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ORIGINAL PAPER

Outside the forest stand: Analysis of urban forest buffer zones to implement nature-based solutions – A case study of Poznań (Poland)

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ABSTRACT

Urban forests are important and highly valuable natural elements of urban green infrastructure (GI). The tightening of developed areas in the vicinity of urban forests results in negative changes in water relations, the disruption of the continuity of wildlife corridors, and the growing number of users, which has an impact on the degradation of urban forest ecosystems. This study, conducted in Poznań, Poland, provides an analysis of urban forest buffer zones regarding land use type, the high greenery ratio, and the planning decisions that could serve as a nature-based solution (NbS). The study shows a significant change in developed land area in the urban forest buffer zones with the width of 500 m and 100 m. That change occurred between 1997 and 2019 and should be a matter of concern. Coverage of the buffer zones with high greenery, which turned out to be very diverse, could be treated as a forest extension and an element mitigating the negative transition between the forest and the city. Different land use types were taken into consideration, especially in developed areas. The buffer zones of urban forests should be developed with spatial planning tools like data management and decision-making to mitigate the negative impact of the developed areas on the forests. The development of the concept of supporting green infrastructure in urban forest buffer zones, regardless of land use type was also part of the study.

KEY WORDS

canopy ratio, forest edge, high greenery, spatial planning, urban forest

Introduction

It is estimated that 60% of the world's population will live in cities by 2030. Seventy four percent of the European population lived in urban areas in 2019 (United Nations, 2018). Therefore, it is vital to mitigate the effects of climate change in cities. Thus emerged the concept of nature-based solutions (NbS) (Cecchi, 2015). Nature-based solutions are ways of thinking about nature and its role in mitigating the adverse effects of climate change. NbS is an umbrella concept which differs from traditional urban greenery management by giving special attention to societal and economic goals (Seddon *et al.*, 2020). NbS include green infrastructure, ecosystem services,

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landscape functions, and natural capital (Albert *et al*., 2017). NbS lead to growing awareness of natural processes taking place in the environment and the rediscovery of old concepts, like acting with nature, not against it (Sowińska-Świerkosz and Garcia, 2022). These concepts are being incorporated into urban management strategies (Eggermont, 2015).

Urban forests are sources of ecosystem services in cities. Trees in cities reduce urban heat islands (Chen *et al*., 2020), mitigate water runoff (Szota *et al*., 2019) and drought impact (Gillner *et al*., 2015), store carbon (Weissert *et al*., 2014), and reduce air pollution (Yang *et al*., 2005; Selmi *et al*., 2016). However, in the past few years, researchers have pointed out that urban trees also suffer from worsening growth conditions and that urban forests must adapt and be adapted to climate change to help cities and benefit people (Ordóñez Barona and Duinker, 2014; Brandt *et al*., 2016). Due to climate change and an inevitable anthropogenic impact on the urban environment, green areas require additional spatial planning and tools of protection from excessive urbanisation (Weber and Wolf, 2000). Protecting urban forests is a common strategy in Western European cities management (Konijnendijk, 2003). However, urban forest management should offer more than such protection. It should allow for the spatial development of forests and other green infrastructure areas and restrict the anthropogenic impact in the surroundings of GI to precisely planned places only. It is also necessary to consider the nearest neighbourhood of urban forests as a forest extension to help build urban forest resilience. Unfortunately, conscious planning and development of forest buffer zones is not a common practice in city management in Poland (Jim, 2011). New investments in unbuilt plots affect the surrounding open spaces (Antrop and Van Eetvelde, 2000). Invested land use types like built-up areas rarely ensure the provision of ecosystem services (Dyson *et al*., 2018; Ziter and Turner, 2018). When it comes to housing areas, it depends on when the site was constructed as well as the household characteristics such as socioeconomic status (Lowry *et al*., 2012; Mockrin *et al*., 2019). Therefore, specific guidelines on arranging the plots are needed for developed areas in the immediate vicinity of city forests. This way of planning and managing green infrastructure faces environmental challenges and could be recognised as an NbS (Zwierzchowska *et al*., 2019).

The ecological benefits of urban forest ecotones have been broadly investigated. According to Kark (2017), ecotones are places that deserve high conservation investments because of their role in speciation. Godefroid and Koedam (2007) found that rare species of plants are more common on forest edges. On the other hand, other researchers have proved that invasive species are also frequent in these areas (McDonald and Urban, 2006). Land use changes in ecotone zones could be used as an indicator for the provision of landscape services (Yang *et al*., 2020). Forest edge areas significantly affect the stability of forest protective and climatic functions (Hladnik *et al*., 2020). Only a few studies on urban forest buffer zones consider the spatial planning approach and landscape management aspects. Fry and Sarlov-Herlin (1997) presented the functions of different forest edges in relation to their landscape structure and multifunctional objectives. Fors *et al*. (2018) showed that forest ecotones could be enhanced when residents participate in their management in areas near their gardens.

The subject of inventories of urban greenery based on data derived from airborne laser scanning (ALS) and digital aerial photographs has been repeatedly discussed in scientific studies. ALS data are used to produce digital surface models (DSM). Land cover elements like high and low greenery, bare soil, water bodies and soil sealing could be identified from high-resolution digital infrared (CIR) imagery (Lambarki *et al*., 2021).

Our study was conducted in Poznań (Poland), a medium-sized Central European city. According to the Forest Act (Ustawa, 1991), urban forests in Polish cities with more than 50,000 inhabitants are considered protective forests. The main objectives of this study were as follows:

(1) to highlight land use changes in urban forest buffer zones in the period 1997-2019; (2) to examine the linkage of land use type to the high greenery ratio in urban forest buffer zones; and (3) to indicate the potential of urban forest buffer zones analysis, which ought to be incorporated in spatial planning practice. The objectives mentioned above will allow researchers and city planners to pay more attention to urban forest buffer zones. These zones are frequently neglected in the literature and city planning practice. Our approach is specific and we believe that it is worth being developed.

Study area

The study was conducted on forests located within the city limits of Poznań (Poland; 52°24' N, 16°57' E) and on areas located in their immediate vicinity (Parysek and Mierzejewska, 2006). The population of Poznań is 533 830, and its area is 262 km^2 (GUS, 2022). The total area of urban forests is 3,694.4 ha, *i.e.*, 14% of the city area. The share of urban forests in the total urban green space system area is about 25% [according to self-studies]. Today the urban green space system is treated as a green and blue infrastructure area, covering urban forests, open waters, arranged green space, and open space areas (Fig. 1). The city of Poznań developed in a favourable location, which was typical of early medieval settlements in Central Europe. It is located at the crossing of the Warta River and its tributaries Bogdanka and Cybina, which still determines the layout of green and open spaces versus urban development areas. In Poznań, the design of 'the urban green space system' was introduced and implemented as early as the 1930s (Łukasiewicz and Łukasiewicz, 2016). This system framework has been preserved to this day. It is a major element of the city's spatial structure and is taken into consideration in successive master plans (Macias and Dryjer, 2010).

