Ancient forests and their indicators in urban areas: the role of long-term proximity, area, and distance from the city center

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Abstract. Urban areas are complex and ever-changing systems, whose natural surroundings are profoundly influenced by urbanization processes. In the face of such changes, there is an urgent need to evaluate the state of nature within cities from the perspective of spatial planning and nature conservation. We consider forest specialists, which are unable to colonize new forests rapidly, as indicators of long-standing woodlands in the city area. The main aim of this study was to determine the distribution patterns of forest specialists and to explore their correlation with ancient forests. We hypothesize that it is not just the occurrence of ancient forests that determines the distribution and richness of forest plants. We also explore the so-called 'adjacent grid permanent forests'; the area of forest-patches, and their location in relation to the city center. Our first task was to examine the changes in the city's forest coverage and pinpoint the location of ancient forests. The study employed historical maps and cartographic works. With the aid of GIS tools, it was possible to depict changes in forest cover over the past 200 years. The distribution of the studied indicator species, overlaid on changing forest cover, unveiled a strong correlation with historical land use. Our findings highlight that both ancient forests and adjacent permanent forests are vital for preserving forest species. Proximity to the city center significantly impacts the occurrence of forest specialists, which are often absent even from areas with ancient forests. However, they may be present despite no detection of ancient or grid permanent forests in the outskirts. This could be due to the existence of small, long-standing tree patches that had a much greater chance of being preserved far from the city center and were not depicted on old maps. Although these micro-refuges may harbor individual forest species adequately, larger ancient and permanent forest areas are needed to maintain the higher number of forest specialists. Our results helped identify the areas most suitable for afforestation, considering the preservation of forest continuity and the migration possibilities of forest plants.

Key words: ancient forests, forest history, forest plants, indicator species, Łódź city, urbanization

1. Introduction

The development of built-up areas continues to grow worldwide, albeit at varying rates, together with its many ecological and evolutionary consequences (Uchida et al., 2021). This dynamic expansion plays a crucial role in transforming land-use patterns, leading to habitat degradation, fragmentation, and loss of biodiversity (Li et al., 2022). It is also closely linked to the percentage of the population living in urban areas (United Nations, 2019; Simkin et al., 2022). However, this growth comes at a cost, as urban areas absorb natural and valuable ecosystems within their boundaries, thus depleting natural areas (Chen et al., 2020; Dudkiewicz et al., 2021). The development of cities significantly affects crucial ecosystems such as forests (Hoffmann et al., 2017). By providing a variety of ecosystem services, urban forests play an extremely valuable role in ensuring a high quality of life in urban areas by supporting adaptation to climate change and its mitigation (Rahim et al., 2024).

There is an urgent need to evaluate the state of forests within cities and to skillfully shape urban areas to preserve and enhance biodiversity as the complexity of ecological systems. It is therefore crucial to find appropriate indicators whose presence reflects historical changes in the city's natural systems (Kohsaka, 2010). One such indicator is the number of plant species; this richness can reflect the status of various elements of the forest environment (Kurowski & Witosławski, 2009). However, to conduct an ecological evaluation of the forest patches within the city area, it is necessary to identify specific bioindicators, such as forest specialists. In the case of European plants, the concept of ‘ancient forest indicators’ has been developed (Peterken, 1974).

As these ancient forest species were once part of these ecosystems, they can be used to gain a comprehensive insight into them. On the one hand, their presence indicates the long-term and continuous existence of the forest habitat (not necessarily an ancient and old tree-stand); such data can often suggest the old-time origin of the forest and can provide valuable information for nature conservation purposes (Dzwonko & Loster, 2001). Such ancient forest indicators typically colonize new areas weakly and slowly, rarely achieving dispersal ability beyond one meter per year (Bossuyt et al., 1999; Matlack, 1994). This limited dispersal ability is considered a key factor determining their usefulness as bioindicators (Dyderski et al., 2017). On the other hand, ancient forest species are also encountered and observed in secondary forests; in these newer habitats, the effective development of the undergrowth is determined by the maintenance of the continuity of adjacent patches of both ancient and new forests, and their sufficient long-term existence (Orczewska, 2010). The proportion of ancient forest indicator species found in a new forest is directly, and negatively, influenced by its distance to an ancient forest (Brunet & Von Oheimb, 1998a; Dzwonko, 2001).

In this study, we analyzed the distribution patterns of ancient forest indicators in Łódź City, Central Poland. The urbanization history of this area over the last 200 years is unique on a European scale and possibly even worldwide. Although Łódź was granted city rights in 1423; its development followed a different path to other medieval cities. The region had been characterized for centuries by extensive forested areas; however, in the second half of the 19th century, it underwent an unprecedented transformation due to urbanization and the development of the textile industry. During this dynamic period, the population of the city grew from 767 in 1820 to 600,000 in 1914 (Koter, 1969). While the forest cover in the area reached almost 70% in the 17th century, it dramatically declined in later years (Grzegorczyk, 2009). Hence, the region is a good example of an area that was subject to considerable forest restriction in a short time; this raises an intriguing question of whether the ancient forest specialists were able to survive within the area of this industrial city.

