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Landscape Ecological Evaluation of Cultural Patterns for the Istanbul Urban Landscape

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Abstract: With the widespread population growth in cities, anthropogenic influences inevitably lead to natural disturbances. The metropolitan area of Istanbul, with its rapid urbanization rate, has faced intense pressure regarding the sustainability of urban habitats. In this context, landscapes comprising patches affected by various disturbances and undergoing temporal changes must be analyzed, in order to assess city-related disturbances. In this study, the main objective was to understand how urbanization changed the function of the spatial distribution of the urban mosaic and, more specifically, its relationship with the size, shape, and connection among land-use classes. For this purpose, we took Besiktas, a district of Istanbul, as the study area. We evaluated the landscape pattern of the urban environment in two stages. First, we used medium-resolution satellite imagery to reveal the general interactions in the urbanization process. Landscape- and class-level landscape metrics were selected to quantify the landscape connectivity, and the distances between classes (green areas and artificial surfaces), patterns, and processes, using five satellite images representing a time span of 51 years (1963, 1984, 1997, 2005, and 2014). The general landscape structure was examined by looking at the temporal–spatial processes of artificial surface and green areas obtained from these medium-resolution satellite images. The trends in selected landscape-level metrics were specified and discussed through the use of a moving window analysis. We then used Pleiades high-resolution satellite imagery (2015) to analyze the landscape structure in more detail. This high-resolution base image allows us to recognize the possibility of classifying basic cultural landscape classes. The findings regarding the spatial arrangement of each class in the areas allocated to 14 cultural landscape classes were interpreted by associating them with the landscape functions. Finally, particulate matter (PM_{10}) concentration data were collected and evaluated as an ecological indicator, in order to reveal the relationships between landscape structure and landscape function. In short, we first evaluated the whole landscape structure using medium-resolution data, followed by the classification of cultural landscapes using high-resolution satellite imagery, providing a time-effective—and, therefore, essential—auxiliary method for landscape evaluation. This two-stage evaluation method enables inferences to be made that can shed light on the landscape functions in an urban environment based on the landscape structure.

Keywords: Pleiades satellite image; landscape pattern; cultural landscapes; landscape function; urban ecosystem; landscape ecology; PM_{10} concentration

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1. Introduction

Human activities disrupt the balances established in ecosystems, sometimes irreversibly. This deterioration can lead to serious problems, not only aesthetically but also economically and even for human health, in the long term. As environmental problems have reached such levels that they may have a global impact, issues such as the "Environment" and "Sustainability" have become the main topics considered by both the European

Union and United Nations Support Programs. As in Goal 11 “Make cities and human settlements inclusive, safe, resilient and sustainable”, described within the UN Sustainable Development Goals (SDGs), such topics are related to our environment and quality of life [1–3]. From this point of view, it is understood that handling the potential of the environment, in line with sustainability principles, has become an international responsibility.

The European Green Deal, the primary goal of which is to regulate the European climate and emissions rates by 2050, has also identified "Preserving and restoring ecosystems and biodiversity" and "Accelerating the shift to sustainable and smart mobility" as main agenda items. The main objective of the strategy determined by the European Commission for the protection of biological diversity until 2020 was to "prevent loss of biodiversity and decline in ecosystem services". The Green Deal aims to improve declining ecosystems by at least 15% by 2030 [4]. The basis of achieving this goal lies in developing an inventory of areas that need to be protected, developed, and improved, in terms of cultural values and biological diversity, based on natural–cultural indicators [5,6].

Human beings consider how the landscape shapes itself to be chaotic or unorganized. As a result, they attempt to control and shape landscape evolution through deliberate and intended actions. However, these actions do not always provide the outcomes they were planned to, as the landscape is composed of many different components, which have their own dynamics and orders of change. This composition can be evaluated as a system that includes its own features and, therefore, we must look at these components in a holistic manner [7–10].

One of the most compelling challenges that humans pose against nature is urbanization. Urbanization combines aspects related to population crowding, thus resulting in denser urban areas and the spread of residents and buildings outside the urban center [11,12]. With the influence of urbanization, the water regime of cities deteriorates, the natural relief changes, natural soil characteristics disappear, and urban heat island effects occur. Changes in the landscape pattern and function can lead to various consequences, starting from the degradation of green systems at the regional scale to the disappearance of biotopes at the local level.

Of all the problems related to urbanization, the most important one is that cities are not sustainable. As cities coexist with human beings and surrounding systems, they are regarded as heterogeneous and complicated, and lack the ability to quickly adapt. Thus, it is tough to predict or monitor the course of events in cities. Nevertheless, in this situation, planning and new designs can be helpful, according to the knowledge of city ecology and sustainability principles [13–15].

Understanding human spatial and material relations and changes in the natural environment is essential to ensuring sustainability. Cities, as energy and material consumption nodes, are not sustainable per se, and they accelerate global ecological degradation. However, cities and their residents play a leading role in ensuring urban sustainability [16,17]. According to the modern understanding of landscape ecology, conceptual models and tools are needed to help analyze and reveal the nature–society interactions at the center of the sustainability debate [15]. With the same awareness, practical tools that refer to protection–utilization balances should be used in planning and management decisions, especially regarding urban landscapes with sensitive balances [18–21].

At the urban scale, habitats are the stepping stones of green network systems, and are essential in urban areas. Urban green areas also have critical functional features for specific purposes, such as filtering the air, balancing noise and the climate, and providing environments for recreational activities. Re-structuring degraded green networks is extremely important for the sustainability of the urban ecosystem. For example, a quality vegetative layer that penetrates structural surfaces has an effect that prevents the formation of heat islands in cities [22,23]. According to Lehmann et al. (2014), urban green areas are essential indicators for ecosystem services in urban habitats, when considered spatially and structurally. In addition, they exhibit properties suitable for the evaluation of microclimatic features [24,25].

Cultural landscapes are areas whose natural features have been changed by human activities, manifesting in the form of layered patterns that leave traces in the landscape. Together with natural features, these layers give a landscape its defining, historical, aesthetic, symbolic, and memorable character. Therefore, it is necessary to define cultural landscapes, develop policies to protect their values, manage the spatial and social changes that occur over time, and enable sustainable uses [26–29]. Due to these high-capacity indicative qualities, many studies have focused on cultural landscapes in an urban environment.

The main concern of natural conservation is protecting species and their habitats. Therefore, identifying and mapping the habitats created by the natural and cultural landscape is essential for the in situ conservation of biological diversity [30].

Cultural landscapes are essential components of the environment shaped by human interventions. They mirror the past and indicate the future while hosting highly diverse anthropogenic uses and natural–cultural heritage. Moreover, landscapes are located between ecosystems and biomes [31]; thus, their quality and diversity constitute a common resource. Therefore, revealing cultural landscapes within urban landscapes and evaluating the relations between them at the regional scale constitute a strong basis for a holistic approach.

Focusing on cultural landscapes in the planning process is of great importance in protecting and promoting biodiversity and supporting sustainable development, increasing the quality of life and comfort of residents [18,19,32–36].

Modern technology has made satellite images with higher spatial resolution available for various applications, such as urban mapping, spatio-temporal change detection, and urban sprawl monitoring [20,21,37].

As manual classification techniques are difficult and time-consuming, it was deemed appropriate to classify satellite images at two different resolutions (medium and high) with the help of remote sensing techniques. Medium-resolution satellite images are divided into two classes using controlled classification techniques, in order to make general evaluations. Then, a high-resolution Pleiades satellite image was divided into 14 cultural landscape classes using the normalized vegetation index (NDVI) (Table 1).

Table 1. Land use/land cover (LU/LC) classes obtained from medium- and high-resolution satellite images.

Satellite	LU/LC Class
Landsat 4, 5, 7 TM, ETM+	Artificial surface, green area
Pleiades (2015)	Garden, openness in garden, grove, openness in grove, cemetery, openness in cemetery, park, openness in park, roadside green area, openness in roadside green area, building, water surface, firm ground, road

The mapping of LU/LC classes provides important outputs for landscape analysis and assessment, and has been widely used in the literature. Evaluating the data obtained as a result of classification using landscape metrics provides access to important findings at the class and landscape level, especially regarding the landscape structure, in a short time. Landscape metrics have been widely used in the literature as an effective tool to reveal the structure and configuration of landscape structure [21,38–49]. In this study, we conduct landscape pattern analysis to evaluate cultural landscapes, and support the findings obtained from this analysis using the PM_{10} concentration, which is an important ecological indicator.

PM has been shown to have a positive relationship with urbanization. Studies examining the relationships between green systems and the concentration of particulate matter in the air have shown that PM density is closely related to the quality and quantity of the green system [50–54]. For this reason, PM_{10} was used as an ecological indicator in this research.

Based on this view, the focal points of this research are as follows: (a) the effect of urbanization on the spatial transformation of cultural landscapes; (b) the interactions between cultural landscape patterns and PM_{10} concentrations; and (c) the relationships between landscape structures and indicative urban habitats.

2. Materials and Methods

2.1. Material

Istanbul is a metropolitan city with an E–W extension, adjacent to the Black Sea and the Marmara Sea, with a characteristic structure similar to the Bosporus, and is in a highly strategic position, in terms of various components. As the research area, the Besiktas district is in the middle of the European Bosporus Side of the city of Istanbul, between 41°02′31″ N. latitudes and 29°00′26″ E. longitudes. Its total surface area, including the buffer zone, is 37.8 km^2 (Figure 1).

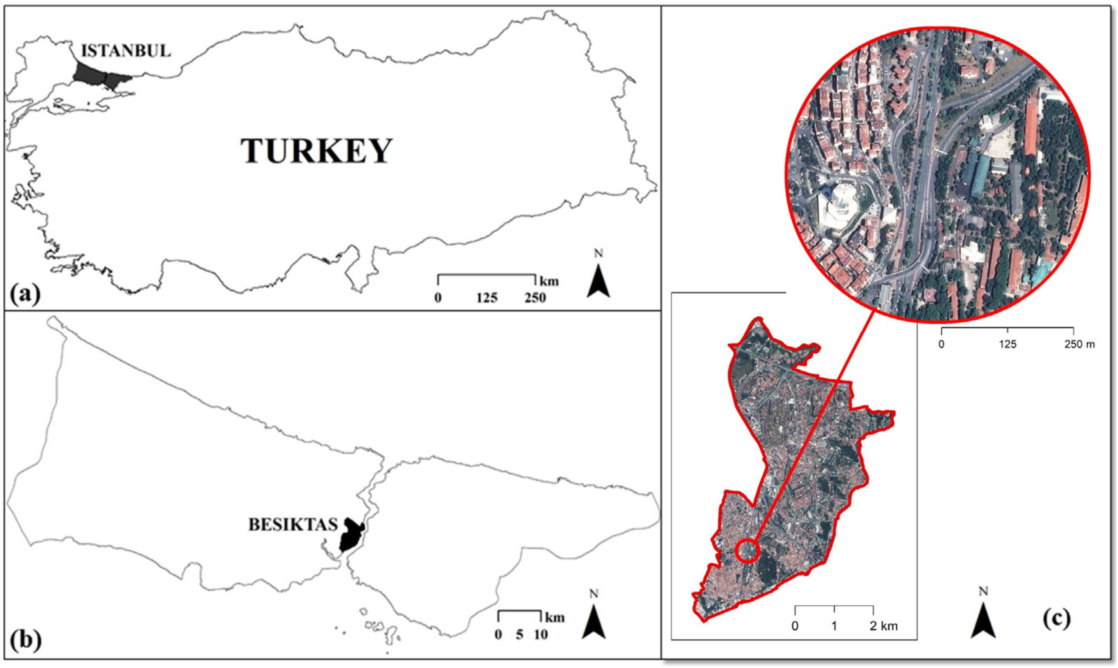


Figure 1. (**a**) Turkey and Istanbul city; (**b**) Istanbul and Besiktas district; (**c**) RGB Pleiades image of Besiktas district.

Besiktas drew our attention, as it is both in the city center and possesses marine and terrestrial transportation opportunities. The heavy pressure of urbanization accelerates landscape changes, bringing the risk of subjecting the green areas of Besiktas to rapid housing transformation. It is noteworthy that the population doubled from 1963 until 1985 (from 107,442 to 204,911 people), then fluctuated slightly in 2000 (190,813 people), 2007 (191,513 people), and 2014 (188,793 people), with relatively small differences (of 1000–3000 individuals) [55].

2.2. Methods

With a holistic perspective, our research aimed to evaluate the landscape pattern and processes at different levels through the use of ecological indicators. Based on the configuration of the landscape pattern, this evaluation revealed the main forces shaping the landscape functions in the urban environment. The flow chart below details the methods applied at different stages of the evaluation (Figure 2).

