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Original Research

Historical Land Use, Actual Vegetation, and the Hemeroby Levels in Ecological Evaluation of an Urban River Valley in Perspective of Its Rehabilitation Plan

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Abstract

The rehabilitation of landscapes along river valleys play an ever more important role in urban management. The first step is evaluation of natural conditions of green areas. We propose a validation method based on analysis of land use changes in the last 200 years, actual vegetation mapping, and the hemeroby concept. The field study was conducted in the Sokołówka River valley in Łódź city (Central Poland). All analyses were performed using the GIS software. The results show that after World War II, during urbanization and industrialization of Łódź, a surprising increase in the forest cover and a decline of agricultural areas have been observed in the study area. The current naturalization of the landscape should be used for rehabilitation projects.

Keywords: ecological indicators, hemeroby, land use change, urban river, vegetation evaluation

Introduction

As a result of spatial urban development, non-urbanized arable and forest areas of significant natural and social value are included within urban boundaries. Their presence, along river valleys in particular, is one of the conditions necessary for sustainable urban development and maintenance of the rivers' capacity for self-regulation within the biotic environment [1]. Currently, most of the world's population live in cities, which is why the evaluation, cultivation and rehabilitation of green areas along river valleys play an ever more important role.

The first step in restoration plans involves recognizing the current natural conditions and identifying the relics of natural ecosystems that will become refuges for native flora and fauna. In the restoration process, these refuges are of huge importance as diaspora sources of local species [1, 2]. At this point, it should be possible to take measurements aimed at restoring fragments that have been most transformed [3].

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The evaluative indicators are used in ecology and environmental planning for evaluation of the conservation status of an area or for verification of management efficiency [4]. Ecological evaluation of the landscape is based, inter alia, on the occurrence of umbrella species [5], the diversity of biotope types, and the occurrence of valuable biotopes [6] or landscape metrics [7]. Frequently the ecological evaluation is based on mapping of actual vegetation, which is a good indicator of the conservation status of ecosystems [8-10]. In the transformed landscapes, current vegetation primarily results from human activity, and to understand the dynamic processes in communities, special attention should be paid to analysis of the land use history during the last decades or hundreds of years [7, 11].

Validation methods also use the hemeroby concept, which was proposed by Jalas [12] and developed by Sukopp [13]. According to Sukopp [13] and Kowarik [14], hemeroby is defined as a holistic indicator of the cultural impact on an ecosystem, and thus includes all the consequences that occur as a result of both intended and unintended anthropopressure. Hemeroby is most often used to assess the anthropogenic transformation of phytocoenoses and ecosystems [13-17], but as a concept it is also used for the purpose of landscape-based analysis, serving as an indicator of the ecological value and landscape diversity, as well as of the extent of the anthropogenic transformation [18-20]. Homogenization of the vegetation and the occurrence of ruderal communities dominated by alien invasive species are symptomatic of the synanthropization process. Modified river valleys in cities often act as corridors along which invasive species migrate [21].

The SWITCH (Sustainable Water Management Improves Tomorrow's Cities' Health) Project, financed by the European Commission, addressed inter alia the following issues related to the concept of river valley restoration in Łódź, Poland: increase water retentiveness in the city landscape; reduce stormwater flow peaks by a series of ponds and reservoirs; restore wetlands; and preserve and increase biodiversity in the catchment by restoration of river corridors and ecotone zones [22].

The key elements in the city's current ecological system include valuable areas, natural refuges, whose fragments were preserved in Łódź despite 200 years of intensive urbanization [23].

An ecological evaluation of the landscape of the Sokołówka River valley – one of the small rivers in Łódź – was the main objective of this study. Three elements of the landscape evaluation were applied: analysis of changes in land use during 200 years, actual vegetation mapping, and hemeroby concept adaptation. The result of this analysis allowed us to answer the question: how much conservation and how much rehabilitation do we need? And where do we need them?

Materials and Methods

Study Area

Łódź is a city of 800,000 inhabitants (an agglomeration of 1 million inhabitants), located in central Poland (Fig. 1). The city area is divided between 18 catchments drained by small urban streams. During the industrial revolution in the early 1830s, the streams were channelized and set underground, thus becoming part of the storm water system of the city.