The main aim of our study was to determine the distribution patterns of forest specialists and explore their correlation with ancient forests. We hypothesize that the distribution and number of forest specialists are influenced not only by the presence of ancient forests but also by other factors. Additionally, we examine forest continuity within the basic research area of 1 km^2, including 'adjacent grid permanent forests', the area of forest patches, and their location in relation to the city center. The initial task of the study was to analyze the changes in forest cover that have occurred in the city over the last 200 years and to identify the distribution of ancient forests.

2. Materials and Methods

2.1. Łódź city as a study area

Łódź is the fourth largest city in Poland in terms of area (293.25 km²), and the fourth most populous (655 279). It is located in central Poland, a short distance from the geographical center of the country (Statistical Yearbook of Łódź City, 2022). The climate is moderate with a transitional character between the influence of continental and oceanic climates. The entire area of Łódź lay within the range of the Middle Polish glaciations; thus, the landscape of the city is characterized by post-glacial hills (Dmochowska-Dudek & Majecka, 2014). Currently, the hydrological network of Łódź consists of 20 small rivers, with a total length of 115 km (Jokiel & Maksymiuk, 2011). Its vascular plant flora encompasses approximately 1170 species, which represents nearly 75% of all those found in Central Poland (Witosławski, 2006). The area represents the potential habitats of deciduous forests; mostly subcontinental oak-hornbeam forests *Tilio-Carpinetum* Tracz. 1962 and acidophilous oak forests *Calamagrosito-Quercetum* (Hartm. 1934) Scam. et Pass. 1959. The river valleys are characterized by riparian forest habitats with alder and ash *Fraxino-Alnetum* W. Mat. 1952 (Hereźniak et al., 2011; Matuszkiewicz, 2008). Despite the industrial character of the area, the northern part of the city is home to Łagiewniki Forest, this being one of the largest urban forests in Europe (Kurowski, 2001), covering an area of approximately 1200 ha (Fig. 1). The potential natural vegetation of Łagiewniki Forest, dominated in terms of area by the three aforementioned phytosociological units, is representative of the entire area of the city.

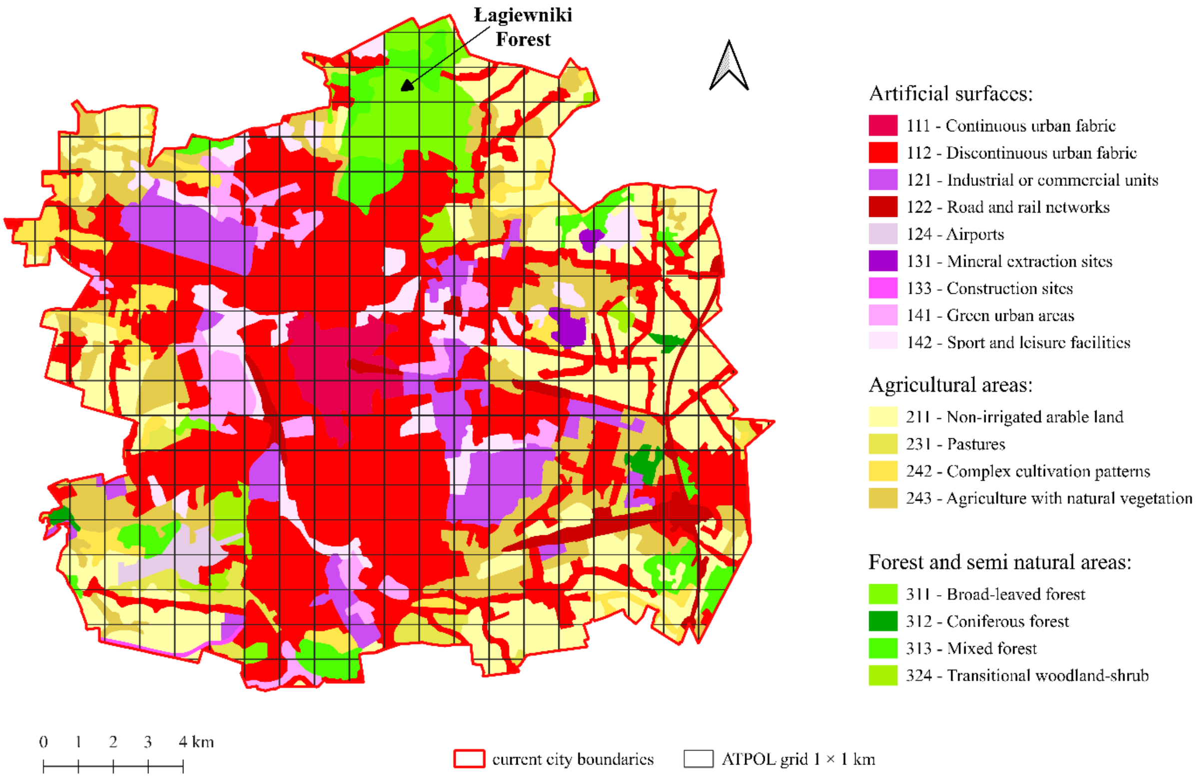

Figure 1. The study area – general land use within the current administrative boundaries of Łódź city. Land use units according to Corine Land Cover 2018 (https://land.copernicus.eu/) in ATPOL grid 1 × 1 km