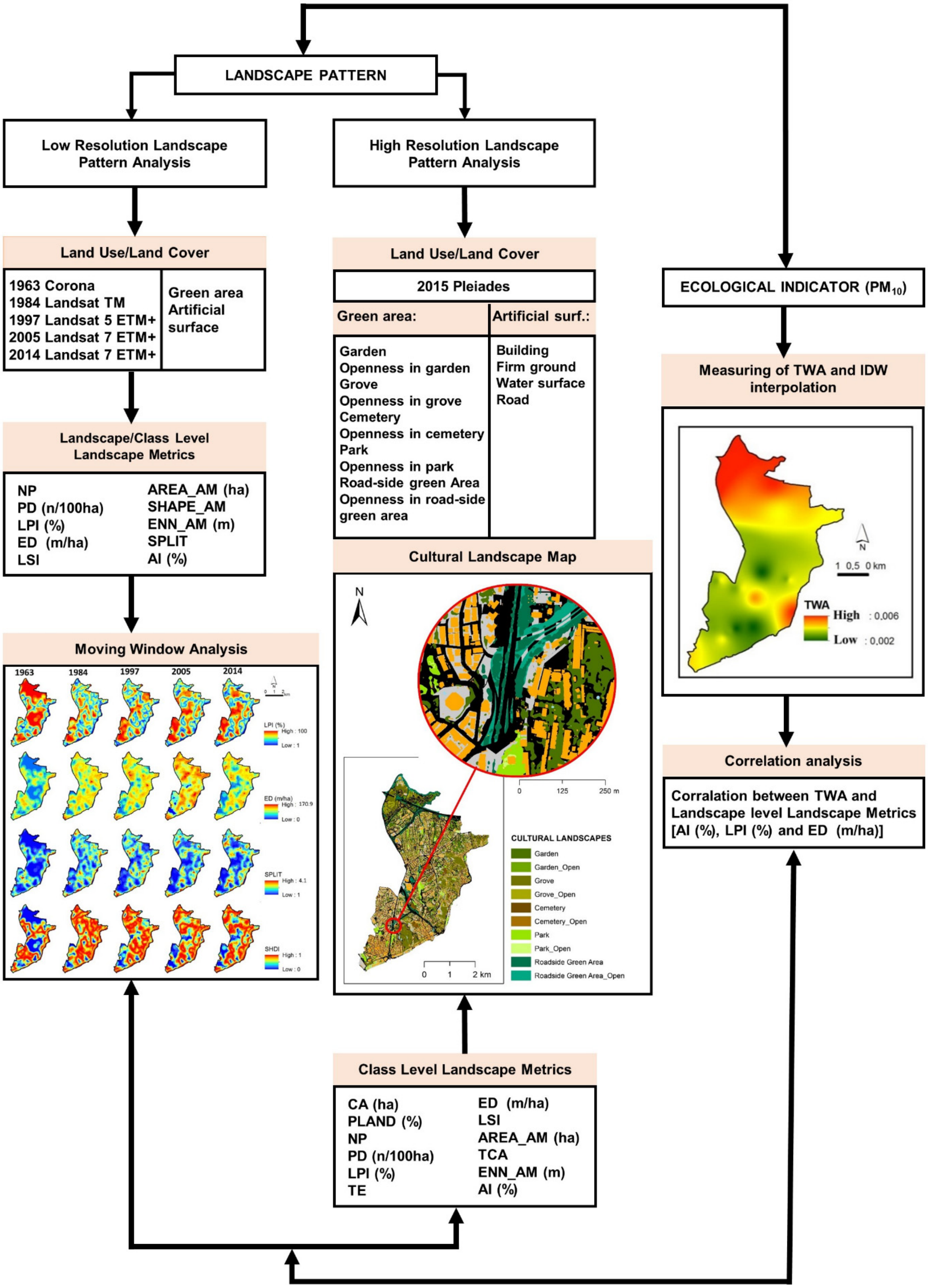


Figure 2. The flow chart of methods applied for the research.

First, we obtained two LU/LC classes (green area, and artificial surface) from medium-resolution images (Landsat) using a pixel-based classification method. Then, we used the normalized difference vegetation index (NDVI) to extract classes from high-resolution satellite imagery. Finally, we obtained a cultural landscape map.

We subjected the classified data to low- and high-resolution landscape pattern analysis, using landscape and class-level landscape metrics for the low-resolution evaluation. We also spatialized landscape-level landscape metrics using the Moving window module of the Fragstats software [44]. Finally, we used class-level landscape metrics for the high-resolution assessment.

We took the PM_{10} concentration as an ecological indicator. For this purpose, we used on-site TWA measurements as a reference and mapped them using the IDW interpolation method. Then, we compared this map with the maps created for landscape-level metrics. For comparison, we evaluated the relationships between PM_{10} concentration and landscape-level metrics using Spearman's coefficient and Pearson's correlation analyses.

As a result, the findings obtained from the two-stage landscape pattern analysis were evaluated with respect to the PM_{10} ecological indicator. Finally, conclusions about the cultural landscape types in the research area could be reached.

2.2.1. Image Processing

The image processing stage was carried out at two levels: medium-resolution images to reveal the general situation of the landscape pattern and determine the transformations exhibited over 51 years, and high-resolution images to reveal cultural landscapes. Satellite images with different resolutions and technical specifications were used for the research (Table 2).

Table 2. Satellite images and features used for the research.

Satellite	Spatial Resolution (m)	Spectral Resolution (µm)	Radiometric Resolution	Temporal Resolution
Landsat 4, 5, 7 TM, ETM+ (1984, 1997, 2005, 2014)	Bants 1, 2, 3, 4, 5, and 7—30 m Bant 6—120 m (for ETM+ Bant 6—60 m, Bant 8—15 m)	B1: 0.441–0.514 B2: 0.519–0.601 B3: 0.631–0.692 B4: 0.772–0.898 B5: 1.547–1.749 B6: 10.31–12.36 B7: 2.064–2.345 B8: 0.515–0.896 (for ETM+)	8 bit	16 days
Pléiades (2015)	2 m multi-bant, 50 cm panchromatic	B1: 0.430–0.550 B2: 0.450–0.620 B3: 0.590–0.710 B4: 0.740–0.940 PAN: 0.470–0.830	12 bit	26 days

LULC changes were examined using five satellite images representing 51 years. For this purpose, Landsat TM and Landsat ETM+ (1984, 1997, 2005, and 2014) images with 30 m × 30 m resolution were utilized. Due to the absence of a Landsat image representing the 1960s, Corona satellite imagery (1963) at 5 m × 5 m resolution was used. These images were recorded on film with cameras, in the form of photographic prints. In addition, scanned and digitized images were used as raster data with 5 m × 5 m spatial resolution. To compare with the data produced from Landsat satellite images, the Corona data were re-sampled to 30 m × 30 m.

The maximum likelihood classification algorithm was used to produce thematic classes [56]. Two different LULC classes were determined: green areas, and artificial surfaces (Figure 3).

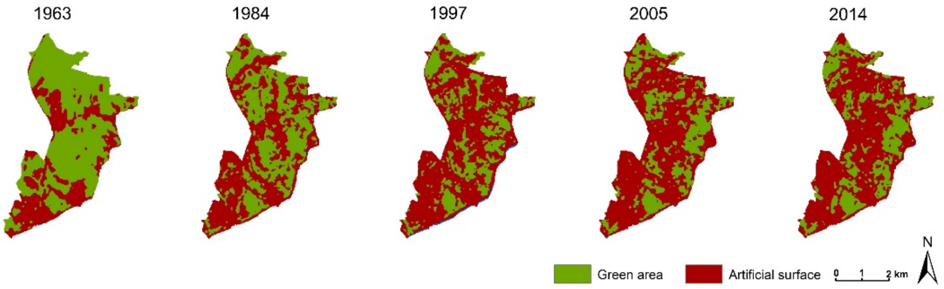


Figure 3. Times series LULC. Spatio-temporal dynamics of landscape structures.

For the study, 100 pixels were selected from the classification results on Landsat (1984, 1997, 2005, and 2014) images, which we compared with old maps and aerial photographs of the area [57]. We used the kappa statistic to test the reliability of comparative data. As general classes were preferred, the accuracy rates were high. Consequently, we reached a kappa accuracy rate of 90–93% (Table 3).

Table 3. Accuracy rates of classified Landsat images.

Classified Image	Overall Accuracy (%)	Kappa Coefficient	Classified Image	Overall Accuracy (%)	Kappa Coefficient
1984	90	0.8607	2005	93	0.8994
1997	90	0.8579	2014	92	0.8772

We obtained above-expected accuracy values for the classes and used them as input in the analysis.

Pleiades satellite images presenting a high spatial resolution were considered appropriate to derive data for distinguishing cultural landscapes. For this reason, we utilized these data for evaluation purposes at this stage [58].

It is possible to differentiate settlement, forest, and agricultural areas with limited values by selecting them according to normalized difference vegetation index (NDVI) values [59,60]. Therefore, we created an NDVI map to distinguish between green and artificial areas in the Pleiades satellite imagery. While sub-classifying artificial surface and green area classes, we used a 1/25,000-scaled base map of the area to mask some layers. In addition, we detailed the sub-classes using the manual digitization method. In total, we obtained 14 cultural landscape classes: garden, openness in garden, grove, openness in grove, cemetery, openness in cemetery, park, openness in park, roadside green area, openness in roadside green area, building, water surface, firm ground, and road.

We used previous maps of the region, satellite images, and Google Earth Pro v.7.3.6., as well as the opinions of experts who know the region, in order to determine the classification of areas and conduct accuracy analyses of the Pleiades satellite imagery results.

2.2.2. Pattern Analysis

As the landscape structure is an essential indicator of the landscape function, it is crucial to obtain information regarding the spatial distribution and arrangement of the LU/LC classes, in terms of perceiving the landscape from a holistic perspective [41,61–63].

The number of patches, the proportion of each patch type, and the spatial arrangement of patches are essential components in determining landscape patterns [64,65]. The landscape composition and configuration affect ecological processes independently and interactively. Therefore, it is vital to understand what component of the landscape pattern is being quantified by a particular metric [41,66]. Some landscape metrics that describe similar landscape characteristics are correlated, but each landscape index reflects a different urban landscape aspect [67]. Regression equations can reveal that the information expressed by landscape metrics is usually not based on a single component, but on the complexity of several components of spatial patterns. Therefore, it is crucial to evaluate the landscape structure using landscape metrics representing a combination of structure, composition, and configuration [65,68,69].

Landscape metrics offer a wide range of options to evaluate the landscape structure, from agricultural areas to mining/quarry sites, from wetlands to forests. The critical issue here is that the expert who makes the evaluation prefers the metric set that will best reveal the spatial arrangement of the landscape structure, depending on the subject investigated [20,67,70–80].

According to several authors, spatial metrics can be used to characterize urban forms. They represent critical determinants such as shape, configuration, and distribution in urban landscape planning, thus providing an opportunity to evaluate the nature of the change in the urban structure [41,46,61,81–88]. Therefore, selecting a complete set of landscape metrics is essential when analyzing the landscape structure [89]. We investigated the landscape composition and configuration of the research area to identify the expanding footprints of habitats using the most appropriate landscape metric combination. In this way, we represent patch complexity, aggregation, and diversity. We used a set of landscape metrics for this research at the class and landscape levels, for all identified time intervals (Table 4). We selected them among the “highly universal and consistent landscape structure components” defined by Cushman et al. (2008) [42]. Previous research focusing on correlational relationships between metrics was also considered [21,47,65,77,90,91]. Topaloğlu et al. (2020) applied principal component analysis (PCA) to summarize the information of a data set containing classes described by several correlated metrics. The findings from this study also helped us to create a complementary but non-repetitive set of metrics [21].

Table 4. Landscape-level metrics used for this research [44].

Metric Name	Abbrev.	Description
Class area (ha)	CA	The total area of the class
Percentage of landscape (%)	PLAND	The percentage of the landscape comprised of a particular patch type
Number of patches	NP	The number of patches of a corresponding patch type (class)
Patch density (n/100 ha)	PD	The number of patches of a corresponding patch type (class) per unit area
Largest patch index (%)	LPI	The area (m^2) of the largest patch in the landscape divided by the total landscape area (m^2)
Total edge (m)	TE	The sum of the lengths (m) of all edge segments in the landscape
Edge density (m/ha)	ED	The sum of the lengths (m) of all edge segments in the landscape, divided by the total landscape area (m^2)
Total core area (ha)	TCA	The sum of the core areas of each patch (m^2)
Landscape shape index	LSI	A standardized measure of patch compactness that adjusts for the size of the patch
Patch area (area-weighted) (ha)	AREA_AM	The area-weight mean patch size
Shape index (area-weighted)	SHAPE_AM	The weighting patches according to their size, on contrary to the LSI in which the total length of edge is compared to a landscape with a standard shape (square) of the same size and without any internal edge
Euclidean nearest-neighbor dist. (A.W.) (m)	ENN_AM	The shortest straight-line distance (m) between a focal patch and its nearest neighbor of the same class
Splitting index	SPLIT	The number of patches obtained by subdividing the landscape into equal-sized patches based on the effective mesh size
Aggregation index (%)	AI	The ratio of the observed number of like adjacencies to the maximum possible number of like adjacencies given the proportion of the landscape comprised of each patch type, given as a percentage
Shannon’s diversity index	SHDI	The SHDI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion
Shannon’s evenness index	SHEI	The SHEI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion, divided by the logarithm of the number of patch types

For low-resolution landscape analysis, the land-use data sets (1963, 1984, 1997, 2005, and 2014) were first converted into grid format (pixel size: 30 m × 30 m). For the high-resolution landscape evaluation, the obtained cultural landscape map (2015) was first converted into grid format (pixel size: 1 m × 1 m), in order to be able to carry out synoptic metric analyses and further analyses using the FRAGSTATS package (v.4) [44]. The 8-cell neighbor rule was applied for standard analyses. We concentrated first on class-level metrics, in order to monitor local impacts and their consequences on region-level changes.