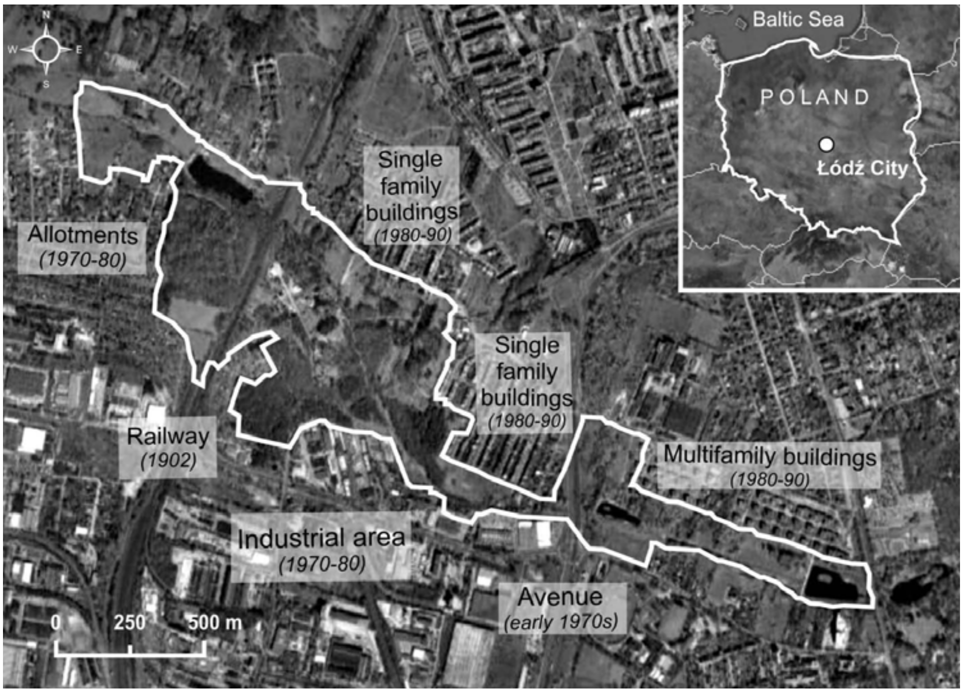

Fig. 1. The study area – ecotone buffer zones in the Sokołówka River valley in Łódź and location of urban and industrial areas in its vicinity (based on orthophotomaps 2002-04, materials from the City Council of Łódź).

Table 1. Hemeroby degrees in urban ecosystems, after Blume and Sukopp [31].

Hemeroby level	Anthropopressure intensity
A-hemerobic (not represented in the study area)	Lack of anthropogenic impact, flora and vegetation unaffected by human pressure.
Oligo-hemerobic	Minor anthropogenic impacts are observed, however, they do not modify the substrate.
Meso-hemerobic	Weak to moderate, or periodic anthropogenic factors.
Eu-hemerobic	Continuous and strong anthropogenic impacts causing strong modifications of the substrate.
Poly-hemerobic	Continuous and very strong anthropogenic impacts. Vegetation is characterized by a high degree of specialization and pioneer nature.
Meta-hemerobic	Continuous impact of anthropogenic factors that are so strong they exceed the tolerance of plants.

The small Sokołówka River valley is modified and its bed is regulated, but some small seminatural fragments have been preserved. In the 19th century it was situated between the cities of Łódź and Zgierz and thus it was only affected by the 20th century changes resulting from progressive urbanization [24]. Ecotone buffer zones, i.e. not built-up areas in a section of the Sokołówka River valley between Zgierska Str. and Żabieniec Str. (Fig. 1), that cover 102 ha were chosen for this analysis.

Historical Land Use

Historical changes in land use were identified on the basis of archival topographic maps and the actual vegetation mapping. The following materials were used in archival analysis: Topographic Data of the Kingdom of Poland (the Map of the Congress Kingdom) issued in 1843, field mapping: 1822-39, scale 1:126,000; The Łódź City Atlas, Sheet IV: Łódź and its environs in the first half of the 19th c., scale: 1:30,000 [25]; the Polish Military Geographical Institute (WIG) topographic maps, 1932-39, scale 1:25,000; the Polish General Surveyor topographic maps, 1970-90, scale: 1:25,000.

