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An Assessment of the Ecological Landscape Quality (ELQ) of Nature-Based Solutions (NBS) Based on Existing Elements of Green and Blue Infrastructure (GBI)

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Abstract: Different types of nature-based solutions (NBS) affect various dimensions of ecological landscape quality (ELQ) in a range of ways. To analyze this issue, the study assessed 14 ELQ indicators based on the application of spatial data. Five potential types of NBS based on existing elements of green and blue infrastructure (GBI) were analyzed at the city level (Lublin, Poland), including: parks (Ups), forests (UFs), waters (UWs), allotment gardens (AGs) and woods (Ws). The analysis revealed that different types of potential NBS contribute in contrasting ways to the improvement of various dimensions of ELQ. UFs were found to make the biggest contribution to the maintenance of ecological processes and stability as well as to aesthetic values. Ws together with AGs proved crucial to maintaining a high level of diversity at the landscape scale and also contributed to preserving the ecological structure. UWs and UPs, mainly due to their high level of anthropogenic transformation, had no outstanding impact on ELQ. The application of landscape-based surrogates proved useful in providing approximate information on the ecological values of different types of NBS when other data types are either unavailable or are only available at a high cost and with considerable time and effort.

Keywords: urban ecology; ecological indicators; green/blue infrastructure; landscape quality; Nature based solutions; remote-sensing

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1. Introduction

Nature-based solutions (NBSs) are a multidisciplinary umbrella concept which links social and economic benefits with the notion of 'nature'. These solutions should be either inspired by, supported by or copied from nature; furthermore, the use of nature should be treated as a priority and not a supplement to conventional infrastructure. NBS should also be cost-effective, resource-efficient and locally adopted [1] and lead to multiple benefits by supporting sustainable development [2]. Moreover, stakeholders' participation, policy and management capability and performance in the long term are emphasized as core features of NBS [3,4,5]. Consequently, NBS can be defined as solutions that are oriented to urgent problem(s), that simultaneously address environmental, social and economic challenges by the use of plants, water and/or chemical processes, that are inspired by nature, that provide multifunctional benefits and that have considerable management potential and economic efficiency [6]. The broad goals of NBS reflect the idea of sustainability by searching for innovative solutions to manage the natural environment in a way that balances benefits for both nature and society [7]. By working with nature rather than against it, communities can develop and implement solutions that will pave the way towards sustainable city development [8]. The NBS concept is congruent with many 'Sustainable Development Goals', including tackling poverty (e.g. urban gardens), good health and well-being (e.g. urban forests), reducing inequalities (e.g. open green spaces), clean water (e.g. constructed wetlands), climate actions (e.g. avenue of trees), life on land (e.g. plant shelter belts) and industry, innovation and infrastructure (green roofs).

The NBS concept is closely connected with many existing concepts, including green and blue infrastructure, urban green spaces, urban gardens, urban forests and urban waters. Therefore, according to a report by the EC [3], actions that enhance the existing green (historical) infrastructure to resolve urgent challenges should be treated as a sort of NBS, alongside next to more novel solutions such as constructed wetlands and green roofs and walls. Elements of urban green/blue infrastructure (GBI) may be created as independent NBS actions, or enlarged, fitted out, linked and improved in order to implement NBS projects [9]. Different types of NBS, however, affect ecological landscape quality (ELQ) in a range of ways. ELQ is understood as an ecological condition of a given landscape, being an effect of superimposing upon a set of environmental components, processes and phenomena that are subjected to a direct outcome or a side effect of human activity [10]. ELQ can be assessed both: (1) from the 'ground' perspective, by the direct, in-situ analysis of quality of different components of the environment, such as water, air and soil, and (2) from 'a bird's-eye view' perspective, by analyzing the structure and connectivity of land use/land cover (LU/LC) patches based on remote sensing data and a spatial approach [11]. Regarding the first perspective, given that most NBS projects deal with conservation, restoration and cultivation goals [9], they have a multitude of positive effects on all environmental components. These include enhancing natural capital, promoting biodiversity, mitigating water runoff, increasing water retention and infiltration, contributing to climate change adaptations and carbon sequestration, reducing emissions, mitigating the urban heat island effect and removing pollutants [12,13,14]. Regarding the second perspective, NBS generally contribute to improving ELQ and promoting 'good-quality' landscapes by bringing more natural features and processes into landscapes and seascapes [3]. NBS may also improve the connectivity of biologically active areas at the city level and provide a bridge between urban/peri-urban areas and natural areas. NBS are particularly applied when considering 'landscape-scale' initiatives, such as regional/national strategy for afforestation or flood protection. In addition, the area and the configuration of vegetation patches influence the stability of ecological processes and affect the amount of carbon capture [5]. However, the extent to which different types of NBS help to improve ELQ at the landscape scale remains unclear.

To answer this question, the main aim of the research was to assess the ELQ of diverse types of NBS (limited to existing elements of green and blue infrastructure with the potential to be considered NBS) at the city scale (Lublin, Poland) via the application of landscape-based indicators. The practical aim was to indicate which NBS action makes the greatest contribution to improving the ecological state of the urban landscape and thus sustainable urban development.

2. Materials and Methods

The study consisted of three main stages: (1) identifying potential NBS among the existing elements of green and blue infrastructure (GBI) functioning in the analyzed area; (2) detecting spatially the NBS within the study area; (3) calculating the ELQ indicators (Figure 1). The approach adopted did not include a detailed assessment of each element of GBI in Lublin from the point of view of fulfilling all the necessary criteria of NBS proposed by Sowińska-Świerkosz and García [6]. Instead, it was assumed – according to the criteria presented in Table 1 and Table 22 – that they have the potential to be considered NBS as either an independent action or one that may be enlarged, fitted out, linked and improved to implement NBS projects [9].