Moving window analysis provides a spatially detailed evaluation of fragmentation indices [44]. Furthermore, moving window analysis allowed us to connect landscape-scale resource utilization to suitability models of setting structure in Besiktas. Wiens (1989) has stated that the moving window size relates measurable patterns to ecological processes [92]. We found that a round-shaped window with a 250 m radius was most effective in generating continuous results with an available cell scale of 30 by 30 m. Moving window analysis was used to output the ED, LPI, SHAPE-MN, and SIDI metrics as maps at the landscape level. Class- and landscape-level metrics were calculated and interpreted for low- and high-resolution data in these stages.

2.2.3. Environmental Indicator (PM_{10})

Particulate matter (PM) was used as an environmental indicator, in order to reveal the effects of landscape changes on the environment. We used PM_{10} values as an indicator for the analysis. Therefore, in situ, we measured PM values using a portable TSI Incorporated DustTrak II Meter. The PM meter obtains a 90° light scattering sensor and a particle volume range of 0.1–10 µm. Considering the 15-minute automatic calculation time of the time-weighted average (TWA) value (8-hour period per day) by the device, we measured PM_{10} for 15 minutes. Measurements were made randomly on days with appropriate weather conditions (no precipitation and wind intensity less than 3 m/h) every three months for one year. The measured values were generalized to the whole area using the inverse distance-weighted (IDW) interpolation method.

We constructed fifty random points considering the existing habitats and extracted dependent and independent values of these points using raster data sets; in particular, we used PM_{10} TWA values as dependent variables and landscape metrics of 2014 obtained from the moving window analysis as independent variables in the Pearson and Spearman correlation analyses. Thus, we obtained the correlation between selected landscape metrics and particulate matter densities. Using this method, we obtained landscape metrics with significant correlation. We tested the individual correlations between independent and dependent variables at significance levels of 0.01 and 0.05 (i.e., $p > 0.01$ or $p > 0.05$).

3. Results and Discussion

The findings of each stage were compared with the findings of the other stages. In this way, a holistic landscape pattern assessment was reached.

3.1. Low-Resolution Landscape Characterization

While the ratio of green areas in Besiktas municipalities was 67.6% in 1963, it decreased to 47.4% in 1984 following the construction of the first Bosporus Bridge in the 1970s. It further decreased to 31.9% in 1997, following the construction of the second Bosporus Bridge in 1988. In this period, especially from the 1980s, new constructions such as hotels, business centers, and shopping malls caused the business area center of Besiktas to develop and rapidly build up in this direction.

Although there were increases in green areas in 2005 and 2014, there was not much recovery (32.3% and 33.8%, respectively). Over the same period, there was a marked increase in artificial surfaces: 32.3% in 1963, 52.6% in 1984, 67.4% in 1997, 67.5% in 2005, and 66.1% in 2014. It is worth noting that there was a rapid acceleration in this increase in 1984, for the abovementioned reasons. The effect of this rapid change between green areas and artificial surfaces on habitat quality and fragmentation was studied, according to the landscape metrics at class and landscape levels. Landscape-level metric assessments allowed changes in the landscape structure to be interpreted and evaluated throughout the research area (Table 5). At the same time, the class-level analyses revealed the changes between habitats. Spatial heterogeneity results are shown at both landscape and class levels (Figures 4 and 5).

Table 5. Landscape-level indexes from 1963 to 2014.

Metrics	**Year**					**Metrics**	**Year**				
	1963	**1984**	**1997**	**2005**	**2014**		**1963**	**1984**	**1997**	**2005**	**2014**
NP	73	118	151	148	134	SHAPE_AM	4.4	7.12	7.6	7.09	6.87
PD (n/100 ha)	4	6.48	8.28	8.11	7.35	ENN_AM (m)	64.5	64.9	64.5	64.5	67.4
LPI (%)	62.8	41.5	65.4	65.2	63.9	SPLIT	2.39	3.66	2.29	2.3	2.38
ED (m/ha)	40.8	76.5	75.5	67.7	69	AI (%)	93.8	88.6	88.7	89.8	89.8
LSI	6.05	9.68	9.64	8.94	8.82	SHDI	0.64	0.7	0.67	0.64	0.65
AREA_AM (ha)	763.2	497.2	794.9	794	764.6	SHEI	0.58	0.63	0.61	0.59	0.59

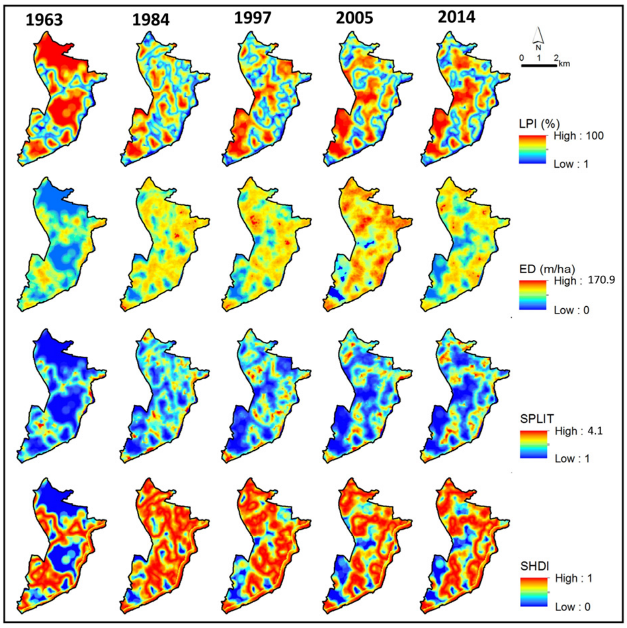


Figure 4. Landscape-level moving window (250 × 250 m) analysis results for LPI, ED, SPLIT, and SHDI indexes.

According to Forman and Godron (1986), the edge density determines the shape of a patch, and can further indicate the distribution of plant and animal species [93]. At the landscape level, especially from 1963 to 1984, the increase in edge metrics indicates that fragmentation became an increasingly dominant factor in the Besiktas landscape. After constructing the first Bosporus Bridge in 1984 and the second Bosporus Bridge in 1997, landscape-level ED reached approximately 76 m/ha. Although this increase was lower in the following period, ED was still higher, compared to 1963. The border between patches is important in forming corridors. Therefore, contrasting patches also indicate connections. According to Ranney et al. (1981), microclimatic changes, wind, and light progression along a high-contrast edge are more likely than on a low-contrast edge in a patch [94]. Patch isolation is also a function of the contrast between the patch and its ecological neighbor. Shape metrics are crucial in revealing the landscape order.

The distance to the nearest neighbor is an indicator defining the distance from a patch to other patches with the same characteristics, which is essential for determining the quality of a habitat. Research has shown that fewer living species in habitats suffer from isolation due to fragmentation; in particular, many studies on birds have discussed this aspect [95,96].

At the landscape level, SHAPE_AM and LSI showed increasing trends, indicating that the landscape pattern became more irregular over time, indicating a disturbance effect due to the presence of people.

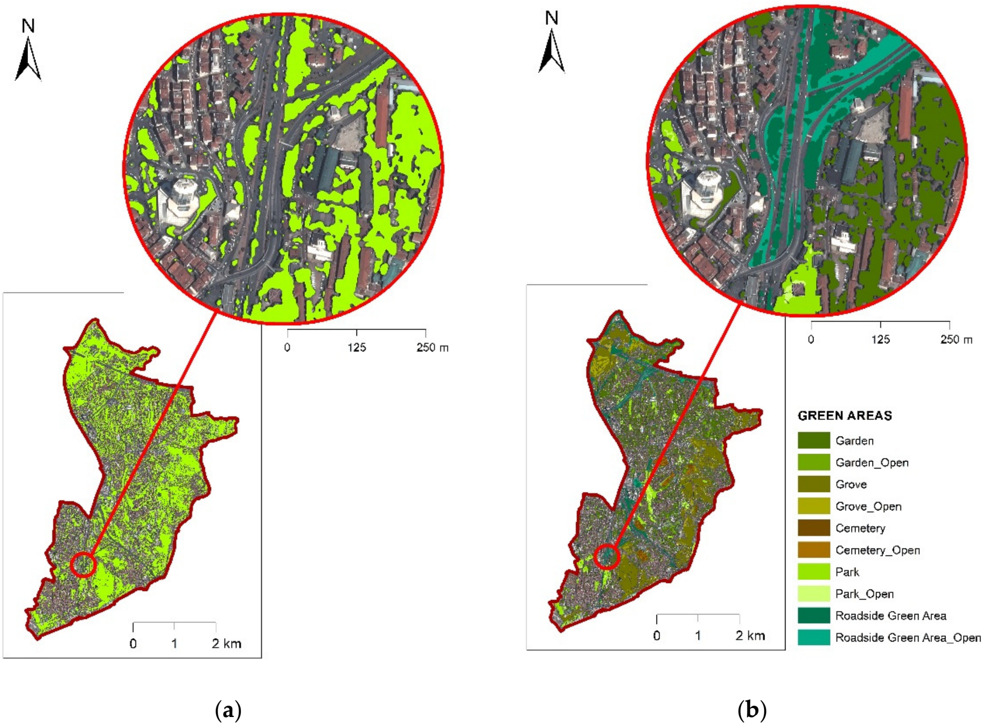


Figure 5. The green area layer obtained by NDVI (**a**) was divided into ten cultural landscape classes using a manual classification technique (**b**).

SPLIT is calculated as the number of patches obtained while splitting the entire landscape into equal-sized patches. SPLIT rose from 2.4 to 3.7 during the period 1963–1984, indicating the influence on the landscape and the fragmentation of the natural landscape in this period. The decline and increase in the following period indicate that the landscape is still not stable against this violent change observed in 1984.

From the analysis in Figure 4, it can be observed that the SPLIT value was higher in settlements in 1963, the complication in the entire Besiktas landscape increased in 1984, and it shifted in later periods, with the division of green surfaces being increased.

The SHDI reflects the complexity and heterogeneity in the landscape. The exchange of SHDI in Besiktas was striking from 1963 to 1984. The 6% increase in this index over this period indicates that the heterogeneity of the whole landscape and the number of scattered patches were increasing. During this period, as mentioned above, the construction of the Bosporus Bridge resulted in a rapid change, and scattered landscape patches appeared. In the following period, this change was more stable. The results indicate that the maximum evenness of the area's distribution was 64% in 1963, 70% in 1984, and 65% in 2014. The fact that the index values in the landscape are not too high indicates an irregular distribution of different patch types in the area. Figure 4 shows the spatial variation of the SHDI. In 1963, only heterogeneous structures were observed in places open to settlement. In 1984, all Besiktas landscapes gained heterogeneous structure, which increased until 2014. With the increase in aggregation, patches in the settlement areas reduced in the western part of the research area.

The SHEI value results indicate that large landscape types no longer play a dominant role in the Besiktas district, the average patch area is similar, and the patches tend to show a uniform distribution. Like the SHDI, the SHEI changed remarkably from 1963 to 1984. However, in the following period, it presented an improvement, showing that large landscape types no longer play a dominant role, the average patch area has become more similar, and the patches tend to have a uniform distribution. The indices show that the maximum uniformity of area distribution was 58% in 1963, 63% in 1984, and 59% in

2014. The Besiktas landscapes index values were not very high, indicating an irregular distribution of different patch types in the landscape.

After the holistic evaluation of the landscape pattern, we used class-level landscape metrics to reveal the reasons for the changes in more detail. As the water surfaces in the area obtained from medium-resolution satellite images were distributed in small units (e.g., swimming pools), we did not include them in the class-level metric evaluation. We completed the low-resolution assessment of the research area by calculating the metrics of the green area and artificial surface classes (Table 6).

Table 6. Class-level landscape indexes and the change between each data adapted from 1963, 1984, 1997, 2005, and 2014 classifications show the urban fragmentation process in Besiktas.