2.2. Changes in forest cover for the last 200 years

The changes in forest cover that have taken place in Łódź were determined based on maps and cartographic studies from the past 200 years. Although the remains of ancient forest complexes are known to be present, no attempts have been made to perform a systematic analysis of changes in forest cover based on GIS tools within the current administrative boundaries of the city. As such, the present studies represent the first of their kind for Łódź, fitting into the trend of research on ancient forests and spatial analyses of their extent. The starting point for these analyses was to obtain the appropriate maps, i.e. those which clearly and accurately delineate the forests and greenery of the former Łódź. The data for the 19th century were derived from the Topographic Map of the Kingdom of Poland, created around 1830 (Topograficzna Karta Królestwa Polskiego, 1830), and for the 20th century from a 1937 map by the Military Geographic Institute (Wojskowy Instytut Geograficzny, 1937).

Finally, the base maps for the 21st century comprised two eco-physiographic studies, approved within the currently valid Study of Conditions and Directions of Spatial Development of the city of Łódź dated 2018; these were obtained from the website of the Municipal Urban Planning Office in Łódź (Studium uwarunkowań i kierunków zagospodarowania przestrzennego miasta Łodzi, 2018). These maps served as the basis for further analysis. They were appropriately merged, trimmed to the current city boundaries and calibrated to geographic coordinates using GIS software (QGIS in ver. 3.28.15 and ArcMap in ver. 10.8) (Esri, 2020; Flenniken et al., 2020). Forest distribution was digitized by creating polygon features on shape files, resulting in accurate maps of forest cover within the city area for three periods: the beginning of 19th, 20th, and 21th centuries.

2.3. Ancient forest and grid permanent forest

To identify the ancient forests in the studied region, a common part of the polygons representing forest patches in the city was selected using the QGIS intersection function to create a map of forests that have likely persisted continuously for the past 200 years, i.e. *ancient forests*. The concept originates from Great Britain (Peterken, 1977; Rackham, 1980), where remnants of primary forests and secondary forests formed before a specifically-established boundary date were identified for the first time (Peterken & Game, 1984). For most European countries, this data is assumed to be the mid-18th century (Wulf, 1997); however, for Poland, it may be the turn of the 18th and 19th centuries, depending on the availability of cartographic materials (Dzwonko & Loster, 2001).

The analysis was then refined according to the Polish ATPOL cartographic grid system used for surveying vascular plant distribution (Verey, 2017; Zając, 1978). The area of ancient forest in each 1 × 1 km ATPOL grid square was calculated and to determine the distribution of ancient forest indicators in city of Łódź.

The analysis included a *Grid permanent forests* category, defined as forests that were permanently maintained within the area of an 1 km ATPOL grid square throughout the entire analyzed period, but did not necessarily remain in the same geographic place. By introducing such a category, it was possible to analyze whether forest indicators depended on permanently-available forests in the closest neighborhood. Briefly, the occurrence of forest was determined in three examined periods in each square: if the existence of a forest patch was noted throughout the entire studied period, it was assigned to the *Grid permanent forests* category. In addition, minimal forest area maintained during the whole period was calculated for each grid square. This method indicated areas that may not necessarily demonstrate strict continuity in the same place, as in the case of ancient forests, but only their neighboring existence, which may have significant implications for the distribution of ancient forest indicators.

2.4. Forest specialist: ancient forest indicators

The indicator species of ancient forests are typically shade-tolerant perennial plants or hemicryptophytes, with heavy seeds and limited dispersal abilities (Hermy et al., 1999). Five ancient forest indicator plants were selected for this study: *Anemone nemorosa* L., *Ficaria verna* Huds., *Oxalis acetosella* L., *Viola reichenbachiana* Jordan ex. Bor. and *Maianthemum bifolium* (L.) F.W. Schmidt. Species like *Anemone nemorosa* and *Ficaria verna*, with short-distance dispersal mechanisms, such as myrmecochory, exhibit lower abundance in recently-established forest complexes than in adjacent ancient forests (Bossuyt et al., 1999; Brunet & Von Oheimb, 1998b; Matlack, 1994). All chosen species are listed as indicator plants of ancient deciduous forests in Poland (Dzwonko & Loster, 2001) but have also been mentioned in lists for Germany (Wulf, 1997), Sweden (Brunet & Von Oheimb, 1998b) and Belgium (Honnay et al., 1998) and have been included on the general list for Europe (Hermy et al., 1999). They are representative for the deciduous forests which primarily occurred in the study area and are plants easy to observe in the field.