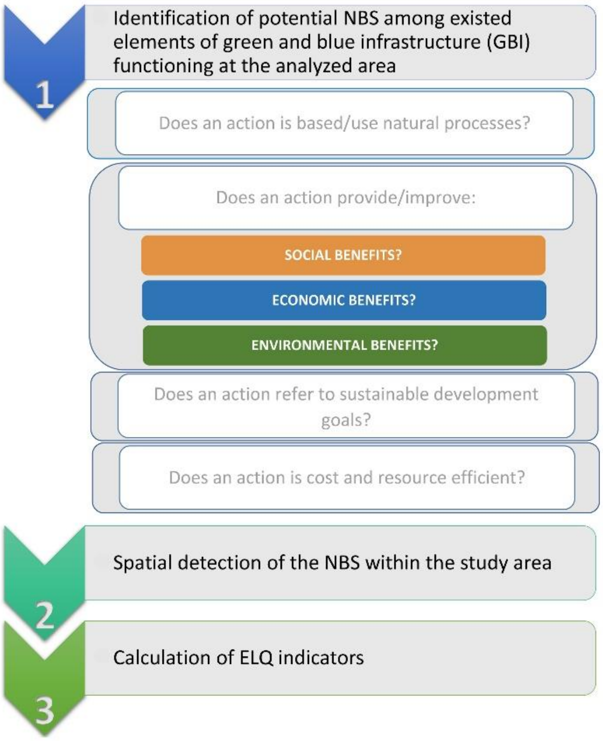

Figure 1. Methodological framework.

2.1. Study area

The city of Lublin is a cultural, scientific and economic centre and communication hub in eastern Poland. It is the capital of the Lubelskie Voivodeship. In 2020, the population of Lublin reached almost 340,000. Lublin is characterized by a varied topography, a low river network density and a moderately developed natural structure dominated by forests, which constitute 11% of the city's area. The ecological system of the city is inextricably linked with three river valleys, which also represent the main ecological corridors. The most important of these corridors is the Bystrzyca River valley, on which a retention reservoir was built in the 1970s (Zalew Zemborzycki). This is located in the southern part of the contemporary city. In addition to river valleys, there are dry valleys in the city, which have been developed as urban parks or wooded areas. Allotment gardens form another important element of Lublin's green infrastructure, patches of which are located throughout the city, including in the centre (Figure 2).

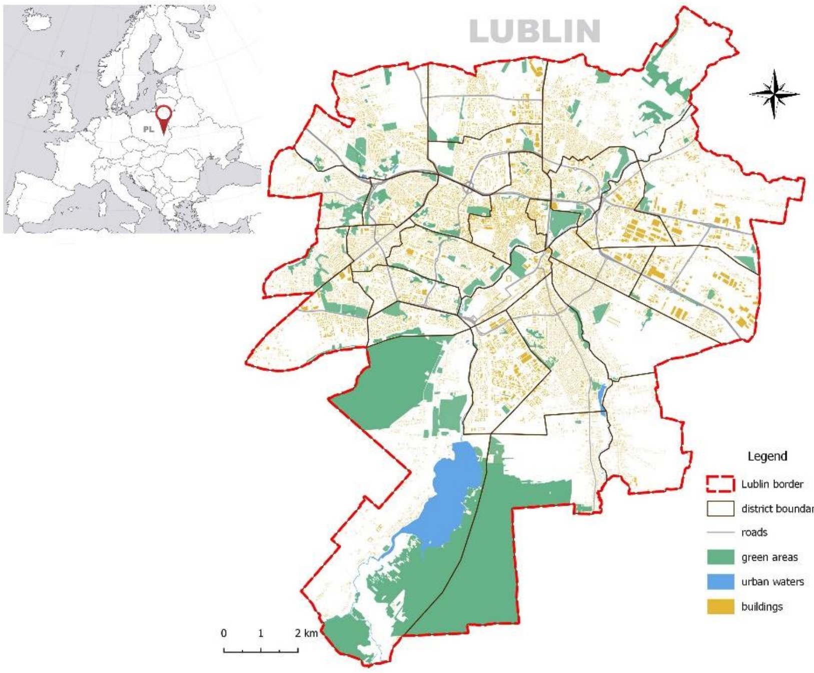

Figure 2. Location of the study area and spatial structure of the city.

2.2. Identification of potential NBS among existed elements of GBI at the Lublin city scale

To detect GBI actions that can be regarded as NBS among the existing elements in Lublin, a four-level procedure was adopted. This procedure was based on the performance questions referring to the four core ideas for clarifying the NBS concept proposed by Sowińska-Świerkosz and García [6] (Table 1).

Table 1. Performance questions and criteria of considering existed elements of GBI as potential NBS.

Is an action based on or use natural processes?
NBS refer to actions that 'use nature' or are 'powered by nature' [3]. The conscious use of plants and/or water must be a priority and not a supplement to conventional infrastructure [15]. As there is no consensus on the scope of human intervention on NBS [16, 17,18], minimal or no-intervention management approaches that involve some intervention as well as intrusive ecosystem management approaches may be treated as NBS.
Does an action provide or improve social, environmental and/or economic benefits?
The second criterion is based on three questions proposed by the EC [8] to define whether an action can or cannot be framed as NBS. These questions pertain to different types of benefits: social, environmental and economic. The fourth question – 'Does it have a net benefit for biodiversity?' is not included in the procedure to avoid restricting types of action to those that focus on biodiversity.
Does an action refer to the 'Sustainable Development Goals?
The third criterion reflects the challenge–orientation of NBS seeking to alleviate a well-defined environmental, social and economic challenge. This challenge–orientation means that it is directed to providing a solution to a previously detected problem [19]. This aspect is crucial to distinguishing among NBS and other green interventions [20]. Taking the present study's aim into account, whether a given action relates to the idea of sustainable urbanization was determined by indicating the Sustainable Development Goal [21] to which it contributes.
Is an action cost- and resource-efficient?

The fourth criterion relates to the efficiency of NBS actions in terms of costs and resources [1,7, 22], i.e. the cost of a solution's implementation, management, monitoring and damage over a certain period of time should not exceed the potential environmental and social benefits. In addition, economic viability refers to the promotion of renewable sources of energy and the use of rainwater or treated water instead of drinking water to irrigate and maintain solutions [5].

2.3. Spatial detection of the potential areas of NBS within the study area

Different types of GBI were spatially detected as potential NBS in the previous stage of the research, based on the Polish Database of Topographic Objects [23], updated to Orthophotomap (pixel size 0.5m, 2019). In reference to each type of GBI as potential NBS were treated areas fulfilling the criteria presented in Table 2.

Table 2. Criteria of considering each type of GBI as potential areas of NBS.