CA

Year	1963	1984	Change	1984	1997	Change	1997	2005	Change	2005	2014	Change	Total Change
Green area	19	58	−39	58	102	44	102	88	−14	88	89	1	70
Artificial surface	46	53	−7	53	21	−32	21	42	21	42	37	−5	−9

PD

Year	1963	1984	Change	1984	1997	Change	1997	2005	Change	2005	2014	Change	Total Change
Green area	1.04	3.18	−2.14	3.18	5.6	2.42	5.6	4.82	−0.78	4.82	4.88	0.06	3.84
Artificial surface	2.52	2.91	−0.39	2.91	1.15	−1.76	1.15	2.3	1.15	2.3	2.03	−0.27	−0.49

The results show the increasing fragmentation of green areas and a tendency to transform into small scattered patches in these habitats; however, this increase was not regular. Besiktas district was known as a land of mulberry in the 1960s ("mulberry shake for 2.5 Lira"). When the Bosporus Bridge was on the agenda in the 1970s, Besiktas became a focal point in terms of transportation. As the main arteries—such as Barbaros Boulevard and Buyukdere Avenue—pass through the city's centre, the construction of the Bosporus Bridge already made the central city a knot point. The coastal road, which operated independently from this artery in the past, was thus linked to the interior. This change was the most crucial reason for the changes observed in 1984. The change in the PD peaked in 1997, due to a similar effect in 1988, which brought the second Bosporus Bridge to the square. The ring road of the bridge neighbouring the district from the north—the Trans-European Motorway (TEM)—entered Besiktas with the connection of Levent, serving as an element that increased the demand for new constructions. The renewal of all parks in the Municipality of Besiktas in 2000 helped to decrease the PD in the following period. In this period, the municipality afforested streets and parks, using thousands of tree seedlings, which can be observed as a partial improvement.

LPI

Year	1963	1984	Change	1984	1997	Change	1997	2005	Change	2005	2014	Change	Total Change
Green area	62.81	30.47	32.34	30.47	4.22	−26.25	4.22	6.51	2.29	6.51	7.35	0.84	−55.46
Artificial surface	13.54	41.5	−27.96	41.5	65.44	23.94	65.44	65.19	−0.25	65.19	63.92	−1.27	50.38

The LPI is a highly representative indicator of the proportion of the largest class in the simulated landscape and, at the class level, is considered a parameter reflecting the abundance of classes [65]. Large patches are essential for maintaining more species. In this context, the LPI is one of the most influential metrics of landscape fragmentation. When the LPI was examined in the Besiktas landscape, it did not display a regular change. The LPI index decreased from 1963 to 1984, increased from 1984 to 2005, and then decreased again. Tragically, however, the most significant patch belonged to green areas, and artificial surfaces tended to increase regularly. The increase in aggregation in these areas was expected to have various consequences. Figure 4 indicates that the largest patch in 1963 covered the green areas. In 1984, the patches started to shrink. After 1997, the largest patch was formed of artificial surfaces, with the aggregation of the western settlements. This largest patch appears to be growing in the west–east direction.

ED

Year	1963	1984	Change	1984	1997	Change	1997	2005	Change	2005	2014	Change	Total Change
Green area	39.43	73.3	−33.87	73.3	69.79	−3.51	69.79	64.23	−5.56	64.23	65.71	1.48	26.28
Artificial surface	39.72	75.82	−36.1	75.82	74.89	−0.93	74.89	66.87	−8.02	66.87	67.75	0.88	28.03

Green areas and artificial surfaces showed increases in edge and contrast. In particular, the tendency to increase edge/contrast in green areas may have led to changes in microclimatic conditions, due to the differentiation of wind and light intensity. The ED was low due to the large green surface patch, while the rapid ED increase in 1984 spread to the entire Besiktas landscape. It can be seen, from Figure 4, that it reached its highest value in 2005.

LSI

Year	1963	1984	Change	1984	1997	Change	1997	2005	Change	2005	2014	Change	Total Change
Green area	6.19	11.85	−5.66	11.85	13.64	1.79	13.64	12.47	−1.17	12.47	12.43	−0.04	6.24
Artificial surface	8.82	12.71	−3.89	12.71	10.92	−1.79	10.92	10.37	−0.55	10.37	10.33	−0.04	1.51

The LSI is another important indicator that reflects the heterogeneity of landscape patches [97]. The patch shape quickly became complex in both artificial surfaces and green areas after 1984. This transformation indicates that construction of the Bosporus Bridge formed a breaking point regarding shape irregularity. The LSI values of these two habitats showed an initial upward trend, followed by a decline. Due to the rapid fragmentation, patches with more complicated shapes emerged in both landscapes. As mentioned above, the decrease was related to the aggregation of artificial surfaces and the afforestation of refuges, streets, and parks. However, the changes related to the bridges were focused on artificial surfaces in 1984 and on green areas in 1997. This change indicates that the second bridge had a stronger effect on the geometrical degradation of green areas. According to the settlements, green areas seem to present a more complex shape characteristic due to fragmentation. Buechner (1989) has suggested that the shape of a patch has a particular effect on the mobility of mammals in the patch [98]. In this sense, an increase in shape irregularity in green areas may have led to a significant decrease in the number of mammals, especially in woodlands. On the other hand, the fact that there were many formal irregularities suggests that the core area did not develop in such habitats.

Table 6. *Cont.*

AREA_AM

Year	1963	1984	Change	1984	1997	Change	1997	2005	Change	2005	2014	Change	Total Change
Green area	1066	375.5	690.5	375.5	44	−331.5	44	56.2	12.2	56.2	58.3	2.1	−1007.7
Artificial surface	131.5	607.4	−475.9	607.4	1159	551.9	1159	1150	−9.3	1150	1127	−23	995.5

The AREA_AM index is essential for representing the degree of aggregation or fragmentation of patches in a spatial manner. According to the simultaneous data, AREA_AM showed the highest index value in artificial landscapes; that is, artificial landscapes had a more scattered distribution. In green areas, the indices were all at low levels, indicating that the patches were of smaller size and presented a scattered distribution. While there was an increasing trend in artificial surfaces, green areas showed a noticeable decline over time. From 1963 to 2014, the AREA_AM values decreased to 58.3 ha in green areas. To the contrary, artificial areas increased to 1127 ha. This change also indicates the dominance of artificial patches, signifying that the artificial landscapes separate green areas and deepen the extent of fragmentation. Therefore, AREA metrics are also important for providing information about the core area. As it protects them from the adverse effects at the edge, the core is an important area for plants and animals [99]. The decrease in AREA_AM at the landscape level indicates that the core area also declines. This situation is an indication of the shrinkage, fragmentation, and even losses of large patches. Rapidly advancing settlements and scattering in settlements can be attributed to the increased core area of artificial surfaces. Accordingly, the loss of or change in species can be hypothesized, especially in the woodland areas of the Istanbul landscape, which has significant ecological importance.

ENN_AM

Year	1963	1984	Change	1984	1997	Change	1997	2005	Change	2005	2014	Change	Total Change
Green area	61.51	67.6	−6.09	67.6	72.94	5.34	72.94	71.56	−1.38	71.56	77.73	6.17	16.22
Artificial surface	70.23	62.22	8.01	62.22	60.39	−1.83	60.39	60.79	0.4	60.79	61.77	0.98	−8.46

The difference in ENN_AM between patches was considered together with NP and LPI, providing important information about the urban pattern [76]. At the general landscape level, ENN_AM showed that the distance between similar patches had increased. When examined at the class level, there was an increase in this metric for green areas and a partial decreasing tendency for artificial surfaces, due aggregation.

SPLIT

Year	1963	1984	Change	1984	1997	Change	1997	2005	Change	2005	2014	Change	Total Change
Green area	2.53	10.24	−7.71	10.24	129.9	119.7	129.9	100.44	−29.5	100.44	92.46	−7.98	89.93
Artificial surface	42.86	5.7	37.16	5.7	2.33	−3.37	2.33	2.35	0.02	2.35	2.45	0.1	−40.41

For artificial surfaces, SPLIT presented a steady decline; meanwhile, in green areas, it showed a rapid increase until 1997 and a partial decrease afterwards. The SPLIT values provide further proof that the focal patch type in green areas gradually decreased and was divided into smaller patches. In artificial areas, the opposite phenomenon was observed.

AI

Year	1963	1984	Change	1984	1997	Change	1997	2005	Change	2005	2014	Change	Total Change
Green area	95.53	88.79	6.74	88.79	84.04	−4.75	84.04	85.66	1.62	85.66	85.99	0.33	−9.54
Artificial surface	90.21	88.5	1.71	88.5	91.42	2.92	91.42	91.92	0.5	91.92	91.85	−0.07	1.64

The AI is an indicator that depicts the degree of aggregation of patches in the landscape [100]. As indicated by the index values examined earlier, it tended to decrease in green areas and increase in artificial surfaces—a sign of loss in green areas and gradual gathering and granular dispersion of artificial surfaces. As mentioned above, these (increasing/decreasing) tendencies were not regular. The spatial variation of the AI was similar to that of the LPI (see Figure 4), as the growth of patches increases the AI.

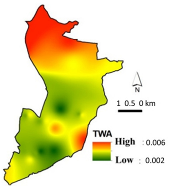
By evaluating the metrics at low-resolution level of selected classes within a time-series perspective, we can conclude that the green areas have lost their holistic structure over time, splitting into small units which move away from each other. As a result, they transformed into a complex configuration structure with weakened habitat quality. On the other hand, while the artificial surfaces primarily presented a dispersed and heterogeneous structure, over time, they became closer and formed clusters. This alteration reflects the scattered structure, increased heterogeneity, and disorganized structure of the landscape until 1984. Later, shaping, clustering, and diversity indices reflected a recovery.

The domination of artificial surfaces over the landscape led to the fragmentation of green areas between 1983 and 1997. The construction of Bosporus bridges (one built in 1973 and the other in 1988) and ring roads was the main reason for this disruption. Determining similar spatial transformations with an interim of 14 years is crucial in modelling the impacts of such constructions on the landscape. In particular, through the use of moving window analysis, spatial evaluations were possible, providing us with the means to determine the fragile areas affected by urbanization. These findings comprise essential clues regarding effective landscape analysis method.

3.2. Relationship between Landscape Metrics and PM_{10} Concentartion

Next, we calculated the individual correlations between PM_{10} and landscape-level landscape metrics over the research area. As the PM_{10} measurements were carried out in 2014, the variation between the metric values obtained until 2014 was considered, in order to ensure that the data were comparable. The measured values were generalized and mapped using the inverse distance-weighted (IDW) interpolation method (Table 7).

Table 7. Spearman's coefficient analysis and Pearson correlation analysis results and TWA map created by the IDW interpolation method.

Spearmen's Coefficient Analysis				**Pearson's Correlation Analysis**				
TWA	**AI**	**LPI**	**ED**	**TWA**	**AI**	**LPI**	**ED**	
2014	$-0.527^{(**)}$	$-0.377^{(**)}$	$0.385^{(**)}$	2014	$-0.359^{(*)}$	$-0.351^{(*)}$	$0.291^{(*)}$	
Diff. 1963–2014	$0.380^{(**)}$	$0.422^{(**)}$	$-0.387^{(**)}$	Diff. 1963–2014	$0.397^{(**)}$	$0.467^{(**)}$	$-0.418^{(**)}$	
TWA	**PD**	**SHEI**	**SHDI**	**TWA**	**PD**	**SHEI**	**SHDI**	
2014	$0.440^{(**)}$	$0.317^{(*)}$	$0.330^{(*)}$	2014	$0.288^{(*)}$	$0.317^{(*)}$	$0.324^{(*)}$	
Diff. 1963–2014	$-0.386^{(**)}$	$-0.374^{(**)}$	$-0.377^{(**)}$	Diff. 1963–2014	$-0.403^{(**)}$	$-0.462^{(**)}$	$-0.466^{(**)}$	

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). N = 50.

Studies have shown that the quality (e.g., biomass, species diversity), size, and shape of green areas affect the PM level. The penetration of vegetation into artificial surfaces in the urban area can facilitate the absorption of particulate matter. The connectivity of the green system also has an important effect on PM concentration [52,101,102].

The landscapes of Besiktas changed rapidly during the period 1963–2014. The associated changes degraded the quality of habitats by causing fragmentation and environmental changes. Therefore, we performed correlation analysis between landscape-level metric values in the relevant metric maps and PM_{10} concentration, measured at test points.

Aggregation significantly affected the PM_{10} level, mainly in residential areas. Considering that the clusters were more abundant in artificial areas, it can be stated that excess clustering on artificial surfaces significantly affects the PM_{10} exposure level. This results in an increase in clusters on artificial surfaces, which may indicate a decrease in ventilation within the city [103]. PM_{10} has been positively correlated with artificial surfaces in previous studies [104,105].