The distribution of the examined species in the Łódź area was analyzed using data from the *Atlas of Distribution of Vascular Plants in Łódź* (Witosławski, 2006). The original cartograms were transformed into ESRI shapefiles. Species distribution was updated to the ATPOL 1 km grid system and used to supplement the data from the current floristic exploration. This allowed the distribution of the studied species to superimposed on the background of changes in forest cover, thus highlighting factors that may influence their occurrence.

2.5. Data analysis

In in each 1 km² grid square, the ancient forest area and permanent forest area were correlated with the corresponding indicator species richness (species number per grid square) using the Pearson correlation index. Indicator species richness was also correlated with the area of ancient forest, and with minimal area of permanent forests within each 1 km² grid square.

The variability of the forest area in terms of indicator species richness is given as box plots with a trend line for mean values.

The occurrence of ancient forests and permanent forests were also cross-validated with the indicators. The spatial pattern of the grids with studied forest categories but without indicators was identified, as well as grids with indicators but without studied forests. Therefore, the distances of the grid squares identified in the cross validation from the city center were determined; any differences in distance between cross-validated groups were tested using the non-parametric Mann-Whitney U-test (*viz.* grids with forests and without species vs. grids with species and without forests).

All statistical analyses and box-plot generation were performed using the STATISTICA ver. 13.3 software package (StatSoft, 2011).

3. Results

3.1. Changes in the forest cover in the city and the ancient forest distribution

The analysis of forest cover based on historical cartographic data indicates that significant changes have occurred in Łódź over the past 200 years (Fig. 2). The first half of the 19th century was characterized by the presence of large forest complexes, which covered a total area of 99.66 km² and constituted 33.9% of the city's area. They were found in various locations, including the currently urbanized city center. Although the number of forest polygons was small (27), they had a large mean area, i.e. 369.1 ha.

In the 20th century, the landscape underwent significant changes, with many of the forested areas being cleared. During the period, the forest area decreased fourfold to 22.57 km², which represented 7.7% of the current area of the city. Compared to the previous period, the mean size of the forest patches dramatically decreased to 10.4 ha, but their number increased to 216. Only one large forest complex, spanning 1200 ha, remained in the northern part of the city: Łagiewniki Forest.

In the early 21st century, the forested area increased to 37.65 km², constituting 12.8% of the total area of the city; however, this area is significantly fragmentated, consisting of 874 objects, mean area of only 4.3 ha, dispersed throughout the city.

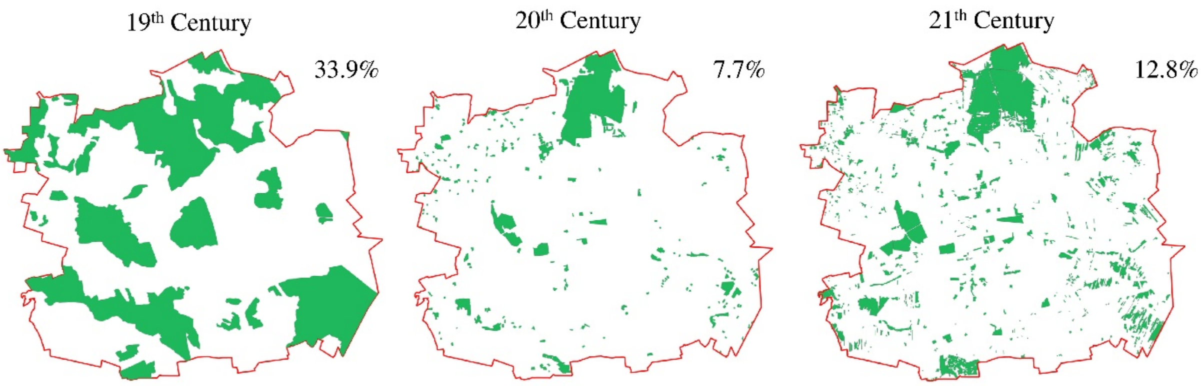

Figure 2. Changes in forest cover (green) within the current boundaries of Łódź city over the last 200 years

The areas indicated as forests in each of the examined periods can be considered as having persisted for at least 200 years within the current boundaries of Łódź (Fig. 3). Their total area is 12.6 km², constituting 4.3% of the area of the city. The remnants of these ancient forests within the city, besides Łagiewniki Forest, also include tree-stands in parks currently located in the city center.