As potential areas of NBS based on Urban Waters (UWs) were considered:
• polygons of the minimum area of 500m2 (0.05ha) (adopted by the authors due to the lack of formal and methodological foundations); • water easily accessible to every citizen (private ponds next to houses were excluded); • water bodies which serve social functions such as angling, swimming, nature observation, relaxation.
As potential areas of NBS based on Urban forests (UFs) were considered:
• polygons of the minimum area of 1000m2 (0.1ha) (according to the minimum area of forest patch in Polish regulation); • areas which serve social functions such as jogging, biking, mushroom picking, nature observation, relaxation
As potential areas of NBS based on Allotment Gardens (AGs) were considered:
• all the plots of gardens according to BDOT classification
As potential areas of NBS based on Urban Parks (UPs) were considered:
• Ups according to BDOT classification with a predominance of grassy or semi-permeable surfaces
As potential areas of NBS based on Wooden Areas (Ws) were considered:
• polygons of the minimum area of 1000m2 (0.1ha) (by analogy to the minimum area of forest patch in Polish regulation) • dense rows of trees along roads • dense rows of trees along rivers • green squares within or next to residential areas

2.4. Calculation of ELQ indicators

Based on a non-systematic review of previous papers [10, 11, 24, 25, 26], certain ELQ indicators were selected and calculated at the class level. A correlation analysis of these indicators was performed to reduce the number of indices to a practicable level and to avoid duplication. This analysis based on the results of a Spearman's rank correlation (p = 0.05) for each pair of indices. If the obtained absolute correlation coefficient amounted to 0.9 or more, only one of the two indices was retained. As a result, 14 indicators were analyzed further (Table 3), referring to the four main aspects crucial for assessing ecological quality at the landscape scale: (1) maintenance of ecological processes and ecosystem stability; (2) diversity; (3) continuity of ecological structures; and (4) aesthetic landscape values [27].

Table 3. Calculated ELQ indicators .

Abbreviation	Indicator name	Unit	Formula/description	Reference to dimensions of ELQ
MPA	Mean Patch Area	ha	-	S; C
PLAND	Percentage of landscape occupied by a given potential type of NBS	%	-	S; D; C
BAA	Biologically Active Area	%	As BAA was considering areas covered by vegetation and water	S; C; A
$AT_{natural/semi-ntural/antr\ no\ 1/\ antro\ no\ 2}$	Percentage of areas occupied by patches of different levels of anthropogenic transformation	%	Levels of anthropogenic transformation of LC forms according to Sowińska-Świerkosz (2016)	S; D; C
ECOLBAR	Density of Ecological Barriers	m/ha	As Ecological Barriers were considering paved roads	S; C; A
PD	Patch Density	nos/100 ha	$PD = \frac{n_i}{A}(10{,}000)(100)$ n_i = number of patches in the landscape of patch type (class) i A = total landscape area (m^2)	S; D; C
ED	Edge Density	m/ha	$LSI = \frac{.25\sum_{k=1}^{m} e_{ik}^{*}}{\sqrt{A}}$ e_{ik} = total length (m) of edge in landscape between patch types *(classes) i and k; in-	S; D; C; A

			cludes the entire landscape boundary and some or all background edge segments involving class i A = total landscape area (m^2)	
LPI	Largest Patch Index	%	$$LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A}(100)$$ a_{ij} = area (m) of patch ij. A = total landscape area (m)	S; D
FRAC_MN	Mean Fractal Dimension Index	-	$$FRAC = \frac{2\ \ln(.25\ p_{ij})}{\ln\ a_{ij}}$$ p_{ij} = perimeter (m) of patch ij a_{ij} = area (m^2) of patch ij	S; A
COHESION	Patch Cohesion Index	-	$$COHESION = \left[1 - \frac{\sum_{j=1}^{n} p_{ij}^{*}}{\sum_{j=1}^{n} p_{ij}^{*}\sqrt{a_{ij}^{*}}}\right] \cdot \left[1 - \frac{1}{\sqrt{Z}}\right]^{-1} \cdot (100)$$ p_{ij} = perimeter of patch ij in terms of number of cell surfaces. a_{ij} = area of patch ij in terms of number of cells. Z = total number of cells in the landscape	S; D; C
SLOPE	Slope	%	-	D

Note: S: Maintenance of ecological processes and ecosystem stability; D: Diversity; C: Continuity of ecological structures; A: Aesthetic landscape values

3. Results

3.1. Identification of potential NBS types

The assessment based on the four-level procedure showed that within Lublin, five elements of GBI can be regarded as potential NBS types (Table 4): (1) urban parks, (2) urban forests, (3) urban water, (4) allotment gardens and (5) wooded areas. These represent elements of historical urban GBI that may be regarded as unsophisticated NBS, their effectiveness being limited [9]. Given that for an action to be regarded as an NBS it is not always necessary that 100% of the ingredients are present, but merely a majority [6], actions with partial effectiveness were also included in the subsequent part of the research.

Table 4. Criteria of considering analyzed elements of GBI as potential types of NBS