All maps were georeferenced, drawn, and analyzed using the ArcGIS 9.2 cartographic software package [26].

Actual Vegetation Mapping

Vegetation was mapped in 2008 with a scale of 1:5,000. The field mapping method was based on orthophotomaps as a cartographical backing [27]. Orthophotomaps from 2002-04 were used in this case study, with 1 pixel − 0.5 m resolution and the 1992 Polish Coordinate System. In some cases, the precise position of phytocoenoses may need to be located by a GPS receiver.

Vegetation units are defined as uniform phytocoenoses with regard to their phytosociological character according to the Braun-Blanquet method [28], naturalness and succession stage. The nomenclature of vascular plants in this paper follows "Flora Europaea" [29] and the nomenclature of plant communities follows Matuszkiewicz [30].

An actual vegetation map was drawn and analyzed using ArcGIS [26].

Ecological Validation

Analysis of historical land use and actual vegetation allowed us to detect places that have not been affected by land use change in the last 200 years and have presently quite natural or seminatural vegetation. This analysis also allowed us to detect patches where succession or regeneration of phytocoenoses is observed and should be used in the project of rehabilitation.

General landscape validation was done by:

- designation of hemeroby levels in the study area; the hemeroby scale should be adapted according to Blume and Sukopp [31] (Table 1); the lowest, i.e. a-hemerobic level is not represented in the Sokołówka Valley; the main task was to convert the real vegetation units to corresponding hemeroby levels; the result is a map showing the distribution of hemeroby levels.
- detection of vegetation patches dominated by alien species, which are mostly associated with human-transformed habitats.

Validation maps were drawn and analyzed using ArcGIS [26].

Results

Land Use Changes over the Last 200 Years

Analysis of changes in land use during the last 200 years indicates a far-reaching transformation of the landscape structure in the ecotone zones of the Sokołówka River valley (Table 2, Fig. 2).

At the beginning of the 19th century the landscape in the Sokołówka valley had typically agro-forest character. During the industrial revolution in the 19th century that took place in nearby Łódź, the Sokołówka valley was affected by a gradual transformation process. During this period, the forest area decreased from about 24% to only 11%. Whereas the contribution of transport infrastructure (rail and roads) increased (up to 10%), as well as the contribution of residential and industrial buildings (up to 10%). At the beginning of the 20th century, the largest area of water reservoirs existed in the valley (Table 2, Fig. 2a).

Table. 2. Contribution of land use forms in the total area of the ecological buffer zones in the Sokołówka River valley in Łódź since the early 19th century.

Land use form	Early 19th c. (approximate values)	1930-45	1970-80	2008
Water reservoirs	~3	5.3	2.2	3.1
Wet meadows, rushes	~25	20.5	17.3	7.3
Fields, fallows, dry meadows	~43	36.0	25.3	17.8
Shrubs, clumps of trees, orchards	no data	6.5	4.9	20.3
Forests	~24	11.6	34.7	38.2
Roads	~4	7.2	8.9	6.3
Railway	0	3.1	2.8	2.9
Cemetery	0	0.8	0.0	0.0
Buildings, factories, outcrops	<1	9.0	3.9	4.1

World War II was followed by trend changes. Despite the fact that Łódź was growing as a center of the textile industry and the location of new industrial and residential areas in the vicinity of the valley, in most cases, the studied ecotone zone was affected by the gradual limitation economic activity, especially the disappearance of traditional forms of agricultural use. This transformation was reflected in the increased cover of forest and shrubs − from 18% to over 58% (Table 2, Fig. 2c) and a decrease in the contribution of fields, meadows and rushes − from 56% to 25% (Table 2. Fig. 2b).

The effect of the reduced human activity in the floodplain is also a considerable decrease in the area of water reservoirs in the 1970s (Table 2, Fig. 2a). This trend has been hampered in recent times as a result of reservoir rehabilitation, inter alia under the SWITCH project.