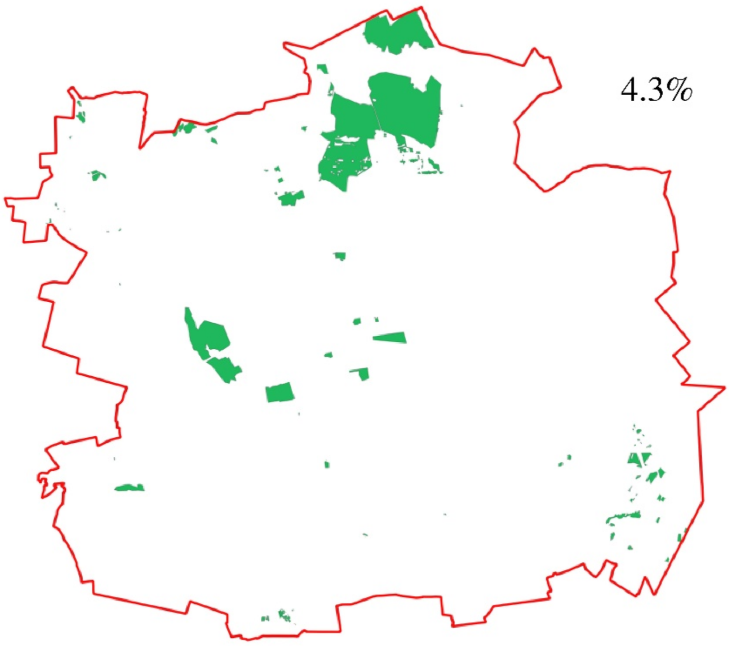

Figure 3. Ancient forests within the current boundaries of Łódź city (i.e. areas with continuous forest cover since the first half of the 19th century)

3.2. Relation between ancient forest indicators, ancient forest and grid permanent forests

Out of a total of 348 squares (1 × 1 km) designated in the Łódź area, indicator species were found in 151 (43.4%) of them. A number of squares including all studied indicator species were noted in the northern, northwestern, and southwestern parts of the city. Additionally, some indicator plants were also observed in the city center where densely built-up and urbanized areas dominate. Although the occurrence of indicators is significantly associated with both studied forest categories (Fig. 4), a higher correlation index was noted for grid permanent forests (r = 0.610) than for ancient forests (r = 0.528) (Fig. 4). It was also noted that in terms of their areas in the same location, ancient forests were strongly correlated with the grid permanent forests (r = 0.932; $p < 0.05$).

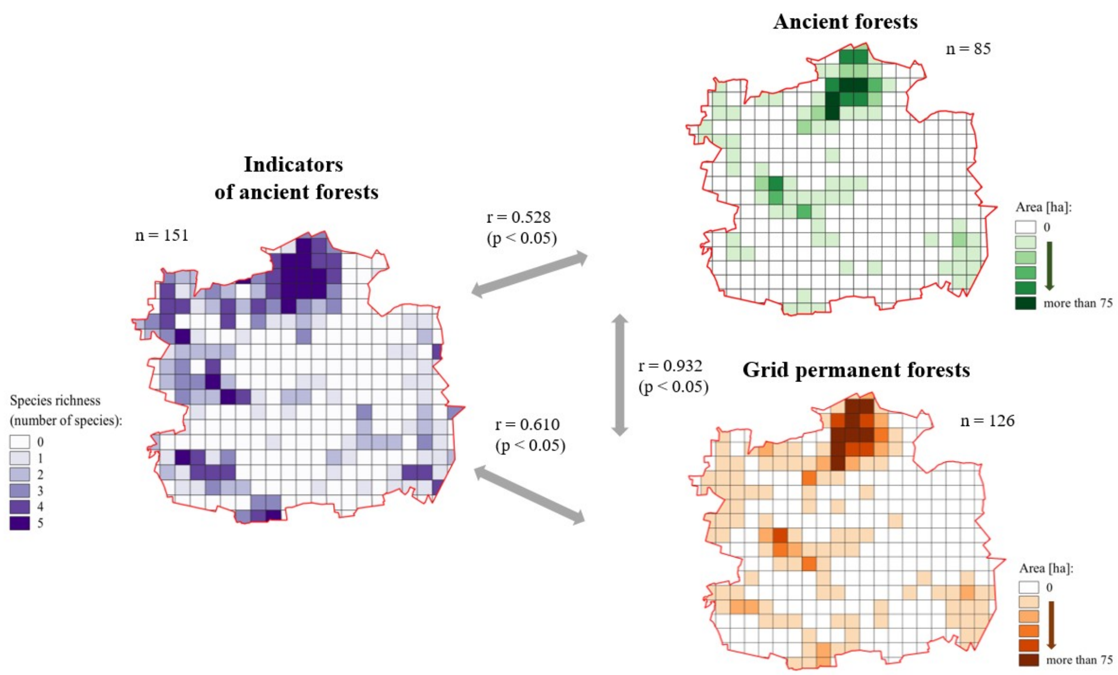

Figure 4. Relationships between the presence of ancient forest indicators (number of species per 1km^2) and the distributions of ancient forests and grid permanent forests with the current boundaries of Łódź city. n – numbers of grids of a given category. The values given above the arrows represent the Pearson correlation indexes and the statistical significance of the relationships between the two.

The area of the forest patches also appears to influence the number of ancient forest indicators (Fig. 5). While a large forest area is not usually needed for the occurrence of single species, the required area increases exponentially with higher numbers of indicators. This observed pattern holds for the ancient forests (Fig. 5A) and the minimum area of grid permanent forests within a particular grid square (Fig. 5B). It is worth noting, however, that in both categories, high variations in species number were noted with regard to the various ranges of forest area.

