

Article

Recreational Evaluation of Forests in Urban Environments: Methodological and Practical Aspects

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Abstract: This literature review shows that there is no up-to-date common approach to assess the recreational potential of forests. The aim of the study is to present methodological and practical aspects of the evaluation of forests in urban environments for recreational purposes based on the example of urban forests in Poznań (Poland). In this research, the following evaluation criteria were selected: types of forest habitats, ages of dominant species, stand composition, stocking index, the share of undergrowth, soil cover, canopy closure, and surface water. All these criteria are presented in the forest management plan (FMP). We prove that the majority of stands within the study area (81.86%) have medium potential for recreational purposes. Moreover, regarding recreation services, documents existing within the study area are not specified enough. The undoubted advantages of the proposed method are a forestry perspective on the problem, a uniform dataset included in FMPs, data availability, and the possibility of comparing data from different areas.

Keywords: evaluation; urban forests; recreation; forest management; nature-based solutions



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1. Introduction

Cities occupy only two percent of the planet's surface, but at the same time, their inhabitants use 75 percent of their natural resources. The world is urbanizing quickly, too: by 2050, 70 percent of the global population will live in cities and towns. Sustainable urban development is crucial, therefore, for ensuring the quality of life of the world's people. Forests and trees in urban and peri-urban environments, if properly managed, can make important contributions to the planning, design, and management of sustainable, resilient landscapes [1].

Urban forests fulfill multiple conflicting functions [2]. Nevertheless, the main objective of urban forests is to meet the recreational needs of people and to contribute to the ecological and physical structure of the city [3]. Decisions regarding the management and protection of urban forest spaces are usually made with a single goal in mind, be it the conservation of biodiversity or contributions to the social fabric of a neighborhood [4,5]. The management of such areas should focus on access, safety, and active human uses [5]. What is more, successful management should maximize the educational value of urban forests for local communities (especially youth) [1,6].

The social ecosystem services of forests are constantly gaining importance [7,8]. Paying attention to the social and ecological values of forests has increased mainly due to the requirements of multifunctional forest planning, which aims to integrate sociocultural and environmental issues [9,10]. Both psychological and physical human health may be positively affected by contact with nature [11–28]. Forests provide various opportunities for active outdoor recreation as well as for quiet relaxation and an escape from

daily urban stress [13]. During the COVID-19 pandemic, especially in the period of the greatest lockdown, we could see the key importance of forest areas located in cities for the psychophysical recreation of their inhabitants. Urban forests have become the main recreational areas for people, guaranteeing active and safe relaxation [29]. The observed development of the trend of the recreational use of forests in cities is also related to the process of urban development in the form of smart cities. According to the compensatory theory [30], city dwellers in an urbanized space with high ICT saturation need close contact with nature to rest effectively. This is ensured by forest enclaves, pocket prairies, and gardens [31].

Thus, forestry cannot ignore forest recreation as part of reality [32], especially nowadays, when most of the population is concentrated within agglomeration areas. Tourism and recreation impose major pressure on forested areas, which may be considered to have unassailable scenery or forms of recreation. On the other hand, forests will fulfill all their services only if they are appropriately developed for recreational purposes. Thus, the processes of preparing the concepts and designs of land development—together with placing linear, planar, and punctual elements, as well as developing these elements by furnishing them with recreational facilities, which, altogether, create the so-called street furniture—seem to be very important [33]. Access to recreational areas needs to be analyzed as part of planning processes in order for planners and policymakers to be able to compare the effects of different scenarios, and understanding how people perceive their access to recreational areas is an important basis for urban green structure management [34].

The process of evaluating natural elements may be important for, e.g., environment management, geotechnical and geological–engineering issues, nature protection, tourism, and recreation. The evaluation procedure values selected attributes of particular sites, areas, features, or processes to determine their usefulness for a given purpose. The evaluation of biotic and abiotic elements of the environment is a common procedure in studies on the relationships between nature and humans [35]. The valuation of forest ecosystem services can be used for forest resource conservation and management to both enhance sustainable resource use and persuade policymakers about the importance of particular forms of management [36–39]. Therefore, the valuation process offers incentives to managers for sustainable forest management [40,41].

The evaluation research conducted in Europe deals with the evaluation of different forest services, such as recreation, structure, or the management of forests. This research mostly uses a wide range of elicitation methods. The results are usually based on the stated preferences (e.g., the Contingent Valuation Method—CVM, Consumer Expenditure Surveys—CE, and expert surveys) and differing (regional) contexts [42], as well as a general overview of environmental valuation [43]. Such analyses are usually based on subjective criteria. Indeed, relatively few studies on the methodological basis of the recreational evaluation of selected indicators concerning forests have been conducted. The assessment of the usefulness of forests for recreation usually requires the analysis of a broad set of criteria that can guarantee objectivity and multidimensionality [8,44]. However, considering that a single selected criterion may also be useful and knowledge-building, the key question is whether to consider recreational infrastructure or not.

In fact, among the cultural services of forests, recreation, tourism, and aesthetic services are the most evaluated [45]. On the other hand, there is no up-to-date common approach to evaluating the recreational potential of forests. What is more, there is a lack of survey methodology presentation in existing research, and there are limited papers on the methodical approaches [46]. Therefore, there is a definite need for research that will fill in the missing gap in the practical implementation of the objective criteria for evaluating forests in urban environments. The novelty of the presented research is the fact that our study area has not been investigated in this context before. Existing Polish research, even when dedicated to recreation, is not focused on forests in urban environments [47–51]. None of this research presents the same evaluation criteria catalog or the same scoring scheme, as we do.

The aim of this study is to propose and test a catalog of evaluation criteria for forests in urban environments for recreational purposes. We assumed that no recreational infrastructure facilities would be assessed. This will allow us to investigate the natural potential of forests in urban environments without existing infrastructure. The analysis of the proposed approach is presented using the example of the city of Poznań (Poland). Moreover, this study is the first one considering the mentioned aim of the study within urban forests in Poland.