The areas belonging to the urban green space system are under heavy investment pressure. Many of them were built up because of wrong decisions like locating housing development in the river valleys. As a result, the ecological continuity of green space structures was disrupted

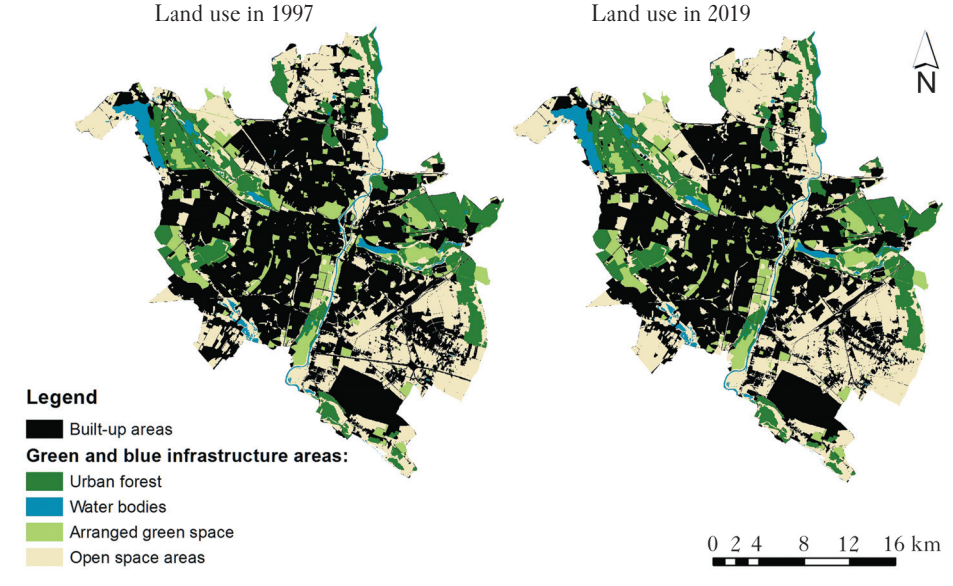

Fig. 1.
A map of the study area, the city of Poznań, land use structure in 1997 and in 2019. Source: own elaboration.

(Raszeja and Gałecka, 2015). Until recently, there used to be large areas of farmland, meadows, and spontaneous vegetation on the outskirts of Poznań (Gałecka-Drozda and Zachariasz, 2017). As elements complementing the urban green space system they could significantly influence the climate in the city (Bedla and Halecki, 2021). Today they are disappearing because of the emergence of residential buildings scattered in these areas. The situation is exacerbated by the incoherent policies of Poznań and neighbouring communes concerning the spatial continuity of green and blue infrastructure areas. Poznań faces urban sprawl problem, which can be characterized by the loss of the inhabitants within the city, and their increase in the neighbouring communes. New housing developments emerge in the former agricultural land. New spatial layout results from former arable land plots rather than from a coherent planning strategy. The biggest urban sprawl concentration occurs on the western outskirts of the city (Budner, 2018; Bonenberg *et al*., 2021). Urban forests, located mainly on the outskirts of the city, as well as their immediate surroundings are exposed to increasingly heavy anthropogenic impacts. Their present-day layout was determined by river valleys crossing the city in two directions and implementing the assumptions of the urban green space system planned in the 1930s.

Urban forests in Poznań are not uniform in terms of management structure and administrative structure, which causes specific management problems (Jaszczak and Wajchman-Świtalska, 2014; Jaszczak and Wajchman, 2015). About 61% of them are administered by the Zakład Lasów Poznańskich – a state-owned local government venture (Jackowiak, 2011). About 32% is managed by PGL Lasy Państwowe (State Forests Holding), directed by the Regional Directorate of State Forests in Poznań. The rest of the urban forests belong to different, mainly private, entities. Urban forests in Poznań are a refuge for biological and landscape diversity and provide leisure and recreational facilities for the city's inhabitants. Various riparian forests, connected with river valleys, are the most valuable natural vegetation type. However, degenerated forms of deciduous forests dominated by oaks and hornbeams and Scots pine plantations are the most common form of forest vegetation in Poznań (Macias and Dryjer, 2010). The main forest formative species is pine *Pinus sylvestris* L. Among the remaining species, those worth mentioning are deciduous ones: oak *Quercus* sp., birch *Betula pendula* Roth., hornbeam *Carpinus betulus* L., maple *Acer platanoides* L., poplars *Populus* sp., and alder *Alnus* sp. The average age of a forest stand is about 70 years old, resulting from the intensive afforestation after World War II. Despite the low resistance of coniferous stands to pests and diseases, the health condition of urban forests in Poznań is satisfactory (Macias and Dryjer, 2010; Jaszczak and Wajchman-Świtalska, 2014).

Methods

The forest areas were digitised with the GIS software ArcGIS 10.5.1 based on the available orthophoto maps and land cover maps (DSM) from the resources of the Poznań Spatial Information System (SIP), which were imported as WMS layers. The digitised forest complexes were simplified by including minor areas located in the forests but used for other purposes (*e.g.*, single housing plots, meadows, horticulture and arable land). The external border of the forest and highly afforested areas were defined as the outline of polygons with simplified forest complexes. GIS analysis is part of the first and second stages of the research.

The research was carried out in three stages. The first stage involved an analysis of the vicinity of Poznań urban forests, where a buffer zone width of 500 m was assumed. This stage aimed to determine general trends and the extent of changes in land use around the forests. At the same time, we wanted to identify changes in land use not only at the forest boundary line but also in a wider zone which affects its functioning. In this stage, the vicinity of the forests was classified into one of five general categories of land cover: (1) development areas; (2) open waters;

(3) arranged green space; (4) open spaces (fields, former farmlands, meadows); and (5) forests outside the city (Table 1). The predominant land cover type was taken into account when assigning an area to a particular category. Next, the length of the forest boundary adjacent to a particular land cover category was measured. The length of the forest boundaries within and beyond the city limits was calculated separately given the peripheral location of the forests and to check whether Poznań and the adjacent communes differed in their spatial policies. The forest vicinity was examined at two-time points. The first referred to the status quo in 2019. The other referred to the status quo in 1997, which was chosen because it was the first time when all city's area was covered by good-quality orthophoto maps. 2019 shows the state before the COVID-19 pandemic, which triggered a large investment movement. The research was based on good-quality orthophoto maps provided by the Spatial Information System of the City of Poznań (SIP Poznań). We analysed the SUiKZP (the study of conditions and directions of spatial development) and simulated possible changes in land cover. SUiKZP specifies the potential target development of land in a city or commune. We analysed SUiKZP for both Poznań (SUiKZP, 2014) and the communes near the urban forests (SUiKZP, 2000, 2010, 2011a, b, 2013; 2016a, b, 2017).

