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ENHANCING ECOLOGICAL CORRIDORS IN RURAL AREAS AND IMPLICATIONS FOR LANDSCAPE PLANNING AND MANAGEMENT IN LESZNO COMMUNE IN CENTRAL POLAND

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ABSTRACT

Aim of the study
The paper presents the research aimed at recognition, evaluation, and improvement of ecological connectivity within the area of Leszno commune area, focusing on the establishment of new ecological corridors and the enhancement of existing ones in rural area adjacent to forest ecosystems, part of the Kampinoska Primeval Forest belonging to the Kampinoski National Park, Central Poland, in the middle of Central European Lowland.

Material and methods
The desk research consisted of two sections: prior to the field study and after the field study. During the field research, the study area, located in the middle and south parts of Leszno municipality in Poland, was observed and documented. The original methodical approach has been used, applying the division of the study area into landscape units for further detailed analysis, and enabling precise addressing of recommendations. By assessing vegetation cover, dominant vegetation levels, and their continuity within and beyond agricultural units, important insights on the ecological value of each unit were gained.

Results and conclusions
Negative impact of roads on ecological corridors was identified as a major challenge. The importance of vegetation along roads and within habitat passages in mitigating the ecological isolation was recognized. Enhancing vegetation cover and creating various types of green corridors – as linear, stepping stones, and landscape ones – connecting forests, and also along roads, while maintaining a zone free of high vegetation directly next to road (due to the requirement of maintaining visibility for drivers), are proposed as measures to mitigate road impacts, preserve connectivity, and promote the movement of species.

Keywords: ecological corridors, ecological connectivity, biodiversity conservation

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INTRODUCTION

Urban sprawl, economic growth, transportation infrastructure expansion, and land-use changes have detrimental impact on natural habitats, resulting in habitat fragmentation (Wang et al., 2021; Popescu et al., 2022; Shen and Wang, 2023). This fragmentation occurs when habitats become separated and broken apart without the loss of the habitat itself (Beita et al., 2021). Agricultural landscapes, both in Europe and in other parts of the world, experience significant fragmentation due to the expansion of intensively cultivated regions, resulting in reduced forest sizes (Dondina et al., 2018). Unfortunately, this process negatively impacts biodiversity, ecological resilience, and the ability of plant and animal populations to move freely (Hess and Fischer, 2001; Popescu et al., 2022).

The fragmentation of habitats poses a risk to species survival (Bennett, 1990). Even small breaks in habitats such as forests can pose barriers for many species, pushing them to the brink of extinction (Jordán, 2000; Baum et al., 2004; Dondina et al., 2018). In fact, studies estimate that a significant percentage of mammal, bird, and amphibian species are at risk of extinction due to habitat loss and fragmentation (Tianet al., 2022). The fragmentation of habitats leads to increased edge habitat area, and decreased actual habitat area, affecting species that rely on interior habitats (Hill, 1995).

Problem with landscape fragmentation concerns both rural and urban areas. Research suggests that landscape connectivity, even at a moderate level, can promote biodiversity and enhance the security and performance of ecosystems in urban areas (Cannas et al., 2018). Ecological corridors, both natural and man-made, are essential for reducing habitat separation, preserving wildlife, and restoring connectivity in human-dominated areas (Lepczyk et al., 2017; Liu et al., 2018; Lelechère and Bergès, 2021). As the climate changes, these corridors become even more crucial for species to migrate and adapt to new conditions (Handel et al., 2012). The movement of species is necessary to maintain ecological and evolutionary progression also in the face of climate change (Handel et al., 2012). Creating large-scale ecological corridors can help living organisms adapt to global warming and facilitate species movements (Correa Ayram et al., 2016; Merenlender et al., 2022).

Ecological corridors, whether land-based (green corridors) or aquatic (blue corridors), play a crucial role in connecting habitat patches, facilitating species movement, enhancing biodiversity, and preserving ecological functions (Sanderson et al., 2003; Perzanowska, 2005). Green corridors, often also referred to as greenways in urban settings, provide linear green spaces following natural or man-made features such as rivers or railways (Lynch, 2019; Beita, et al. 2021). These corridors not only serve as recreational areas for people but they also function as pathways for wildlife, addressing the scarcity of natural green spaces in urban and suburban areas (Lynch, 2019).

Ecological corridors encompass various features such as rivers, river valleys, coastal belts, mountain passes, and linear patches such as riparian areas along streams, windbreaks, forest remnants, fencerows in agricultural areas, roadside vegetation, and hedgerows (Rosenberg et al., 1997; Tikka et al., 2001; Rozenau-Rybowicz and Baranowska-Jasnota, 2008; Merenlender et al., 2022). These corridors play a crucial role in improving the movement of plants and animals between larger patches of habitat, facilitating genetic exchange, and preventing the isolation of populations (Rosenberg et al., 1997; Gregory et al., 2021; Lelechère and Bergès, 2021).

Ecological corridors can take on different forms, depending on their purpose, size, and the setting in which they are situated (Beita et al., 2021). There are many divisions into types of ecological corridors. Firstly, in order to provide clearer terminology for corridors that support biotic processes (e.g., plant propagation, genetic exchange, animal movement), they can be categorized into three distinct types: migration, dispersal, and commuting corridors (Jongman and Pungetti, 2004). Another division, due to the structure of the natural landscape includes continuous (linear) and discontinuous (stepping stones) corridors (Perzanowska, 2005).

In urban areas, greenways can provide similar benefits as ecological corridors, although their narrow width and the presence of non-native plant species may limit their effectiveness in promoting the migration of native animals (Hess and Fischer, 2001). However, as climate change progresses and species are forced to seek more favourable habitats, the presence of green pathways that permit animals to enter and travel across urbanized zones becomes increasingly significant (Lynch, 2019). Greenways offer a feasible solution to facilitate species movements and enhance ecological connectivity when creating larger areas of habitat within urban environments would be impractical (Lynch, 2019).

The design and maintenance of ecological corridors require clear and precise objectives tailored to the particular location and species involved (Hess and Fischer, 2001, Meiklejohn et al., 2010). Flexibility is crucial for accommodating different species and ecological processes, effectively facilitating movement and conservation efforts (Tewksbury et al., 2002). Successful ecological corridor design includes considering factors such as landscape structure, species behaviour, and desired outcomes (Hess and Fischer, 2001; Meiklejohn et al., 2010).