Does an action use nature/natural process?	**Does an action provide/improve social benefits?**	**Does an action provide/improve environmental benefits?**	**Does an action provide/improve economic benefits?**	**Does an action refer to the 'Sustainable Development Goals?**	**Is an action cost- and resource-efficient?**
Urban parks (UPs)[13,28, 29]					
YES	YES	YES	YES	YES	PARTIALLY
UPs consist of lawns, trees, shrubs and flowers; paved paths and playgrounds are gradually replaced by semi-permeable or green surfaces.	UPs possess recreational and historical value; they are of great ornamental and perception value; UPs are meeting places and offer contact with nature.	UPs contribute to carbon sequestration, seed dispersal, erosion prevention, water purification, air purification, habitat quality and noise reduction.	UPs provide benefits in terms of the economic development of the community and tourism.	Good health and well-being; sustainable cities; life on land; climate actions; reduce inequalities.	Maintenance of UPs requires continuous and usually costly actions such as planting, watering and mowing, restoration and repair of elements of small architecture, lighting and cleaning.
Urban forests (UFs) [30, 31, 32]					
YES	YES	YES	YES	YES	YES
UFs consist of trees and shrubs; paved surfaces such as parking and roads are a rarity.	UFs offer recreational functions and contact with nature; they contribute to psychological and physical health; they have educational, research and teaching functions.	UFs contribute to air purification, global climate regulation, urban temperature regulation, noise reduction and runoff mitigation.	UFs provide benefits in terms of the economic development of the community and tourism.	Good health and well-being; sustainable cities; life on land; climate actions; duce inequalities.	UFs require a minimum level of human intervention and do not involve the use of electricity and running water.
Urban waters (UWs) [33, 34, 35, 36, 37]					
YES	YES	YES	YES	YES	PARTIALLY
Both natural and artificial UWs function based on natural processes.	UWs support aquatic life, enable relaxation and improve physical and mental health; they possess intangible values to citizens such as amenities and a sense of place for fishing communities; they are of great aesthetic value.	UWs support biodiversity, freshwater storage, hydrological balance, climate regulation, flood protection, water purification and oxygen production and fertility; they provide a physical refugium from predation and are used as nursery and feeding areas.	UWs are a source of food provisioning, energy production and drinking water supply; they contribute to flood hazard reduction; they are used in industry and agriculture production	• No poverty; good health and well-being; sustainable cities; climate actions; life below water; • life on land.	UWs' efficiency depends on the case study. There are resource-efficient water bodies and water bodies, especially dam reservoirs, which require maintenance and large amounts of money.
Allotment gardens (AGs) [10, 38, 39, 40]					
YES	YES	YES	YES	YES	PARTIALLY
The key "building material" of AGs is greenery: edible and flourishing plants, fruit trees, herbs and grasses and in some cases also water structures.	AGs provide a source of relaxation, hobbies and contact with nature; they promote outdoor activities.	AGs provide a source of relaxation, hobbies and contact with nature; they promote outdoor activities.	AGs provide low-cost food and have a positive impact on reducing medical expenses.	Tackling poverty;good health and well-being; • clean water; sustainable cities; responsible consumption; • life on land.	Most AGs possess rainwater recovery devices and composters and are not equipped with electricity; some AGs possess photovoltaic panels and re-used building materials.
Woods(Ws)[41,42, 43]					
YES	YES	YES	YES	YES	YES

Trees and shrubs are the only materials.	Ws contribute to noise reduction; they increase walkability through providing greater feelings of safety; they are of great ornamental, aesthetic and amenity value; they are ofgreat recreational value when other forms of greenery are not available.	Ws reduce pollutant emissions, improve surface run-off, improve soundscape quality, create habitats and have a shading and cooling effect.	Wide strips of trees along roads can to some extent replace expensiveacoustic screens; they may produce fruits.	Good health and well-being; sustainable cities; climate actions; • life on land.	Ws require watering only during the first few years after planting; after these periods they are self-sufficient.

3.2. Detection of the potential areas of NBS within the study area

Based on the existing elements of GBI, potential NBS occupy nearly 20% of the city's area (Figure 3). The largest area and thus the highest percentage share comprises patches of UFs (60% of the area of potential NBS, i.e. 12% of the city area) (Table 5). This type, however, is characterized by the smallest number of patches (8), but with a significant mean area amounting to 219.54 ha. The smallest area and thus the lowest percentage share comprises patches of UPs (3.4% of the area of potential NBS, i.e. 0.67% of the city area). The share of other potential NBS types is quite similar and amounts to approximately 2% of the city's area. AGs and Ws feature the highest numbers of patches (70 and 71, respectively), with average sizes of 6 ha and 3.58 ha, respectively. In addition, patches constituting AGs together with patches of UPs feature quite similar areas (AGs: AREAmin = 6.00; S.D. = 8.15; UPs: AREAmin = 8.26; S.D. = 6.37).

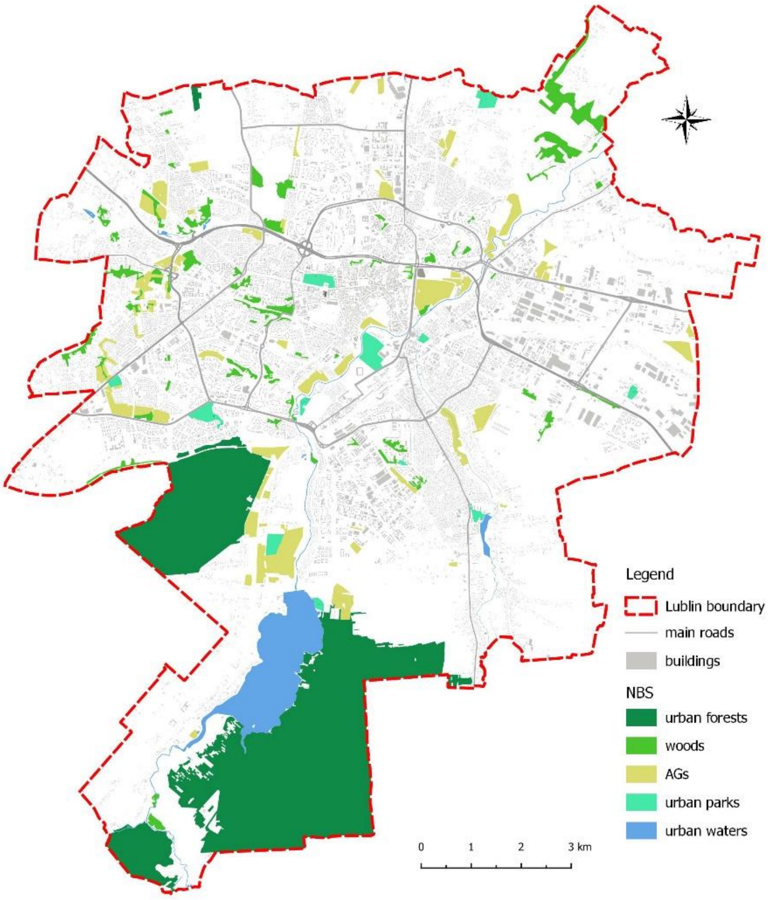

Figure 3. Localization and typology of NBS detected within the study area.

Table 5. Spatial characteristic of different types of potential NBS.