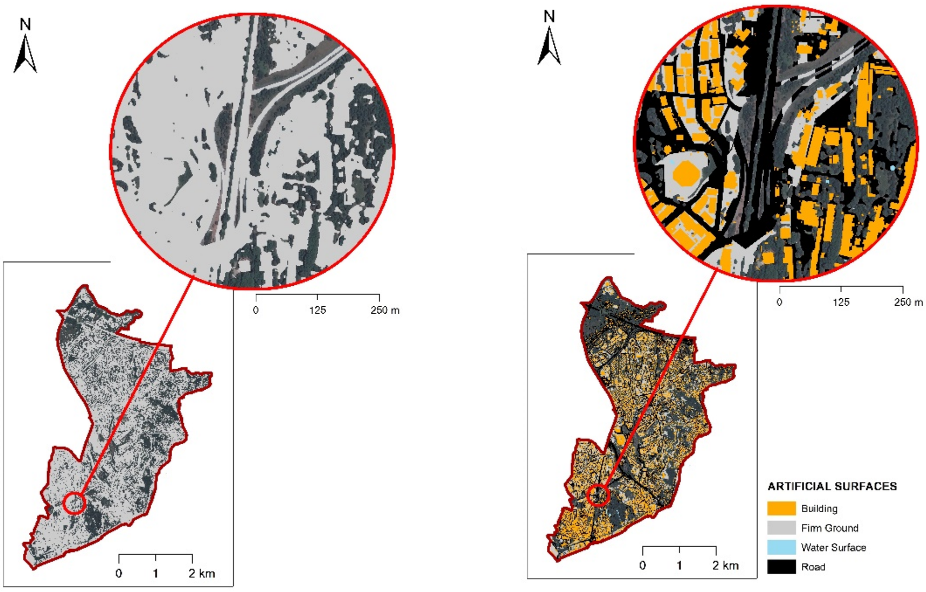
A more heterogeneous and uneven landscape distribution decreases the PM concentration. SHEI—one of the general landscape metrics—presented a significant negative relationship with the PM_{10}. The SHEI reflects the landscape heterogeneity of patches and is sensitive to the distribution of patches. High values of this index indicate dispersed landscapes. When the landscape is better distributed, the relationship between each land-use type and the interaction between the sink and source landscapes will be closer, further reducing PM pollution [106].

The results show that a high PD and a high ED were associated with much higher PM_{10} exposure levels than in less dense and less developed areas. Based on this analysis, we can conclude that landscape metrics are helpful in not only predicting the quality of habitats, but also in estimating the PM_{10} levels and the combination of both parameters, being indicative of urban health.

In the correlation analysis, moderate correlations were observed for the LPI, the AI, and the PD, and near-moderate correlations with the ED, the SHEI, and the SHDI. Based on these significant relationships, in the next step, comments are developed regarding the relationship between the habitat quality and the PM_{10} of cultural landscape classes obtained from high-resolution satellite imagery.

3.3. High-Resolution Landscape Characterization of Cultural Landscapes

Through a comprehensive literature review, we compiled species that are likely to live in the research area under normal conditions, included in five fauna groups (birds, small mammals, small butterflies, reptiles, and amphibians), which can indicate the effects on urban habitats [32,33]. In the next step, indicator species of habitats were identified among these listed species. The identified species were observed at 19 test points in field surveys, conducted randomly over two years to obtain representative results for all four seasons, and were associated with habitats in terms of criteria such as shelter, nutrition, and reproduction. Based on this relationship, the green area and artificial surface layers obtained from the high-resolution Pleiades satellite imagery were divided into cultural landscape classes (Figures 5 and 6). The green areas were divided into ten cultural landscapes (garden, openness in garden, grove, openness in grove, cemetery, openness in cemetery, park, openness in park, roadside green area, and openness in roadside green area). These landscapes were manually classified by overlaying the green area layer with the Pleiades satellite imagery (Figure 5).



(**a**) (**b**)

Figure 6. The artificial surface layer (**a**) was divided into building, water surface, firm ground, and road landscapes with the help of the base map (**b**).

The artificial surface layer obtained by remote sensing techniques from the Pleiades satellite imagery was divided into four cultural landscapes (building, water surface, firm ground, and road) within the boundaries of the research area. The mentioned cultural landscapes were obtained by cutting the polygons of the current map from the artificial surface layer (Figure 6).

As a result, a cultural landscape map of the research area was obtained by combining the layers obtained for the green areas and artificial surfaces. Furthermore, during the classification process, the habitat requirements of indicator fauna groups were considered (Figure 7).

A unique classification system which focuses on the habitats offered by the urban landscape was chosen. The fact that this unique classification system was taken as a basis while interpreting the unit-corridor matrix relations served as a guide in interpreting the pattern–function relations and priorities.

3.4. Pattern Analysis and Functional Findings of Cultural Landscapes

The 14 cultural landscape classes obtained were subjected to pattern analysis through the use of class-level metrics, and evaluated according to the main landscape functions they reflect (Figure 8).

The PLAND values for determining cultural landscape types indicated that the water surfaces were negligible, the green areas only covered an area of 38.3%, and the artificial surfaces were dominant, with a proportion of 61.65%. These findings demonstrate the impact of urbanization. Among the green areas, gardens had the most significant percentage, while groves had a critical portion. These indicators reveal the classes that should be focused on in landscape planning and management processes. Roads were the class that occupied the most space. The fact that the associated LPI value was also high indicates that this class dominates the landscape in large part.

The cultural landscape classes obtained by considering the indicator fauna groups on the high-resolution satellite image were also evaluated, according to their main landscape functions. We interpreted the findings of the high-resolution analysis regarding the landscape structure in detail, considering the outputs of Aksu and Küçük (2020) on the biotope quality of the research area [19].

Building (1): In urban landscapes, buildings are spatial components that dominate the landscape. In the research area, the spatial distribution of roof surfaces had a ratio of 21.39% (Figure 8). The fact that the NP value was very high, although they covered the surface of the research area at a high rate, shows that small but many units were distributed over the entire area. However, the relatively high TCA and ED values also show that this class is concentrated with holistic structure in certain areas, despite its configuration. The low ENN_AM value also supports this finding. The concentration of buildings which appear as the characteristic structures of many urban landscapes and compete with green spaces reveals the necessity of considering buildings from a different perspective. In the research area, where artificial surfaces dominate the green areas, and in areas with a similar urbanization process, it can be seen how essential the functions of creating habitats and harmonizing the buildings with their environmental potential are. Depending on the floor height, the formation of an artificial topography in the structured urban environment draws attention as the main factor triggering this aspect.

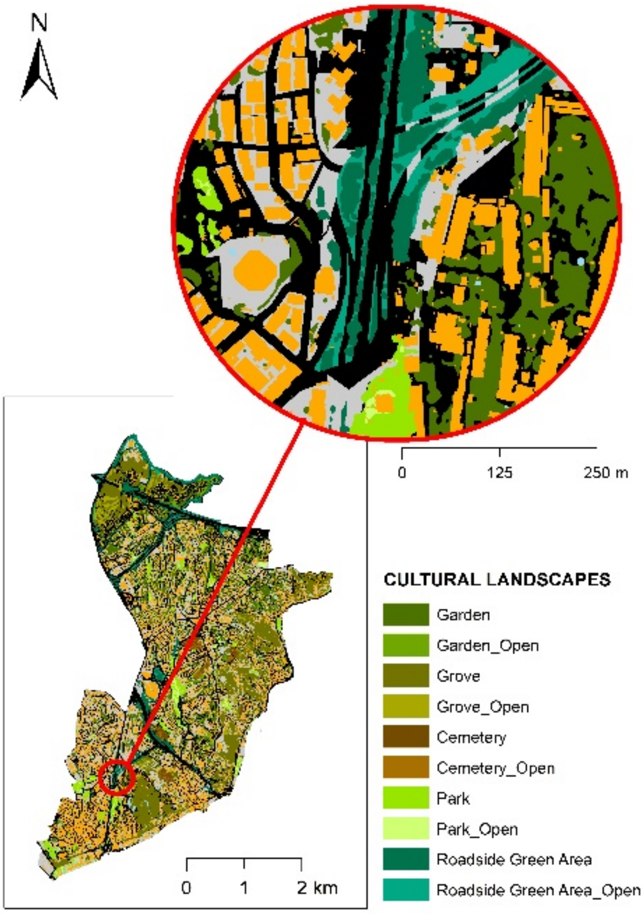


Figure 7. A cultural landscape map was obtained by taking indicator fauna groups as a reference for subcategorizing the green area and artificial surface layers.

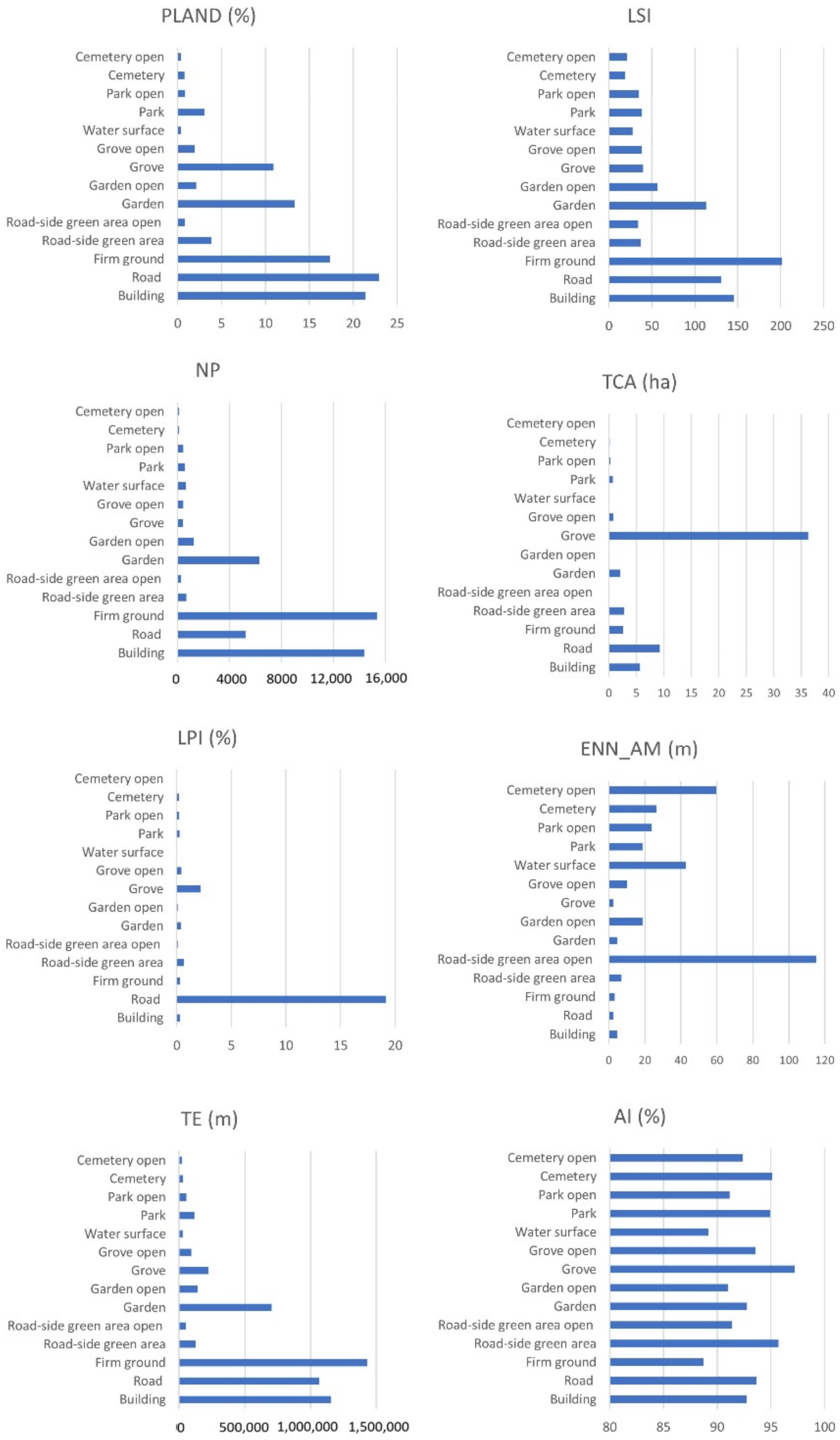


Figure 8. The cultural landscapes' class-level indexes (PLAND, NP, LPI, TE, LSI, TCA, ENN_AM, and AI).

On the other hand, the buildings that dominate the urban ecosystem, as in the research area, should be evaluated in terms of their functional features. For example, they could be used for water regime regulation, eliminating problems related to urban topography, and creating habitats for some living species (e.g., bats, swallows, seagulls, sparrows, crows, reptiles, and so on). Therefore, we can evaluate buildings as components of the urban ecosystem. They may benefit from their existing sustainable potentials (e.g., solar/wind energy harvesting and passive ventilation/lighting systems). Moreover, they may either provide or keep away structures that contribute to climate change (e.g., supporting energy efficiency, preferring green roof-facade systems, and/or smart materials). Although buildings are perceived as disruptive elements of the urban ecosystem, as they create artificial surfaces, they can constitute a shelter and breeding place for many species through simple measures to be taken on the roof and facade surfaces. Considering all of these features, building surfaces should be perceived as important biotopes, and their contribution to the landscape function should be focused on.

Road (2): Road networks are considered a separate class as they constitute a barrier due to their linear structure and have a disintegrating effect on habitats [61]. In the research area, roads were the most dominant class, in terms of the area they covered. Their linear structures play a dominant role in the landscape pattern of the research area. Roads with high ED, TCA, LPI, and LSI values are expected to exhibit a near-geometric character, considering their linear structure. On the other hand, these structures, which may move away from geometry, show how dominant they are in the landscape structure. The low ENN_AM value also supports this finding. Roads close to each other may intersect at many nodules, forming an integrated and complex grid structure.

