100: 268595 x 125 kg = 3.4% (Stores 25 kg of carbon per tree per year)	× < 10%	× ≥1 0%	**1**			
Governance and Management	**22**	Budget allocated to biodiversity initiatives	The percentage of the local budget allocated to biodiversity	× < 3%	3% ≤ ×	1			
	23	Biodiversity projects	The number of biodiversity projects implemented annually in the city	× < 3%	3% ≤ ×	4			

	24	Existence of a local government unit dedicated to biodiversity or ecosystem services		No	Yes	4	23	0.15	3.45
	25	Local biodiversity strategy and action plan		No	Yes	1			
	26	Local government agencies involved in biodiversity management	The number of local government agencies involved in inter-agency cooperation pertaining to biodiversity issues	× < 5	5 ≤ ×	1			
	27	Non-governmental organizations (NGOs) in biodiversity efforts	The number of non-governmental organizations involved in inter-agency cooperation pertaining to biodiversity issues	× < 5	5 ≤ ×	1			
	28	Outreach and public awareness initiatives	The number of outreach or public awareness events on biodiversity or nature awareness held in the city each year	× < 10	10 ≤ ×	4			
	29	Percentage of agricultural land used for non-agricultural purposes	(Non-purpose land use rate of agricultural land) / (urban area) x 100	10% < ×	× ≤ 10%	1			
	30	Green areas *per capita*	(Active urban green areas) / (The population of the city) x 100	× < 10 m^2	10 m^2≤×	1			
	31	Visitors to protected and green areas	(The number of visitors) / (The number of city population) x 100	× < 10%	1% ≤×	4			
	32	Ecological bridges	(The number of ecological bridges) / (The number of bridges) x 100	× < 10%	10% ≤×	1			
					Biodiversity Performance Score:				**9.45**

There are approximately 600 endemic plant species within the borders of the province (Fakir *et al.* 2005). There are many studies revealing the biodiversity richness in various regions of Isparta at the microscale within the district borders, nature parks, national parks, mountainous regions, and wetlands (Fakir *et al.* 2005; Tabur and Ayvaz 2005; Karaca *et al.* 2006; Aslan and Ayvaz 2009; Japoshvili *et al.* 2009; Güngör *et al.* 2015; Özen and Fakir 2015; Negiz *et al.* 2017; Özçelik 2017; Özçelik 2019; Aydın 2021; Kaytanlıoğlu *et al.* 2023; Özçelik 2023, Öztürk 2024). The mentioned studies focus on the diversity of birds, plants, insects, fungi, *etc.* found in the natural environment in a particular region. The city center is typically regarded as the commercial, cultural, historical, political, and geographical center of a city. The city center is the area where the city's most important public and semi-public services are located, where there is a diversity of urban uses, where there is a node in the transportation network with squares and passages opened to pedestrian transportation, where the population reaches its highest level with pedestrian and vehicle circulation, and where the highest land values are formed.

City centers are settlement areas that have high population density and a structured infrastructure but are also semi-natural areas that are generally artificially created. Since people decide on the process of creating cities, cities cannot be expected to fully reflect the natural biodiversity richness of their immediate surroundings. Although the rich biodiversity of Isparta was revealed in previous studies conducted within the borders of Isparta province, as a result of our current study, it was concluded that the biodiversity potential of Isparta city center is low. The high biodiversity richness of Isparta could not be sufficiently utilized in the city center.

There may be several reasons why Isparta has a rich biodiversity but low biodiversity in the city center. Factors such as urban development activities, the creation of artificial ecosystems, the use of exotic-invasive plant species, and the scarcity of natural/native plant and animal species have reduced the biodiversity potential in the city center. Isparta city center is characterized by dense human settlements, construction, and infrastructure projects. Such urban development causes the reduction of natural habitats, ecosystem fragmentation, and the shrinkage of habitats for native species. Green areas are generally limited in city centers, which contributes to the decrease in biodiversity. Parks, gardens, and other green areas provide important habitats for biodiversity, but the inadequacy of such areas in city centers negatively affects the level of biodiversity. City centers are full of intense human activities.

Factors such as traffic, industrial activities, pollution, and noise have negative effects on biodiversity. Such stress factors make it difficult for some species to survive in the city center. Isparta's natural areas (for example, forests, lakes, *etc.*) are located outside the city center. Since the city center is far from these natural areas and there are no green corridors between these areas, it is not possible to transfer the rich biodiversity to the city center by natural means. This results in relatively low biodiversity in the city center. Not using native, natural plant species in landscape areas can lead to a decrease in biodiversity. Native species have adapted to the ecosystem of the region and have developed symbiotic relationships with the local fauna. However, when exotic or ornamental plants are used instead of these species, the balance and diversity of the ecosystem are disrupted. In the city center of Isparta, only stray animals and a few bird species live as animal species. The lack of natural or semi-natural areas in the city center leads to the lack of suitable habitats for wildlife. Such areas are critical for the preservation of biodiversity because many species shelter, feed, and reproduce in these areas. The lack of these areas can be seen as another important reason for the low biodiversity in the city center. The introduction of

alien and invasive exotic species into the landscape can undermine the competitiveness of native species and threaten biodiversity. These species can encroach on the habitats of native plant and animal species, leading to a decline in biodiversity. For these reasons, the richness of biodiversity in Isparta's natural environment does not overlap with the richness of biodiversity in the city center.