	Number of patches	Total area (ha)	% of potential NBS	% of Lublin area	Mean area (ha)	Area standard deviation (S.D.)
Urban parks	12	99.16	3.41	0.67	8.26	6.37
Urban forests	8	1756.28	60.47	11.91	219.54	385.89
Urban waters	32	347.57	11.97	2.36	10.86	59.07
Allotment gardens	70	420.22	14.47	2.85	6.00	8.15
Wooden areas	71	280.98	9.67	1.91	3.58	6.51
Sum: Area (ha)						**2904.21**
Sum: % of Lublin area						**19.69**

3.3. Calculation of ELQ indicators

The analysis of the obtained results of landscape-based indictors, showed that different potential types of NBS contribute differently to the ecological quality at the landscape level.

Regarding the maintenance of ecological processes and ecological stability, the biggest potential possesses UFs. They feature the highest values of indicator such as PLAND (11.91), MPA (219.54) and LPI (7.91) pointing indirectly that analyzed type of LC possess sufficient total habitat area for existence of species inhabited it such as birds and predatory mammal species [25, 27]. Besides, patches of UFs are characterized by 98% contribution of biological active areas including both natural (nature reserve) and semi-natural LC forms (Table 6). The lowest contribution to maintenance of ecological stability features Ws of relatively low values of MPA (3.58ha) and the highest values of ED (7.81) as well as the most disperse spatial structure (COHESION=95.41). As so, from the spatial perspective, except for a few species of birds and synanthropic plants, they do not constitute a potential habitat for a wider group of organisms.

From the point of view of the diversity analysis at the landscape level, AGs and Ws are of the highest contribution as they are characterized by the large number of patches (70 and 71 respectively), the highest density (PD=0.47), and disperse located (COHESION=96.75 and 95.41 respectively) within the entire city structure. Besides, geomorphological indictors including SLOPE proven the Ws high contribution to diversity dimention: varied topography promote the existence of different plant species [44]. Due to the aggregated character of UFs patches, they are of low impact on landscape-level diversity.

The analysis of continuity of ecological structures showed the law negative impact of ecological barrier in the case of UPs, and Ws (ECOLBAR=0.00 and 3.21 respectively).

Besides, Ws and AGs are evenly distributed with the study area thus positively contribute to the continuity of forms of greenery. The positive impact of the latter, however, is affected by the high quite density of paved roads crossing gardens structures (ECOLBAR=5.97). The same applied to UFs of the highest density of ecological barriers (ECOLBAR=6.87).

Regarding the aesthetic landscape values, quite similar values of FRAC_MN approaching to '1' indicated that shape of analyzed potential NBS types is approaching to square, which is characteristic for city structures dominated by rectilinear man-made elements. Values of BAA and AT indicators, however, showed that due to the high share of natural and semi-natural green and blue areas which are generally positively perceived by people, UFs are of the highest contribution to aesthetic values; and analogues Ws of the lowest.

Table 6. Results of ELQ indicator calculation.

Indicator abbreviation	Urban parks	Urban forests	Urban waters	Allotment gardens	Wooden areas
MPA [ha]	8.26	219.54	10.86	6.00	3.58
PLAND [%]	0.67	11.91	2.36	2.85	1.91
BAA [%]	88.12	98	100	~90*	95.15
$AT_{natural}$ [%]	0.00	1.43	0.00	0.00	0.00
$AT_{semi-natural}$ [%]	0.00	96.57	10.93	0.00	0.00
$AT_{antro\ no\ 1}$[%]	88.12	0.00	89.07	90.00	95.15
$AT_{antro\ no\ 2}$[%]	11.88	2.00	0.00	10.00	4.85
ECOLBAR [m/ha]	0.00	6.87	not applicable	5.97	3.21
PD [nos/100 ha]	0.08	0.07	0.20	0.47	0.47
ED [m/ha]	1.26	3.72	6.61	6.76	7.81
LPI [%]	0.16	7.91	2.30	0.38	0.38
FRAC_MN [-]	1.07	1.11	1.13	1.09	1.15
COHESION [-]	96.87	99.69	99.89	96.75	95.41
SLOPE [%]	Max 20 Avarage 3	Max 36 Average 2	Lack of data	Max 5 Avarage 1	Max 48 Avarage 8

*Calculated based on data from Sowińska-Świerkosz et al. (2021) based on the mean area of AGs and mean area of cabin and paved surfaced.

4. Discussion

4.1. Elements of urban GBI as potential types of NBS

The research conducted was based on the assumption that elements of GBI within the city of Lublin have the potential to be regarded as unsophisticated types of NBS. The result presented in Table 4 was found to support this statement, as the analyzed types of GBI fulfilled most of the criteria proposed by Sowińska-Świerkosz and García [6]. First, these elements were found to provide and/or improve environmental, social and economic benefits, such as with respect to recreational and spiritual or cultural ecosystem services, physical and mental health, carbon sequestration, air purification, noise reduction, biodiversity and, in the case of AGs and UWs, food provisioning [9, 13, 45]. In addition, the analyzed elements of GBI were found to help tackle various global problems, reflecting the Sustainable Development Goals, primarily good health and well-being, sustainable cities, responsible consumption, climate actions and life on land and in water [46]. A more complex issue, however, was the aspect of GBI's cost- and resource-efficiency. To be regarded as NBS, an action should be both cost-efficient (meaning that it produces good results without costing a lot of money) and resource-efficient (meaning that it uses building materials, natural resources and energy in a sustainable manner, while having minimal impact on the environment) [1, 47]. Furthermore, the cost of a solution's implementation, maintenance or transformation should not exceed the potential benefits gained [3, 5]. Understanding of the economic efficiency of most of the analyzed elements of GBI remains limited. For example, UGs require continuous planting, watering and mowing; moreover, most AGs are not equipped with renewable sources of energy. Therefore, we considering analyzed elements of GBI as unsophisticated types of NBS of which effectiveness is limited. To unambiguously define whether a given element can or cannot be classified as NBS, each element should be analyzed separately based on detailed criteria, for example, by calculating the NBS effectiveness indicators proposed by Sowińska-Świerkosz and García [5], which include level of social acceptance, perceived level of aesthetic value, existence of political support and guidance, existence of rainwater recovery devices, amount of energy produced from renewable sources and carbon and heat absorption capacity. Such an approach is necessary, as possessing all the major features linked to NBS does not axiomatically render elements of GBI a successful ecosystem-based solution. We agree with Nesshöver et al.'s [7] conclusion that the biggest difference between the concepts of GBI and NBS pertains to the difference between the terms "infrastructure" and "solution". GBI can be regarded as NBS provided that it contributes to the solving of the problem(s) encountered [48] and has a high level of economic efficiency [6]. Therefore, in order to be congruent with the concept of NBS, the analyzed elements of (historical) GBI should be somehow altered, for example by enlarging their area, fitting out with devices dedicated to the use of rainwater, linking renewable sources of energy and implementing NBS projects [9].