Current Vegetation in the Ecotone Buffer Zones in the Sokołówka River Valley

Forest and seminatural communities in hydrogenic habitats (4 types of communities, 62 patches, 18.2% of the area). In the dynamic circle of humid forest, there are tall

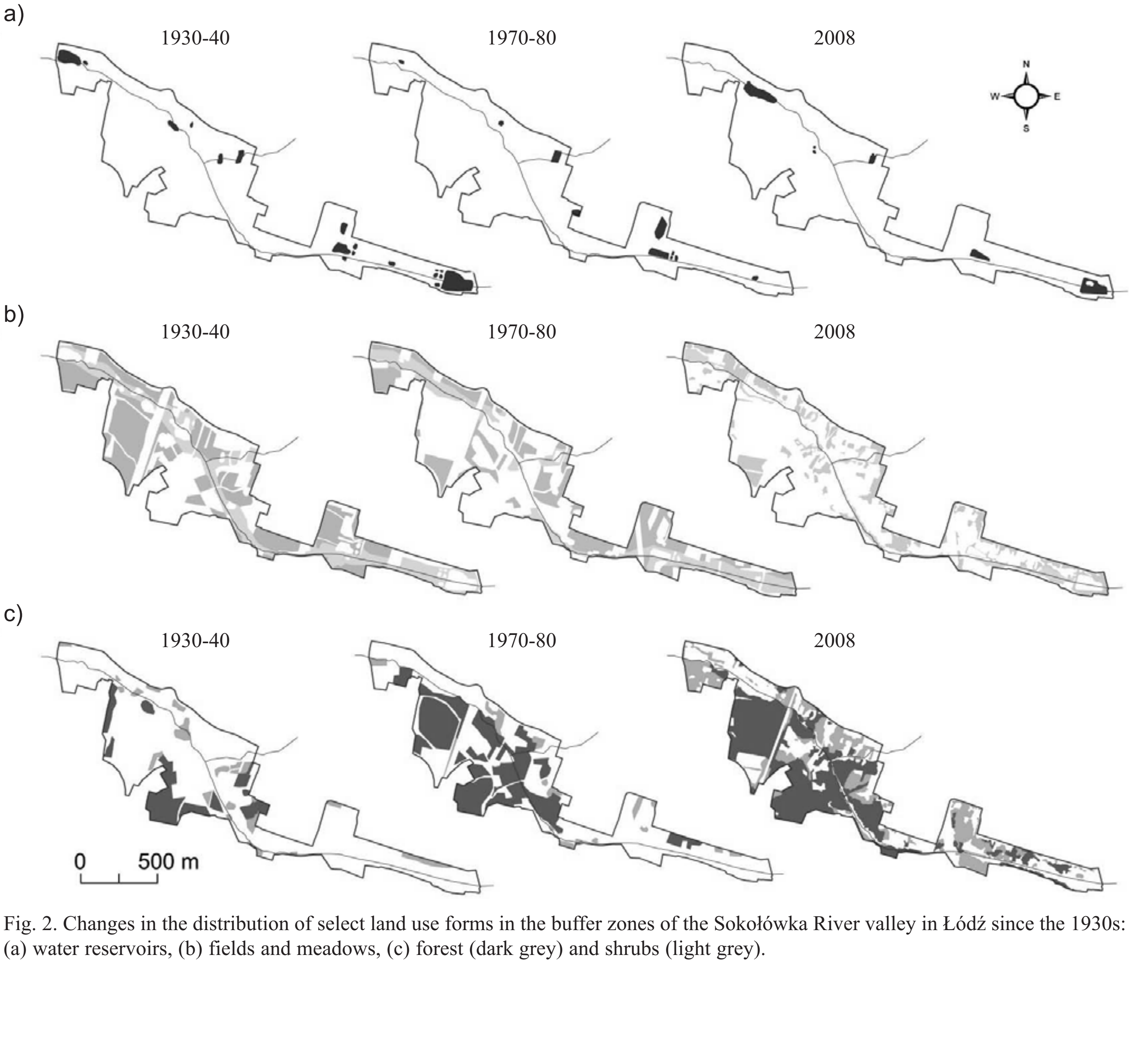

Fig. 2. Changes in the distribution of select land use forms in the buffer zones of the Sokołówka River valley in Łódź since the 1930s: (a) water reservoirs, (b) fields and meadows, (c) forest (dark grey) and shrubs (light grey).