Ecological corridors support forest ecosystem development by facilitating the movement of species, genetic exchange, and maintaining ecological connectivity, which are essential for the long-term health and sustainability of forest ecosystems. A study by Tewksbury et al. (2002) provides evidence of the importance of ecological corridors for forest ecosystems. The researchers found that corridors can significantly enhance the movement of plants and animals between habitat patches, thereby reducing the isolation of populations and increasing genetic diversity within forest ecosystems. This increased connectivity is vital for the long-term survival and adaptation of species in the face of environmental changes.

The matrix, which refers to the "non-habitat" part of the landscape, plays a fundamental role in integrating corridors and habitat patches, influencing connectivity and species behaviour (Braum et al., 2004; Meiklejohn et al.; 2010). It ranges from areas dominated by human activities to semi-natural areas such as urban areas, agricultural land, grasslands, or forests, serving as both a habitat and a physical impediment to migration (Braum et al., 2004; Meiklejohn et al., 2010).

In industrialized countries, the development and implementation of ecological networks have gained attention as strategies for preserving biodiversity and facilitating sustainable use of natural resources (Bennett, 2004). Ecological networks are organized systems of naturally occurring or semi-natural landscape components designed and managed to protect ecological functions and support diverse species (Bennett, 2004). By integrating corridors, patches, and nodal areas into a cohesive and balanced system, these networks aim to address the problem of significant ecological fragmentation.

Moreover, ecological corridors, whether land-based or aquatic, play a crucial role in connecting habitat patches, facilitating species movement, enhancing biodiversity, and preserving ecological functions. Green corridors and greenways serve as valuable pathways for wildlife, and they also provide opportunities for human interaction with nature in urban areas. The design and maintenance of ecological corridors require clear objectives, flexibility, and consideration of the matrix and ecological nodes. Furthermore, the development and implementation of ecological networks are essential strategies for preserving biodiversity and mitigating the effects of ecological fragmentation.

Research results so far indicate there is an urgent need to create ecological networks as compact and effective as possible in rural and urban areas, to halt biodiversity decline, including biodiversity of forests. Therefore, in the present authors' opinion, it would require mixed approach in landscape planning to build a kind of ecological truss using all types of natural refuges and all types of ecological corridors of different ranks leading to the greening of the whole area (Żarska et al., 2006). Research presented in this paper is an attempt to develop such a mixed methodical approach to landscape planning in terms of biological diversity protection – to find and use every opportunity to create green infrastructure.

The aim of the present study was: to identify the types of ecological corridors and possibilities of creating new ones; to support the forests of The Kampinoski National Park within the surrounding agricultural landscape in the area of Leszno commune; to determine the functions and rank of these corridors; and, finally, to offer guidelines for shaping the ecological structure of landscape in terms of preserving and increasing biodiversity.

MATERIALS AND METHODS

Study Area

Leszno municipality is located within the Masovia Region (Masovian Voivodeship), in the western part of the Warsaw County, Central Poland (see: Figure 1).

The total area of the commune is 125.03 km^2, of which 51% is used for agricultural purposes (including 39% of arable land). The commune has an agricultural profile and serves as an important farming centre in the Warsaw region, focusing on vegetables, cereals, and root crops. The northern part of the commune, approximately 46% of its territory, lies within the area of the Kampinoski National Park (KNP) and the Natura 2000 area – PLC 140001 Puszcza Kampinoska, protecting the Kampinoska Primeval Forest, while the central area and the majority of the southern area fall within the buffer zone of the Park (the "Community"). Furthermore, the area stretching between the southern border of the KNP and provincial road No. 580 is designated as Warsaw's Protected Landscape Area. It is important to note that only a few small sections of the municipality located along its southern border are not included under legal nature protection mechanisms (http://archiwum.leszno).

In the strategic plan of the Leszno commune, three distinct zones can be identified, forming latitudinal strips of land. The northern strip of the commune primarily encompasses the Kampinoski National Park and Nature 2000 area mentioned above. This area is characterized by extensive forests, with relatively small shares dedicated to various development purposes. Within this northern strip, two settlements can be found: the village of Kępiaste – Łubiec and the village of Roztoka. The middle strip comprises the areas adjacent to provincial road No. 580 between Warsaw and Sochaczew, and is the primary location for new development projects within the commune. It serves as the urbanization development zone, particularly for single-family housing. The last land strip encompasses the areas located south of the buildings along the road No. 580, where the agricultural function prevails. The whole commune is also centrally transected with regional road No. 579 of meridian direction. In the middle and southern part (forestless terrain) of the commune main settlement units are located, including the villages of Leszno (capital of the of the commune), Zaborów, and Wilków (along district road No. 580).