The results of the evaluation, based on the elaborated methodology, show clusters of areas characterized by different potentials for recreation. Such an approach is useful for managers and allows for the planning of recreational infrastructure, implementing changes to existing arrangements of infrastructure, or planning to exclude some areas, e.g., of high natural value from recreational usage. Moreover, by using the scheme we propose, managers will be able to update the state of knowledge on the given area's recreational potential, especially when the new forest management plan (FMP) appears. In Poland, the FMP is updated every 10 years. Thus, it is obvious that some characteristics of stands will significantly change, e.g., the ages of dominant species, the stocking index, the share of undergrowth, or canopy closure. As a result, some stands may turn out to become more attractive or unattractive for recreation.

2. Materials and Methods

2.1. The Study Area

The study was conducted in the urban forests of Poznań City (W Poland; 52°24' N, 16°57' E; 60–154 m a.s.l.). Poznań has a population of 550,700 inhabitants and covers an area of 262 km². Urban forests comprise 13% of the city area [52] and are administratively divided into four municipal forest ranges: Zieliniec, Antoninek, Marcelin, and Strzeszynek. In total, the area exceeds 2466.60 ha. The study area is divided into 2 categories: water-protecting and/or soil-protecting forests, with a share of 13.79% of the total area, and forests available for recreation, with a share of 86.21% [53].

Within the study area, the dominant species are *Pinus* spp. (47.94%), *Birch* spp. (16.81%), *Quercus petraea* (Matt.) Liebl. (11.60%), and *Tilia* spp. (5.50%) [54].

Urban forests that are situated in close vicinity to residential and built-up areas are roughly fragmented. In general, the city is characterized by a shortage of natural resources. Urban sprawl areas, industrial wetlands, and landfills occupy more and more land, destroying not only the landscape values but also reducing the possibilities of settlement and recreation [55].

2.2. Methodological Stages of Research

This research is built around cluster analysis techniques, which are procedures of evaluation that can be used to assess green areas [56]. Forest areas with assigned scores for the set of qualitative and quantitative variables were grouped with a weighted k-means algorithm [57]. Then, on the basis of developed groups, we provided a classification of these areas with regard to the recreational potential.

This study is based on the Forest Management Plan for the Municipal Forests of the City of Poznań for the period from 1 January 2013 to 31 December 2022 [54]. From the perspective of forestry, the FMP is a basic source of data about a selected forest and contains a description and evaluation of the condition of the given forest, as well as the objectives, tasks, and methods of forest management.

The criteria assessed in this study come from the forest inventory, which is part of the FMP. From the features presented in the forest inventory, we selected seven evaluation criteria that are strictly dedicated to the characterization of the forest and may affect recreational activity: the type of forest habitats, the age of dominant species, the stand composition, the stocking index, the share of undergrowth, soil cover, and canopy closure. The additional criterion that characterizes the forest landscape is surface water (Figure 1). Simultaneously, we found that other features included in the forest inventory are not

significantly related to recreation; this concerns diameter at breast height, forest stand quality, merchantable timber volume, the current annual increment, and the site index of the stand.

<p>Type of forest habitats</p> <ul style="list-style-type: none"> • fresh mixed coniferous forest, fresh mixed broadleaved forest, fresh broadleaved forest • dry coniferous forest, fresh coniferous forest • moist coniferous forest, moist mixed coniferous forest, moist mixed broadleaved forest, moist broadleaved forest, flooded broadleaved forest • swamp coniferous forest, swamp mixed coniferous forest, swamp mixed broadleaved forest, alder swamp forest, ash-alder swamp forest
<p>Age of dominant species</p> <ul style="list-style-type: none"> • >80 years • 41–80 years • 21–40 years • 1–20 years or non-productive forest lands for regeneration
<p>Stand composition</p> <ul style="list-style-type: none"> • ≥ 4 species • 3 species • 2 species • 1 species
<p>Stocking index</p> <ul style="list-style-type: none"> • <0.5 • 0.5–0.7 • 0.8–0.9 • ≥1.0 or areas of a selection structure or without stocking index
<p>Share of undergrowth</p> <ul style="list-style-type: none"> • 0–10% • 11–30% • 31–70% • >70%
<p>Soil cover</p> <ul style="list-style-type: none"> • mosses, herbs • soil not covered or litter or mosses and berries • turf • turf or weeds
<p>Canopy closure</p> <ul style="list-style-type: none"> • open • broken • moderate • complete closure or clearcut areas, blanks, unforested areas, establishments without closure
<p>Surface water</p> <ul style="list-style-type: none"> • lakes • rivers, streams • ponds, storage reservoirs, swamps, peatlands • no access

Figure 1. Evaluation criteria and their scales used in the study.

In the evaluation methodology, the catalog of criteria is not only of key importance but also a scoring scheme. Existing research presents the scoring scheme data from the 1970s to the present day [46,58–61], and none of them were applied to a common international level or were the basis of more than one survey. For instance, Supuka I Vreštiak [59] used a mixed score approach (ascending–descending scale with scores from 1 to 6, then scores from 5 to 4); Levandowska et al. [62] used a 0–2-point scale to assess the recreational potential of urban forests, while Ważyński [60] and Dudek [61] used an increasing scores approach (scores from 1 to 5). Therefore, in this research, a 4-point ordinal scale was used to establish the point values for the qualitative variables. In order to determine the weights of the individual criteria, we analyzed studies from a recreational perspective, including the visual perception of forests, the evaluation of aesthetic values, preferences for forest landscapes, satisfaction with rest in forest areas [63–65], and the regeneration of mental and physical health through various types of active rest carried out in forests [66]. Then, research was carried out in a group of experts using the Delphi method [67]. The group of experts belonged to the research network GeoLabTur (Geographical Laboratory of Tourism) and had extensive experience in both research and applications in many local and regional locations. Experts were presented with the items listed in Table 1, the evaluation criteria, with a proposal of their weights on a scale from 1—the least important factor—to 3—the most important factor—with a request to confirm or verify the weight values. The research was conducted with the participation of five experts in three rounds in July 2022. Their results are presented in Table 1. The research procedure was guided by the conclusions presented in the study “Estimation of Recreational Potential of Urban Forests” ([68], p. 6): regarding the methods to investigate forest landscapes, “(1) the optimum amount of indices to characterize each forest landscape comprehensively and (2) objectivity and simplicity of investigation”. The methodological stages of the research are presented in Figure 2.