herb communities, rushes and wet meadows that include phytosociological alliances: *Convolvulion sepium*, *Aegopodion podagrariae*, *Filipendulion*, *Magnocaricion*, and *Calthion*. During spontaneous succession, nitrophilous thickets, brushes and groups of alder trees were formed. In the western part of the study area, and especially in the central section of the valley, fragments of alder forest have been preserved, representing *Fraxino-Alnetum* and *Ribeso nigri-Alnetum* associations. The transformation of the ground and the soil, and the regulation of the river bed together with a decreased groundwater level were the main causes of the synanthropization of the wetland vegetation.

By analyzing the current vegetation and changes in land use we can indicate the ecological processes that occur in wetlands (Fig. 3). Most often we can observe the various stages of secondary succession in areas of former wet meadows, rushes and water reservoirs, and in the typical anthropogenic habitats, such as a regulated river bed and shores in new reservoirs. In many of ruderal patches, the succession is inhibited by regular cutting of biomass.

A special case of the forest and scrub vegetation transformation is observed in secondary boggy places (Fig. 3), which is a consequence of a railway embankment built over 200 years ago.

Forest and seminatural communities in mineral habitats (6 types of communities, 65 patches, 35.7% of the area). Semi-natural vegetation at higher locations and in mineral habitats is reflected in fresh meadows from the *Arrhenatherion* alliance. Small areas with sandy surfaces in the abandoned fields and on the valley slopes are covered with psammophilous grasslands from the *Corynephorion canescentis* alliance. The pre-forest stage of succession in such habitats includes brushes and young woods with pine, oak, birch, and aspen, as well as meadow and grassland flora. As a result of silviculture practices, or long-term succession, surrogate forests with pine and birch stands developed in the oak-hornbeam forest *Tilio-Carpinetum* habitat.

Anthropogenic communities in ruderal and transformed habitats (7 types of communities, 159 patches, 36.0% of the area). In the first and the second phase of spontaneous succession in the modified habitats, there are ruderal tall herb communities from the *Dauco-Melilotenion* alliance (especially an association with *Artemisia* and *Tanacetetum*) and the *Arction lappae* alliance. In areas permanently used by humans, such as trodden places and lawns, low "carpet" communities from the *Polygonion aviculatis* alliance are developed. Spontaneous succession in habitats transformed by humans leads to ruderal thickets and secondary forests with dominance of alien woody species and ruderal herbs. Groups of trees or planted alleys and orchards have similar character, although they have now been naturalized.

Ecological Evaluation

Only fragments of forest relicts have survived in the studied part of the valley. Well-preserved forests in hydrogenic habitats are exemplified by alluvial alder-ash forest, *Fraxino-Alnetum*, and bog alder forest, and *Ribeso nigri-Alnetum* (including a spring subassociation of *Rn-A chrysosplenietosum*). In mineral and drier habitats, small patches of oak-hornbeam forest, *Tilio-Carpinetum*, and mixed pine-oak forest, *Querco roboris-Pinetum*, have been preserved.

It was possible to identify four of the most natural parts of the ecotone buffer zone of the Sokołówka River in Łódź (numbers according to Fig 4):

1. Relicts of alluvial and humid forest at the bottom and on the slopes of the valley near the railway include phytocoenoses of alluvial and oak-hornbeam forest.
2. Patches of alder bog and alluvial forest on the eastern part of the railway bank. As the railway bank hinders the natural water run-off, the forest floor is flooded for most of the year. However, some plants that are rarely