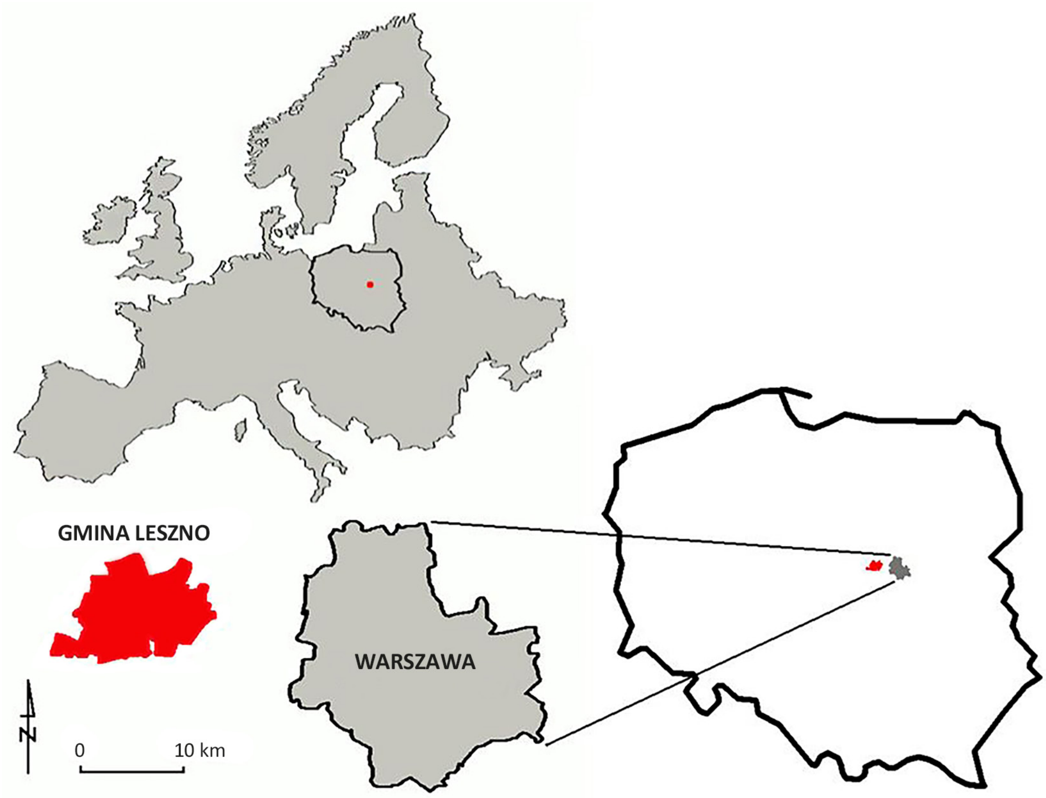


Fig. 1. Location of Leszno commune in Poland (source: Author's own elaboration)

The southern zone of the commune encompasses an area serving the agricultural production, with farm buildings concentrated along streets with a loosely structured layout. Occasionally, single-family housing can be found interspersed within this predominantly agricultural space (http://archiwum.leszno).

Indoor research and field study

Research work was divided into two main components: field study and desk research. The desk research consisted of two stages: prior to the field research, and after the field research. The field study was conducted on April 30th and May 1st, 2023. During the field research, the study area, located in the middle and south parts of Leszno commune in Poland, was observed and documented. The observations were made from both ground level and aerial perspective, using a drone. Photographic documentation was collected to capture the relevant ecological features and landscape characteristics. The next step of the field research involved the determination of different types of plant communities within the study area. Information on the composition, structure and diversity of plant species within each community was recorded. Additionally, the field research focused on identifying the dominant species in the existing tree plantings within the study area.

In addition to the field study, the desk research was divided into two parts: prior to the field research, and after the field research. Prior to the field study, information about the studied area was collected through literature, documents, and maps. This data provided insights into the ecological characteristics, land use patterns, and existing infrastructure of Leszno commune. Based on the collected information, the study area and its characteristics were described, taking into account ecological and spatial aspects. This characterization helped in identifying key landscape features, ecological assets, and potential constraints within the study area.

After the field research, the commune was divided into agricultural spatial-landscape units according to the methodology proposed by Żarska (2006), using maps, photographs, and the findings from the field research. These spatial-landscape units were defined based on ecological characteristics, land use patterns, and connectivity potential. The boundaries of each unit were determined, with the view to creating a comprehensive division map that visually represented these units and their ecological and landscape features.

Furthermore, the agricultural units of the commune were valorised using a predefined scale consisting of several different categories of evaluation. The following six categories were considered, according to Żarska (2006): the size of vegetation cover (including farming crops and other plants planted by humans), dominant levels of vegetation cover, connections within the analysed unit, connections with neighbouring units, variety of types of plant communities within the unit (the areas with farming crops were also analysed, because synanthropic plant communities were found there), and variety of tree and shrub species in plant communities. Each category had a maximum of 3 or 4 points assigned. The numbers of points possible to obtain for each criterion are explained below:

1. Vegetation cover in the evaluated area, including farming crops:
   - 1 point: Poor vegetation cover (< 25%)
   - 2 points: Small percentage of vegetation cover (26%–50%)
   - 3 points: Medium amount of vegetation cover (51%–75%)
   - 4 points: High percentage of vegetation cover (> 75%)
2. Dominant layers of vegetation cover:
   - 1 points: Herbs dominate
   - 2 points: Shrubs dominate
   - 3 points: Trees dominate
   - 4 points: Mixed vegetation dominates (all layers together)
3. Ecological connections within the analysed unit:
   - 0 points: Plant communities are not connected
   - 1 point: Poorly connected
   - 2 points: Medium level of connection
   - 3 points: Great level of connection
4. Ecological connections with the neighbouring units:
   - 0 points: Plant communities are far away from one another and not connected
   - 1 point: Poorly connected
   - 2 points: Medium level of connection
   - 3 points: Well connected

5. Variety of tree types in the unit (single trees, rows, clusters, densely growing plants):
   1 point: 1 – 2 types of plant communities
   2 points: 3 types of plant communities
   3 points: more than 3 types of plant communities
6. Variety of tree and shrub species in plant communities:
   1 point: 1 or 2 species present
   2 points: 3 species present
   3 points: 4 species present
   4 points: 5 or more species present

Based on the total number of points obtained, the areas were categorized into having very low ecological value (< 10 points), low ecological value (from 10 to 14 points), medium value (from 15 to 19 points), or high value (from 20 to 24 points). However, due to the limitations regarding drone usage and transportation within the National Park, only agricultural areas outside of the park were included in the valorisation process, whereas agricultural areas in the north part of the commune were not subjected to score assignment. The occurrence and rank of ecological corridors were determined based on the collected data and field research findings. The ecological significance and connectivity of each corridor were assessed and ranked according to their importance for landscape connectivity and biodiversity conservation.

Based on the research findings, indications for landscape shaping were determined. These indications considered the field study results, the division of agricultural spatial-landscape units (see: Figure 2), and the identification of ecological corridors. Recommendations were provided to enhance landscape connectivity, promote biodiversity, and integrate ecological corridors into the landscape planning framework.

Finally, maps were prepared (see: Figure 3) for each previously analysed agricultural part of Leszno commune. These maps included the identified ecological corridors, and proposed changes or improvements to be made in each area, based on the research findings.

RESULTS AND DISCUSSION

The map presented in Figure 2 illustrates the division of Leszno commune into agricultural spatial-landscape units (Żarska, 2006) and highlights various features and land uses within the area. The map was created based on the combination of field research findings, collected data, and existing maps and documents.

The map in (Figure 2) highlights agricultural landscape areas, marked with letter "A", where arable lands dominate, however, these encompass also grasslands, meadows, surface water, vegetation on private gardens. These areas represent conventional farming practices. There are a total of 11 agricultural areas in the south part of the commune, with a significant concentration in the southernmost part.

The points for each category and agricultural unit are shown in Table 1, along with the sum of points for each unit. Based on the total points obtained in the valorisation assessment, the agricultural units can be categorised and subdivided into three classes, representing different levels of ecological value. The first class includes agricultural units with a low ecological value, scoring from 10 points to 14 points. These units are A5 and A6, both of which obtained 11 points, and unit A3, which obtained 12 points. They exhibit little vegetation cover, limited connectivity within and between the units, and a lack of diversity in terms of plant communities and species. These units require significant improvements in vegetation cover and connectivity in order to enhance their ecological value and promote biodiversity conservation.