As the primary factor in the fragmentation of green areas, roads also affect many processes in the urban ecosystem. Due to the insufficient infiltration capacity of the artificial surfaces that dominate the research area, the precipitated water that passes to surface runoff may follow the linear road networks. Again, due to the structure exhibiting continuity along this line, wind flows are artificially directed, thus forming wind corridors. Heavy metals, engine oil, fuel residues, and substances that change pH values (e.g., salting carried out to prevent icing, especially in winter) can accumulate on roads, adversely affecting many landscape functions. Road networks, together with other artificial surfaces, can trigger the formation of urban heat islands. They also carry pollutants, which combine with precipitated water that passes as the surface runoff along the line, thus negatively affecting neighboring habitats. As road networks have a key impact on essential cycles in the urban ecosystem, they should be handled and planned keeping such factors in mind.

Firm Ground (3): Firm ground is typically located as a transition zone between buildings and green areas. For this reason, their spatial and structural features are important. The artificial topography, which is formed depending on the building density, causes the formation of micro-climatic conditions such as wind shadow corridors and increased surface runoff (due to high slope degrees), which are specific to the urban environment [19]. The increase in impermeable firm ground, which generally affects ecological cycles in a negative way, can prevent precipitated water from meeting with the soil, causing many problems due to surface runoff and wasted productive water. Due to these critical properties, hard ground was also included in the classification. It was found that this class—which ranked third in terms of area size—was represented by many units. The fact that the LSI value was the furthest from the geometric indicated that the hard ground presented an organic form. However, it was the class with the highest TE and lowest LPI and TCA values, indicating that the units belonging to the class did not exhibit a holistic character. Therefore, in order to interpret the organic shape structure of the firm ground class areas, it is necessary to focus on the character of the classes to which they are adjacent.

Roadside Green Area (4): In the urban ecosystem, roadside green areas are elements accompanying roads that encourage the fragmentation process, in the form of dissection with their linear structures [61,107]. These features connect green areas in clusters or units. The green texture of roadside green areas differs in terms of the species it contains, dependent on the presence of herbaceous or woody vegetation. For this reason, openness in these areas is considered as a different class. The main factors that negatively affect the vitality and diversity of roadside green areas are gas emissions, wind-shadow canyons, and the selection of wrong plant species for plantations. The woody texture in these areas is vital for flying species such as birds, butterflies, and bats, but can be dangerous for species belonging to other indicator groups, as they accompany the roads. Although they play critical functional roles, when their metric values were examined, it was found that they did not gain an integrated and dominant structure in the manner that roads did. The main reason for this problem was that, compared to the PLAND of roads (22.95%), only 3.85% of the total area consisted of roadside green areas. Together with relatively low TCA, ED, and LPI values, the ENN_AM value was approximately three times that of the road class value, indicating that roadside green areas are insufficient in this urban landscape. Considering that they play an important role as a buffer between green areas and artificial surfaces, in terms of landscape functions and the prevention of deterioration in many functional flows, it is clear that they are essential in the urban ecosystem.

Openings in Roadside Green Areas (5): This biotope is especially important for small butterflies which need openings to live. Many butterfly species could be observed, especially in the roadside green areas where flowering mixed herbaceous vegetation was formed.

Garden (6): Building gardens are important landscapes that act as a buffer between buildings and their environment, ameliorating the disintegrating effect of buildings. This class includes the woody green tissue that forms the immediate surroundings of buildings. This texture is especially suitable for small birds, such as robins and sparrows, and can offer habitat and shelter to reptiles and small mammals. In the research area, garden was the green area class with the highest coverage (13.28%). However, although it covered more area than groves, it was found that this class consisted of many small units with low LPI and TCA and high NP and TE values. In addition, the fact that the LSI value was higher than that of the groves indicated a fragmented structure, rather than exhibiting a more natural structure; the ENN_AM value was also higher than that of the grove units, supporting this fragmented structure.

The plant species preferred in the building gardens determine the animal species that can benefit from that green area. As a result of landscape design implementations, exotic species were commonly encountered along with natural plant species in gardens. Although this situation leads to various problems, it is effective in increasing biological diversity.

Openings in Gardens (7): Herbaceous vegetation and soil areas near buildings are included in this class. This cultural landscape is vital as a home for reptiles such as tortoises, mammals such as rabbits, and small butterflies [19,108].

Grove (8): Groves can host all indicator animal groups, depending on their vegetative diversity, and have high potential for biodiversity [19,109]. They constitute the centers of the green system in urban areas that are in an intensive spatial transformation process. Their protection and development within the urban green system are crucial for the continuity of the whole system. In the research area, groves presented a rate of 10.94%.

The fact that this was the class with the highest TCA value in the research area makes the groves the only alternative for those species that distinguish between edge and core habitats to live in the urban environment. With their qualified core and edge habitats and a wide variety of natural and exotic woody plants, groves are home to many living things in the urban environment. Their holistic nature also enables them to play a dominant and essential role in the green network. The fact that the ENN_AM value was also low is another indicator of the holistic structure of the groves within the research area. Therefore, the development of this class is important to continue the urban ecosystem, in terms of quality and quantity. Regulations effective with respect to the water regime and climatic conditions, improving air quality, and protecting and developing biodiversity, should be included in planning and management processes.

Openings in Groves (9): Although groves generally have tree-dominated dense woody vegetation, there are also open areas, covered with herbaceous vegetation or soil surface. These openings constitute an ideal living environment for creatures that need more light to live and increase the biodiversity of groves. Therefore, it is appropriate to consider them as a separate class as they differ in these features.

Water Surface (10): Water surfaces are vital for all living things in the urban ecosystem and indispensable for many species as a habitat. However, it was determined that the water surfaces in the research area were very few and insufficient, in terms of quality. Although the PLAND ratio of water surfaces was the lowest, the high NP and ENN_AM values and low AI values indicate that the water surfaces in the study area were typically represented as small disconnected units. According to the experience gained from field studies, most of these small water surfaces are swimming pools that are cleaned with chemicals. Therefore, the water surfaces, which were already insufficient in terms of area, are also weak in terms of quality. This situation constitutes a problem that disrupts the continuity of the urban ecosystem and, in this respect, urgently needs to be addressed.

Park (11): Park areas are the class representing woody vegetation in public areas under the responsibility of the metropolitan municipality or district municipality. In these areas, where intensive use is generally seen, species that have adapted to human life attract attention. Considering the PLAND value, when the edge–core area relations (TE and TCA) and LPI values (third place) of the parks were examined, we found that they can constitute a stepping stone between the block units formed by groves and gardens. For this reason, it is essential to manage the design and arrangement processes of parks in the research area with this awareness. The connector positions of parks in the green network should be considered both in the selection of plant species and in the design of artificial surfaces.

Openings in Parks (12): This class includes openings within park areas covered with herbaceous vegetation or soil cover. Although these openings are not expected to serve timid species in park areas where human utilization is intense, they are considered a separate class, allowing specific species that have adapted to human activities and which need openings to live.

Cemetery (13): Cemeteries are areas where physical interventions such as pesticides and pruning are made at a minimum level. In addition, as they are not exposed to intense human use, they constitute a quiet environment. In this respect, they are important habitats for relatively timid species that cannot find shelter in other urban biotopes. The age of a cemetery is essential, in terms of the vegetation quality. While old cemeteries host old trees, the vegetation of new cemeteries consists mainly of bushes or young trees with lean structures. As such, no species that need tree hollows to shelter in were observed in new cemeteries.

However, ancient cemeteries may serve as a stepping stone for many species, especially between groves and other biotopes. All the cemeteries in the research area were areas with a certain age of tree texture. Although they are ecologically precious areas, they constitute a small percentage in the research area (0.76%). Therefore, when examined in terms of PLAND, NP, and ENN_AM values, cemeteries should be considered in terms of providing shelter to different species with the integrated units they form, even though they cannot be considered in a connective position within the landscape structure.

Openings in Cemeteries (14): Openings with herbaceous vegetation or soil-covered surfaces in cemeteries are considered a separate class, as they have different characteristics appealing to different species.

3.5. PM_{10} Concentration and Habitat Relations

The fact that the NP-dependent PD value, which is positively correlated with PM_{10}, was high for the building and firm ground classes indicates that hardscapes play an essential role in controlling the particulate matter density in the urban ecosystem. The choice of green systems or smart materials with the ability to absorb pollutants, especially as roof and facade materials, can significantly contribute to balancing the PM concentration in the entire urban landscape.

Considering the negative correlation between the AI and PM_{10}—which we interpret as decreasing PM while clustering increases—the high AI values in groves and roadside green areas indicate how vital these green areas are in the urban ecosystem. Preserving the holistic structure of groves is extremely important, in terms of habitat quality and biodiversity protection. Therefore, the high aggregation index value of this class is promising. Roadside green areas can potentially curb the adverse effects of roads which suppress the urban ecosystem in terms of pollutants such as noise, emissions, and PM. It is crucial for the units belonging to these areas to be clustered and gain a continuous structure as much as possible, in order to be linearly effective.

The results of this research informed us that the ecological indicator–landscape structure relationship, which provides inferences, contains important clues regarding the urban ecosystem. Furthermore, we determined that PM is significantly correlated with metrics that are indicators of landscape structure. For this reason, looking at the relationship between PM and metric values obtained from high-resolution satellite imagery and/or detailed DEM data in future research is expected to enable more detailed interpretations [110].

4. Conclusions

In metropolitan areas such as Istanbul, where the urbanization pressure is intense, research is of vital importance to ensure the continuity of the urban ecosystem. Landscape plans should focus on ecosystem relations and the inclusion of implementation strategies, thus guiding development plans within the sustainability framework. In areas where rapid transformation processes are experienced, it is necessary to produce comprehensive, practical, and up-to-date data on the deterioration/transformation rates. In this sense, the landscape structure, which can be evaluated at wide scale through the use of RS and GIS technologies, provides important clues for the urban ecosystem. Furthermore, the spatial arrangement and structure can be used as indicators, in terms of landscape functions.

In the first stage, we revealed and interpreted the change trends of green areas and artificial surfaces over a 51-year period using freely accessible Landsat (Corona for 1963) satellite imagery with medium-level resolution. After this general evaluation, we examined the spatial relationships of cultural landscapes that shape the urban ecosystem in more detail, using high-resolution Pleiades satellite images. In addition, we measured the PM_{10} concentration (in 2014) at 50 test points representing different cultural landscapes in the research area. Finally, we interpreted the results by comparing them with the general and detailed data obtained for the landscape structure. We also analyzed the correlations between PM_{10} and landscape-level landscape metrics.

The most striking results achieved in this comprehensive and multi-component study are summarized below:

- The two-stage landscape pattern evaluation method, based on the temporal–spatial findings related to the landscape structure of the research area, enabled the interpretation of the spatial arrangement of landscape classes on a more detailed scale and the determination of administrative priorities regarding landscape functions.
- An interpretation of the relationships between landscape structure, particulate matter concentration, and habitat quality provided essential findings for the urban ecosystem.
- Results from the low-resolution data revealed significant correlations between particulate matter concentration and landscape structure indices. Examining these relationships at more detailed scales can significantly contribute to the evaluation of important components, such as habitat quality, biodiversity, and microclimatic relationships in the urban ecosystem.
- Assessing the landscape structure through a detailed holistic approach ensures that the habitat relationships can be evaluated more accurately and comprehensively. Different resolution RS data (satellite images and orthophotos) available on a wide scale facilitate such an evaluation.

- The research was productive in creating an ecological basis within a short time, which is extremely important for the evaluation and management of urban landscapes experiencing a rapid transformation process.
- Associating cultural landscape types with the living environments of indicator species enabled us to establish a bridge between landscape structure and important factors for landscape function, such as water cycle, pollutants, and climate. In this way, the landscape structure could be evaluated as an indicator of landscape functions.
- An alternative model was created, in order to associate species–habitat relations, by looking at landscape structure–ecological indicator interactions.
- We revealed a holistic view of the spatial transformation processes in urban landscapes, which have dynamic drivers at the local, regional, national, and international levels that serve to accelerate urbanization. Such an assessment is crucial for ensuring the sustainability of the urban ecosystem and presenting a model for similar landscapes. Moreover, the proposed framework allows lead landscape planners and managers to better assess cause–effect relationships.