The second stage involved detailed investigations to identify the share of high greenery in the immediate vicinity of the forest, which was considered its extension. In this stage, the width of the buffer zone was limited to 100 m, which made it possible to narrow down the vicinity to one land use type. Here, it was necessary to precisely identify the land use type (areas with roads, industrial areas, areas with facilities providing services, multi-family housing areas, single-family housing areas, dispersed development areas, allotment gardens, public areas of arranged green space, areas with meadows, trees, and shrubs, former farmlands with successive vegetation, arable lands, open waters, and forests outside the city limits (Table 2). Former farmland was identified and compared to the archival orthophotos from SIP Poznań, where those farmlands still exist. The share of high greenery (trees and shrubs) in separated homogeneous sections corresponding to land use type was calculated. A CIR orthophoto map of Poznań (from SIP Poznań) was used to measure the high greenery ratio. Graphic software (Adobe Photoshop CS3) in which pixels with high greenery were counted was used for the measurements. Pixels were distinguished with the magic wand tool with the tolerance set to 20. The proportion of high greenery was calculated as a relation of the area covered with hardscape elements and low greenery (lawns,

Table 1.

Share and changes in the main land cover types in the immediate vicinity of the urban forests in Poznań in the 500-metre-wide buffer bone. Source: own elaboration

	Type of area in the vicinity of forest	The length of the border with the forests in 1997 [km]	Share [%]	The length of the border with the forests in 2019 [km]	Share [%]	The potential length of the border with the forests according to the SUiKZP [km]	Share [%]
Within city limits	urban developments	38.27	27.96	52.29	38.20	70.50	51.50
	open waters	5.95	4.35	5.95	4.35	5.15	3.76
	arranged green space	27.06	9.94	26.63	9.63	25.47	8.78
	open space	65.61	57.75	52.02	47.83	35.77	35.96
Beyond city limits	outskirts forests	12.24	36.60	13.94	41.69	13.62	40.73
	developments	4.52	13.52	8.87	26.53	11.76	35.17
	open waters	2.24	6.70	2.24	6.70	2.24	6.70
	arranged green space	1.08	3.23	0.00	–	0.00	–
	open space	13.36	39.60	8.39	25.09	5.82	17.40

Table 2.

Share of high greenery in the 100-metre-wide buffer zone of urban forests in Poznań vs. land use types in 2019. Source: own elaboration

Land use		The length of the border with the forests [km]	Average share of high greenery [%]	Min.-max. share of high greenery[%]
Urban developments	roads	3.91	10.17	2-26.5
	industrial areas	8.71	10.83	0-23.15
	facilities providing services	6.73	13.51	1.5-25
	multi-family houses	9.32	13.32	0.5-28.8
	single-family houses	19.36	21.16	7-31.5
	scattered houses	12.13	20.45	3.2-65
Arranged green space	allotment gardens	14.40	32.33	12.7-50.6
	arranged public green space	12.23	37.57	4.5-63.1
Open space	meadows and areas with trees	12.13	25.35	2-58.3
	former farmlands with successive vegetation	22.07	28.14	4.5-85
	farmland	27.21	5.69	0-23.3
Other	open waters and forests beyond city limits	22.13	–	–

perennials) to the area covered by crowns of trees and shrubs. Then the relationship between the share of high greenery and the land use type was determined. The first stage showed that the trends and the scale of changes in the vicinity of forests located within the city limits and in the suburban area were similar to each other. For this reason, the division into the buffer zone within and beyond the city limits was abandoned in the second stage.

The third (last) stage of the research involved checking whether the vicinity of forests was treated in a special way in the spatial policy of the city and what provisions could support the development of a favourable buffer zone of urban forests. To fulfil this task, the spatial planning documents were analysed. Two types of documents are used in local planning practice in Poland: 'the study of conditions and directions of spatial development' (SUiKZP), a document referring to the entire commune, expressing the spatial policy of the commune rather than a local legal act; and a local spatial development plan (MPZP), which usually refers to a small area but is a local legal act whose provisions are binding. Local spatial development plans should be compatible with the provisions of SUiKZP, but in practice, this is not always so. The preparation of a local spatial development plan depends on the will of the commune, which is not obliged to cover the whole area with these plans. We analysed SUiKZP for Poznań and the neighbouring communes as well as checked the coverage and provisions of local spatial development plans (MPZP – provided by SIP Poznan and Spatial Information System of the Poznan County) concerning forests and their vicinities.

Results and discussion

Poznan urban forests' boundary has either remained unchanged since 1987 or it has been enlarged (Ważyński, 1987; Macias and Dryjer, 2010). The year 1987 was the last time the city area was expanded. Urban forests have a special status in Forest Act (Ustawa, 1991) as protective forests, and they are also protected by the Farm and Woodland Conservation Act (Ustawa, 1995). The procedure of land use transition from forest to other forms is very complicated and administra-

tively expanded (Janeczko *et al.*, 2019). The permanence of urban forests is also supported by local spatial planning policy, where forests are excluded from development. The above-mentioned legal acts and local documents help retain the scope of urban forests.

CHANGES IN URBAN FOREST BUFFER ZONES. Forests are some of the most valuable elements of the urban green infrastructure. Conserving forests, protecting them from investments, and building a network of spatial connections between urban forests and other green/open space areas are of key importance for developing an effective natural system in the city. Currently, almost 40% of the area surrounding forests located within the city limits of Poznań is covered by urban developments. The urban green and blue infrastructure, where open areas predominate, occupies slightly more than 60% of the vicinity of urban forests (Table 1). In comparison to 1997, the area of developments in the vicinity of urban forests increased by 10% even though the city's population decreased slightly. The biggest changes took place in the north part of the city, around the small urban forest complex 'Żurawiniec', where multifamily housing and campus emerged. The second area with significant changes is an urban forest called 'Lasek Marcelinski' located near the western city border. According to the SUiKZP of Poznań (2014), the area of developments tightening the boundaries of urban forest complexes may increase by 13%. If the provisions of the SUiKZP are fully implemented, more than half of the vicinity of urban forests will be built up (Fig. 2).

The analysis of the vicinity of the urban forest with the urban green and blue infrastructure areas showed permanent links with the areas of arranged green space and open waters that did not change much. However, the share of these connections is small. Allotment gardens and cemeteries are usually areas of arranged green space in the vicinity of urban forests in Poznań. Dynamic changes occur in the third component of the urban green infrastructure, *i.e.*, open spaces (wastelands, unarranged green space, farmlands). The length of forest boundaries near open space areas is decreasing in favour of urban development areas. The length of forest boundaries near open areas being reduced in favour of urban development areas is 18.56 km. Single-family houses are usually scattered in the vicinity of urban forests; this is a very unfavourable phenomenon because it will cause the rapid degradation of open spaces despite the low density of building developments. Such degradation is understood as a loss of ecological connections, habitats, cultural landscape heritage, and pollution (Christiawan, 2019), and, last but not least, loss of open space potential as an area for the city's future green infrastructure (Rupprecht and Byrne, 2016).

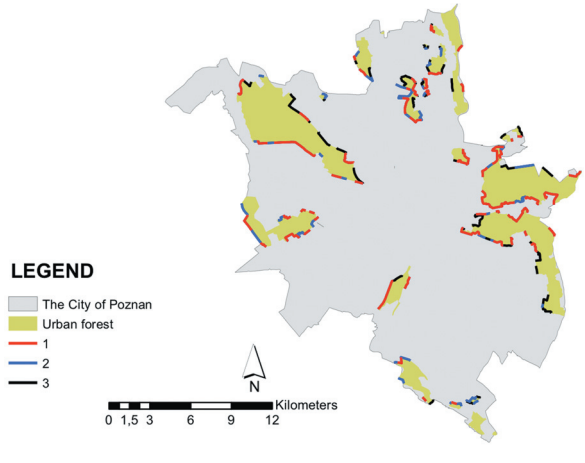

Fig. 2.