The second class comprises agricultural units with a medium ecological value, scoring between 15 points and 19 points. Units falling into this category include A1, A7, A8, and A9. These units exhibit moderate to high vegetation cover, varying levels of connectivity within and between units, and some diversity in terms of plant communities and species. While these units have a solid foundation for ecological value, further efforts are needed to strengthen connectivity, enhance diversity, and promote sustainable land management practices to maximize their potential for biodiversity conservation and ecosystem services.

The third class represents agricultural units with a high ecological value, scoring between 20 points and 24 points. Units A2, A4, A10, and A11 fall into this category. These units showcase a high percentage of vegetation cover, strong connectivity within and between the units, and a diverse mix of plant communities and species. They serve as important ecological corridors and provide valuable habitats for biodiversity. These

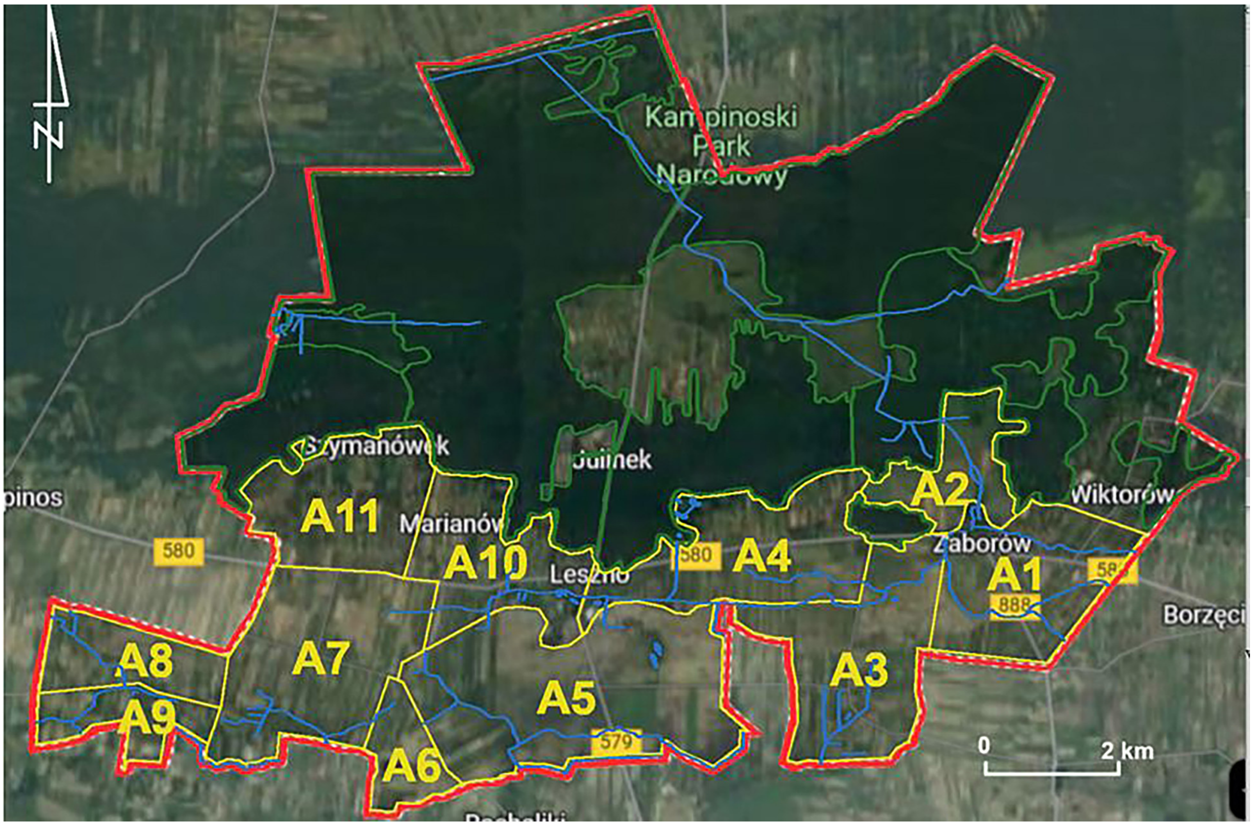


Fig. 2. Leszno commune: division into agricultural spatial-landscape units; explanations in Table 1 (source: Author's own elaboration, using https://maps.google.com/)

Table 1. Leszno commune: results of ecological valorisation (source: Author's own elaboration)

Evaluation criteria	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
Vegetation cover in the area	3	4	2	3	1	2	3	2	2	4	4
Dominant levels of vegetation cover (herbs, shrubs, trees)	3	4	2	4	2	2	3	2	3	4	4
Connections within the analysed unit	3	3	2	3	2	1	3	3	3	4	4
Connections with the neighbouring units	3	3	1	3	2	1	2	3	3	4	4
Variety of types of plant communities within the unit	4	4	3	4	3	4	4	3	4	4	4
Variety of tree and shrub species within plant communities	1	3	2	2	1	1	3	2	2	4	4
Sum of points	17	21	12	20	11	11	18	15	17	24	24