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References

1. European Union Environment. Available online: https://europa.eu/european-union/topics/environment_en (accessed on 26 August 2022).
2. UN-Environment Programme. Available online: https://www.unenvironment.org/ (accessed on 26 August 2022).
3. UN–Sustainable Development Goals (SDGs). Available online: https://sdgs.un.org/goals#goals (accessed on 8 September 2022).
4. The European Green Deal, 2021. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed on 26 August 2022).
5. Sundseth, K.; Creed, P. *NATURA 2000, Protecting Europe's Biodiversity*; European Commission, Directorate General for the Environment: Brusselles, Belgium, 2008; ISBN 978 92 79 08308 2.
6. COM–Commission of the European Communities. Our Life Insurance, Our Natural Capital: An EU Biodiversity Strategy to 2020. Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. Brussels, 3.5.2011; COM (2011) 244 Final. Available online: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0244&from=de (accessed on 20 September 2022).
7. Zonneveld, I.S. The land unit–A fundamental concept in landscape ecology, and its applications. *Landsc. Ecol.* **1989**, *3*, 67–86. [CrossRef]
8. Antrop, M. Landscape change: Plan or chaos? *Landsc. Urban Plan.* **1998**, *41*, 155–161. [CrossRef]
9. Bailey, R.G. *Ecoregion-Based Design for Sustainability*; Springer: New York, NY, USA, 2002; ISBN 0-387-95430-9.
10. Steinhardt, U.; Blumenstein, O.; Barsch, H. *Lehrbuch der Landschaftsökologie (Textbook of Landscape Ecology)*; Springer: Berlin/Heidelberg, Germany, 2005; ISBN 3-8274-1448-2. (In German)
11. Forman, R.T.T. *Urban Regions. Ecology and Planning Beyond the City*; Cambridge University Press: Cambridge, UK, 2008; ISBN 978-0-521-67076-0.
12. Forman, R.T.T. *Urban Ecology: Science of Cities*; Cambridge University Press: Cambridge, UK, 2014; ISBN 978-0-521-18824-1.
13. Wu, J. Urban sustainability: An inevitable goal of landscape research. Editorial. *Landsc. Ecol.* **2010**, *25*, 1–4. [CrossRef]
14. Wu, J. Urban ecology and sustainability: The state-of-the-science and future Directions. *Landsc. Urban Plan.* **2014**, *125*, 209–221. [CrossRef]
15. Potschin, M.; Haines-Young, R. "Rio+10", sustainability science and Landscape Ecology. *Landsc. Urban Plan.* **2006**, *75*, 162–174. [CrossRef]

16. Rees, W.; Wackernagel, M. Urban Ecological Footprints: Why Cities Cannot be Sustainable and Why They are a Key to Sustainability. *Environ. Impact Assess. Rev.* **1996**, *16*, 223–248. [CrossRef]
17. Solarski, M.; Krzysztofik, R. Is the Naturalization of the Townscape a Condition of De-Industrialization? An Example of Bytom in Southern Poland. *Land* **2021**, *10*, 838. [CrossRef]
18. Aksu, G.A.; Musaoğlu, N.; Uzun, A. An auxiliary tool for landscape evaluation Ecological risk analysis based on analytic hierarchy process. *Fresenius Environ. Bull.* **2017**, *26*, 84–92.
19. Aksu, G.A.; Küçük, N. Evaluation of urban topography–biotope–population density relations for Istanbul–Besiktas urban landscape using AHP. *Environ. Dev. Sustain.* **2020**, *22*, 733–758. [CrossRef]
20. Sertel, E.; Topaloğlu, R.; Şallı, B.; Yay Algan, I.; Aksu, G. Comparison of Landscape Metrics for Three Different Level Land Cover/Land Use Maps. *ISPRS Int. J. Geo-Inf.* **2018**, *7*, 408. [CrossRef]
21. Topaloğlu, R.H.; Aksu, G.A.; Ghale, Y.A.G.; Sertel, E. High-resolution land use and land cover change analysis using GEOBIA and landscape metrics: A case of Istanbul, Turkey. *Geocarto Int.* **2021**. [CrossRef]
22. Bentrup, G. *Conservation Buffers. Design Guidelines for Buffers, Corridors, and Greenways*; General Technical Report SRS 109; Department of Agriculture, Forest Service, Southern Research Station: Asheville, NC, USA, 2008.
23. Gartland, L. *Heat Islands: Understanding and Mitigating Heat in Urban Areas*; Earthscan: Oxford, UK, 2008; ISBN 978-1-84407-250-7.
24. Lehmann, I.; Mathey, J.; Rößler, S.; Bräuer, A.; Goldberg, V. Urban vegetation structure types as a methodological approach for identifying ecosystem services–Application to the analysis of micro-climatic effects. *Ecol. Indic.* **2014**, *42*, 58–72. [CrossRef]
25. Boehnke, D.; Krehl, A.; Mörmann, K.; Volk, R.; Lützkendorf, T.; Naber, E.; Becker, R.; Norra, S. Mapping Urban Green and Its Ecosystem Services at Microscale—A Methodological Approach for Climate Adaptation and Biodiversity. *Sustainability* **2022**, *14*, 9029. [CrossRef]
26. Lennon, J. Cultural Landscape Management Practice: Some Australian Case Studies. In *Conserving Cultural Landscapes Challenges and New Directions, Part IV: Confronting the Everyday Challenge of Cultural Landscape Management*; Taylor, K., St Clair, A., Mitchell, N.J., Eds.; Routledge: London, UK, 2015; ISBN 9781315813226.
27. Kaim, D.; Kozak, J.; Ostafin, K.; Dobosz, M.; Ostapowicz, K.; Kolecka, N.; Gimmi, U. Uncertainty in historical land-use reconstructions with topographic maps. *Quaest. Geogr.* **2014**, *33*, 55–63. [CrossRef]
28. Skaloš, J.; Weber, M.; Lipský, Z.; Trpáková, I.; Šantrůčková, M.; Uhlířová, L.; Kukla, P. Using old military survey maps and orthophotograph maps to analyse long-term land cover changes—Case study (Czech Republic). *Appl. Geogr.* **2011**, *31*, 426–438. [CrossRef]
29. Petit, C.; Lambin, E. Impact of data integration technique on historical land-use/land-cover change: Comparing historical maps with remote sensing data in the Belgian Ardennes. *Landsc. Ecol.* **2002**, *17*, 117–132. [CrossRef]
30. Güngöroğlu, C.; Musaoğlu, N.; Türkkan, M.; Yöntem, O.; Yılmaztürk, A.; Çayır, G. *CBS Destekli Uzaktan Algılama Teknikleri Kullanılarak Biyotop Tiplerinin Sınıflandırılması ve Haritalanması (Köprülü Kanyon Milli Parkı Örneği). (Classification and Mapping of Biotope Types Through GIS-based Remote Sensing Techniques–The Example of the Köprülü Kanyon National Park–)*; Ministry of Environment and Forests; South-West Anatolia Forest Research Institute (SAFRI): Antalya, Turkey, 2008. (In Turkish)
31. Odum, E.P.; Barrett, G.W. *Fundamentals of Ecology*; Thomson Brooks/Cole: Boston, MA, USA, 2005; ISBN 978-0534420666.
32. Kutzenberger, H. *Animal Ecology and Landscape Planning, Pilot Project in the Context of Cultural Landscape Research*; Research Area Cultural Landscape, Federal Ministry of Science and Transport: Vienna, Austria, 1998; Volume 3.
33. Kutzenberger, H. Animal Ecological Characterization of Cultural Landscapes as a Basis for Landscape Planning. Ph.D. Thesis, University of Natural Resources and Applied Life Sciences, Vienna, Austria, 2001.
34. Hampicke, U. *Kulturlandschaft–Äcker, Wiesen, Wälder und ihre Produkte. (Cultural Landscape–Fields, Meadows, Forests and their Products)*; Springer: Berlin/Heidelberg, Germany, 2018; (In German). ISBN 978-3-662-57752-3.
35. Türkeş, M.; Musaoğlu, N.; Özcan, O. Assessing the vulnerability of a forest ecosystem to climate change and variability in the western Mediterranean sub-region of Turkey: Future evaluation. *J. For. Res.* **2018**, *29*, 1177–1186. [CrossRef]
36. Yagmur, N.; Tanik, A.; Tuzcu, A.; Musaoglu, N.; Erten, E.; Bilgilioglu, B.B. Opportunities Provided by Remote Sensing Data for Watershed Management: Example of Konya Closed Basin. *Int. J. Eng. Geosci.* **2020**, *5*, 120–129.
37. Tuzcu, A.; Dervişoğşu, A.; Musaoğlu, N.; Tanık, A. Determination of Land-Use/Cover and Water Turbidity of Wetlands by Using High Resolution Satellite Image. In Proceedings of the International Symposium on Applied Geoinformatics (ISAG 2019), Istanbul, Turkey, 7 November 2019; Volume 1, pp. 154–158.
38. Riitters, K.H.; O'Neill, R.V.; Hunsaker, C.T.; Wickham, J.D.; Yankee, D.H.; Timmins, S.P.; Jones, K.B.; Jackson, B.L. A factor analysis of landscape pattern and structure metrics. *Landsc. Ecol.* **1995**, *10*, 23–39. [CrossRef]
39. McGarigal, K. *Encyclopedia of environmetric. Landscape Pattern Metrics*; Wiley: Chichester, UK, 2002; Volume 2, pp. 1135–1142.
40. Southworth, J.; Nagendra, H.; Tucker, C. Fragmentation of a landscape: Incorporating landscape metrics into satellite analyses of land-cover change. *Landsc. Res.* **2002**, *27*, 253–269. [CrossRef]
41. Leitão, A.B.; Miller, J.; Ahern, J.; McGarigal, K. *Measuring Landscapes. A Planner's Handbook*; Island Press: Washington, DC, USA, 2006; ISBN 1-55963-899-0.
42. Cushman, S.A.; McGarigal, K.; Neel, M.C. Parsimony in landscape metrics: Strength, universality, and consistency. *Ecol. Indic.* **2008**, *8*, 691–703. [CrossRef]
43. Uuemaa, E.; Antrop, M.; Roosaare, J.; Marja, R.; Mander, Ü. Landscape metrics and indices: An overview of their use in landscape research. *Living Rev. Landsc. Res.* **2009**, *3*, 1–28. [CrossRef]