Growth of the developed areas in the immediate vicinity of forests in Poznań

(1) forest boundary with developed areas in 1997; (2) forest boundary with developed areas emerged between 1997-2019; (3) further growth of developed areas next to forest boundary, prognosis based on the SUiKZP. Source: own elaboration.

Because the forests are usually located on the city's outskirts, spatial connections beyond the city limits should also be analysed. The green and blue infrastructure areas dominate those urban developments; they occupy more than 70% of the vicinity of forests. However, forests located outside the city were also included in the green and blue infrastructure (over 40% of the vicinity). A forest continuum would be the most valuable solution. It was a basic assumption of the green space system in the 1930s, when the authorities planned to connect urban forests with larger forest complexes located outside the city, such as protected areas, which the city inhabitants could use for recreation (Kodym-Kozaczko, 2005). Connections with suburban forests are elements undergoing minor changes. However, the borderline length of the areas near forests located beyond the city limits is about 14 km, mostly in the north of Poznań. Few such connections with the main urban forest complexes can be found in the east and west. The trend of changes in the vicinity of forests within and beyond the city limits is convergent; the area of developments is increasing at the expense of open spaces. The analysis also showed that the increase in new real estate developments (expressed as a percentage) in the vicinity of forests outside the city was greater than that in the city. The reason can be found in the short-sighted spatial policy of the neighbouring communes. Also, the coverage of MPZP in most cases is below 50% (Mrozik *et al.*, 2020). This trend is expected to reverse in the long term as there will be a higher increase in real estate developments in the city.

Analysis of high greenery ratio. The general analysis results revealed a negative and inevitable trend of tightening urban developments in forest surroundings (Table 1, Fig. 2). Therefore, it was necessary to determine the degree of coverage of these areas with high vegetation, like parks and other arranged green spaces that could be treated as a forest extension and as an element levelling the sharp transition between the forest and the city. The assumption was that the vicinity of high greenery in urban development areas was the most favourable from the point of view of urban forests and that it could be a factor supporting the green infrastructure system. The study conducted by Zhang *et al.* (2019) showed that the tree canopy was the best land cover as it enabled the creation of wildlife corridors.

Therefore, the second stage of the research involved calculating the share of high greenery within a distance of 100 metres from the urban forests and checking the areas of different land use as potential forest buffer zones. The analysis of the share of high greenery showed that it was

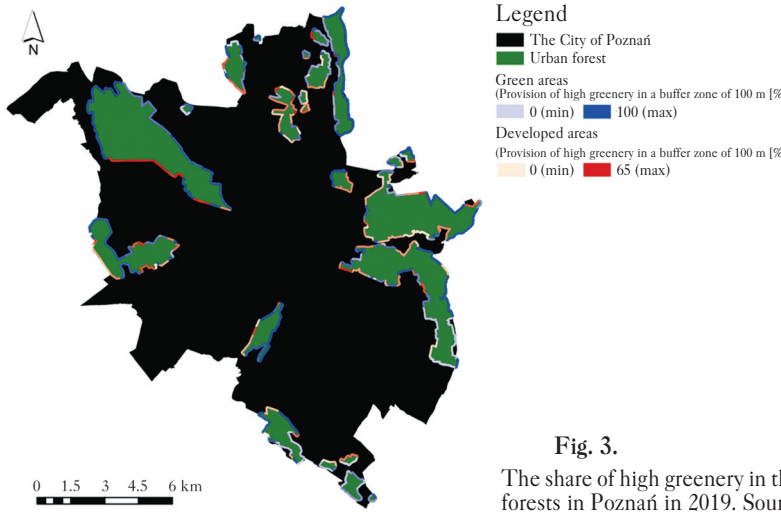

Fig. 3.
The share of high greenery in the buffer zone of city forests in Poznań in 2019. Source: own elaboration.

considerably diversified within individual land use types. The share of high greenery in the buffer zone with urban development areas was analysed separately from areas with arranged green spaces and open spaces (Table 2).

Some regularities were observed in the different types of urban developments. The highest coverage with a high greenery value (65%) concerns scattered development areas, which often occur in areas with an advanced stage of secondary succession. The highest average share of high greenery was found in areas with single-family houses in the range from 7 to 31.5%. Besides calculating the share of high greenery, we were also concerned about particular city's district specifics like history and plot size. According to that, the highest values were observed near the oldest buildings located in the city. The greenery is mature in these areas. The plots with greenery are larger than those currently allocated for new single-family houses. Roads and industrial areas are characterised by the lowest share of high vegetation in the urban development areas which depend on the space occupied by roads and industrial plants. Here, the discrepancies ranged from 0 to 26.5%. Their neighbourhood is unfavourable for urban forests (Przewoźniak, 2002; Ratajczyk *et al*., 2010). The multi-family houses in the vicinity of forests are relatively new, located in relatively small plots with no space for high greenery. The share of older multi-family houses is small. A neighbourhood with multi-family houses has a share of high greenery from 0.5 to 28.8%.

For comparison, the share of high greenery in arranged green spaces and open spaces was also analysed (Fig. 3). The highest average values of the share of high greenery were noted in arranged green spaces (allotment gardens and public arranged green spaces). Sizable discrepancies were observed in public arranged green spaces given the presence of recreational glades and low greenery in some areas adjacent to forests. The largest differences in the tree canopy ratio were observed in open spaces (from 0 to 85%). Former farmlands were characterised by the highest share of high vegetation. In some cases, stages of secondary succession resulted in areas densely covered by trees. For this reason, post-agricultural areas were considered a favourable neighbourhood for forests, and they may eventually become their extension. As far as arable lands are concerned, high greenery was found only along wooded strips, mostly as a part of balks. The average share of tall greenery in this type of area is 5.69%. The multi-layer ecotone zone can be developed there, but mostly on the side of urban forest plots. Agricultural practices enabled the colonisation of trees on the arable field side. That is why the minimum share of high greenery could be 0% there.

Hladnik *et al*. (2020) described the formation of the edges of suburban forests in Ljubljana and found that in the vicinity of built-up areas, the forest had steep edges and a large number of high trees. However, if the forest border was open and there was enough space, a multi-storey ecotone zone could develop. Hence typical ecotone zones in urban forests developed only in places adjacent to open spaces. The edge of the forest is sharp in areas bordering urban developments. In this context, it is particularly significant to treat development areas as places where high vegetation can be an extension of the forest and its buffer zone.

The vicinity of green and open spaces is the most favourable for urban forests (Nowak *et al*., 2001). Significant differences in the share of high greenery in these areas show that it cannot be treated as the main criterion indicating a good neighbourhood for urban forests. However, this indicator can be used in reference to urban development areas, where high greenery most strongly mitigates the negative impact of these areas on neighbouring forests (Bodnaruk *et al*., 2017; Rötzer *et al*., 2019). This criterion could also be used for built-up areas near urban green spaces. Our research showed built-up areas' large but unused potential as places enhancing urban forest buffer zones.