Urban biodiversity has started to gain importance because of the increasing artificialization of cities and the increase in the density of construction, and therefore it has become the main component of urban planning and management policies for its conservation, sustainability, and applicability. For this purpose, strategic biodiversity action plans should be prepared and implemented for each city. Through calculating the biodiversity performance of each city, strategic actions are predicted according to its level, which can be monitored and audited periodically. In this way, the performance of the city will be determined, and local administrators, politicians, decision-makers, and planners will play an important role in producing environmentally friendly solutions. This will increase the awareness of the city's population and lead to more effective decisions.

It is expected that the problems arising in urban areas and the possible effects of climate change may negatively affect the character and lifestyle of the city, as well as negatively affect the biodiversity system and capacity. It is necessary to develop environmentally friendly and ecological-based solutions to reduce or prevent the possible impacts and negative effects of climate change in cities. To this end, the protection, enhancement, and sustainability of urban green spaces and natural systems, which are considered as carbon sinks, are among the priority actions. To protect urban biodiversity, scientific studies should be conducted on the number, density, content, relationships, and interactions of existing species and biotopes in the urban environment, *etc*., and an inventory should be made. Urban ecosystem management plans are required for the protection and sustainability of urban ecosystem services. Defining thresholds for biodiversity performance indicators in the urban biodiversity monitoring process will facilitate remedial action. As a result, it will serve as a guide for managers, decision-makers, and planners to improve biodiversity awareness in projects and practices, land-use decisions, prioritization of development investments, and decision-making processes. Biodiversity monitoring is a complicated and nuanced issue, and understanding the existing matrix of measurement methods is a necessity for understanding the underlying phenomenon; therefore, policy makers need to have access to this information. In this context, monitoring mechanisms at the urban scale should be structured to disclose the current state, identify, and monitor the consequences, identify the needs, take improvement actions, and implement them for the conservation and sustainability of urban biodiversity.

To increase biodiversity in the city center of Turkish cities, connections between wildlife corridors and green areas should be ensured, organic maintenance methods should be used, and native and appropriate plant species should be used. Non-native invasive plant species should not be planted, existing habitats or vegetation structures should be diversified, and animal diversity should be increased by increasing the food source, food, clothing, and electrical appliances, among others. Waste of consumer goods must be reduced and people must be educated about biodiversity, ecosystems, threats to them, and ways to improve them.

Protected areas are geographical areas defined and managed by law to ensure the long-term protection and continuity of ecosystem services and cultural values with nature. The goals and efforts made since the adoption of the Convention on Biological Diversity (1992) have slowed down the extinction process in nature somewhat but have not been

enough to reverse the downward trend of biodiversity loss. In the WWF-Türkiye (2023) report, it was stated that while the ratio of protected areas on a global scale to the terrestrial surface was 2.6% in 1970 since then it has increased fivefold in the past 50 years and reached a high of 13.2% in 2020. In Türkiye, one of the richest Mediterranean countries in terms of species and habitat diversity and known for its high endemism rate, the total net area of protected areas was 10,576 km^2 as of 2013, and the ratio of these areas to the country's surface area was only 1.3%. The total net area of protected areas is 37,395 km^2 by the end of 2023, and the ratio of these areas to the country's surface area is 4.8% (Ministry of Agriculture and Forestry 2024). While the total area of protected areas in the world was about 2 million km^2 in 2000, as of 2020, this number reached 26,947,375 km^2 (WWF-Türkiye 2023). The Protected Planet Report (2020) states that great progress has been made in the field of protected areas since 2010, with documented protected and conserved areas including 22.5 million km^2 of terrestrial and inland water ecosystems and 28.1 million km^2 of coastal waters and oceans, an increase of more than 21 million km^2 since 2010. About 4% of Türkiye's territorial waters have the status of a legally protected area (WWF-Türkiye 2023). Protected areas need to be increased in line with new international goals for sustainable Turkish cities. To ensure the healthy functioning of the world, at least one-third of terrestrial and marine ecosystems must be protected and everything in these areas must be allowed to continue its natural dynamics. Özçelik (2023) stated in a study that he identified around 20 important areas that need to be protected within the borders of Isparta province and that only 8 of them have legal protection status.