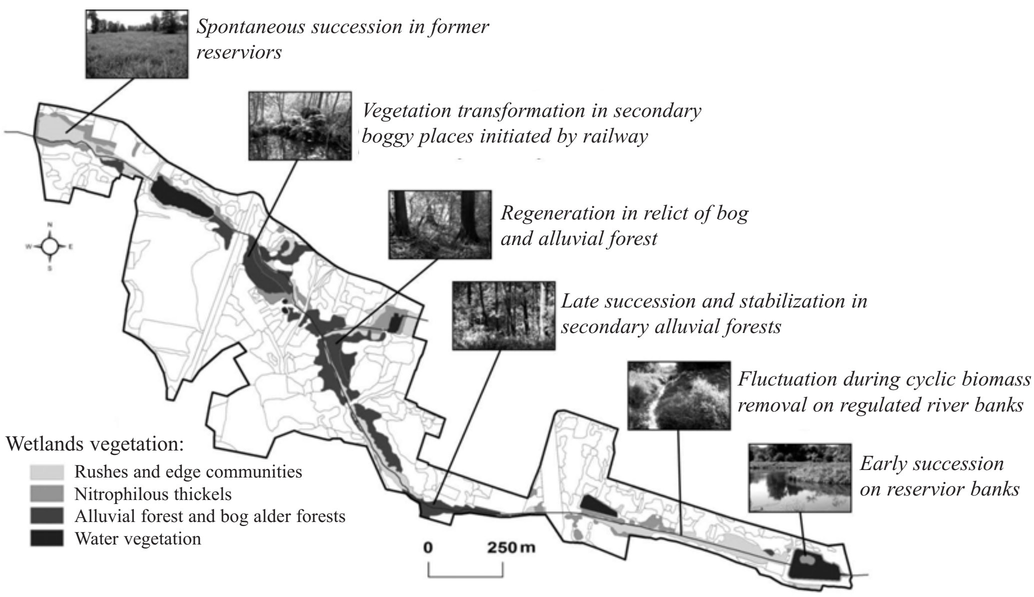

Fig. 3. Examples of recently observed ecological processes in wetland vegetation of the ecotone buffer zones in the Sokołówka River valley in Łódź.

Table 3. Actual vegetation units identified in the Sokołówka valley in Łódź and their assignment to the hemeroby levels.

Vegetation units	Hemeroby levels					
	o	*ms*	*β*	*α*	*p*	*mt*
Alluvial forest	x	x				
Bog alder forest	x	x				
Oak-hornbeam forest	x	x				
Surrogate forest with pine and birch in oak-hornbeam forest habitats		x				
Mixed forest with pine and oak		x				
River edge tall herb communities and rushes		x	x			
Thickets and clusters of alluvial forest trees		x	x			
Pssamophilous grasslands		x	x			
Degenerated fresh meadow communities		x	x			
Thickets with meadow and grassland flora		x	x			
Overgrown tree alleys and clusters of oak-hornbeam forest trees		x	x			
Ruderal thickets and ruderal young woods			x			
Orchards to run wild			x			
Ruderal, spontanerous herb communities			x	x		
Used and abandoned fields			x	x		
Ruderal forest communities			x	x		
Water reservoirs and pond vegetation			x	x		
Low "carpet" communities in tread places and lawns				x	x	
Buildings, factories, and roads with low plant cover				x	x	x

Hemeroby levels: *o* – oligo-hemerobic, *ms* – meso-hemerobic, *β* – *β*-eu-hemerobic, *α* – *α*-eu-hemerobic, *p* – poly-hemerobic, *mt* – meta-hemerobic.

found in the area can be observed: *Calla palustris*, *Iris pseudacorus*, and *Valeriana sambucifolia*.

3. Relicts of natural forest at the convergence of the Sokołówka River and Brzoza River. In the lower areas, a bog alder forest and an alluvial forest have been preserved, and in the upper areas there is a phytocoenosis of oak-hornbeam forest.
4. Former evangelical cemetery and its vicinity currently occupied by well-preserved phytocoenosis of oak-hornbeam forest. Certain legally protected plants can be found on the forest floor: *Hedera helix*, *Convallaria majalis*, and *Vinca minor*.

Ecological validation was based on hemeroby levels assigned to actual vegetation units (Table 3). The most natural, oligo- and meso-hemerobic patches cover nearly half of the study area, more than 9% and 40% respectively. The heavily anthropogenic, poly- and meta-hemerobic patches in the Sokołówka River valley cover over 8% of the total area and create a mosaic of patches.