Urban forest buffer zones in spatial planning – reality vs potential. To some extent, changes in the vicinity of urban forests result from planning documents which determine land use. The current trend of tightening development areas around urban forests results from insufficient approaches to the green and blue infrastructure in spatial planning (including not designating areas for the development of new green areas). However, the high variability in the share of high greenery in the built-up areas, which was observed in the second stage of the research, showed potential for developing a favourable neighbourhood of urban forests there. The relatively high shares of high greenery in the areas with single-family houses result from a coincidence or individual plot owners' preferences rather than intentional spatial policy measures taken by the authorities. The forest extension potential in built-up areas should be reinforced by spatial policy and soft measures encouraging planting and maintaining high greenery in private areas in the vicinity of forests. The city authorities could influence the shape of the built-up areas by using planning instruments that would specify the size of the plots, the maximum building areas, the share of bioactive areas, the types of fences, or the need to plant high greenery in a specific part of the plot. Planning instruments should be used to shape the buffer zone of urban forests. Still, their effectiveness would depend on the coherence of the spatial policies of the city and its neighbouring communes.

The protection of forests results from their legal status expressed in the Forest Act (Ustawa, 1991). Urban forest in Poznań has a big coverage of MPZP, which also helps in its protection (Table 3). Local spatial development plans (MPZP) covering 78.4% of urban forests in Poznań, has protective character with the focus on counteracting new developents. The remaining 21.6% is protected by provisions expressed in SUiKZP of Poznań (2014). However, these provisions are only declarative and not legally binding. The spatial policy concerning the forest buffer zone is unclear. Local spatial development plans cover only 48.7% of the area of urban forest buffer zones in Poznań and only 60% of the open spaces adjacent to forests, though these areas change dynamically. The requirements concerning new buildings should be as restrictive as possible and it should restrictively impose the shape of the buffer zone in the vicinity of forests. The analysis of local spatial development plans showed that the authorities did not adopt a separate approach to plots located in the neighbourhood of urban forests, nor did they use any tools that would improve the situation in the forest surroundings.

The main problem is planning excessively large areas for development in the city, which causes the dispersion rather than accumulation of new buildings in several different places. New places should be designated when there is no more space in others. This is a common planning problem in Poland. According to Kaczmarek (2017), all the resources of residential areas cannot be used even within 20-30 years. In consequence, valuable natural areas are being degraded, and the anthropogenic impact is dispersed, whereas the infrastructure is fragmented and inefficient. The inclusion of selected post-agricultural areas in forest resources would be of key importance. The vicinity of forests is a highly attractive investment area, and its development

Table 3.

Local spatial development plans (MPZP) for urban forests in Poznań and its surroundings in 2019. Source: own elaboration

	Coverage of MPZP [%] / amount of plans	Amount of MPZP with separate approach to forest / the vicinity of forest
Urban forest	78.4 / 32	32
Urban forest buffer zones	48.7 / 89	0

is inevitable. However, it is necessary to secure strategic areas to preserve and create a network of ecological links between forest complexes.

As mentioned above, spatial planning potential in shaping urban forests buffer zones is not adequately used. This problem could be partly explained by existing problems in Polish spatial planning rules: local plans (MPZP) do not cover the area of the entire municipality; there are numerous valid plans with different levels of accuracy (Badach and Raszeja, 2019); plans for different municipalities are not integrated; and the plans use rather soft regulations so as not to restrict the freedom of property rights (Niedziałkowski and Beunen, 2019). On the other hand, the concept of urban forest buffer zones covering different land use types is new, and the consciousness of its potential is low so far. It can be considered as one of the ways to implement NbS in urban areas, including different, not only municipal, actors.

Conclusions

The study showed significant changes in the urban forest buffer zone where open space is disappearing. The forecast based on the planning documents showed that this negative trend would continue.

As an increase of build-up, especially residential areas, in the urban forest neighbourhoods seems inevitable, the emphasis should be on the highest possible share of high greenery within build-up areas in the buffer zones. High greenery enables the mitigation of sharp forest edges and can serve as forest extension. What happens spontaneously in open landscapes, where forests are surrounded by multi-layered ecotone zones, could be incorporated in cities where green infrastructure could be supported regardless of land use.

It is necessary to establish well-planned and properly managed buffer zones in the immediate surroundings of forests to ensure their sustainability, as they are not protected by spatial planning. The concept of urban forest zones needs to be seen not only as a local planning issue but also as a solution inspired and supported by nature. Urban forest buffer zones analysis is worth incorporating in spatial planning practice.

Authors' contributions

Conceptualisation – A.G-D. and L.B.; methodology – A.G-D.; software – A.G-D.; validation – A.G-D. and L.B.; formal analysis – A.G-D.; resources – A.G-D.; data curation – A.G-D.; writing-original draft preparation – A.G-D. and L.B.; writing-review and editing – A.G-D. and L.B.; visualisation – A.G-D.; supervision – L.B. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declare no conflict of interest.

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References

Albert, C., Spangenberg, J., Schröter, B., 2017. Nature-Based Solutions: Criteria. *Nature*, 543: 315-315. DOI: https://doi.org/10.1038/543315b.

Antrop, M., Van Eetvelde, V., 2000. Holistic aspects of suburban landscapes: Visual image interpretation and landscape metrics. *Landscape and Urban Planning*, 50: 43-58. DOI: https://doi.org/10.1016/S0169-2046(00)00079-7.

Badach, J., Raszeja, E., 2019. Developing a framework for the implementation of landscape and greenspace indicators in sustainable urban planning. Waterfront landscape management: Case studies in Gdańsk, Poznań and Bristol. *Sustainability*, 11: 2291. DOI: https://doi.org/10.3390/su11082291.

Bedla, D., Halecki, W., 2021. The value of river valleys for restoring landscape features and the continuity of urban ecosystem functions – A review. *Ecological Indicators*, 129: 107871. DOI: https://doi.org/10.1016/j.ecolind.2021.107871.

Bodnaruk, E.W., Kroll, C.N., Yang, Y., Hirabayashi, S., Nowak, D., Endreny, T.A., 2017. Where to plant urban trees? A spatially explicit methodology to explore ecosystem service tradeoffs. *Landscape and Urban Planning*, 157: 457-467. DOI: https://doi.org/10.1016/j.landurbplan.2016.08.016.

Bonenberg, W., Bonenberg, A., Wen, Q., 2021. The morphology of the urban sprawl phenomenon in the Poznan Metropolitan Area. *Lecture Notes in Networks and Systems*, 272: 224-231. DOI: https://doi.org/10.1007/978-3-030-80710-8_27.

Brandt, L., Lewis, A.D., Fahey, R., Scott, L., Darling, L., Swanston, C.A., 2016. Framework for adapting urban forests to climate change. *Environmental Science & Policy*, 66: 393-402. DOI: https://doi.org/10.1016/j.envsci.2016.06.005.