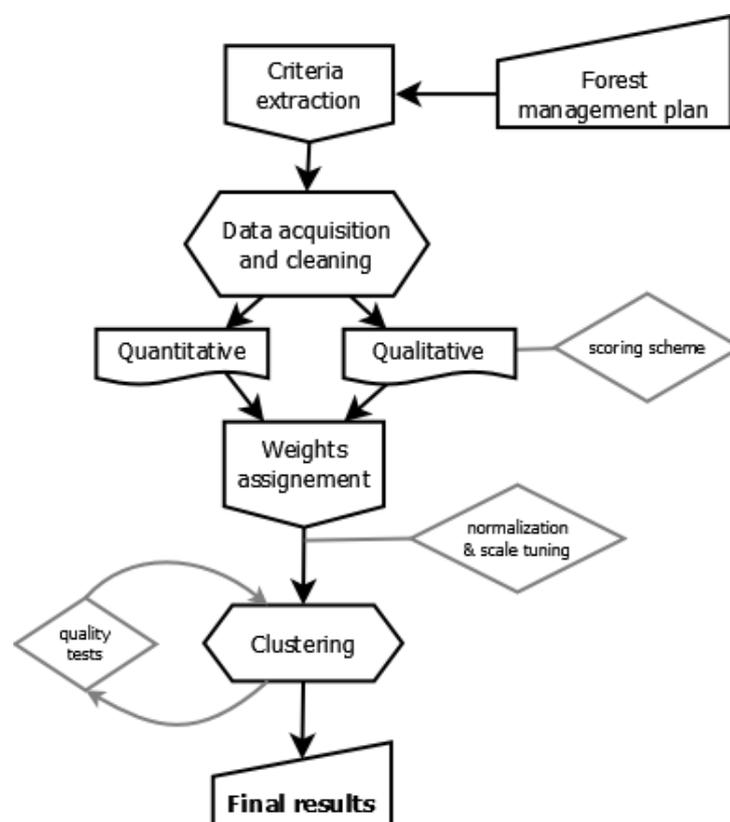


Figure 2. Methodological stages of research.

Table 1. The scoring scheme used in this study.

Criteria	Description	Weight	Scores
Type of forest habitat (k1)	Fresh mixed coniferous forest, fresh mixed broadleaved forest, fresh broadleaved forest	1	4
	Dry coniferous forest, fresh coniferous forest		3
	Moist coniferous forest, moist mixed coniferous forest, moist mixed broadleaved forest, moist broadleaved forest, flooded broadleaved forest		2
	Swamp coniferous forest, swamp mixed coniferous forest, swamp mixed broadleaved forest, alder swamp forest, ash–alder swamp forest		1
Ages of dominant species (k2)	0-200 (112 values)	2	Numerical variable—no scores were assigned
Stand composition (k3)	0-14 (15 values)	3	Numerical variable—no scores were assigned
Stocking index ¹ (k4)	0-1.5 (15 values)	2	Numerical variable—no scores were assigned
Share of undergrowth (k5)	0-150 (15 values)	3	Numerical variable—no scores were assigned
Soil cover (k6)	mosses, herbs	2	4
	Soil not covered, litter, or mosses and berries		3
	Turf		2
	Turf or weeds		1
Canopy closure ² (k7)	Open	3	4
	Broken		3
	Moderate		2
	Complete closure or clearcut areas, blanks, unforested areas, establishments without closure		1
Surface water (k8)	Lakes	2	4
	Rivers, streams		3
	Ponds, storage reservoirs, swamps, peatlands		2
	No access		1

¹ A quantitative measure of the area occupied by trees, usually measured in terms of well-spaced trees or the basal area per hectare relative to an optimum or desired level of density. ² The proportion of sky hemisphere obscured by vegetation when viewed from a single point. Source: Elaborated on the basis of [45,46,54,55,58–61,63–66,69–81].

2.3. Evaluation Arrangements

Many scoring schemes presented in the literature are varied and impossible to compare with each other; thus, we elaborated our own scoring scheme. Nevertheless, we adopted the general assumptions of existing methods of forest evaluation. Each criterion in our research is based on the forestry sector and supported by adequate references below.

2.3.1. Type of Forest Habitats

We adopted the approach that resulted from the literature review. Fresh mixed coniferous forests, fresh mixed broadleaved forests, and fresh broadleaved forests are more suitable for recreation than flooded forests or swamps [45,54,69–71]. The frequently modified method of evaluating forests is the method used by the Polish Forest Research Institute (IBL method) [47,69,72,73]. The main evaluation criteria of this method are the type of forest habitat and the ages of the stands. The IBL method distinguishes 5 degrees of the

suitability of stands for recreational use. The most useful stands get a score of 1, while unattractive stands receive a score of 5.

2.3.2. Ages of Dominant Species

We consider the ages of dominant species according to age classes specified in the forestry sector. Older stands and mature trees are highly preferred by society [46,58–60,69,73,76]. The results of research on landscape preferences [77,82–84] also confirm the above statement. Scoring schemes, if provided, are very varied, e.g., an ascending–descending scale [59] or an increasing scale [60,61]. In this research, we propose an increasing scale.

2.3.3. Stand Composition

The most desirable stands, from the point of view of landscape attractiveness, are mixed or deciduous forests, as well as those varied in terms of species composition [55,85–88]. The species composition of the stand was also recognized by Stępień [73], who determined the following levels of recreational value: (a) multi-species stands, various forms of mixing—great recreational value; (b) mixed stands composed of 3–4 species, a predominance of group mixing—average recreational value; (c) mixed stands composed of 2–3 species, a predominance of single mixing—low recreational value; (d) monocultures—no recreational value. Therefore, we stated that the more species in a stand, the better it is for recreation.

2.3.4. Stocking Index

We adopted the approach that resulted from the literature review. Gołos [78] found that dense and dark stands with a stocking index of 1.0 or more are the least attractive in terms of recreation. In a representative, nationwide survey, the respondents created a description of the most attractive stand, which can be described as tall and old, mixed and bright, and sparse [75,79]. Such stands allow for better conditions to observe nature and provide a better sense of security, and the occurring breaks ensure visibility and, thus, affect a positive perception of the surrounding landscape. At the same time, the indications regarding the preferred stand density, in comparison with the results of research on preferred ages and heights, do not allow for the determination of a constant relationship of preferences, which indicates that the respondents do not clearly associate the relationship between these features with the number of trees per unit area in stands [78]. In the case of stands for which more than one story was distinguished, the stocking index was summed up.