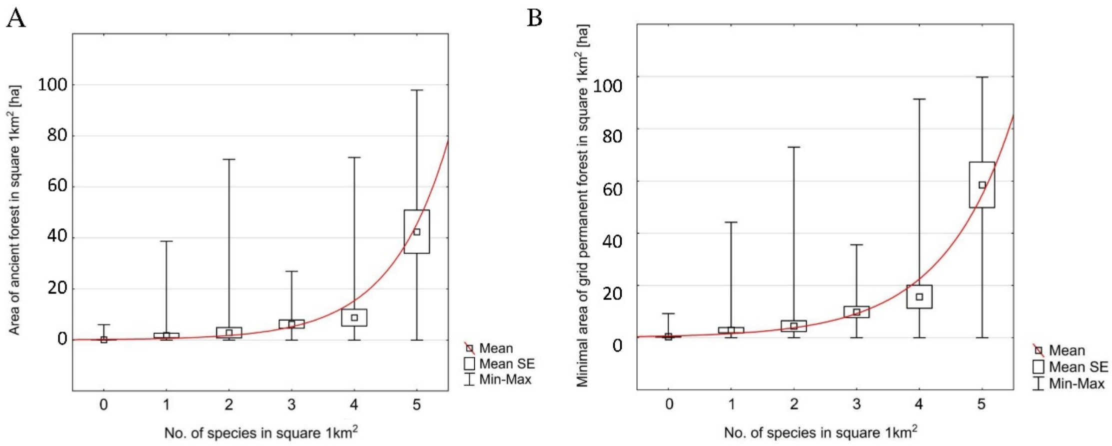

Figure 5. Relationship between indicator species richness and the area of the ancient forests (A) and minimal area of grid permanent forests (B) per 1 km grid square in Łódź city.

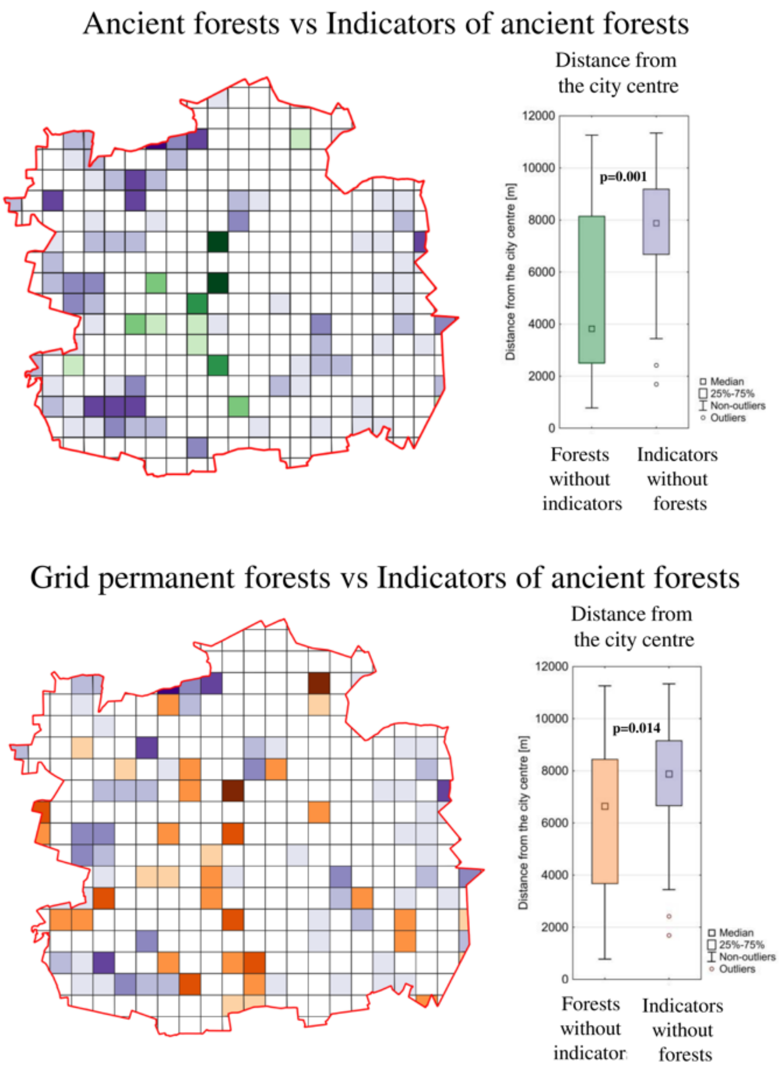

Figure 6. Cross-validation of ancient forests and grid permanent forests against ancient forest indicators. The distributions of the forests without indicators, and the indicators without forests are given in the maps, and the variation in their distance from the city center is given in boxplots. The p-value given in the boxplots indicates the statistical significance of the distance from the city center according to the Mann-Whitney U-test.

The presence of indicator plants did not necessarily coincide with ancient forest (Fig. 6). Indeed, 80 squares harbored indicators but no ancient forests, while another 62 with indicators did not include grid permanent forests. In both cases, a similar spatial pattern was observed: forests without indicators were located in the city center, while indicators without forests were found significantly further from the city center, i.e. on the outskirts (Fig. 6).