The awareness of local governments in Turkish cities regarding the environment and biodiversity and the capacity to implement these projects determine whether the proposals will be successful or not. The implementation of the specified recommendations will not cause high costs. Sufficient financial resources are being transferred to provincial municipalities in Türkiye. These transferred funds should be used efficiently on priority issues. At this point, the action that needs to be taken is for local governments to demonstrate a strong will. Isparta's current infrastructure is at a level that will support the implementation of these projects. Local and central institutional structures related to biodiversity should be established in Isparta. Institutions and organizations related to biodiversity, the number of projects implemented in these institutions, and administrative infrastructure should be increased. The number and financial resources of non-governmental organizations related to biodiversity should also be increased. Creating a biodiversity inventory involves costs such as data collection, field studies, employment of experts, and the use of GIS (Geographic Information Systems) software. This process does not have a large additional cost for local governments. The capacity of local governments to implement these projects depends on their human resources, technical equipment, and budget status. All provincial municipalities in Türkiye employ professional disciplines such as agricultural engineers, landscape architects, environmental engineers, and zoologists. Likewise, GIS software has begun to be integrated into Turkish municipalities and the establishment of urban information systems has been made mandatory by the central government. These processes are a necessary investment for long-term planning and sustainability of cities and do not bring high costs. Local governments, central government funds, international environmental projects, and academic institutions are qualified to provide financial support for this project.

Defining the legislation on urban biodiversity and integrating this data into planning processes is of critical importance in terms of applicability. Strengthening the legislation will ensure the successful implementation of these recommendations.

The environmental awareness of the local people and their interest in such projects directly affect the feasibility of the proposals. If the public supports projects aimed at increasing biodiversity, the success of these projects increases. Urban society should be informed about biodiversity; educational research and monitoring activities should be carried out. Ensuring public participation in projects and conducting awareness-raising activities will increase the feasibility of the suggestions. Likewise, Gül *et al.* (2013) stated in a study that city dwellers demand the establishment of recreational green areas with water surfaces and visual value in cities. If projects are designed to increase the quality of life of the public and contribute positively to the environment, it is expected that the public will have a positive attitude towards these projects. Projects such as increasing green areas in particular may receive widespread support because they directly benefit the daily lives of the public. Local governments and civil society organizations should inform the public about these projects and organize educational programs that encourage participation. The public's reactions to such projects determine how successful the proposals will be in practice. Designing projects in accordance with the needs and expectations of the public will increase social acceptance. Therefore, the public's views should be sought and participation in the projects should be ensured.

Urban forests are home to a significant percentage of the species found in the nearby natural ecosystem, including endangered species. A significant portion of a country's tree canopy can be the urban forest, which includes plants in urban parks, woodlots, abandoned buildings, and residential areas (Alvey 2006). Urban forests and trees allow cities to welcome wildlife back into our neighborhoods by providing habitat for migratory species and pollinators. They also often have greater tree diversity than rural forests and thus serve as repositories of genetic diversity. For these reasons, the quantity and quality of urban forests in cities should be increased.

The use of pesticides has a negative impact on biodiversity. Such agents can have immediate harmful effects on organisms directly exposed to them, and changes in habitats and the food chain can have long-term effects. After decades of use in agriculture, their toxicity and ability to accumulate in soils and the food chain have been recognized, and these pesticides have been a major factor in the decline of our current natural resources, ecosystems, and biodiversity. Pesticide-intensive agriculture is a major contributor to the loss of biodiversity. The misuse and overuse of pesticides contaminates nearby soil and water supplies, causing loss of biodiversity, wiping out populations of beneficial insects that serve as natural enemies of pests, and reducing the nutritional value of food. For this reason, the use of chemical pesticides in agriculture should be abandoned in favor of products that do not harm nature, and biological control should be preferred.

Urban agriculture can bring many environmental, financial, and social benefits to the neighborhood. According to Clucas *et al*. (2018), urban agriculture promotes pollinator habitats, increases plant, animal, and insect biodiversity, and supports soil health and fruit and vegetable production. Natural filtration of air and water, promotion of soil carbon sequestration, provision of shade, and the ability to reduce extreme temperatures are all benefits of planting tree crops and diverse plant species in urban areas (Santo *et al*. 2017). Integrating urban agricultural areas into cities should provide financial, environmental, and economic benefits.