2.3.5. Share of Undergrowth

We did not encounter many examples of undergrowth evaluation taking into account a specific percentage share. In this case, we modified the criteria according to Ważyński [60,80], who selected the following groups: (a) available stands—no undergrowth layer taking or up to 10% of the area; (b) moderately accessible stands—undergrowth layer taking up 11% to 30% of the area; (c) stands that are difficult to access—undergrowth layer taking up 31% to 70% of the area; (d) unavailable stands—undergrowth layer above 70% of the area.

2.3.6. Soil Cover

Due to the subjective perception of the height of grasses and herbaceous undergrowth, the criterion adopted in this study was the type of cover, which is a forest term. The research shows that forest landscapes with a lush green undergrowth cover are rated higher by society than those with a bare cover, devoid of vegetation [82,89–91]. On this basis, soil covers appearing in the forest taxation (mosses, herbs, soil not covered, litter; mosses and berries; turf, weeds) have been divided into usefulness groups for recreation.

2.3.7. Canopy Closure

People prefer bright stands to dense forests [4,92]. Society's preference for bright stands is known due to, *inter alia*, the research by Coles and Bussey [4] and nationwide

research conducted in Poland [79]. In the presented methodology, we recognized that the full canopy closure of stands is the least beneficial for recreational purposes, as it causes shading in the forest interior, which may make orientation in the field difficult. Hence, we found open and broken canopy closure to be the most favorable. The form of canopy closures is of particular importance to camping, observing nature, and orientation in the field.

2.3.8. Surface Water

Highly natural landscapes with a high proportion of surface water provide a source of values widely used in recreation. In urbanized areas, their share is usually small. They are most often found in places that are not suitable for development. In Poznań, these are mainly riverside areas. Recreation is very intense within them [81]. Due to the presence of lakes within the city's administrative borders, they are considered the most attractive element among surface water objects. Rivers and streams were found to be somewhat less attractive due to their often-limited accessibility. Ponds, retention reservoirs, swamps, or peat bogs received 2 points in the adopted methodology, which proves their low value for recreation purposes. However, their landscape value was recognized, as well as the fact that they can be the object of nature observation or the object of interest for photographers.

2.4. Weighted Clustering of the Forest Areas

To extract and evaluate specific groups from the dataset with regard to the recreational potential, we employed clustering techniques. These techniques are basically an area of unsupervised learning [93]. There are plenty of clustering algorithms, and we made use of the k-means approach [94,95] with the modification described by Ripley [96]. The method allows for the inclusion of individual weights for observations, according to Table 1. The algorithm iteratively minimizes the distance between the cluster center (centroid) and the different observations. In each iteration, the centroid is moved to the mean of the coordinates within a given group and new clusters are created. The procedure is repeated until no further changes in clusters occur. A detailed description and formal investigation can be found, i.e., in Pena et al. [97] or Ripley [96]. In our research procedure, we took the usual measure of distance, which is Euclidean (the distance is defined as $distance(x, y) = \sum_i^n (x_i - y_i)^2$). For the stocking index and the share of undergrowth, we reversed the scale (the scale for each value was reversed according to the formula $\max(x_i) - x_i$, as the lower values of these variables are better for recreational purposes). Assigned scores were used for computations of qualitative variables; numerical values were used in the case of quantitative variables. In a further step, we scaled each variable to have a mean (μ) of 0 and a standard deviation (σ) of 1 to match the standard normal distribution. Therefore, data were scaled according to the formula:

$$z = \frac{x - \mu}{\sigma}, \quad (1)$$

The clustering algorithm a priori determines the number of clusters within the data. Therefore, we used the average silhouette method [98] together with the elbow method [99] to measure the quality of grouping. The silhouette method computes the coefficients of each point that measure how similar a point is to its own cluster compared with other clusters on the basis of the formula

$$s(i) = \frac{b(i) - a(i)}{\max(b(i), a(i))}, \quad (2)$$

where $b(i)$ is the average distance of the point with all the points in the cluster closest to its cluster; $a(i)$ is the average distance of the point with the points within the same cluster; $s(i)$

is the silhouette coefficient. The total score is the average of all these points. In turn, the elbow method defines clusters on the basis of a simple variation minimization principle:

$$\min\left(\sum_{k=1}^k \text{Var}(C_k)\right), \quad (3)$$

where C_k is the specific cluster, k , and Var is the within-cluster variation. The optimal number of clusters, in this case, is the so-called “elbow point”, the point where the graph creates the shape of an elbow.

3. Results

3.1. Descriptive Analysis

Within the study area, dominant forest habitats (81.97%) are those considered the most useful for recreation, i.e., fresh mixed coniferous forest, fresh mixed broadleaved forest, and fresh broadleaved forest. Since its share is quite significant, the spatial distribution of this feature is even. The most attractive stands, at ages of over 80 years, have a share of 12.1%, while the largest share (68.1%) constitutes stands with ages of 41–80 years. When analyzing the location of these stands, one can see that they are in the vicinity of Warta River; the lakes Rusałka and Strzeszyńskie; the ponds Antoninek and Browarny; and in the immediate vicinity of Fort I, a Natura 2000 area: “Fortifications in Poznań”. The vast majority of stands (75.89%) have six or more species, which makes them very attractive for forest users. These stands are evenly distributed across the study area. Stands characterized by the most preferable stocking index at the level of >0.5 constitute only 2.41%, while the biggest share (49.83%) has stands with stocking indexes from 0.5 to 0.7. The spatial analysis of this feature shows a great dispersion. Stands characterized by poor accessibility with a share of undergrowth at the level of $>70\%$ are dominant (42.71%). Stands recognized as the most preferable (0–10% of undergrowth) with a share of only 9.64% are scattered throughout the study area and do not form a denser complex. Some clusters of stands, in which there is no understory or undergrowth or for which their shares are up to 10%, are noticeable in the immediate vicinity of the Miłostowo Municipal Cemetery in “Uroczysko Bogucin”, “Uroczysko Sławie”, and “Uroczysko Piotrowo”. The study area is characterized by soil covered with mosses and herbs (53.39%) and turf (31.34%). Clusters of stands with mosses and herbs are located by the lakes Rusałka, Strzeszyńskie, and Kierskie and “Uroczysko Marcein”, “Uroczysko Dębina”, “Uroczysko Piotrowo”, and “Uroczysko Piątkowo”. Within the study area, the biggest share has stands with undesirable moderate canopy closure (57.52%) and complete closure or clearcut areas, blanks, unforested areas, and establishments without closure (18.83%).