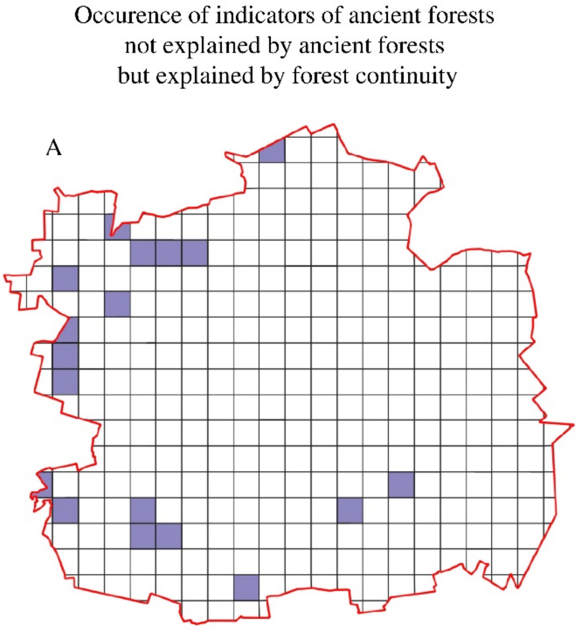

Figure 7. The occurrence of ancient forest indicators explained by grid permanent forest but not by ancient forests (A) and indicators not explained by either forest category (B)

In 18 squares, indicators were accompanied by grid permanent forest, but without any of ancient forest (Fig. 7A). In contrast, 62 squares harbored ancient forest indicators but not any of either ancient or permanent forest. In both cases, these grid squares with the indicators tend to be dispersed throughout the city outskirts (Fig. 7).

4. Discussion

Our analysis of forest cover within the current administrative borders of Łódź city over the last 200 years indicates that the continuity of forest conditions was seriously disrupted in the first half of the 20th century. However, this forest cover appears to have increased over the last decades. The trend has been noted in other locations in Central Europe, but mostly in rural areas (Bomanowska & Kiedrzyński, 2011; Ossowska & Janiszewska, 2016). As such, the indication of a similar trend in the area of the city can be surprising; however, similar results have also been noted in previous case study from the Łódź city (Kiedrzyński et al., 2014). Our findings are also in accordance with those obtained for Warsaw, which was the only one of nine studied European cities to demonstrate an increase in forest cover in the hinterlands (broad periphery) at the beginning of the 21st century (Hoffman et al., 2017). Moreover, recent years have seen a noticeable current trend towards the development of green areas in cities, which has been achieved through systematic planting of new greenery, including forests, and increasing the area of existing plots (Niewiadomski, 2013). In the case of Łódź city, spontaneous afforestation has occurred in locations closer to the city center during recent decades and increasing forest cover is visible throughout the entire area.

This observed trend suggests an opportunity to recover forest biota that have lost their positions in past centuries. However, to confirm this, it is first necessary to understand the patterns of occurrence of the key components of forest biodiversity, these being plant indicators of ancient forests. The present study examined whether such occurrence depends on the presence of ancient forests, which currently cover only 4.3% of the area of Łódź city. It is worth noting that the term *ancient* refers to the continuity of the forest environment, rather than age or naturalness of tree-stands, as it could have been modified over the years (Dzwonko & Loster, 2001; Peterken, 1993).

As the indicator species of ancient forests are characterized by limited mobility, their distribution in the landscape is strongly influenced by the land use history (Peterken & Game, 1984). Our results show that the studied ancient forest indicators are strongly linked to the history of the forests identified in the study area, resulting from the distribution of ancient forests. However, a better explanation for their presence or absence should also include other factors.

To more thoroughly understand this distribution, our analysis included the category of *grid permanent forests*, defined as the continuous presence of forest within the area of a studied grid square (1 km squares); this definition does not necessarily require the continuity of forest in the same geographic spot, as required by that of ancient forests. Our findings show that ancient forest indicators are more closely associated with the area of the grid permanent forests, i.e. the minimal area of forests which have persisted throughout the entire studied period, than with the presence of ancient forests. These findings suggest that the existence of forest specialists should depend *inter alia* on the long-term occurrence of closely-situated forest patches. While forest plants may disperse for up to one kilometer over a decade, a distance less than 500 m or even 200 m could be more effective (Brunet, 2007; Honnay et al., 2002). Indeed, a strong correlation (r = 0.93) was found between the areas of ancient and grid permanent forests in the same location, indicating that patches of ancient forest were almost always present in the locations from where forest species could migrate, or in the local area acting as a source of forest species dispersal.