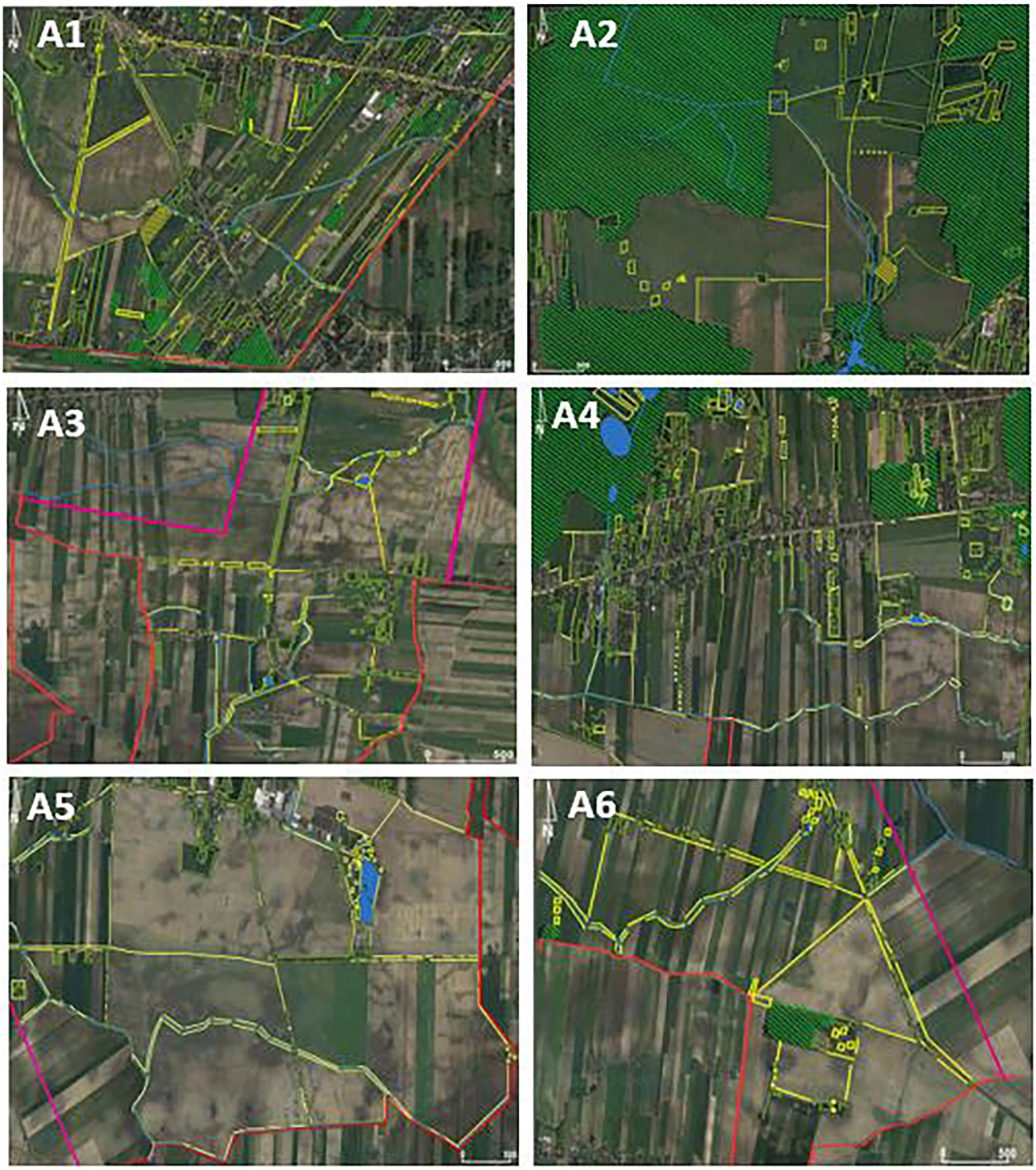
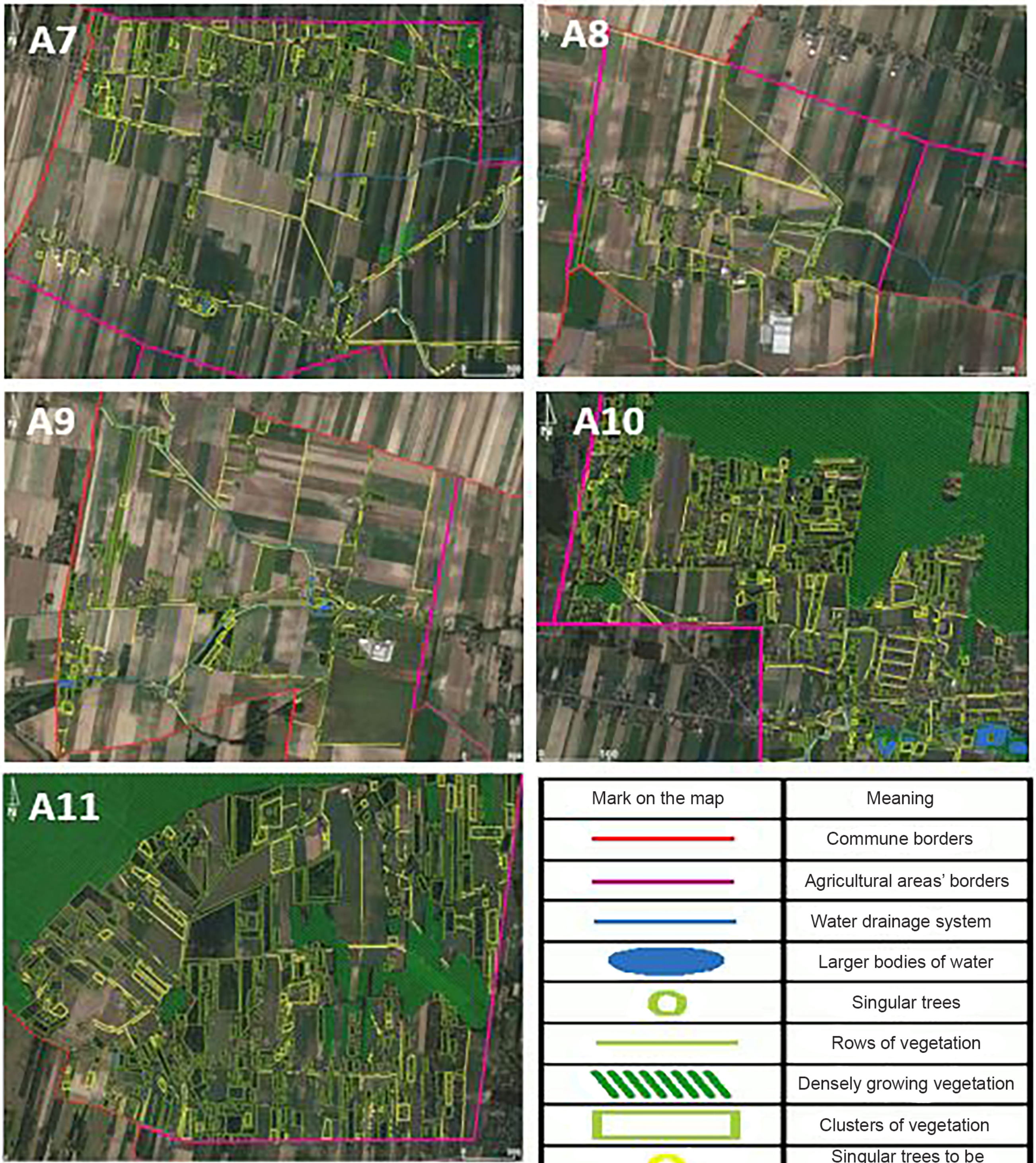