4.2. Impact of analyzed potential types of NBS on ecological landscape quality

The analysis clearly revealed that with regard to the Lublin city scale, different types of potential NBS contribute in varied ways to improving ecological quality at the landscape level. Among them, however, UFs and Ws proved to be of the greatest importance (Figure 4). UFs, due to their high compactness, were found to make the biggest positive contribution to the maintenance of ecological processes and ecosystem stability, but on the other hand, the same spatial characteristic indirectly explained on their low impact on diversity as well as the continuity of ecological structure at the landscape scale. UFs also proved to be particularly important from the aesthetic point of view, as natural LC forms are widely perceived as having the highest value, followed by semi-natural and anthropogenic forms [49]. Ws also proved to have a different impact depending on the analysis level of EQ. These areas are crucial for the maintenance of a high level of diversity and the continuity of ecological structure at the landscape scale, as presented within the entire city spatial structure. Their low mean area of patches, however, indicates that they are not capable of maintaining important ecological processes and having a significant positive impact on ecosystem stability. AGs, which were found to be evenly distributed across the study area, positively contribute to the continuity of ecological structure as well as diversity analysis at the landscape scale, as has also been demonstrated by another study [9]. Their positive impact, however, was found to be affected by the rather high density of paved roads and the homogeneous relief of the land. Surprisingly, the obtained results indicated that UWs have no outstanding impact on ELQ. This is primarily due to the high level of anthropogenic transformation of the two main water bodies within the Lublin city structure: the Zemborzycki Reservoir (which is a dam reservoir) and the Bystrzyca River valley (which is subjected to strong anthropopressure) [50]. UPs also showed no specific impact on the analyzed dimensions of ELQ, due to the small number of parks and their modest total area as well as the relatively low share of biologically active areas.

It must be stressed here, however, that the above conclusions were formulated only based on the landscape-based surrogates, which indirectly explain the ecological state of a given area based on the application of substitute data. They provide only approximate information on ecological values, although they are of great importance when other data types are not available or are solely available at a high cost and with considerable time and effort [25, 44]. We are aware of the fact that an overall conclusion on the impact of different types of NBS on ELQ must be based on the application of a set of data sources and methods [8, 51]. The usefulness of surrogates, however, has been proved by some previous researchers when assessing the effectiveness of NBS projects [4, 19, 52, 53]. As there is a lack of available data to calculate a total set of indicators crucial for a comprehensive assesment of NBS' environmental impacts [3,7, 52], the result of this study may be treated as a rough estimate of the actual impact.

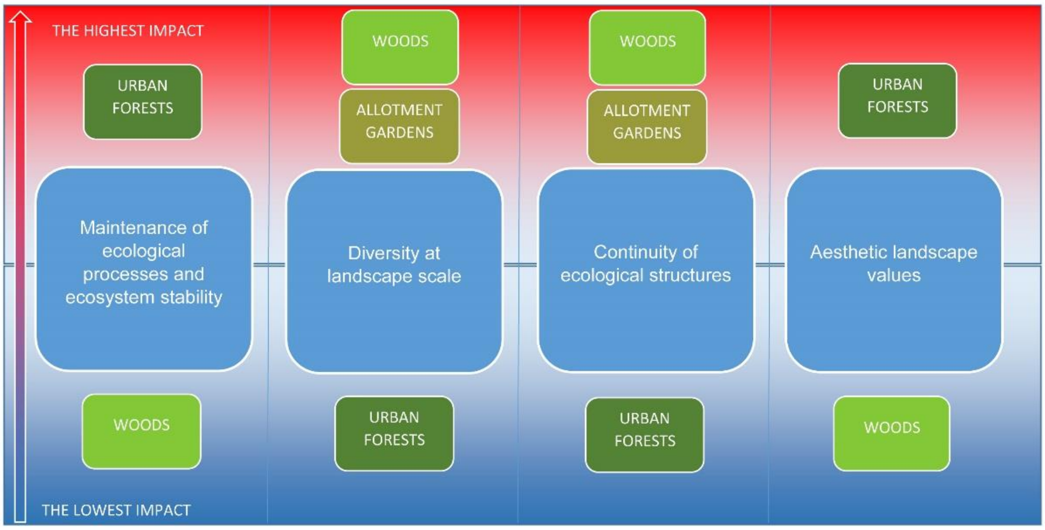

Figure 4. Ideogram of analysed potential types of NBS based on the GBI impact on Ecological Landscape Quality.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, B.S.Ś and J.W.; methodology, B.S.Ś.; software, J.W. and M.M.Ś.; validation, B.S.Ś., J.W. and M.M.Ś.; formal analysis, B.S.Ś.; investigation, B.S.Ś.; resources, B.S.Ś., J.W., M.M.Ś; data curation, B.S.Ś., J.W., M.M.Ś.; writing—original draft preparation, B.S.Ś.; writing—review and editing, M.M.Ś.; visualization, M.M.Ś.; supervision, B.B.Ś.; project administration, M.M.Ś.; funding acquisition, B.S.Ś. All authors have read and agreed to the published version of the manuscript." Please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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References