Budner, W., 2018. Suburbanizacja w obszarze metropolii Poznań, *Biuletyn Stowarzyszenia Rzeczoznawców Majątkowych Województwa Wielkopolskiego*, 49 (1): 26-34.

Cecchi, C., 2015. Towards an EU research and innovation policy agenda for nature-based solutions and re-naturing cities. Final report of the Horizon 2020 expert group on nature-based solutions and re-naturing cities. Luxembourg: Publications Office of the European Union, 74 pp. DOI: https://doi.org/10.2777/479582.

Chen, J., Jin, S., Du, P., 2020. Roles of horizontal and vertical tree canopy structure in mitigating daytime and nighttime urban heat island effects. *International Journal of Applied Earth Observation and Geoinformation*, 89: 102060. DOI: https://doi.org/10.1016/j.jag.2020.102060.

Christiawan, P.I., 2019. Designing the mitigation model of urban sprawl potential impact in suburban Denpasar, Bali. *Journal of Physics: Conference Series*, 1363: 012100. DOI: https://doi.org/10.1088/1742-6596/1363/1/012100.

Dyson, K., Ziter, C., Fuentes, T.L., Patterson, M.S., 2018. Conducting urban ecology research on private property: advice and lessons learned in the field; *PeerJ Preprints*, 6: e26457v2 DOI: https://doi.org/10.7287/peerj.preprints.26457v2.

Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., *et al.*, 2015. Nature-Based Solutions: New influence for environmental management and research in Europe. *GAIA – Ecological Perspectives for Science and Society*, 24: 243-248. DOI: https://doi.org/10.14512/gaia.24.4.9.

Fry, G., Sarlöv-Herlin, I., 1997. The ecological and amenity functions of woodland edges in the agricultural landscape; a basis for design and management. *Landscape and Urban Planning*, 37: 45-55. DOI: https://doi.org/10.1016/S0169-2046(96)00369-6.

Gałecka-Drozda, A., Zachariasz, A., 2017. Tereny postagrarne w największych miastach Polski. *Prace Komisji Krajobrazu Kulturowego*, 38: 57-70.

Gillner, S., Vogt, J., Tharang, A., Dettmann, S., Roloff, A., 2015. Role of street trees in mitigating effects of heat and drought at highly sealed urban sites. *Landscape and Urban Planning*, 143: 33-42. DOI: https://doi.org/10.1016/j.landurbplan.2015.06.005.

GUS, 2022. Rocznik Statystyczny Poznania, dział V Ludność. Poznań: Urząd Statystyczny w Poznaniu, Wielkopolski Ośrodek Badań Regionalnych – Dział Opracowań Zbiorczych, pp. 72-93. Available from https://poznan.stat.gov.pl/files/gfx/poznan/pl/defaultstronaopisowa/1154/4/1/rocz_poznan_2021_dzial_05_ludnosc.pdf.

Godefroid, S., Koedam, N., 2007. Urban plant species patterns are highly driven by density and function of built-up areas. *Landscape Ecology*, 22: 1227-1239. DOI: https://doi.org/10.1007/s10980-007-9102-x.

Hladnik, D., Kobler, A., Pirnat, J., 2020. Evaluation of forest edge structure and stability in peri-urban forests. *Forests*, 11: 338. DOI: https://doi.org/10.3390/f11030338.

Jackowiak, B., 2011. Poznań. In: J.G. Kelcey, N. Müller, eds. *Plants and habitats of European cities*. New York: Springer-Verlag, pp. 363-405. DOI: https://doi.org/10.1007/978-0-387-89684-7.

Janeczko, E., Dąbrowski, R., Budnicka-Kosior, J., Woźnicka, M., 2019. Influence of urbanization processes on the dynamics and scale of spatial transformations in the Mazowiecki Landscape Park. *Sustainability*, 11 (11): 3007. DOI: https://doi.org/10.3390/su11113007.

Jaszczak, R., Wajchman, S., 2015. Wybrane aspekty gospodarki leśnej w lasach miejskich Poznania i w Lasach Państwowych. *Sylwan*, 159 (2): 160-167. DOI: https://doi.org/10.26202/sylwan.2014256.

Jaszczak, R., Wajchman-Świtalska, S., 2014. Problems of forest management in municipal forests of the city of Poznań. *Civil And Environmental Engineering Reports*, 12: 45-54. DOI: https://doi.org/10.2478/ceer-2014-0005.

Jim, C.Y., 2011. Holistic research agenda for sustainable management and conservation of urban woodlands. *Landscape and Urban Planning*, 100: 375-379. DOI: https://doi.org/10.1016/j.landurbplan.2011.01.006.

Kaczmarek, T., 2017. Dynamika i kierunki rozwoju suburbanizacji rezydencjalnej w aglomeracji poznańskiej. *Acta Universitatis Lodziensis. Folia Geographica Socio-Oeconomica*, 27: 81-98. DOI: https://doi.org/10.18778/1508-1117.27.06.

Kark, S., 2017. Effects of ecotones on biodiversity. In: *Reference module in life sciences*. Oxford: Elsevier, pp. 1-7. DOI: https://doi.org/10.1016/B978-0-12-809633-8.02290-1.

Kodym-Kozaczko, G., 2005. Rozwój Poznania w planowaniu urbanistycznym w latach 1900-1990. In: T. Jakimowicz, ed. *Architektura i urbanistyka Poznania w XX wieku*. Poznań: Wydawnictwo Miejskie, pp. 21-30.

Konijnendijk, C.C., 2003. A decade of urban forestry in Europe. *Forest Policy and Economics*, 5 (2): 173-186. DOI: https://doi.org/10.1016/S1389-9341(03)00023-6.

Lambarki, R., Achbab, E., Maanan, M., Rhinane, H., 2021. Evaluation of the potential of green roofs applied to an urban fabric using gis and remote sensing data case of the Nador City/Morocco. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 46 (4/W3): 177-184. DOI: https://doi.org/10.5194/isprs-archives-XLVI-4-W3-2021-177-2022.

Lowry, J.H., Baker, M.E., Ramsey, R.D., 2012. Determinants of urban tree canopy in residential neighborhoods: household characteristics, urban form, and the geophysical landscape. *Urban Ecosystems*, 15: 247-266. DOI: https://doi.org/10.1007/s11252-011-0185-4.

Łukasiewicz, A., Łukasiewicz, S., 2016. Rola i kształtowanie zieleni miejskiej. Poznań: Wydawnictwo Naukowe UAM, 154 pp.

Macias, A., Dryjer, M., 2010. Forest cover dynamics in the city of Poznań from 1830 to 2004. *Quaestiones Geographicae*, 29 (3): 47-57. DOI: https://doi.org/10.2478/v10117-010-0022-5.

McDonald, R.I., Urban, D.L., 2006. Edge effects on species composition and exotic species abundance in the North Carolina Piedmont. *Biological Invasions*, 8 (5): 1049-1060. DOI: https://doi.org/10.1007/s10530-005-5227-5.