In contrast to national biodiversity strategies and action plans, which are the basic plans for the conservation and sustainable use of biodiversity at the national level, there are local biodiversity strategies and action plans, which define those at the local level, such as cities. It is recognized that these strategies and action plans are critical for the

implementation of the Convention on Biological Diversity in each country (Avlonitis *et al*. 2012). Because they enable the translation of international and national biodiversity policies and targets into workable action plans at the local level, local biodiversity strategies and action plans are crucial tools for local governments to implement biodiversity conservation and action. A local biodiversity strategy and action plan is a guiding plan that local governments adopt to achieve the best and most practical governance and management of biodiversity and ecosystem services. It is complemented by specific actions. Local biodiversity strategies and action plans are increasingly being developed at the state, provincial, territorial, municipal, and city levels. Therefore, local biodiversity strategies and action plans should be developed for all Turkish cities. Inclusive, participatory, and scientific urban biodiversity management plans should be developed for each city.

This model was tested as a pilot application area in the city of Isparta, and the evaluation showed that urban biodiversity has low potential with a biodiversity performance score of 9.45. The reasons for this can be summarized as follows:

• The presence of few natural areas and agricultural areas within the city,

• The presence of few active and green areas within the city in terms of quality and quantity, especially the fact that green areas are small in size and are fragmented and unequal and unbalanced distribution at the city level,

• Low amount of open and green areas *per capita* in the city (5.87 m^2 *per capita*),

• The presence of few water surface areas (marshes, wetlands, lakes, reservoirs, *etc*.) within the city,

• The presence of many stray animals (dogs and cats) within the city,

• The presence of few natural animals within the city,

• The presence of few natural plant species within the city,

• The intensive use of chemical pesticides in agricultural areas within and around the city,

• Low capacity of trees to capture and store carbon as biomass,

• Inadequacy of the local budget allocated for biodiversity or green areas of the city,

• The absence of strategic projects and actions by the local government regarding biodiversity,

• The presence of insufficient numbers and participation of NGOs related to nature and the environment,

• Opening up 1st and 2nd class agricultural lands within the city to residential developments, *etc*.

The deficiencies identified in line with these results obtained in the city center of Isparta should be addressed as a priority. Strategic policies and actions should be envisaged to increase the number and areas covered by open and green areas in and around the city and to create organic green belts and corridors between green areas and natural areas in and around the city. Thus, green belts and corridors will enable plant and animal species to move safely between habitats in and outside the city and will increase genetic diversity and the survival chances of species. In addition, it will support ecosystem services such as water management, air cleaning, climate regulation, and carbon storage. It will provide ecological and social benefits while protecting the environmental health of cities. It should be aimed at increasing the amount of green areas *per capita* on a city scale and especially to use natural species that are compatible with the region. The natural areas within the city should be protected. Agricultural areas should not be opened to development. The use of chemical pesticides should not be allowed in existing agricultural areas. Solutions that will provide

more suitable living conditions for stray animals in the city, respecting their right to life, should be produced. Local governments should allocate a satisfactory budget for the city's green areas and biodiversity issues. An urban ecosystem and biodiversity commission should be established within the city's municipality. In addition, action-oriented projects on biodiversity should be encouraged, produced, and implemented by local governments. The number of NGOs related to nature and the environment should be increased. Cooperation and coordination should be ensured among relevant stakeholders (local governments, universities, schools, NGOs, official institutions and organizations, city people, *etc*.).

CONCLUSIONS

Rapidly progressing climate change, which is considered the most important global threat of our time, not only has direct effects on economic, social, and human health, but it also affects many species and therefore ecosystems in the world, causing loss of biodiversity. Due to the increasing population and urbanization, the factors caused by climate change affect all cities. City centers are areas under intense human influence, where natural habitats are largely transformed and ecosystem services are degraded. Increasing the resilience of cities is critical for cities to cope with climate-related extreme weather events and natural disasters. Protecting, managing, and restoring ecosystems, known as nature-based solutions, is one of the most efficient approaches to both mitigate and adapt to climate change. Biodiversity, which refers to the variety of life in different ecosystems, has become a necessity not only in rural or natural areas but also in urban areas. Urban biodiversity, which regulates the urban ecosystem, provides multifaceted services and contributions and develops and increases its quality, is becoming more important every day. Efforts to protect and increase urban biodiversity are of great importance in terms of ecosystem health and sustainability.

The current biodiversity potential of a city can also be considered as an indicator of the holistic urban space quality. In this context, in order to reveal urban biodiversity performance, it is necessary to determine the factors, sub-factors, and indicators of performance. Thus, the evaluation of the biodiversity performance of cities can be an important guide for city managers, decision-makers, planners, and other stakeholders in determining the city's strategic plans, objectives, actions, investments, and prioritizations by revealing the city's current status in terms of weaknesses and strengths, threats and risks, and opportunities. As a result, it will be possible to increase awareness of urban biodiversity and to develop healthy urban spaces that support biodiversity in urban planning, design, and applications.