The majority of urban forests in Poznań have no access to surface waters (77.49%). Only 1.84% of stands are by lakes (Rusałka, Strzeszyńskie, and Swarzędzkie), while 6.89% are situated by rivers or streams. They are located within “Uroczysko Naramowice” and “Uroczysko Malta” and are in close vicinity to the lakes Kierskie and Strzeszyńskie. Basic statistics (the mean standard deviation together with the min and max values) for the data described above are presented in Figure 3.

3.2. Clustering Outcomes

The results of testing the quality of grouping for the weighted clustering algorithm are presented in Figure 4. In the case of the silhouette method, the highest score was obtained for four clusters (~ 0.20). In turn, the results for the elbow method are not very visible; however, it could be stated that the three clusters are a good choice (a slight bend at three on the X-axis).

No	Variable	Stats / Values	Freqs (% of Valid)	Graph	Valid	Missing
1	type of habitat [numeric]	Mean (sd) : 3.6 (0.9) min ≤ med ≤ max: 1 ≤ 4 ≤ 4 IQR (CV) : 0 (0.2)	1: 43 (4.9%) 2: 114 (13.1%) 4: 714 (82.0%)		871 (100.0%)	0 (0.0%)
2	age of dominant species [numeric]	Mean (sd) : 60.9 (29.4) min ≤ med ≤ max: 0 ≤ 62 ≤ 200 IQR (CV) : 25.5 (0.5)	112 distinct values		871 (100.0%)	0 (0.0%)
3	stand composition [numeric]	Mean (sd) : 5.4 (2.6) min ≤ med ≤ max: 0 ≤ 5 ≤ 14 IQR (CV) : 3 (0.5)	15 distinct values		871 (100.0%)	0 (0.0%)
4	stocking index [numeric]	Mean (sd) : 0.7 (0.2) min ≤ med ≤ max: 0 ≤ 0.7 ≤ 1.5 IQR (CV) : 0.1 (0.2)	15 distinct values		871 (100.0%)	0 (0.0%)
5	share of undergrowth [numeric]	Mean (sd) : 64.5 (29.5) min ≤ med ≤ max: 0 ≤ 70 ≤ 150 IQR (CV) : 30 (0.5)	15 distinct values		871 (100.0%)	0 (0.0%)
6	soil cover [numeric]	Mean (sd) : 3.2 (0.9) min ≤ med ≤ max: 1 ≤ 4 ≤ 4 IQR (CV) : 2 (0.3)	1: 10 (1.1%) 2: 273 (31.3%) 3: 123 (14.1%) 4: 465 (53.4%)		871 (100.0%)	0 (0.0%)
7	canopy closure [numeric]	Mean (sd) : 2.1 (0.7) min ≤ med ≤ max: 1 ≤ 2 ≤ 4 IQR (CV) : 0 (0.3)	1: 164 (18.8%) 2: 501 (57.5%) 3: 191 (21.9%) 4: 15 (1.7%)		871 (100.0%)	0 (0.0%)
8	surface water [numeric]	Mean (sd) : 1.3 (0.7) min ≤ med ≤ max: 1 ≤ 1 ≤ 4 IQR (CV) : 0 (0.5)	1: 675 (77.5%) 2: 120 (13.8%) 3: 60 (6.9%) 4: 16 (1.8%)		871 (100.0%)	0 (0.0%)

Figure 3. Descriptive statistics for the data used in the study. Source: own computations.

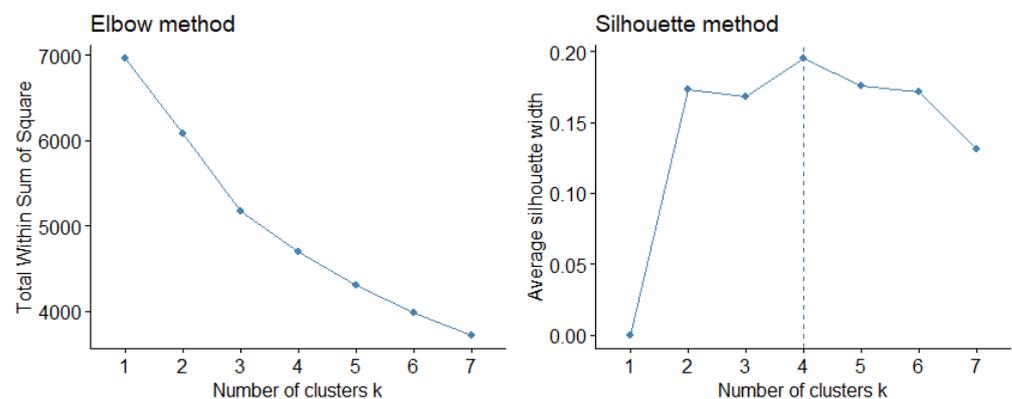


Figure 4. The results of the cluster-fitting analysis.

Accordingly, we developed two clustering models with three and four centroids. We used a hard clustering algorithm [96] that started grouping with an initial number of 25 centroids; the maximum number of iterations was set to 100. We used the *foc-toextra* package by Kassambara and Mundt [100] together with the *cluster* package by Maechler et al. [101]. All computations were performed in the R programming language (4.1.0). Finally, we decided to develop three clusters as the visual evaluation of the results indicated that the fourth group of observations overlapped at several points with cluster 1 and cluster 2. Therefore, it did not make sense from a cognitive point of view. The comparison is plotted in Figure 5.