Mockrin, M., Locke, D., Stewart, S., Hammer, R., Radeloff, V., 2019. Forests, houses, or both? Relationships between land cover, housing characteristics, and resident socioeconomic status across ecoregions. *Journal of Environmental Management*, 234: 464-475. DOI: https://doi.org/10.1016/j.jenvman.2018.12.001.

Mrozik, K., Podawca, K., Drożyńska, D., 2020. Spatial diversification of the implementation of planning and investment processes in the Poznań Metropolitan Area. *Ekonomia i Środowisko*, 75 (4): 64-80.

Myeong, S., Nowak, D.J., Hopkins, P.F., Brock, R.H., 2001. Urban cover mapping using digital, high-spatial resolution aerial imagery. *Urban Ecosystems*, 5 (4): 243-256.

Niedziałkowski, K., Beunen, R., 2019. The risky business of planning reform – the evolution of local spatial planning in Poland. *Land Use Policy*, 85: 11-20. DOI: https://doi.org/10.1016/j.landusepol.2019.03.041.

Nowak, D.J., Noble, M.H., Sisinni, S.M., Dwyer, J.F., 2001. People and trees: assessing the US urban forest resource. *Journal of Forestry*, 99: 37-42. DOI: https://doi.org/10.1093/jof/99.3.37.

Ordóñez Barona, C., Duinker, P., 2014. Assessing the vulnerability of urban forests to climate change. *Environmental Reviews*, 22: 311-321. DOI: https://doi.org/10.1139/er-2013-0078.

Parysek, J.J., Mierzejewska, L., 2006. City profile Poznań. *Cities*, 23 (4): 291-305.

Przewoźniak, M., 2005. Teoretyczne aspekty przyrodniczej rewitalizacji miast: ku metodologii zintegrowanej rewitalizacji urbanistyczno-przyrodniczej. *Teka Komisji Architektury, Urbanistyki i Studiów Krajobrazowych*, 1: 25-34.

Raszeja, E., Gałecka-Drozda, A., 2015. Współczesna interpretacja idei poznańskiego systemu zieleni miejskiej w kontekście strategii miasta zrównoważonego. *Studia Miejskie*, 19: 75-86.

Ratajczyk, N., Wolańska-Kamińska, A., Kopeć, D., 2010. Problemy realizacji systemu przyrodniczego miasta na przykładzie Łodzi. In: M. Burchard-Dziubińska, A. Rzeńca, eds. *Zrównoważony rozwój na poziomie lokalnym i regionalnym – wyzwania dla miast i obszarów wiejskich*. Łódź: Wydawnictwo Uniwersytetu Łódzkiego, pp. 78-97.

Rötzer, T., Rahman, M.A., Moser-Reischl, A., Pauleit, S., Pretzsch, H., 2019. Process based simulation of tree growth and ecosystem services of urban trees under present and future climate conditions. *Science of the Total Environment*, 676: 651-664. DOI: https://doi.org/10.1016/j.scitotenv.2019.04.235.

Rupprecht, C., Byrne, J., 2016. Informal greenspace as green infrastructure? Potential, challenges and future directions. Conference: American Association of Geographers Annual Meeting 2016, San Francisco. DOI: https://doi.org/10.13140/RG.2.1.1470.2481/1.

Seddon, N., Chausson, A., Berry, P., Girardin, C.A., Smith, A., Turner, B., 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B*, 375 (1794): 20190120. DOI: https://doi.org/10.1098/rstb.2019.0120.

Selmi, W., Weber, C., Rivičre, E., Blond, N., Mehdi, L., Nowak, D., 2016. Air pollution removal by trees in public green spaces in Strasbourg City, France. *Urban Forestry and Urban Greening*, 17: 192-201. DOI: https://doi.org/10.1016/j.ufug.2016.04.010.

Sowińska-Świerkosz, B., Garcia, J., 2022. What are Nature-based solutions (NBS)? Setting core ideas for concept clarification. *Nature-Based Solutions*, 2: 100009. DOI: https://doi.org/10.1016/j.nbsj.2022.100009.

SUiKZP, 2000. Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego Gminy Czerwonak (SUiKZP). Uchwała nr 173/XXVIII/2000 Rady Gminy Czerwonak z dnia 14 czerwca 2000 r.

SUiKZP, 2010. Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego Gminy Mosina (SUiKZP) Załącznik nr 1 do uchwały nr LVI/386/10 Rady Miejskiej w Mosinie z dnia 25 lutego 2010 r.

SUiKZP, 2011a. Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego Gminy Swarzędz (SUiKZP) Uchwała Rady Gminy Nr 2011/51 z dnia 22 listopada 2011 r.

SUiKZP, 2011b. Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego Gminy Tarnowo Podgórne (SUiKZP) Uchwała Nr XII/134/2011 Rady Gminy Tarnowo Podgórne z dnia 21 czerwca 2011 r.

SUiKZP, 2013. Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego Gminy Dopiewo (SUiKZP) Uchwała Rady Gminy Nr XLIII/308/13 z dnia 25 lutego 2013 r.

SUiKZP, 2014. Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego Miasta Poznania (SUiKZP), Załącznik Nr 2 Do Uchwały Rady Miasta Poznania Nr LXXII/1137/VI/2014 z Dnia dnia 23 września 2014 r.

SUiKZP, 2016a. Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego Gminy Rokietnica (SUiKZP) Załącznik nr 1 do Uchwały Nr Xviii/181/2016 Rady Gminy Rokietnica z dnia 29 lutego 2016 r.

SUiKZP, 2016b. Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego Gminy Suchy Las (SUiKZP) Uchwała nr XXIII/245/16 Rady Gminy Suchy Las z dnia 27 października 2016 r.

SUiKZP, 2017. Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego Gminy Kórnik (SUiKZP) Załącznik nr 1 do uchwały Nr XL/529/2017 Rady Miasta i Gminy Kórnik z dnia 25 października 2017 r.

Szota, C., Coutts, A.M., Thom, J.K., Virahsawmy, H.K., Fletcher, T.D., Livesley, S.J., 2019. Street tree stormwater control measures can reduce runoff but may not benefit established trees. *Landscape and Urban Planning*, 182: 144-155. DOI: https//doi.org/10.1016/j.landurbplan.2018.10.021.

United Nations, 2018. The World's Cities in 2018 – Data Booklet. United Nations, Department of Economic and Social Affairs, Population Division (ST/ESA/ SER.A/417).

Ustawa, 1991. Ustawa z dnia 28 września 1991 r. o lasach. [The Forest Act]. Dz.U. 1991 nr 101 poz. 444. Available from https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU19911010444 [accessed: 27.04.2021].

Ustawa, 1995. Ustawa z dnia 3 lutego 1995 r. o ochronie gruntów rolnych i leśnych. [The Agricultural and Forest Land Protection Act]. Dz.U. 1995 nr 16 poz. 78.

Ważynski, B., 1987. Lasy komunalne. *Sylwan*, 131 (10): 13-19.

Weber, T., Wolf, J., 2000. Maryland's Green Infrastructure-Using landscape assessment tools to identify a regional conservation strategy. *Environmental Monitoring and Assessment*, 63: 265-277. DOI: https://doi.org/10.1023/A:1006416523955.