Increasing the quantity and quality of open and green areas (parks, gardens, children's playgrounds, sports playgrounds, recreational areas, green roofs, vertical gardens, *etc*.) and natural areas (forests, protected areas, wetlands, *etc*.) in and around the city with high biodiversity potential, creating an organic network system among themselves, improving and developing urban ecosystem services and contributions, and sustainable and healthy urban life are of critical importance and strategic prioritization. Because the amount of green area *per capita* in urban areas is an important indicator that directly affects the spatial quality and living standards of the city. The World Health Organization (2012) determined the lower limit value as 9 m^2 *per capita*. In Türkiye, the amount of green area *per capita* in urban areas must be at least 10 m^2 *per capita*. However,

the vast majority of the cities in Türkiye are below this standard. For example, the amount of green area *per capita* in Isparta is 5.87 m^2.

Biodiversity is not only an environmental/ecological issue but also a social, cultural, and economic issue. Therefore, efforts to increase biodiversity in city centers will not only protect nature but also provide services and contributions to urban people's well-being, positively affecting mental and physical health, reducing stress levels, encouraging physical activity, connecting people with nature, strengthening social ties, creating environmental education and awareness, increasing spatial attractiveness, creating local job opportunities, encouraging social participation, *etc.*

Economic investments and prioritizations to be made in biodiversity will play an important role in reducing urban heat island effect and carbon emissions, ensuring energy efficiency, and preparing cities for the future to be more resilient, livable, and sustainable cities in the fight against climate change. In addition, efforts to increase biodiversity in urban centers and economic investments to be made should be used for the protection and improvement of existing natural area ecosystems and species.

Increasing biodiversity in city centers may initially pose difficulties, such as high costs. However, in the long term, these investments should be seen as one of the cornerstones of creating sustainable cities. Therefore, investments in increasing biodiversity in city centers are of great value not only in terms of the environment but also in terms of social, economic, and health. In situations where resources are limited, biodiversity studies should be prioritized. In this context, it is necessary to determine strategies that will provide the greatest biodiversity gains. The cost of investments to be made in biodiversity can be considered as a very rational and efficient strategy when the multifaceted gains it brings are considered. These investments will be able to provide cost-effective solutions in the long term. Carrying out such studies in city centers may be critical in ensuring that these regions do not become biodiversity deserts. However, it should not be overlooked that these investments should also be aimed at protecting the resource areas richest in terms of biodiversity. Money and effort should be distributed in a balanced way to increase biodiversity in urban centers and to protect natural areas. Both areas complement each other in terms of building a sustainable future and providing ecological, economic, and social benefits. Directing resources to these two areas will ensure the preservation of ecosystems, the improvement of the quality of urban life, and the guarantee of a healthy environment for future generations. With this approach, it is possible to achieve sustainable development goals by allocating sufficient resources not only to increasing biodiversity in urban centers but also to protecting natural areas. Therefore, when making investment decisions, the importance of both areas should be taken into account, and the long-term benefits of investments made in these areas should be taken into account.

When projects to increase biodiversity are planned with a strategic and holistic approach, costs can be minimized. Projects carried out with the cooperation of local governments, the private sector, NGOs, and the public ensure efficient use of resources and help avoid unnecessary expenditures. For example, involving local communities and encouraging volunteer activities can help reduce costs. In addition, re-evaluating existing urban areas and transforming them into green infrastructure can reduce costs by eliminating the need to create new areas. Achieving a balance between nature conservation and economic costs requires a long-term perspective, and in this perspective, any effort to increase biodiversity should be seen as a valuable investment.

Türkiye is a country that offers a wide range of biodiversity with its different geographical and climatic regions. However, while rural and natural areas have rich

biodiversity, unfortunately, it is seen that biodiversity capacity in urban areas is very low and is not considered important. Because current research in Türkiye focuses on biodiversity in natural areas or rural areas, research on urban biodiversity in city centers is very limited, and there is no holistic model measuring urban biodiversity performance. However, within the scope of reducing climate change and adaptation processes and reducing carbon emissions, increasing urban biodiversity capacity and especially increasing carbon sink areas have come to the agenda.