1. Nika, C.E., Gusmaroli, L., Ghafourian, M., Atanasova, N., Buttiglieri, G., Katsou, E. Nature-based solutions as enablers of circularity in water systems: a review on assessment methodologies, tools and indicators. *Water Res* **2020**, 183, 115988, ISSN 0043-1354.
2. Kolokotsa, D., Lilli, A.A., Lilli, M.A., Nikolaidis, N.P. On the impact of nature-based solutions on citizens' health & wellbeing. *Energy Build* 2020, 229, 110527, ISSN 0378-7788.
3. European Commission. *Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions and Re-Naturing Cities*; European Commission: Brussels, Belgium, 2015.
4. Raymond, C.M.; Breil, M.; Nita, M.R.; Kabisch, N.; de Bel, M.; Enzi, V.; Berry, P. An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects. Report Prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas; Centre for Ecology and Hydrology: Wallingford, UK, 2017.
5. Sowińska-Świerkosz B., García J. A new evaluation framework for nature-based solutions (NBS) projects based on the application of performance questions and indicators approach. *Science of Total Environment* **2021a**, 787, Article number 147615, ISSN 0048-9697.
6. Sowińska-Świerkosz B., García J. (2021b): What are Nature-based solutions (NBS)? Setting core ideas for concept clarification? Nature-based solution (under review).
7. Nesshöver, C.; Assmuth, T.; Irvine, K.N.; Rusch, G.M.; Waylen, K.A.; Delbaere, B.; Haase, D.; Jones-Walters, L.; Keune, H.; Kovacs, E.; et al. The science, policy and practice of nature-based solutions: An interdisciplinary perspective. Sci. Total Environ. 2017, 579, 1215–1227
8. Science for Environment Policy, 2021. The Solution Is in Nature. Future Brief 24. Brief Produced for the European Commission DG Environment. Science Communication Unit, UWE Bristol, Bristol.
9. Sowińska-Świerkosz, B., Michalik-Śnieżek, M., Bieske-Matejak, A. Can allotment gardens be considered an example of nature-based solutions (NBS) based on the use of historical green infrastructure? *Sustainability* **2021**, 13, 835.
10. Sowińska-Świerkosza, B., Michalik-Śnieżek, M. The methodology of Landscape Quality (LQ) indicators analysis based on remote sensing data: Polish National Parks Case Study. *Sustainability* **2020**, 12, 2810.
11. Sowińska-Świerkosz, B. The application of surrogate measures of ecological quality assessment: the introduction of the Indicator of Ecological Landscape Quality (IELQ). Ecological Indicators **2017**, 73, 224–234.
12. Ferreira, V.; Barreira, A.P.; Loures, L.; Antunes, D.; Panagopoulos, T. Stakeholders' engagement on nature-based solutions: A systematic literature review. *Resources* **2020**, 8, 121.
13. Xie, L.; Bulkeley, H. Nature-based solutions for urban biodiversity governance. Environ. Sci. Policy 2020, 110, 77–87.
14. Ershad Sarabi, S.; Han, Q.; LRomme, A.G.; de Vries, B.; Wendling, L. Key enablers of and barriers to the uptake and implementation of nature-based solutions in urban settings: A review. *Resources* **2019**, 8, 121.
15. Kronenberg, J.; Bergier, T.; Maliszewska, K. The challenge of innovation disunion: Nature-based solutions in Poland. In *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice;* Kabisch, N., Korn, H., Stadler, J., Bonn, A., Eds.; Springer: Cham, Switzerland, **2017**; pp. 291–305.
16. Eggermont, H.; Balian, E.; Azevedo, J.M.N.; Beumer, V.; Brodin, T.; Claudet, J.; Fady, B.; Grube, M.; Keune, H.; Lamarque, P. Nature-based solutions: New influence for environmental management and research in Europe. *GAIA* **2015**, 24, 243–248.
17. Krauze, K.; Wagner, I. From classical water-ecosystem theories to nature-based solutions—Contextualizing nature-based solutions for sustainable city. *Sci. Total Environ*. **2019**, 655, 697–706.
18. Schaubroeck, T. 'Nature-based solutions' is the latest green jargon that means more than you might think. *Nature* 541 2017, 133-134 https://doi.org/10.1038/541133b
19. Gómez Martín, E., Giordano. R., Pagano, A., van der Keur. P., Máñez Costa. M. Using a system thinking approach to assess the contribution of nature based solutions to sustainable development goals. Science of The Total Environment. 2020. 738(10), 139693. https://doi.org/10.1016/j.scitotenv.2020.139693
20. Albert, C.; Schröter, B.; Haase, D.; Brillinger, M.; Henze, J.; Herrmann, S.; Gottwald, S.; Guerrero, P.; Nicolas, C.; Matzdorf, B. Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute? *Landsc. Urban Plan*. **2019**, 182, 12–21.
21. United Nations Department of Economic and Social Affairs Sustainable Development. Available online: https://sdgs.un.org/goals (15.08.2021r.).
22. Frantzeskaki, N. Seven lessons for panning nature-based solutions in cities. *Environ. Sci. Policy* **2019**, 93, 101–111.
23. Baza danych obiektów topograficznych BDOT 2012. Available online: https://mapy.geoportal.gov.pl/wss/service/pub/guest/kompozycja_BDOT10k_WMS/MapServer/WMSServer (15.08.2021).