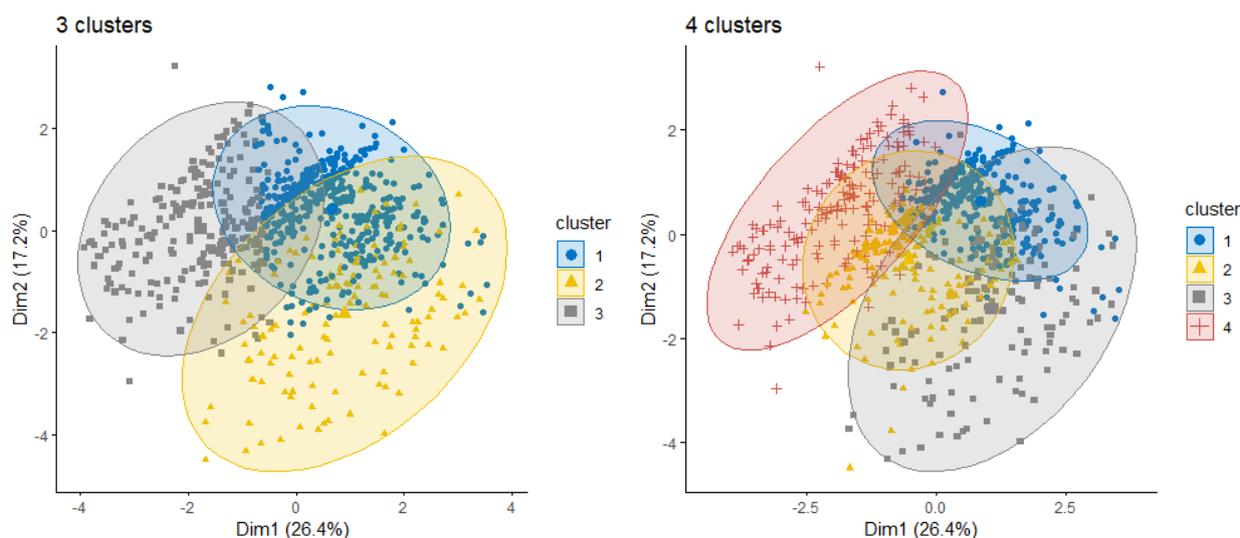


Figure 5. The results of clustering for three and four groups.

We also computed the Euclidean distance matrix to measure the distances between the rows of a data matrix.

On the basis of these computations, in Table 2, we present the results of clustering with the weighted k-means algorithm. We assume that the higher the average score, the higher the recreation potential the forest area has.

Table 2. The average scores for each variable and overall mean values within the clusters*.

Cluster	k1	k2	k3	k4	k5	k6	k7	k8	Mean
1	0.21	0.35	0.13	0.26	−0.40	0.37	0.39	−0.31	0.12
2	0.18	−0.76	−0.38	−0.57	0.76	−0.71	−0.81	−0.25	−0.32
3	−1.40	0.29	0.33	0.26	−0.07	0.01	0.29	1.97	0.21

* k1 is a type of forest habitat; k2 is the ages of dominant species; k3 is the stand composition; k4 is the stocking index; k5 is the share of undergrowth; k6 is the soil cover; k7 is the canopy closure; k8 is the surface water. Source: own computations.

We classified the cluster on the basis of the obtained mean values for all evaluated criteria; therefore:

- Cluster 3 is the cluster with the highest mean value for all criteria (0.21). Two of the eight evaluated indicators are negative, while the rest of them have positive values. The areas within a cluster are classified to have high recreational potential.
- Cluster 2 is the cluster with the lowest mean value for all evaluated criteria (−0.32). Six of the eight indicators were below zero. We assume that this cluster has the lowest recreational potential.
- Cluster 1 is the cluster with the mean value of the criteria between cluster 1 and cluster 2 (mean value of 0.12). Two of the eight variables were lowered than zero. Therefore, we assigned medium recreational potential to this group.

It is also worth noting that the distance between cluster 1 and cluster 3 is lower than between cluster 2 and cluster 3. This means that clusters 1 and 3 are more similar than clusters 2 and 3. However, several nuances are hidden in this type of analysis. For instance, the cluster with the highest recreational potential (3) is also the cluster with the significantly lowest *type of habitat* (k1) and the second lowest *soil cover* (k6) score (-1.40 and 0.01, respectively). In turn, the cluster with the lowest recreational potential (2) has the second highest scores for the *type of habitat* (k1) and *surface water* (k8). These reached 0.18 and -0.25, respectively.

Finally, we visualized the results of the analysis on the map (Figure 6). The outcome is that the majority of assessed areas (481–55%) are characterized by medium recreational potential. These are situated mainly in the western part of the city and cover the forests around Rusalka Lake, Strzeszynek Lake, and Kierskie Lake. The areas are also characterized by good recreational infrastructure (e.g., bike and pedestrian trails, beaches, playgrounds, and places for rest). Other areas with medium potential are located in the far eastern parts of the city: around the New Zoo and near Swarzedz lake. In turn, there are 277 areas characterized by the lowest recreational potential (32%). These areas are mainly situated in the eastern and northern parts of the city. The least numerous is the last group, which contains 113 areas (13%) characterized by the highest recreational potential. These areas are quite rare and usually interspersed with those of medium recreational potency around lakes Kierskie and Strzeszynek, as well as those near Warta River, in relative proximity to the city center.