In this study, the original "UrBioPDeM" for urban biodiversity performance assessment was developed and implemented on the Isparta city scale, and recommendations were made. In the UrBioPDeM model, 4 main factors (habitat type, species, abiotic, governance/management) and 32 sub-factors and indicators were used. The method used in this study was created to develop an assessment tool that can reflect the unique dynamics of Turkish urban centers and was designed by taking into account the specific challenges and conditions of biodiversity in urban centers. This method was created by selecting appropriate indicators and criteria to assess the biodiversity of areas located at the intersection of both natural and urban environments. The method provides a more precise measurement by considering factors such as the presence of natural species in these regions, the status of ecosystem services, and habitat diversity while assessing the biodiversity in urban centers. In the UrBioPDeM, the weights of the factors were determined by taking into account the local dynamics specific to the cities (*e.g.*, social, economic, cultural, and environmental factors). In addition, the complex structure of the urban landscape and human impacts were taken into account in this method, and an assessment tool suitable for the unique ecosystems of urban centers was developed. Since local dynamics differ in various cities in Türkiye, the model can be customized to reflect these differences. In this context, a holistic, flexible, practical, sustainable, updatable, and easily applicable method that can be applied to every city was obtained. Thanks to the flexible structure of the model, the main/sub-factors and indicators and prioritizations used in this method can be adapted and revised according to the local dynamics of the city (social, economic, cultural, political, and environmental characteristics). Thus, a large-scale assessment model has been presented to contribute to the development of effective strategies for the protection and sustainability of biodiversity in urban centers throughout Türkiye.

This model was tested as a pilot application area in the city of Isparta, thus demonstrating that the model can be used as a practical tool for local governments. The UrBioPDeM model supports urban decision-making processes based on concrete data. The model can be integrated into the strategic planning processes of local governments and can be used as an effective tool for the protection, improvement, and development of urban biodiversity.

Obtaining data on the factors, sub-factors, and indicators used in the UrBioPDeM model requires the creation of comprehensive and up-to-date urban databases. These databases are of critical importance for the accurate assessment of the biodiversity performance of cities. The development of such databases for cities in Türkiye will increase the applicability and validity of the model. In many cities in Türkiye, especially in large metropolitan areas, data collection and management infrastructure has been gradually developing in recent years. Geographic information systems (GIS), remote sensing technologies, and digital mapping tools play an important role in this process. The creation, updating, and analysis of all kinds of geographic, spatial, social, and cultural inventory data

belonging to the city within the scope of the newly created and mandatory urban information system in cities in Türkiye further increases the applicability of this model.

The fact that urban local governments in Türkiye are increasingly giving importance to environmental data management and biodiversity projects (urban tree information systems, green area systems, *etc.*) and carrying out action-oriented studies are important developments for the creation of urban databases. In this context, the collection of data required by the UrBioPDeM and the implementation of the model based on this data will be an important step towards improving the urban biodiversity performance of Turkish cities. The criteria and indicators used in the UrBioPDeM model are designed to be integrated with the existing data sources and data of local governments.

Biodiversity performance indicators for a city are indicators that show the current situation, pressures, responses, and benefits to help managers, decision makers, and planners monitor the goals, targets, and strategies of the city's ecosystem services. The developed biodiversity performance indicators were determined using the SMART (specific, measurable, achievable, relevant, and timely) principles. It is also of great importance to define measurement tools for monitoring, auditing, and reporting the sustainability of urban biodiversity. Therefore, the implementation of the model will allow for the accurate assessment of urban biodiversity throughout Türkiye.

This model, which was created for the first time in Türkiye, has a unique feature in Türkiye as a research project aiming to measure the biodiversity of Isparta city center. This situation reveals the originality of our study and fills an important gap in the assessment of biodiversity in urban centers in Türkiye.

For the successful and effective use of this method:

1. A biodiversity inventory should be prepared for each city, digitized in GIS, and included in city information systems.
2. Urban biodiversity should be defined in relevant legislation.
3. Urban biodiversity data should be integrated into key planning decisions (environmental plan and master development plan).
4. Urban ecosystem management plans should be developed for the protection and sustainability of urban biodiversity. In this model, deficiencies that arise according to the performance level should be determined, and strategic actions should be prioritized.
5. The development of urban biodiversity should be linked to planning and urban design and reflected in decision-making processes.
6. Collaboration between relevant stakeholders (institutions, private sector, universities, citizens, NGOs, etc.) in urban biodiversity studies should be ensured.
7. A local urban ecosystem and biodiversity commission should be established in the city.
8. The data to be used for the indicators used in the methodology should be up-to-date and reliable.
9. Measurement tools such as monitoring, auditing, and reporting at the city level must be defined, and administrative mechanisms must be established.

A healthy and livable future for cities will be possible through the implementation of nature-compatible and ecological choices and decisions in discourse and action.

ACKNOWLEDGMENTS

This article was presented at the 1st International Symposium of Biodiversity Studies and only the abstract was published in the symposium book. We would like to thank Dean Southern, a native English speaker, for helping proofread, as well as Dr. Gizem Dinç for preparing Fig 1.

REFERENCES CITED

Alvey, A. (2006). "Promoting and preserving biodiversity in the urban forest," *Urban Forestry and Urban Greening* 5(4), 195-201.