44. McGarigal, K.; Cushman, S.A.; Ene, E. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. 2012. Available online: https://www.scirp.org/(S(lz5mqp453edsnp55rrgjct55))/reference/ReferencesPapers.aspx?ReferenceID=1892846 (accessed on 20 October 2022).
45. Liu, T.; Yang, X. Monitoring land changes in an urban area using satellite imagery, GIS, and landscape metrics. *Appl Geogr.* **2015**, *56*, 42–54. [CrossRef]
46. Szabó, S.; Bertalan, L.; Kerekes, Á.; Novák, T.J. Possibilities of land-use change analysis in a mountainous rural area: A methodological approach. *Int. J. Geogr. Inf. Sci.* **2016**, *30*, 708–726. [CrossRef]
47. Xu, C.; Haase, D.; Su, M.; Wang, Y.; Pauleit, S. Assessment of landscape changes under different urban dynamics based on a multiple-scenario modeling approach. *Env. Plan B Urban Anal City Sci.* **2020**, *47*, 1361–1379. [CrossRef]
48. Zhang, Q.; Chen, C.; Wang, J.; Yang, D.; Zhang, Y.; Wang, Z.; Gao, M. The spatial granularity effect, changing landscape patterns, and suitable landscape metrics in the Three Gorges Reservoir Area, 1995–2015. *Ecol. Indic.* **2020**, *114*, 106259. [CrossRef]
49. Karimi, J.D.; Corstanje, R.; Harris, J.A. Understanding the importance of landscape configuration on ecosystem service bundles at a high resolution in urban landscapes in the UK. *Landsc. Ecol.* **2021**, *36*, 2007–2024. [CrossRef]
50. Batur, A. Association of Particulate Matter (PM_{10}) Concentration with the Urban Green System: Istanbul–Besiktas Sample. Matser's Thesis, Istanbul Commerce University Graduate School of Applied and Natural Sciences, Istanbul, Turkey, 2021.
51. Deng, S.; Ma, J.; Zhang, L.; Jia, Z.; Ma, L. Microclimate Simulation and Model Optimization of the Effect of Roadway Green Space on Atmospheric Particulate Matter. *Environ. Pollut.* **2019**, *246*, 932–944. [CrossRef]
52. Wu, H.; Yang, C.; Chen, J.; Yang, S.; Lu, T.; Lin, X. Effects of Green Space Landscape Patterns on Particulate Matter in Zhejiang Province, China. *Atmos. Pollut. Res.* **2018**, *9*, 923–933. [CrossRef]
53. Kais, K.; Goła´s, M.; Suchocka, M. Awareness of Air Pollution and Ecosystem Services Provided by Trees: The Case Study of Warsaw City. *Sustainability* **2021**, *13*, 10611. [CrossRef]
54. Jaung, W.; Carrasco, L.R.; Shaikh, F.F.E.A.; Tan, P.Y.; Richards, D.R. Temperature and air pollution reductions by urban green spaces are highly valued in a tropical city-state. *Urban For. Urban Green.* **2020**, *55*, 126827. [CrossRef]
55. TUIK. Turkish Statistical Institute, Address Based Population Registration System Results official web site. 2017. Available online: http://tuik.gov.tr (accessed on 26 August 2022).
56. Lillesand, T.; Kiefer, R.W.; Chipman, J. *Remote Sensing and Image Interpretation*, 7th ed.; John Wiley & Sons Inc: Hoboken, NJ, USA, 2015.
57. Foody, G.M. Status of Land Cover Classification Accuracy Assessment. *Remote Sens. Environ.* **2002**, *80*, 185–201. [CrossRef]
58. UHUZAM İTÜ. Available online: http://Www.Cscrs.Itu.Edu.Tr/Assets/Downloads/Pleiadesuserguide.Pdf (accessed on 26 August 2022).
59. Myneni, R.B.; Asrar, G. Atmospheric Effects and Spectral Vegetation Indices. *Remote Sens. Environ.* **1994**, *47*, 390–402. [CrossRef]
60. Richards, J.A.; Jia, X. *Remote Sensing Digital Image Analysis: An Introduction*, 3rd ed.; Springer: Sydney, Australia, 1999.
61. Forman, R.T.T. *Land Mosaics*; Cambridge University Press: Cambridge, UK, 1995; ISBN 978-0-521-479980-6.
62. Antrop, M. The language of landscape ecologists and planners: A comparative content analysis of concepts used in landscape ecology. *Landsc. Urban Plan.* **2001**, *55*, 163–173. [CrossRef]
63. Kupfer, J.A. Landscape ecology and biogeography: Rethinking landscape metrics in a post-FRAGSTATS landscape. *Prog. Phys. Geogr. Earth Environ.* **2012**, *36*, 400–420. [CrossRef]
64. Li, H.; Reynolds, J.F. A simulation experiment to quantify spatial heterogeneity in categorical maps. *Ecology* **1994**, *75*, 2446–2455. [CrossRef]
65. Peng, J.; Wu, J.; Li, W. Evaluating the effectiveness of landscape metrics in quantifying spatial patterns. *Ecol. Indic.* **2010**, *10*, 217–223. [CrossRef]
66. McGarigal, K.; Cushman, S.A. The gradient concept of landscape structure. In *Issues and Perspectives in Landscape Ecology*; Wiens, J., Moss, M., Eds.; Cambridge University Press: Cambridge, UK, 2005; pp. 112–119.
67. Liu, M.; Hu, Y.; Li, C. Landscape metrics for three-dimensional urban building pattern recognition. *Appl. Geogr.* **2017**, *87*, 66–72. [CrossRef]
68. Amiri, B.J.; Asgarian, A.; Sakieh, Y. Introducing landscape accuracy metric for spatial performance evaluation of land use/land cover change models. *Geocarto Int.* **2017**, *32*, 1171–1187. [CrossRef]
69. Lamine, S.; Petropoulos, G.P.; Singh, S.K.; Szabó, S.; Bachari, N.E.I.; Srivastava, P.K.; Suman, S. Quantifying land use/land cover spatio-temporal landscape pattern dynamics from Hyperion using SVMs classifier and FRAGSTATS®. *Geocarto Int.* **2018**, *33*, 862–878. [CrossRef]
70. Leitão, A.B.; Muge, F. The Role of Landscape Metrics in Environmental Planning and Management of Mining Activities. In Proceedings of the APCOM'2001-29th International Symposium on Computer Applications in the Minerals Industries, Beijing, China, 25–27 April 2001; Heping, X., Wang, Y., Jiang, Y., Eds.; Balkema Publishers: Rotterdam, The Netherlands, 2001; pp. 713–718.
71. Colson, F.; Bogaert, J.; Ceulemans, R. Fragmentation in the Legal Amazon, Brazil: Can landscape metrics indicate agricultural policy differences? *Ecol. Indic.* **2011**, *11*, 1467–1471. [CrossRef]
72. Aguilera, F.; Valenzuela, L.M.; Botequilha-Leitão, A. Landscape metrics in the analysis of urban land use patterns: A case study in a Spanish metropolitan area. *Landsc. Urban Plan.* **2011**, *99*, 226–238. [CrossRef]

73. Vaz, E.; De Noronha, T.; Nijkamp, P. Exploratory Landscape Metrics for Agricultural Sustainability. *Agroecol. Sustain. Food Syst.* **2014**, *38*, 92–108. [CrossRef]
74. Ozcan, O.; Aksu, G.A.; Erten, E.; Musaoglu, N.; Çetin, M. Degradation monitoring in Silvopastoral systems: A case study of the Mediterranean region of Turkey. *Adv. Space Res.* **2019**, *63*, 160–171. [CrossRef]
75. Li, E.; Endter-Wada, J.; Li, S. Dynamics of Utah's agricultural landscapes in response to urbanization: A comparison between irrigated and non-irrigated agricultural lands. *Appl. Geogr.* **2019**, *105*, 58–72. [CrossRef]
76. Abedini, A.; Khalili, A.; Asadi, N. Urban Sprawl Evaluation Using Landscape Metrics and Black-and White Hypothesis (Case Study: Urmia City). *J. Indian Soc. Remote Sens.* **2020**, *48*, 1021–1034. [CrossRef]
77. Wolff, S.; Lakes, T. Characterising Agricultural Landscapes using Landscape Metrics and Cluster Analysis in Brandenburg, Germany. *GI_Forum* **2020**, *1*, 89–98. [CrossRef]
78. Wolff, S.; Hüttel, S.; Nendel, C.; Lakes, T. Agricultural Landscapes in Brandenburg, Germany: An Analysis of Characteristics and Spatial Patterns. *Int. J. Environ. Res.* **2021**, *15*, 487–507. [CrossRef]
79. Zhang, L.; Zhai, Z.; Zhou, Y.; Liu, S.; Wang, L. The Landscape Pattern Evolution of Typical Open-Pit Coal Mines Based on Land Use in Inner Mongolia of China during 20 Years. *Sustainability* **2022**, *14*, 9590. [CrossRef]
80. Bao, S.; Yang, F. Spatio-Temporal Dynamic of the Land Use/Cover Change and Scenario Simulation in the Southeast Coastal Shelterbelt System Construction Project Region of China. *Sustainability* **2022**, *14*, 8952. [CrossRef]
81. Miller, W.; Collins, M.G.; Steiner, F.R.; Cook, E. An approach for greenway suitability analysis. *Landsc. Urban Plan.* **1998**, *42*, 91–105. [CrossRef]
82. Tischendorf, L.; Fahrig, L. How should we measure landscape connectivity? *Landsc. Ecol.* **2000**, *15*, 633–641. [CrossRef]
83. Tischendorf, L. Can landscape indices predict ecological processes consistently? *Landsc. Ecol.* **2001**, *16*, 235–254. [CrossRef]
84. Ramachandra, T.V.; Bharath, H.A.; Sreekantha, S. Spatial Metrics based Landscape Structure and Dynamics Assessment for an emerging Indian Megalopolis. *Int. J. Adv. Res. Artif. Intell.* **2012**, *1*, 1. [CrossRef]
85. Scolozzi, R.; Geneletti, D. A multi-scale qualitative approach to assess the impact of urbanization on natural habitats and their connectivity. *Environ. Impact Assess. Rev.* **2012**, *36*, 9–22. [CrossRef]
86. Fan, C.; Myint, S. A comparison of spatial autocorrelation indices and landscape metrics in measuring urban landscape fragmentation. *Landsc. Urban Plan.* **2014**, *121*, 117–128. [CrossRef]
87. Weber, N.; Haase, D.; Franck, U. Assessing modelled outdoor traffic induced noise and air pollution around urban structures using the concept of landscape metrics. *Landsc. Urban Plan.* **2014**, *125*, 105–116. [CrossRef]
88. Prastacos, P.; Chrysoulakis, N.; Kochilakis, G. Urban Atlas, land use modelling and spatial metric techniques. *Cybergeo Eur. J. Geogr. Reg. Urban Plan.* **2017**, *815*. [CrossRef]
89. Wang, H.; Li, C. Analysis of scale effect and change characteristics of ecological landscape pattern in urban waters. *Arab. J. Geosci.* **2021**, *14*, 569. [CrossRef]
90. Szabó, S.; Csorba, P.; Szilassi, P. Tools for Landscape Ecological Planning–Scale, and Aggregation Sensitivity of the Contagion Type Landscape Metric Indices. *Carpathian J. Earth Environ. Sci.* **2012**, *7*, 127–136.
91. Singh, S.K.; Srivastava, P.K.; Szabó, S.; Petropoulos, G.P.; Gupta, M.; Islam, T. Landscape transform and spatial metrics for mapping spatiotemporal land cover dynamics using Earth Observation data-sets. *Geocarto. Int.* **2017**, *32*, 113–127. [CrossRef]
92. Wiens, J.A. Spatial Scaling in Ecology. *Funct. Ecol.* **1989**, *3*, 385–397. [CrossRef]
93. Forman, R.T.T.; Godron, M. *Landscape Ecology*; John Wiley & Sons: New York, NY, USA, 1986; ISBN 0-471-87037-4.
94. Ranney, J.W.; Bruner, M.C.; Levenson, J.B. The importance of edge in the structure and dynamics of forest islands. In *Forest Island Dynamics in Man-Dominated Landscapes*; Burgess, R.L., Sharpe, D.M., Eds.; Springer: New York, NY, USA, 1981; pp. 67–95.
95. Moore, N.W.; Hooper, M.D. On the number of bird species in British woods. *Biol. Conserv.* **1975**, *8*, 239–250. [CrossRef]
96. Whitcomb, R.F.; Robbins, C.S.; Lynch, J.F.; Whitcomb, B.L.; Klimkiewicz, K.; Bystrak, D. Effects of forest. In *Forest Island Dynamics in Man-Dominated Landscapes*; Burgess, R.L., Sharpe, D.M., Eds.; Springer: New York, NY, USA, 1981; pp. 125–205.
97. Gyenizse, P.; Bognár, Z.; Czigány, S.; Elekes, T. Landscape shape index, as a potencial indicator of urban development in Hungary. *Landsc. Amp. Env.* **2014**, *8*, 78–88.
98. Buechner, M. Are small-scale landscape features important factors for field studies of small mammal dispersal sinks? *Landsc. Ecol.* **1989**, *2*, 191–199. [CrossRef]
99. Andrén, H. Effects of Habitat Fragmentation on Birds and Mammals in Landscapes with Different Proportions of Suitable Habitat: A Review. *Oikos* **1994**, *71*, 355–366. [CrossRef]
100. He, H.S.; DeZonia, B.E.; Mladenoff, D.J. An aggregation index (AI) to quantify spatial patterns of landscapes. *Landsc. Ecol.* **2000**, *15*, 591–601. [CrossRef]
101. Abhijith, K.V.; Kumar, P.; Gallagher, J.; McNabola, A.; Baldauf, R.; Pilla, F.; Pulvirenti, B. Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments—A review. *Atmos. Environ.* **2017**, *162*, 71–86. [CrossRef]
102. Viecco, M.; Vera, S.; Jorquera, H.; Bustamante, W.; Gironás, J.; Dobbs, C.; Leiva, E. Potential of particle matter dry deposition on green roofs and living walls vegetation for mitigating urban atmospheric pollution in semiarid climates. *Sustainability* **2018**, *10*, 2431. [CrossRef]
103. Garcia, J.N.P.M.; Cerdeira, R.S.; Tavares, N.A.; Coelho, L.M.R. Studying street geometry influence in PM10 concentration. *Environ. Pollut.* **2012**, *50*, 283–292. [CrossRef]

104. Roselund, M. Environmental Factors in Cardiovascular Disease. Ph.D. Thesis, The Institute of Environmental Medicine, Karolinska Institutet, Stockholm, Sweden, 2005.
105. Vlachokostas, C.; Achillas, C.; Michailidou, A.V.; Moussiopoulos, N. Measuring combined exposure to environmental pressures in urban areas: An air quality and noise pollution assessment approach. *Environ. Int.* **2012**, *39*, 8–18. [CrossRef] [PubMed]
106. Li, S.; Lu, X.X.; He, M.; Zhou, Y.; Li, L.; Ziegler, A.D. Daily CO2 partial pressure and CO2 outgassing in the upper Yangtze River basin: A case study of the Longchuan River, China. *J. Hydrol.* **2012**, *466–467*, 141–150. [CrossRef]
107. Aksu, G.A. Evaluation of Roadside Green Areas in Urban Landscapes in the Framework of Urban Ecosystem. *Eur. J. Sci. Technol.* **2021**, *25*, 736–748.
108. Gandy, M. *Natura Urbana: Ecological Constellations in Urban Space*; MIT Press: Cambridge, MA, USA, 2022; ISBN 9780262046282.
109. Kırca, S.; Çolak, A.H.; Rotherdam, I.D. The Ancient Woodland Concept as a Practical Conservation Tool: The Turkish Experience. In *Ancient Woodlands and Trees: A Guide for Landscape Planners and Forest Managers*; Çolak, A.H., Kırca, S., Rotherham, I.D., Eds.; IUFRO World Series: Vienna, Austria, 2018; Volume 37, pp. 214–241.110.
110. Śliwiński, D.; Konieczna, A.; Roman, K. Geostatistical Resampling of LiDAR-Derived DEM in Wide Resolution Range for Modelling in SWAT: A Case Study of Zgłowiączka River (Poland). *Remote Sens.* **2022**, *14*, 1281. [CrossRef]