Fig. 3. Agricultural areas of Leszno commune, labelled as units A1–A11, and proposed suggestions for changes (scale on the map: 1 cm = 500 m) (source: Authors' own elaboration)



Mark on the map	Meaning
	Commune borders
	Agricultural areas' borders
	Water drainage system
	Larger bodies of water
	Singular trees
	Rows of vegetation
	Densely growing vegetation
	Clusters of vegetation
	Singular trees to be introduced
	Rows of vegetation to be introduced
	Densely growing vegetation to be introduced
	Clusters of vegetation to be introduced

Scale on the maps: 1 cm = 500 m

Fig. 3. cont.

units should be prioritized for conservation and sustainable land management practices to preserve and further enhance their ecological value. There were no units with very low values (less than 10 points total).

The agricultural areas of Leszno commune, labelled as units A1–A11, which illustrate the existing plant communities forming ecological corridors, as well as proposed suggestions for changes were presented in Figure 3. They demonstrate how the proposed modifications would contribute to the creation of a well-connected and functional ecological network, supporting biodiversity of forests and agricultural lands alike, fostering habitat quality, and promoting landscape resilience within Leszno commune.

It is important to note that in the analysis and depiction of vegetation, the term "vegetation" refers to both trees and shrubs. Furthermore, vegetation located on fenced lands was not analysed nor illustrated on the map, ass it does not contribute to landscape connectivity due to the barrier posed by the fences.

The A1 agricultural landscape unit within Leszno commune also includes the water drainage system. The map indicates the presence of numerous patches of densely growing vegetation. Additionally, small clusters of trees are scattered throughout the landscape. These clusters, along with individual trees, form stepping stone corridors. The map highlights the existence of rows of trees along the drainage network, which create linear corridors. Based on the findings and observations, several recommendations for this area were proposed. Firstly, planting rows of trees along the main roads to further enhance connectivity and ecological functionality, and to create natural barriers against wind, noise, and pollution. Secondly, covering the gaps existing between clusters of trees to promote enhanced connectivity and continuity of ecological corridors. Lastly, the focus is placed on enriching the vegetation along the drainage water system. By enhancing the vegetation in this specific area, the ecological value and functionality of the water network can be improved, providing additional habitat and connectivity for various species.

Agricultural area designated as the A2 unit includes portions of forest complexes, which are denoted as densely growing vegetation. These forest complexes serve as important ecological components within the agricultural area. Grasslands and meadows with single trees and clusters of trees, respectively, are present within this agricultural unit as well. A segment of the residential area is also visible. Part of the drainage system is connected to a larger water surface. This water feature plays a significant role in the landscape dynamics and hydrological connectivity of the area. One notable feature in the eastern part of the map is a stepping stone corridor, which consists of big clusters of vegetation, rows of vegetation, and several standalone trees. This corridor effectively connects the forest complexes, thus providing a pathway for species movement and enhancing overall ecological connectivity. The water bodies and waterways in this area are bordered by areas of vegetation, further contributing to the ecological value of the corridor. In the northern part of A2, there are several rows of trees, serving as linear ecological corridors that connect the forest complexes. These corridors play a crucial role in facilitating species movement and gene flow between forested areas. The vegetation located in the visible portion of the residential area appears rich and well connected. Based on the analysis, several proposed changes are recommended for this agricultural unit. The suggestions include creating another stepping stone corridor between two forests by planting additional clusters of vegetation. Additionally, planting rows of trees in the central part of this agricultural unit to form linear corridors connecting all forests is recommended. Covering the gaps in forest with clusters of vegetation would enhance connectivity within this forest complex. Enriching the vegetation surrounding the drainage system by adding rows of trees would create a coherent network of linear ecological corridors in agricultural landscape.

The agricultural area labelled as the A3 unit encompasses various water bodies along with additional smaller water features within the agricultural unit. Housing areas are also present, and these areas exhibit relatively rich vegetation compared to other parts of this agricultural unit. Although there are some scattered rows and small clusters of trees along the drainage system in several places, overall vegetation connectivity is limited. Along the main road, however, there are rows of trees that form a long, linear ecological corridor. Smaller roads also exhibit some vegetation rows, although they are less developed compared to those along the main road. The vegetation near the water bodies is relatively poor in comparison. Based on the analysis, several recommendations can be made to enhance the ecological value and connectivity within the A3 agricultural unit. Enriching the vegetation along the drainage networks by planting rows of trees would create linear corridors, thus facilitating connectivity along these important hydrological pathways. Establishing new plantations near the surface water bodies and waterways, in the form of clusters of trees and rows, would help connect with other plant communities and create coherent ecological corridors. Additionally, adding more rows of vegetation along the smaller roads would further enhance the connectivity and ecological value of the whole agricultural unit. Creating a large stepping stone corridor in the centre of the unit would serve to connect the vegetation near the housing areas with the linear corridor along the main road. This corridor would also link the more remote, separate tree clusters near the commune border.

The agricultural area of the A4 unit includes a portion of the drainage system W, as well as the water bodies and other smaller water features within the agricultural unit. In the western part of the terrain, a section of the densely growing vegetation from the forest complex is visible, while a small fragment can be seen on the eastern side. These forest complexes are marked as densely growing vegetation, indicating their significance in terms of ecological value. Central part of the A4 unit is occupied by a residential area, where the vegetation is relatively well developed, consisting of clusters of trees near the buildings and rows of trees along the roads. The vegetation near the drainage system in this agricultural unit is poorly developed, with only several rows of trees in some areas. The larger water bodies enclosed by vegetation are primarily located within the forest, while the remaining water bodies have limited or no vegetation in their proximity. Clusters of vegetation are present near the borders of the forest complexes, contributing to the overall ecological connectivity in the area. Additionally, a sizable patch of densely growing vegetation near the forest is well connected to this forest complex through clusters of trees. The vegetation on the arable areas within the A4 unit is sparse and lacking in diversity. Based on the analysis, several recommendations can be proposed to enhance the ecological connectivity and vegetation within the A4 unit. These include creating more clusters and rows of trees in the northern part of the agricultural unit, in order to improve connectivity between the forest complexes and cover larger distances between the existing clusters of trees. Planting more rows of trees along the roads would further enhance ecological connectivity in the area. A key recommendation is to establish clusters of trees near the water bodies, and to plant rows of trees along the drainage system, connecting them to create coherent ecological corridors. Additionally, in areas where single trees are present, adding more plants to create clusters would enhance their ecological value. Lastly, efforts should be made to connect vegetation patches, currently separated, with the rest of the landscape to ensure continuous ecological connectivity.