Our findings indicate that the relationship between ancient forests, grid permanent forests, and the occurrence of forest specialists depends on their distance from the city center. It is more likely to find forest patches without indicator species in the city center than on the outskirts, even if there is evidence of their ancient, pre-industrial origin at that location. This is probably due to the management practices used in parks which include remnants of ancient forests. Special attention should be paid when raking litter and planting ornamental plants under tree stands in the city center, which restricts the occurrence of true forest plants (Fornal-Pieniak et al., 2021; Szwed et al., 2009). Some other environmental conditions in the city center, such as lower humidity caused by groundwater reduction and the urban heat island effect, could also be unsuitable for forest plants (Livesley et al. 2016)

The richness of forest plants is strongly dependent on the history and continuity of forest habitats (Dzwonko & Loster, 1988; Stefańska-Krzaczek et al., 2016). Our data show that the spatial distribution pattern of ancient forest indicators is strictly connected with those of the ancient and grid permanent forest in the study area. Our results also indicate that the number of forest species are related to the size of forest patches. Species richness increases exponentially with the mean forest area, indicating that to support multiple species, historically old forest patches need to be large. The statement is in accordance with the species-area relationship formulated in the ‘theory of island biogeography’; however, opposite results have been noted by some authors in different landscapes (e.g. Liira et al., 2014). In our case, the species-area relationship works well only for the average scores. Moreover, the data were obtained from a specific urban and suburban landscape and included very small ancient forests where forest specialists could be absent.

The grid squares in which forest specialists were only associated with the presence of grid permanent forests tended to be located further from the city center; this was also true for the grid squares where the occurrence of forest plants could not be explained by either ancient or grid permanent forests. This could be due to the prevalent land management practices in the suburbs, which are similar to those used in rural landscapes. Small forest patches or only groups of trees had the ability to persist there for centuries, especially along the river valleys. These long-lasting small refuges could be sufficient for the preservation of individual forest species; indeed, other authors have noted that even small patches of forest can function as significant refuges for forest flora (Dyderski et al., 2017; Hermy et al., 1999; Kolb & Diekmann, 2005). Unfortunately, such small tree clumps are not visible on the historical maps used in the present study, and this is one reason why we indicated forest plants in squares without indicating ancient or permanent forests. This could also explain why the locations where the occurrence of forest specialists was not associated with ancient or grid permanent forests tended to harbor fewer species.

It is recommended that spatial planning should aim to enhance connectivity and merge small forest patches within a city. With this in mind, a positive aspect of the current structure of forest cover in Łódź city is that most patches of secondary forests are only separated by relatively short distances. This factor can facilitate the migration of forest species, most importantly, migration to the new forests can happen in patches located close to ancient forests.

Orczewska (2010) indicates that the effective development of forest understory in new forests is fostered by ensuring a sufficiently long continuation of the existence of adjacent patches of ancient and new forests. It should be noted that most available studies focus on the colonization of new forest areas by species of previously agriculturally-used areas (Brunet, 2007; Flinn & Vellend, 2005; Orczewska, 2009). However, the city represents a specific ecosystem where urbanization processes and dynamic changes in land use can significantly influence the potential movement of species from ancient forests to new locations (Dyderski et al., 2017). In Łódź, a number of factors may play significant roles in enhancing forest connectivity: the existence of old parks, which may represent remnants of ancient forests, the creation of new parks since World War II, the implementation of blue-green infrastructure systems, and remnants of natural habitats in the valleys of small rivers (Zalewski & Wagner, 2005; Ratajczyk et al., 2010; Kiedrzyński et al., 2014).

5. Conclusions

While the continuity of forest cover in Łódź has suffered significant disruption in the past, recent decades have seen a steady increase, including the urbanized city center. The distribution of indicator species of ancient forests is strongly associated with land use history, with their presence being significantly influenced by past forest conditions. However, our research also indicates that the distribution of forest specialists is also closely associated with the minimally-maintained area of any forests within a particular 1 km^2 grid square. Our findings confirm that such distribution is influenced by both the ancient forests themselves and any preserved adjacent permanent forests. In practical terms, these kind of permanently occurring forests patches should be considered as conservation targets and biodiversity hotspots.

A significant role in the occurrence of ancient forest plants also depends on the distance from the city center and land use practices. Patches of ancient or permanent forest closer to the city center are more likely to lack forest specialists than those in the outskirts. Conversely, among the grid squares with forest species, those in the outskirts were more likely to lack any ancient or permanent forests. These results could be attributed to the fact that in the outskirts, there are greater numbers of small patches and groups of trees, especially along the river valleys, that have existed for centuries but are not shown on old maps. Such lasting mini-refuges may be sufficient for the preservation of individual forest species; therefore, they should be carefully managed and enlarged as much as practical possibilities allow.

Our research also shows that in general, exponentially larger areas of ancient and permanent forests are needed to maintain greater numbers of species. Considering the history of Łódź, its unique ecosystem, as well as the low average area of forest patches and their fragmentation, there is a need to implement new actions in the spatial planning system, with the aim of establishing and increasing forest connectivity within the city.

To this end, the present findings, the first to be obtained for Łódź, may be of value for indicating areas that would most benefit from afforestation and thus restore the continuity of forestry in the city. Further continuous monitoring of forest plants will also be needed to provide important information on environmental quality and the process of forest regeneration in the city.

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