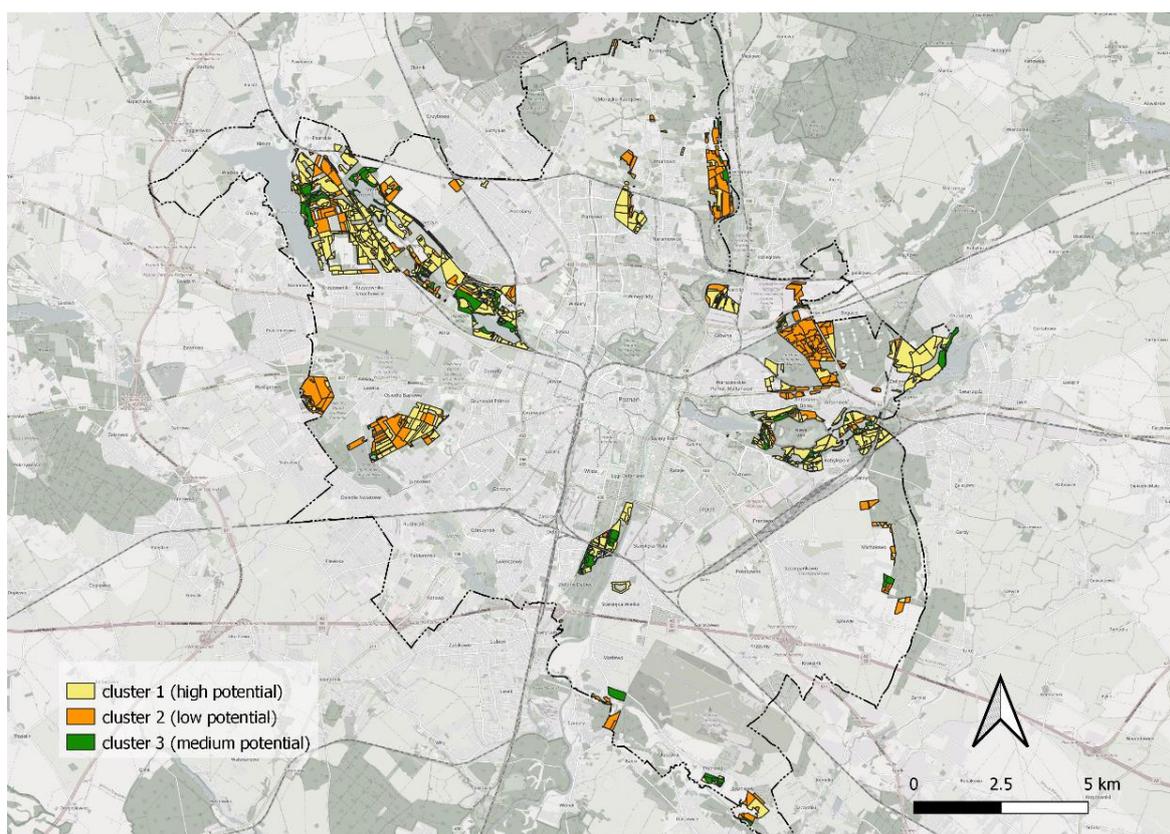


Figure 6. Spatial presentation of the evaluation of urban forests in Poznań (Poland).

The optimistic outcome is that cluster 1 (medium potential) is more similar to cluster 3 (high potential) than to 2 (low potential). The mean distance between clusters 1 and 3 is equal to 0.09, while between clusters 1 and 2, it is equal to 0.44. Together, clusters 1 and 3 constitute 68% of all forest areas. Therefore, the vast majority of forest areas in Poznań have medium or high recreational potential.

4. Discussion

4.1. Evaluation of Forests

A lot of research finds recreational values for forests that score highly [102–106]. Individual preferences may be more influenced by factors such as visibility, accessibility, and the security of the forests. These characteristics of forests are particularly important for users in urban areas [107,108]. Urban forest landscape preferences probably have regional differences, but they may also differ at the city level [109].

The research on the overall evaluation of forest environments, as well as the attractiveness, the ecological and aesthetic values, or the suitability for recreation, presents various criteria, e.g., presenting photographs of forests [109] or questionnaires [110–112]. Some research assesses actual onsite recreation by using camera traps [102,113], and long-term video observation [114], as well as lap sensors, tube sensors, infrared barriers, and pyroelectric sensors [114–118]. However, on the other hand, these methods say nothing or little about the potential of such environments.

In our study, we propose focusing on the evaluation of the elements that characterize the forest itself, which will help to decide where to locate the recreational infrastructure.

4.2. Recreation in a Forest Management Plan

The “Guidelines for the management of municipal forests of Poznań” [53] are pioneering in the whole country. However, they are from 2012, and there is no up-to-date version. Most of their aspects are universal, and they should reflect not only current environmental circumstances but also citizens’ preferences and social situations. Regarding recreation, the document has no particular future aims or specified approaches to development. The section “Technical forest equipment for recreation” is limited to general theoretical rules, e.g., “the technical management of forests and other green areas for recreation consists in designing the recreational facilities, arranging them in a way that ensures natural comfort of rest and minimizing conflicts caused by this procedure in the environment”, “there is the need to individualize the design procedure”, and “there is the need to use natural local materials”. The part describing, e.g., the number of recreational equipment from the time perspective, the length of paths (current and planned), or modernization plans for recreational infrastructure (what and when needs to be repaired) is clearly missing.

The management of urban forests tends to be less production-oriented, less intensive, and smaller in scale than in rural production forests [119]. In general, the management of forests is regulated by forest management plans. However, when it comes to urban forests in Poland, there is either a full or simplified version of the forest management plan [120,121]. Unfortunately, the arrangement of the content of FMPs needs consideration because they often include useless or too specific information [122].

When analyzing the current FMP designed for the study area, the lack of attention to ways of developing the recreation infrastructure is also extremely noticeable. There is only a simple list of recreation facilities. Whereas, over the last decade, recreational activities have changed from passive forms (e.g., rest, relaxation) to more active forms (e.g., running, mountain biking, climbing) [123], nowadays, the demand for suitable infrastructure (e.g., mountain-bike trails, high-rope parks) has increased [124]. Simultaneously, the FMP presents analyses of the current share of forest habitats and volume tables within selected areas for the specific intensity of recreational arrangements.

Modest records on recreational facilities and the lack of description of the goals and aspirations in the implementation of the recreational function are inconsistent with the fact that it is the dominant service of urban forests. Existing documentation is more for forestry than for recreation (both in terms of qualitative and quantitative descriptions).

Additionally, to enable a comfortable rest, recreational facilities should take into account the possibilities and limitations of people with different psychophysical abilities and should implement the principle of “design for all”. One of the high-potential solutions is to create sensory gardens within urban forest areas [120,121,125,126].