The agricultural area of the A5 unit with a small portion of the residential area is visible, located in the northern part. This area exhibits the highest concentration of vegetation within the A5 unit, with clusters of trees near the buildings and rows of trees along the roads. The drainage system and the water bodies are also present in this agricultural unit. Along the drainage system, some rows of trees can be observed, but there is a lack of vegetation near the water body. Overall, the vegetation in this agricultural landscape unit is poorly connected, particularly in the central and southern parts where the arable lands are located. The mid-field vegetation is separated and dispersed, with considerable distances between respective clusters. This fragmentation hinders ecological connectivity in the area. To improve ecological connectivity, several recommendations can be made. Planting rows of trees along the drainage water system would help establish linear corridors and enhance connectivity within the A5 unit. Additionally, creating clusters and rows of trees near the water body would help enclose it within a vegetated environment, fostering habitat connectivity and ecological functionality. Another important suggestion is to establish a long linear corridor in the centre of the unit, consisting of rows of vegetation. This corridor would serve as a crucial connection point, bridging the gaps between the separated, disconnected vegetation patches. Moreover, covering the gaps in vegetation along the roads and other isolated areas using rows of trees and singular trees would further improve connectivity and promote a well-connected ecological network.

The agricultural area of the A6 unit includes a portion of the drainage system and two other small bodies of water. A small fragment of the residential area is also visible. In the southern part of the unit, there is a significant patch of densely growing vegetation near the border of the commune. However, this vegetation patch is currently disconnected from other plant communities within the A6 unit. Along the water drainage system, there are infrequent rows of trees, but the overall presence of vegetation is limited. The majority of vegetation is concentrated near the housing buildings in the northern part of the unit, taking the form of clusters and rows. Some vegetation is also observed along the roads, mainly in the form of rows and singular trees. To enhance ecological connectivity within the A6 unit, several recommendations can be made. Planting more clusters of vegetation in the northern part of the unit would create stepping stone corridors, providing connectivity towards the surface water bodies. Establishing linear corridors using rows of vegetation along the drainage system and the roads is crucial, particularly in the central part of the unit, where the lack of vegetation is most evident. These linear corridors would serve as essential conduits for connecting the vegetation in the northern part of the unit with the surrounding vegetation near the water bodies.

The agricultural area of the A7 unit features small sections of the water drainage systems along with several larger bodies of water. Residential areas are also present within the A7 unit. The most significant concentration of vegetation is observed along the roads, taking the form of rows, small clusters, or single trees. Additionally, vegetation is present near buildings in the residential areas, primarily in the form of clusters. For the visible part of the water drainage system, vegetation features in the form of rows along the water, while the drainage networks also exhibits some rows of trees, although in fewer numbers and with less connectivity. Several small patches of densely growing vegetation are predominantly situated in the northern part of this unit, and they are well connected through the vegetation occurring in the residential area. The vegetation in residential area, on the other hand, is only connected with the vegetation in other residential areas at a single location, being the central part of the unit. To enhance connectivity within the A7 unit, several suggestions can be made. It is recommended to create numerous linear corridors in the form of rows of vegetation, especially along the roads and the drainage system. These corridors would establish a coherent ecological network, facilitating movement and interaction between different plant communities. Furthermore, introducing additional clusters of vegetation near the residential areas would help to fill in the empty spaces between the existing plant communities or enlarge the existing vegetation consisting of single trees or small clusters.

The agricultural area of the A8 unit includes a portion of the water drainage systems as well as the residential area. Vegetation in the A8 unit is predominantly concentrated in the residential area and along the main road. The vegetation near the water drainage system is relatively sparse and primarily consists of short rows of trees and singular trees. However, there is a substantial amount of vegetation along the drainage network, primarily in the form of rows. Several large clusters of vegetation are present within and near the residential area, indicating terrains of higher vegetation density. These clusters provide potential opportunities for connectivity within the A8 unit. In order to improve ecological connectivity in the A8 unit, several recommendations are necessary. Firstly, creating linear corridors along the roads, both drainage systems, and along the borders of the commune would effectively connect all the existing plant communities within this spatial-landscape unit. The second recommendation is to establish more clusters of trees within the A8 unit, which would contribute to enlarging the existing plantings.

The agricultural area of the A9 unit includes the drainage system as well as the water bodies. Furthermore, a residential area is visible. The central part of the A9 unit stands out as the richest in vegetation, particularly near the residential areas and buildings within the unit. Clusters of vegetation are prevalent in these areas. The vegetation along the roads primarily consists of rows of trees and is relatively well developed, albeit with some minor gaps. Along the drainage system, the vegetation predominantly comprises rows of trees. It is notably well developed in the central and southern parts of the unit, while the northern part of the drainage networks features some scattered rows of vegetation, and the connectivity there is not as strong. The water bodies are surrounded by vegetation, and they display good connectivity with other plant communities. To improve ecological connectivity within the A9 unit, several recommendations can be proposed. Firstly, the creation of additional linear corridors, in the form of rows of trees, along the roads and the drainage system would be beneficial. These corridors would enhance connectivity, especially in the northern part of the unit and between fields where gaps in vegetation exist. Secondly, adding more clusters of vegetation is advisable to enlarge and connect the existing clusters within the A9 unit, particularly in the proximity of the large water bodies.

The agricultural spatial-landscape unit A10 has a significant share of the forest complex, indicating a considerable presence of natural vegetation, as well as villages. The water system includes a small portion and two prominent surface water bodies, bigger water bodies (ponds or lakes). The vegetation near the water bodies is highly abundant and well developed, except for a small portion in the southwest area where the drainage network lacks vegetation. The dominant vegetation in this agricultural unit consists of clusters of trees or small patches of densely growing vegetation. Rows of trees are primarily found along the roads, with some near the residential areas. Notably, the vegetation in the residential areas is rich and well connected with the adjacent forest complex and other smaller patches of plant communities. In terms of recommendations for enhancing ecological connectivity, the A10 unit is already well designed with a highly functional ecological network. However, some minor adjustments could further optimize the overall connectivity within the commune. Suggestions include adding rows of trees along the roads, especially in the residential area. Introducing clusters of trees between the existing clusters in the northern part of the A10 unit would contribute to the formation of more densely growing vegetation, potentially expanding the forest complex. Moreover, planting more clusters of trees near the large water bodies would bolster connectivity between terrestrial and aquatic habitats. Lastly, addressing the lack of vegetation in the specified segment of the drainage system by introducing rows of trees and shrubs would further enhance the ecological functionality of that area.