Aslan, E. G., and Ayvaz, Y. (2009). "Diversity of Alticinae (Coleoptera, Chrysomelidae) in Kasnak Oak Forest Nature Reserve, Isparta, Türkiye," *Turkish Journal of Zoology* 33(3), 251-262. DOI:10.3906/zoo-0806-2.

Avlonitis, G., Doll, C., Galt, R., Mader, A., Moreno-Peñaranda, R., Patrickson, S., de Oliveira, J. A. P., and Shih, W. (2012). "Local biodiversity strategy and action plan guidelines: An aid to municipal planning and biodiversity conservation," in: *ICLEI Local Governments for Sustainability*, United Nations University of Advanced Studies, and Secretariat of the Convention on Biological Diversity. DOI: 10.13140/RG.2.2.28707.45607.

Aydın, G. (2021). "Comparison of insect biological diversity parameters in natural and degraded habitats in Gölcük Nature Park (Isparta, Türkiye)," *Turkish Journal of Agriculture and Forestry* 22, 362-365. DOI: 10.18182/tjf.1006039.

Birben, Ü. (2020). "The effectiveness of protected areas in biodiversity conservation: The case of Türkiye," *Cerne* 25(4), 424-438. DOI: 10.1590/01047760201925042644.

Carbonify. (2023). "Carbon dioxide emissions calculator," (https://www.carbonify.com/carbon-calculator.htm) Accessed 28 Sept 2023.

Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., and Calcaterra, E. (2014). "User's manual on the Singapore index on cities' biodiversity" (also known as the City Biodiversity Index). Singapore: National Parks Board, Singapore.

Clucas, B., Parker, I. D., and Feldpausch-Parker, A. M. (2018). "A systematic review of the relationship between urban agriculture and biodiversity," *Urban Ecosystems* 21(4), 635-643. DOI: 10.1007/s11252-018-0748-8

Convention on Biological Diversity. (1992). "The United Nations Convention on Biological Diversity," Reprinted in International Legal Materials 31 (5 June 1992): 818. (Entered into force 29 December 1993).

de Camargo, J. F., da Silva, F. L., and Smith, W. S. (2022). "City biodiversity index and the cities-biodiversity relationship: A case study for Sorocaba, SP, Brazil," *Urban Ecosystems* 25(3), 673-689. DOI: 10.21203/rs.3.rs-363556/v1

European Landscape Convention. (2000). "Council of Europe Landscape Convention (ETS No. 176)," (http://conventions.coe.int/Treaty/en/Treaties/Html/176.htm) Accessed 20 Apr 2023.

Fakir, H., Özçelik, H., and Deligöz, A. (2005). "Endemic plant taxa of protected natural areas in Isparta," in: *Proceedings of the Symposium of Protected Natural Areas*, Isparta, Türkiye, pp. 623-632.

General Directorate of Meteorology (2024). "Seasonal Normals for Provinces (1991-2024)," (https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=ISPARTA), Accessed 14 Aug 2024.

Gül, A., Çatal, Y., Çoban, H. O., Polat, E., Gülcü, S., Yılmaztürk, A., and Topay, M. (2015). *Kent Ağaçları Bilgi Sistemi Modeli [Urban Trees Information System Model]* (Tubitak Project Final Report No. 110Y301), Tubitak Project, Isparta, Türkiye.

Gül, A., Yazıcı, N., and Şahin, C. K. (2013). "Opinions, tendencies and preferences about urban forestry of urban residents: a case study on the Isparta City-Türkiye," *Energy, Education Science and Technology Part A: Energy Science and Research* 30(2), 933-944.

Güngör, H., Solak, M. H., Alli, H., Işıloğlu, M., and Kalmış, E. (2015). "New records for Türkiye and contributions to the macrofungal diversity of Isparta Province," *Turkish Journal of Botany* 39(5), 867-877. DOI:10.3906/bot-1406-28.

Ministry of Culture and Tourism. (2024). "Isparta province map," (https://isparta.ktb.gov.tr/TR-71231/isparta-il-haritasi.html), Accessed 16 Aug 2024.

Japoshvili, G., Kaya, M., Aslan, B., and Karaca, I. (2009). "Coleoptera diversity and abundance in Golcuk Natural Park, in Isparta, Türkiye," *Entomologia Hellenica* 18, 47-55. DOI:10.12681/eh.11607.

Karaca, İ., Aslan, B., Demirözer, O., and Karsavuran, Y. (2006). "A preliminary study on the Orthoptera fauna in Isparta, Türkiye," *Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi* 1(2), 49-52.

Karataş, A., Filiz, H., Erciyas-Yavuz, K., Özeren, S. C., and Tok, C. V. (2021). "The vertebrate biodiversity of Türkiye," in: *Biodiversity, Conservation and Sustainability in Asia,* M. Öztürk, V. Altay, and R. Efe (eds.), Springer International Publishing. Cham, Switzerland. DOI:10.1007/978-3-030-59928-7_10.