The distribution of the patches demonstrates the hemeroby levels in the Sokołówka River valley, allowing the study area to be divided into two general sections. The western part is characterized by more natural vegetation and is considered to be the "outskirts" (Fig. 4). The eastern part, in which we include the "city centre," is dominated by anthropogenic vegetation forms, α-eu-, β-eu, poly- and meta-hemerobic levels (Fig. 4). In the past this part of the valley, especially certain parts of the floodplain area, was used as a dumping ground and actually has ruderal plant communities.

Woody alien species such as *Robinia pseudoacacia*, *Acer negundo*, *Padus serotina*, *Alnus incana*, and *Fraxinus pensylvanica*, play an important role in the structure of the ruderal forest and shrub communities. Applying this landscape transformation assessment method, the study area can also be divided into two parts: the eastern part, dominated by alien species and the western part, dominated by native species (Fig. 5).

Discussion and Conclusions

Anthropopressure contributed to the transformation of river valleys, a process that began during the initial stages of human development. Natural riverside forests with fertile habitats were converted into meadows, rushes, and arable lands, which were then lost to increasing urbanization. Vegetation in most of the European valleys is anthropogenic, and relicts of natural ecosystems are limited to small areas [32, 33].

The landscape around Łódź was transformed in a similar way, but more serious modifications took place in the 19th century during the development of the city as an industrial textile center [24].

Surprising results of our analysis of land use changes in the Sokołówka River valley include a regression of human activity during the urbanization and industrialization period in Łódź after World War II. A significant increase in the forest cover and a decline in the area of fields and meadows are most noticeable. This trend is typical of European and Polish rural areas [11] rather than urban or suburban landscapes [6]. Observed land use changes also potentially caused changes in annual potential evapotranspiration and runoff [34]. The progressive landscape naturalization in the studied valley is a result of its consistent assignment to areas with ecological functions in the city development plans since 1917 [35]. This example shows how important decisions on land use planning are.

Vegetation mapping and land use change analysis allows us to detect the refuges of natural and semi-natural plant communities in the western part of the study area. Hygrophilous forest and rushes, together with rare (for Łódź) examples of flora have been preserved there. This section of the Sokołówka valley is included now within a system of protected areas in Łódź [23]. The landscape is protected in the Polish legal forms of nature conservation: "landscape conservation site" and "sites of ecological use." The valley integrates the urbanized areas of the city center with a broader ecological system based on agrocenoses and natural and semi-natural phytocenoses in the suburban zone. Compliance with the rules of usage and protection of the most valuable sites in the existing and planned forms of nature conservation should be one of the restoration-related goals. The extensive exploitation of the ecosystems should be reversed through a gradual reconstruction of the eu-hemerobic patches, in order to generate meso- and oligo-hemerobic patches.

This validation indicated that the eastern part of the study area, which is closer to the city centre, is dominated by poly- and meta-hemerobic patches and significant contribution of alien woody species communities. Initially, in this section, appropriate water conditions within the tidal frame should be restored, the proportion of alien species in the phytocenoses should be reduced, and the area of forest and shrub vegetation patches should be increased. Additionally, restoration-based measures should make use of the existing meso-hemerobic patches. The developing plan of Sokołówka Park between Zgierska Street and Włókniarzy Alley, which is part of the SWITCH project [22], will be an important element of this landscape transformation.

Mapping is one of the obligatory tools in the indictor-based assessment of landscape functions for suitable landscape planning [36-38]. In this study we proposed transformation of the actual vegetation map into hemeroby levels. This step of analysis allowed us to validate the ecological values of a landscape on a more general level than in the detailed plant communities. Furthermore, it allowed us to specify the planning with regard to restoration measures, as each spatial unit has its own exact borders and is described in the GIS format.