4.3. Implications for Urban Landscape Conservation and Planning

Increasing and restoring the functionality and connectivity of urban and peri-urban natural landscapes can make a valuable contribution to the conservation of natural resources and biodiversity. Habitat fragmentation is the biggest challenge to the conservation of urban wildlife. The more heterogeneous and interconnected the green infrastructure, the more resilient the ecosystems will be. Well-managed urban forests within cities are able to maintain a surprisingly rich variety of habitats and native species while, at the same time, helping conserve natural landscapes beyond city boundaries [1]. The protection of suburban areas should, therefore, be an essential part of the comprehensively understood issues of urban protection and should be investigated on a broader scale of landscapes [127].

Konijnendijk van den Bosch [128] points out that nature-based solutions (NBS) can take many shapes and forms. NBS may be considered an individual tree or a citywide tree canopy cover providing shade and cooling to green roofs with aesthetic and energy-saving functions. When it comes to urban areas, it will be more frequent to have managed ecosystems focused on sustainability and multifunctionality, e.g., managed urban woodlands. On the other hand, the International Union for Conservation of Nature (IUCN) has negated too broad an approach and suggested the elimination of solutions that are just “inspired by” nature (e.g., through biomimicry in architecture and engineering). IUCN considers NBS activities dedicated only to protecting and restoring natural (or modified) ecosystems that address societal challenges adequately and adaptively. At the same time providing for the well-being of individuals and biodiversity benefits. Hence, it is not only about benefits from ecosystems for individuals, it is also about society giving back to nature, e.g., by restoring ecosystems and protecting biodiversity [101].

In our study, we have presented a method of evaluating urban forests that is aimed at evaluating the recreational potential of forests; however, the information we obtained could be used for the protection of woodlands as well. The results show areas with diversified recreational potential; by analyzing only forest criteria, we also obtain information about the location of high-value biodiversity habitat areas that could be excluded from use, thus providing environmental protection. The presented method of evaluation (or some parts of it) may be applicable to any woodland area (e.g., urban, peri-urban, state forests, municipal ownership, private ownership). Focusing on only natural criteria provides objectivity. Since the evaluated features are derived from the science of forestry, they can be assessed worldwide based on the source, which is FMP, or with the help of professional foresters.

To formulate guidelines for the future management of urban forests, it becomes crucial to analyze the given area in terms of the recreation potential, as demonstrated by the results of this research. This will allow for the selection of areas with different potentials that will affect the design and layout of recreation facilities. By considering strictly forest-based criteria, a detailed image of the forests in urban environments appears. As a result, some areas may be excluded from use due to not only low potential but also, for example, the need to protect the environment (e.g., the threat of excessive erosion in dry coniferous forests, the protection of precious species of ground cover in oak–hornbeam forests, etc.).

In Poland, forests located within the administrative boundaries of cities and only 10 km from the administrative borders of cities with more than fifty thousand people are considered protective forests [129]; the general objectives of their management should be protection, maintenance, and, finally, reconciliation of protection with access to the public. The following recommendations are for the whole study area according to the assessed characteristics.

The environment of fresh mixed coniferous and broadleaved forests, dominant within the study area, is suitable for all types of recreation. These forest habitats are universal in terms of biotherapeutics and recreation. In such habitats, there is a relatively low threat of pollen allergens. There are no specific guidelines. In contrast, swamp forests, despite their health values, are not suitable for intensive recreation. They are characterized by low soil resistance to trampling, variable water relations, the occurrence of mists, and cold air outflows. Recreational use should only take place along designated paths [130].

For stands aged 15–20 years, we recommend improving the breeding and health quality of the future stand and increasing its resistance to unfavorable development conditions and threats to both biotic and abiotic factors with intermediate cuttings. For stands aged 21–50 years, intermediate cuttings are aimed at shaping the structure of the stand and its spatial diversity, with the creation of conditions (older stands) for initiating natural regeneration or introducing plantings. For stands aged 51–60 years, intermediate cuttings are aimed at the final regulation of canopy closure. At the same time, for stands at this age, sanitation and landscape-shaping cuttings are recommended [103]. In order to minimize the potential damage to the natural environment resulting from forestry works, we recommend leaving alone valuable clumps of old trees as well as some hollow trees [53].

The stocking index, the share of undergrowth, and canopy closure result from the stage of stand development; therefore, no straight guidelines can be provided.

The stand composition of the study area is attractive; however, we recommend maintaining significant species diversity and introducing foreign and decorative species.

In low-moisture conditions, soil covered with mosses (dominant within the study area) is very flammable, which is a serious threat to the natural environment. Thus, watchful observation is recommended.

The above recommendations for the study area are independent of the existing “Guidelines for the management of municipal forests of Poznań”, which we found to be too general.

4.4. The Study's Limitations

The main limitation of the evaluation of forests in urban environments is that there are limited papers on methodical approaches considering the suitability of forests for recreation. As previously mentioned, existing ones were not applied to more than one study. This makes it impossible to compare the results and have a wider discussion. There is much more research on society's visual preference for forests, mostly based on questionnaire surveys.

5. Conclusions

The objective of this study was to evaluate the urban forests of Poznań for recreational purposes. We took into account nine features of the forest's environment, excluding manmade objects. Therefore, our study shows the attractiveness of the forest itself. Using a scoring method, we identified three levels of recreational potential for urban forests within the study area (low, medium, and high).

The main conclusions are as follows:

- The majority of the study area (55%) has medium potential for recreation purposes;
- High-potential stands (13%) and low-potential stands (32%) can move up to a higher category mainly through reasonable active and passive forest management;
- There is a lack of strategy for recreational functions in the existing FMP and “Guidelines...” [39] within the study area;
- The lack of reasonable forest management and a disregard for public preferences regarding the appearance of the forest, supported by research, may contribute to reducing the attractiveness of stands.

The presented set of criteria is our voice in the discussion on the methodology of the evaluation of the environment of urban forests. Assessing features included in FMPs make the proposed approach as impartial as possible, mainly due to a uniform dataset in the FMPs and data availability. This provides the possibility of comparing data from different areas. Since recreation within urban forests is dominant among others services, it should not be neglected in any documentation. The obtained results may be the basis for the location of recreational infrastructure, the development of conservation goals, the exclusion of certain areas from use by the public, and the conscious management of recreation.

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