24. McGarigal, K., S.A. Cushman, M.C. Neel, and E. Ene. 2002. FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst, available at the following web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html.
25. Uuemaa, E., Antrop, M., Roosaare, J., Marja, R., Mander, U. Landscape metrics and indices: an overview of their use in landscape research. *Liv. Rev. Landsc. Res.* **2009,** *3*, https://doi.org/10.12942/lrlr-2009-1.
26. Cassatella C., Peano A. (Eds.) Landscape Indicators. Assessing and Monitoring Landscape Quality. *Springer Netherlands*: 2011; pp. 222, DOI 10.1007/978-94-007-0366-7
27. Sowińska-Świerkosz B., Soszyński. D. Landscape structure versus the effectiveness of nature conservation: Roztocze region case study (Poland). *Ecological Indicators*. **2014**. 43, 143-153. https://doi.org/10.1016/j.ecolind.2014.02.018.8.
28. Breuste, J., Haase D., Elmquist. T. Urban landscapes and ecosystem services. In *Ecosystem services in agricultural and urban landscapes*, ed. Sandhu H., Wratten S., Cullen R., Costanza R., Hoboken: Wiley. 2013 ; 83–104.
29. Mexia T., Vieira J., Príncipe A., Anjos A., Silva P., Lopes N., Freitas C., Santos-Reis M., Correia O., Branquinho C., Pinho P. Ecosystem services: Urban parks under a magnifying glass, *Environmental Research*. **2018**, 160, 469-478, https://doi.org/10.1016/j.envres.2017.10.023.
30. Escobedo, F.J.; Kroeger, T.; Wagner, J.E. Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. *Environ. Pollut*. **2011**, 159, 2078–2087.
31. Jaszczak R. , Wazynski B. , Wajchman-Switalska S. Legal aspects of urban forestry in Poland. *Sylwan*. 2017, 161, 8, 659−668.
32. Nesbitt, L.; Hotte, N.; Barron, S.; Cowan, J.; Sheppard, S.R.J. The social and economic value of cultural ecosystem services provided by urban forests in North America: A review and suggestions for future research. Urban For. Urban Green. 2017, 25, 103–111 Nesbitt, L.; Hotte, N.; Barron, S.; Cowan, J.; Sheppard, S.R.J. The social and economic value of cultural ecosystem services provided by urban forests in North America: A review and suggestions for future research. *Urban For. Urban Green*. **2017**, 25, 103–111.
33. Urquhart, J., Acott, T. A Sense of Place in Cultural Ecosystem Services: The Case of Cornish Fishing Communities. *Society & Natural Resources* 2014. 27(1), pp. 3-19, DOI https://doi.org/10.1080/08941920.2013.820811
34. Newton A., Brito A. C., Icely J. D., Derolez V., Clara I., Angus S., Schernewski G., Inácio M., Lillebø A. I., Sousa A. I., Béjaoui B., Solidoro C., Tosic M., Cañedo-Argüelles M., Yamamuro M., Reizopoulou S., Tseng H., Canu D., Roselli L., Maanan M., Cristina S., Ruiz-Fernández A. C., de Lima R. F., Kjerfve B., Rubio-Cisneros N., Pérez-Ruzafa A., Marcos C., Pastres R., Pranovi F., Snoussi M., Turpie J., Tuchkovenko Y., Dyack B., Brookes J., Povilanskas R., Khokhlov V. Assessing, quantifying and valuing the ecosystem services of coastal lagoons, *Journal for Nature Conservation*. **2018.** 44, 50-65. https://doi.org/10.1016/j.jnc.2018.02.009.
35. Gunawardena, A., Iftekhar, S., Fogarty, J. Quantifying intangible benefits of water sensitive urban systems and practices: an overview of non-market valuation studies. Australasian Journal of Water Resources. 2020. 24(1), pp. 46-59. https://doi.org/10.1080/13241583.2020.1746174
36. Wu, W., Maier, H.R., Dandy, G.C., Arora, M., Castelletti, A., The changing nature of the water–energy nexus in urban water supply systems: a critical review of changes and responses. Journal of Water and Climate Change, 2020. 11(4): 1095-1122. Doi https://doi.org/10.2166/wcc.2020.276
37. Szkup, R. Use *of Family Allotment Gardens by a Metropolitan Community*; Wydawnictwo Uniwersytetu Łódzkiego: Łódź Poland, 2013; p. 246, (In Polish). Available online: https://wydawnictwo.uni.lodz.pl/produkt/uzytkowanie-rodzinnych-ogrodowdzialkowych-rod-przez-spolecznosc-wielkomiejska/ (accessed on 15 August 2021).
38. Klepacki, P.; Kujawska, M. Urban allotment gardens in Poland: Implications for botanical and landscape diversity. *J. Ethnobiol.* **2018**, 38, 123–137.
39. Bartłomiejski, R.; Kowalewski, M. Polish urban allotment gardens as 'slow city' enclaves. *Sustainability* **2019**, 11, 3228.
40. Matasov, V., Belelli Marchesini, L., Yaroslavtsev, A., Sala, G., Fareeva, O., Seregin, I., Castaldi, S., Vasenev, V., Valentini, R.: IoT monitoring of urban tree ecosystem services: possibilities and challenges. *Forests*. **2020**, 11, 775. https://doi.org/10.3390/f11070775.
41. Olivero-Lora S., Meléndez-Ackerman E., Santiago L., Santiago-Bartolomei R., García-Montiel, D. Attitudes toward Residential Trees and Awareness of Tree Services and Disservices in a Tropical City. *Sustainability* **2020**, 12, 117. https://doi.org/10.3390/su12010117
42. Fluhrer T., Chapa F., Hack J. A Methodology for Assessing the Implementation Potential for Retrofitted and Multifunctional Urban Green Infrastructure in Public Areas of the Global South. *Sustainability*. **2021**, 13(1):384. https://doi.org/10.3390/su13010384.
43. Sowińska-Świerkosza, B. Critical review of landscape-based surrogate measures of plant diversity. *Landsc. Res.* **2020**, 45 (7), 819–840.
44. Raymond, C.M.; Frantzeskaki, N.; Kabisch, N.; Berry, P.; Breil, M.; Nita, M.R.; Calfapietra, C. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environ. Sci. Policy* **2017**, 77, 15–24.
45. Kabisch, N.; van den Bosch, M.; Lafortezza, R. The health benefits of nature-based solutions to urbanization challenges for children and the elderly—A systematic review. *Environ. Res*. **2017**, 159, 362–373.
46. Maes, J., Jacobs, S. Nature-Based Solutions for Europe's Sustainable Development. A journal of the Society for Conservation Biology. 2015. Pp. 1-4. doi: 10.1111/conl.12216
47. Hanson, H.I.; Wickenberg, B.; Olsson, J.A. Working on the boundaries—How do science use and interpret the nature-based solution concept? *Land Use Policy* **2020**, 90, 104302.

48. Sowińska-Świerkosz B., Soszyński D. 2019 The index of the Prognosis Rural Landscape Preferences (IPRLP) as a tool of generalizing peoples' preferences on rural landscape. *J. Environ. Manag.* **2019,** 248, 109272. https://doi.org/10.1016/j.jenvman.2019.109272.
49. Sender J., Kułak A.,. Phytocenotic structure and physico-chemical properties of a small water body in agricultural landscape. *ACTA AGROBOTANICA* **2014,** Vol. 67 (2), 2014: 31–40
50. Rutt, R.L., Gulsrud, N.M. Green justice in the city: a new agenda for urban green space research in Europe. *Urban For. Urban Green* **2016**,19, 123–127. https://doi.org/ 10.1016/j.ufug.2016.07.004.
51. Kabisch, N., et al. Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecol. Soc.* **2016,** 21, 39.
52. Chausson, A., et al. Mapping the effectiveness of nature-based solutions for climate change adaptation. *Glob. Chang. Biol.* **2020**, 26, 6134–6155.