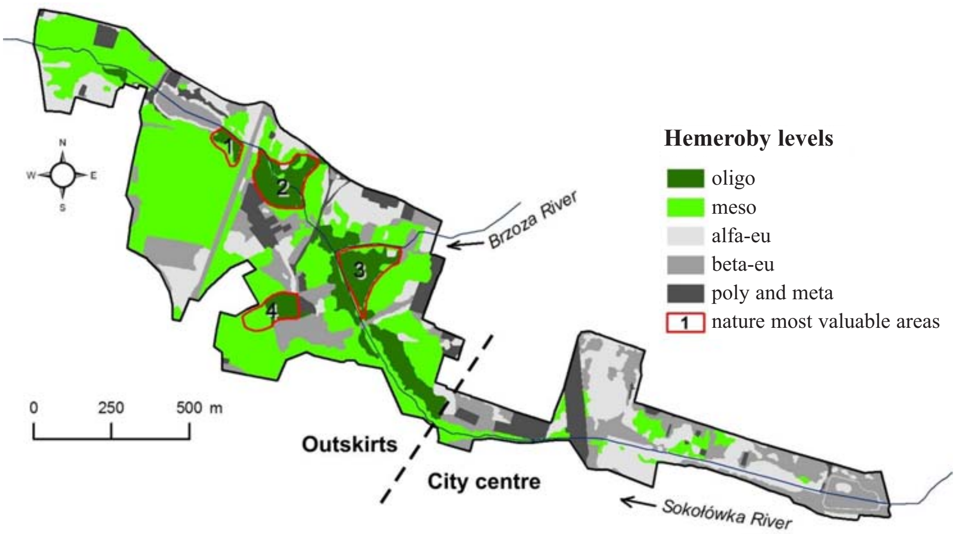

Fig. 4. Distribution of patches showing the hemeroby levels and most valuable natural areas in the Sokołówka River valley based on a transformation of the real vegetation map.

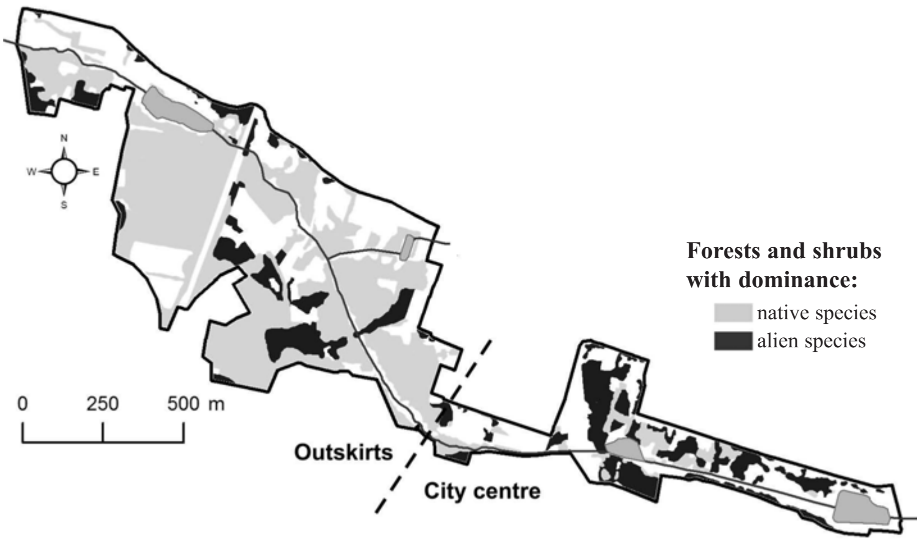

Fig. 5. Distribution of forest and shrub communities dominated by native and alien species in the ecotone buffer zones in the Sokołówka River valley in Łódź.

The method of landscape ecological validation used in this study, which includes land use changes, vegetation mapping, hemeroby levels, and alien species dominance in communities as indicators, is an example of multivariate assessment. This ecological validation could be a part of multidimensional models of landscape assessment proposed by Gómez-Sal et al. [39], which also includes "productive" and "economic" dimensions.

The ecological dimension in landscape evaluation analyzes the landscape as an ecosystem and shows which landscape maintains basic ecological processes and services [39]. The identification of ecological processes in plant communities is possible when the current structure of phytocoenoses is compared with the land use history. We noticed, that large spaces in the study area are affected by secondary succession, which is an effect of reduction in the intensity of human activities in recent decades. The observed spontaneous naturalization of the landscape should be used for rehabilitation projects.

As far as ecosystem restoration policies are concerned, two divided sections in the Sokołówka River valley represent different priorities. According to Hulse and Gregory's concept [40], the "outskirts" have high ecological potential with low demographic and economic constraints and the "city center" has low ecological potential with high demographic and economic constraints.

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