Weissert, L.F., Salmond, J.A., Schwendenmann, L., 2014. A review of the current progress in quantifying the potential of urban forests to mitigate urban CO_2 emissions. *Urban Climate*, 8: 100-125. DOI: https://doi.org/10.1016/j.uclim.2014.01.002.

Yang, J., Mcbride, J., Zhou, J., Sun, Z., 2005. The urban forest in Beijing and its role in air pollution reduction. *Urban Forestry and Urban Greening*, 3: 65-78. DOI: https://doi.org/10.1016/j.ufug.2004.09.001.

Yang, Y., Wang, K., Liu, D., Zhao, X., Fan, J., 2020. Effects of land-use conversions on the ecosystem services in the agro-pastoral ecotone of Northern China. *Journal of Cleaner Production*, 249: 119360. DOI: https://doi.org/10.1016/j.jclepro.2019.119360.

Zhang, Z., Meerow, S., Newell, J.P., Lindquist, M., 2019. Enhancing landscape connectivity through multifunctional green infrastructure corridor modeling and design. *Urban Forestry and Urban Greening*, 38: 305-317. DOI: https://doi.org/10.1016/j.ufug.2018.10.014.

Ziter, C., Turner, M.G., 2018. Current and historical land use influence soil-based ecosystem services in an urban landscape. *Ecological Applications*, 28: 643-654. DOI: https://doi.org/10.1002/eap.1689.

Zwierzchowska, I., Fagiewicz, K., Poniży, L., Lupa, P., Mizgajski, A., 2019. Introducing nature-based solutions into urban policy – facts and gaps. Case study of Poznań. *Land Use Policy*, 85: 161-175. DOI: https://doi.org/10.1016/j.landusepol.2019.03.025.

STRESZCZENIE

Poza drzewostanem: analiza stref buforowych lasów miejskich jako narzędzie do wdrożenia rozwiązań opartych na przyrodzie – studium przypadku Poznania

Lasy miejskie są ważnymi i bardzo cennymi elementami zielonej infrastruktury miejskiej (GI). Wzrost udziału terenów zabudowanych i wiążące się z nim uszczelnianie gruntu w sąsiedztwie lasów miejskich skutkuje negatywnymi zmianami stosunków wodnych, zaburzeniem ciągłości korytarzy ekologicznych oraz rosnącą liczbą użytkowników, co wpływa na degradację miejskich ekosystemów leśnych. Na tym tle szczególnie istotne wydaje się dokładne przeanalizowanie istniejącego stanu i zmian użytkowania terenu w otulinie lasów miejskich. Badania przeprowadzono w Poznaniu, zakładając jako główne cele: (1) zwrócenie uwagi na zmiany użytkowania terenu

w bezpośrednim sąsiedztwie lasów miejskich (w tzw. strefach buforowych lasów miejskich) w latach 1997-2019, (2) zbadanie powiązania rodzaju użytkowania terenu ze stopniem pokrycia zielenią wysoką w strefach buforowych lasów miejskich oraz (3) wskazanie potencjału stref buforowych lasów miejskich, które powinny zostać uwzględnione w praktyce planowania przestrzennego. Przeprowadzona analiza stref buforowych lasów komunalnych i włączenie ich do praktyki planistycznej może być traktowane jako rozwiązanie oparte na przyrodzie (NbS).

Badania wykonano w trzech etapach. W pierwszym przeprowadzono ogólną analizę sąsiedztwa lasów miejskich Poznania, przyjmując 500-metrową szerokość otuliny. Badano użytkowanie terenu w sąsiedztwie lasów w dwóch punktach czasowych: w 1997 r. i w 2019 r. (ryc. 1). Przeprowadzono także prognozę zmian w otulinie lasów miejskich na podstawie SUiKZP. Drugi etap stanowiły szczegółowe badania mające na celu określenie udziału zieleni wysokiej w bezpośrednim sąsiedztwie lasu, które traktowano jako jego rozszerzenie. Na tym etapie szerokość otuliny została ograniczona do 100 m, co pozwoliło na zawężenie otoczenia do jednego typu użytkowania terenu. Trzeci etap badań polegał na sprawdzeniu, czy sąsiedztwo lasów zostało potraktowane w polityce przestrzennej miasta w szczególny sposób i jakie przepisy mogą wspierać rozwój korzystnej otuliny lasów miejskich. Aby zrealizować to zadanie, przeanalizowano dokumenty z zakresu planowania przestrzennego.

Przeprowadzone badania wskazują na istotny wzrost powierzchni terenów zabudowanych w otulinie lasów miejskich między rokiem 1997 a 2019 (ryc. 2, tab. 1). Prognoza oparta na dokumentach planistycznych wykazała, że ten negatywny trend będzie się utrzymywać. Tendencja spadku udziału terenów otwartych w sąsiedztwie lasów jest taka sama – niezależnie od tego, czy skraj lasu przebiega wzdłuż granic miasta, czy znajduje się wewnątrz miasta. Najkorzystniejsze sąsiedztwo lasów miejskich stanowią tereny zielonej i niebieskiej infrastruktury. Lasy miejskie mają stałe połączenia z wodami otwartymi, lasami podmiejskimi i terenami zieleni, ale ich udział w strefie buforowej lasów jest niewielki.

Ponieważ tereny zabudowy zacieśniają się wokół lasów miejskich, istotne było przeanalizowanie, w jakim stopniu tereny zabudowane są pokryte roślinnością wysoką. Zieleń taką można potraktować jako przedłużenie lasu i strefę łagodzącą ostry kontrast między lasem a miastem. Podobnie jak parki i inne tereny zieleni urządzonej, stanowi ona tradycyjne przedłużenie lasów miejskich. Analiza udziału zieleni wysokiej ujawniła potencjał terenów zabudowanych jako miejsc łagodzących ostrą krawędź lasów. Jednocześnie udział zieleni wysokiej w obrębie jednego rodzaju użytkowania gruntów może być bardzo zróżnicowany. W związku z tym konkretny typ użytkowania terenu (w tym zabudowy) nie odzwierciedla bezpośrednio jego potencjału do wspierania zielonej infrastruktury (ryc. 3, tab. 2). Określenie udziału zieleni wysokiej może pomóc w stwierdzeniu, czy tereny zabudowane mogą służyć jako strefy buforowe lasów miejskich. Przedstawiona w artykule metoda jest prosta i umożliwia prowadzenie analiz na podstawie ogólnodostępnych materiałów kartograficznych i planistycznych. Badania wykazały, że strefy buforowe lasów miejskich już działają, ale bardziej na zasadzie przypadku niż jako efekt zaplanowanej i przemyślanej strategii.

Planowanie przestrzenne stwarza możliwości regulacji zagospodarowania terenu, w tym określenia udziału zieleni wysokiej. Niestety, w Poznaniu ten potencjał nie jest wykorzystany. Ponadto brak jest odrębnych przepisów dotyczących terenów położonych w bezpośrednim sąsiedztwie lasów miejskich (tab. 3). Idea stref buforowych lasów komunalnych powinna być traktowana jako istotna kwestia planowania lokalnego, a także jako rozwiązanie z zakresu NbS.