Kaytanlıoğlu, E. H. T., Negiz, M. G., Gülsoy, S., and Fakir, H. (2023). "Diversity of woody flora in Isparta Gölcük Nature Park and its relations with environmental variables," *Turkish Journal of Forestry Research* 10(1), 23-31. DOI: 10.17568/ogmoad.1075675.

Kohsaka, R., Pereira, H. M., Elmqvist, T., and Chan, L. (2013). "Indicators for management of urban biodiversity and ecosystem services: City biodiversity index," in: *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment*, T. Elmqvist, M. Fragkias, J. Goodness, B. Güneralp, P. J. Marcotullio, R. I. McDonald, S. Parnell, M. Schewenius, M. Sendstad, K. C. Seto and C. Wilkinson (eds.), Springer, London. DOI:10.1007/978-94-007-7088-1_32.

Ministry of Agriculture and Forestry. (2024). "Protected Area Statistics," (https://www.tarimorman.gov.tr/DKMP/Menu/18/Korunan-Alan-Istatistikleri), Accessed Date:14 Aug 2024.

Negiz, M. G., Kurt, E. Ö., and Şentürk, Ö. (2017). "A case study on the account of species-centered medicinal and aromatic plant species richness in Isparta-Yenişarbademli Region woodlands," *Turkish Journal of Forestry* 18(4), 282-288. DOI: 10.18182/tjf.329833

Özçelik, H. (2019). "Biodiversity in the Lakes Region (Türkiye) and its agricultural importance," *Süleyman Demirel University Journal of Natural and Applied Sciences* 23(2), 315-328. DOI: 10.19113/sdufenbed.435174.

Özçelik, H. (2023). "Important plant areas and their characteristics in Isparta province," *Journal of Protected Areas Researc*h 2(1), 26-62. DOI: 10.5281/zenodo.7804534.

Özçelik, H. (2017). "Biodiversity and its economic importance in the lakes region," in: *Proceedings abstract book of the International Symposium on New Horizons in Forestry*, Isparta, Türkiye. pp. 30-42.

Özen, M., and Fakir, H. (2015). "Isparta Kasnak Meşesi Tabiatı Koruma Alanı ve çevresinin florası, *Süleyman Demirel University Journal of Natural and Applied Sciences* 19(3), 48-65. DOI:10.19113/sdufbed.09768

Öztürk, Y. (2024). "Determination and mapping of areas rich in bird diversity in Isparta Province, Türkiye," *Pakistan Journal of Zoology* online first, 1-7. DOI: 10.17582/journal.pjz/20230616140621

Protected Planet Report (2020). "Tracking progress towards global targets for protected and conserved areas," (https://www.unep.org/resources/protected-planet-report-2020), Accessed 14 Aug 2024).

Rio Declaration. (1992). "Rio Declaration on Environment and Development, in the Report of the United Nations Conference on Environment and Development," UN Doc. A/CONF.151/26 (Vol. 1), 12 August 1992.

Ruf, K., Gregor, M., Davis, M., Naumann, S., and McFarland, K. (2018). *The European Urban Biodiversity Index (EUBI): A Composite Indicator for Biodiversity in Cities*, ETC/BD report to the EEA. European Topic Centre on Biological Diversity, Muséum National d'Histoire Naturelle: Paris, France.

Santo, R., Palmer, A., and Brent, K. (2017). *Vacant Lots to Vibrant Plots: A Review of the Benefits and Limitations of Urban Agriculture*, Johns Hopkins, Center for a Livable Future, Baltimore, MD, USA. DOI: 10.13140/RG.2.2.25283.91682

Tabur, M. A., and Ayvaz, Y. (2005). "Birds of Lake Beyşehir (Isparta-Konya)," *Turkish Journal of Zoology* 29(4), 361-369.

Urban Population. (2023). "Isparta kent nüfusu [Isparta urban population]," Nufusu, (https://www.nufusu.com/ilce/merkez_isparta-nufusu#:~:text=Merkez%20n%C3%BCfusu%202022%20y%C4%B1l%C4%B1na%20g%C3%B6re,erkek%20ve%20136.883%20kad%C4%B1ndan%20olu%C5%9Fmaktad%C4%B1r), Accessed 24 Jan 2023.

World Health Organization. (2012). Health Indicators of Sustainable Cities in the Context of the Rio+20 UN Conference on Sustainable Development. WHO, Geneva, Switzerland.

Article submitted: May 17, 2024; Peer review completed: July 31, 2024; Revised version received: August 16, 2024; Further revised version received and accepted: September 24, 2024; Published: October 21, 2024.
DOI: 10.15376/biores.19.4.9285-9309