The western part of agricultural area A11 contains a section of the forest complex. The unit includes a small portion of a residential area. There is also a small water body. The vegetation cover in the A11 unit is generally at a high ecological level, with several patches of densely growing vegetation located in the central and eastern parts of the agricultural unit. Large clusters of trees are found in the northern part, while numerous small clusters of trees are distributed throughout the central and southern regions. Additionally, rows of vegetation can be observed along the roads. Overall, the vegetation cover is well developed in the A11 unit and most plant communities are effectively connected through stepping stone corridors. Given the high level of connectivity and vegetation quality already present, there are only a few suggestions to further enhance the ecological network. Firstly, increasing the number of rows of trees along the roads would separate the larger plant communities, functioning as natural habitats, from the noise and pollution produced by cars; furthermore, it would also provide additional corridors. Secondly, planting more vegetation in areas where singular trees occur would help evolve them into clusters, thereby expanding the patches of densely growing vegetation.

One more important recommendation, beneficial in the presented sample areas and in the most layouts of landscape ecological structure in geographic-climatic zones where forests occur, is: wherever possible, to designate arable lands adjacent to forests for afforestation, and/or to turn these arable lands into permanent grasslands. Such action would lead to the enlargement of existing forests and to creating a friendly neighbourhood in their vicinity.

Reinforcement of landscape ecological structure, including establishment of new wild species migration routes, is especially important in man-made, transformed landscape, where patches of natural vegetation (e.g. forests) are only remnants surrounded by agricultural and urban areas (EUR-lex, 2003; Popesku et al., 2022). Therefore, developing green infrastructure within the landscape is one of the strategic directions of action to achieve sustainable development.

Research shows that the gains in connectivity were 38% higher where new priority corridors were implemented, compared to focusing the restoration efforts solely on enhancing the existing corridors, which resulted in an 11% increase in connectivity (Dondina et al., 2018). Research results presented in this paper indicate that there is a great necessity to do both: maintain the existing ecological corridors, and create new ones, leading to high enrichment of the whole ecological network, while pointing the importance of ecological connectivity at the local level (as (without local connectivity, regional and national ecological corridors will not be much effective)). For local populations of wild species, green infrastructure at the local level is a matter of survival.

Ecological corridors face significant challenges from roads, primarily due to the isolation the latter create, and the negative impact on numerous species through roadkill incidents (Hoctor et al., 2007; Popesku et al., 2022). Our research confirmed the importance of solving problems of road-barriers in species migration, but in the same time, it indicated the necessity to implement various protective activities, by focusing on enhancing vegetation cover and creating green corridors both along roads, and crossing ((under or above) the) roads, in order to mitigate the negative effects of roads on species movement, with special regard to solve these problems at the local level as well.

Designing ecological corridors is an important measure that must be taken in accommodating the movements of species populations. Organisms tend to use the areas surrounding their paths of movement, whether on a daily or on a seasonal basis, and these must be taken into account when constructing a landscape ecology design (Handel et al., 2012; Yemshanov et al., 2019). In our research concept, this requirement is confirmed and fulfilled, and our proposal takes it even further: the emphasis is put on multi-action approach in landscape and land use planning, leading to the creation of a dense ecological net, and to the maximization of biologically active terrains in the whole area. What is more, the parallel operation, proposed in the paper, should be to allocate stripes of arable lands adjacent to forests for afforestation (where possible), or at least for permanent grasslands. In opinion of the authors of this paper, in general, a policy of afforestation and a policy of shaping mid-field plantings should be correlated, and this implies coordination at the local level of management in particular.

Following ecological corridors' effectiveness, monitoring is crucial to enable adaptive management strategies. Adaptive management is a structured, science-based approach that enhances our understanding and lowers uncertainties. It is essential to engage in these practices, in order to increase the chances of achieving the goals of ecological corridor and to gain insights from the already-implemented corridors. Monitoring becomes particularly important in identifying species for which corridors fail to meet their connectivity needs, allowing for targeted interventions (Merenlender and Keeley, 2022).

Additionally, and interestingly, according to van der Windt and Swart (2007), during recent decades the term "ecological corridor" has become a popular concept quite well-known among scientists of life sciences (e.g. ecologists, nature conservators, environmental specialists, spatial planners), politicians, and various stakeholders. In our opinion, it is true in developed countries, but probably not in underdeveloped countries, however it goes without saying that this term has a great "social" potential to be enthusiastically implemented in reality, and not only during landscape or land use planning, especially in EU countries. In any case, ecological corridors and more broadly understood ecological networks should be widely introduced to the current planning, which is also emphasized by Popescu et al. (2022).

CONCLUSIONS

Results of the presented research, conducted in geographic-climatic conditions of the central part of the European Lowland, shows the great importance of landscape and land use planning by introducing ecological corridors, and a broader understanding of ecological networks in agricultural areas surrounding forest refuges, both on the grounds adjacent to forests, and in the areas located further away.

Our research strongly indicates the high importance of the local level in landscape and land use planning, next to equally important regional and national levels of spatial planning and management. Some relevant opportunities to strengthen the landscape ecological structure in rural areas, as well as a variety of possible action, are evident at the local level, and they are crucial for the local population of wild species. The methodical approach used in this research, including area division into landscape-spatial units for inventory and further analysis, enables detailed insights to identify gaps in ecological structure and possibilities to find suitable tools to improve the ecological network, including the continuity of ecological corridors.

The research results clearly indicate the necessity of mixed and multi-action approach through detailed recognition, evaluation, and design of landscape ecological structure, while implementing various solutions, including different types and ranks of ecological corridors with the support of technical ways to minimize ecological barriers in wildlife migration. Ecological enrichment of agricultural landscape, which prevails especially in lowlands in climatic zones that are suitable for farming, is important as a support for the biodiversity of forest, the latter occurring usually in minority within rural areas. It is also important for a greater resilience to climate change.

By assessing the vegetation cover, the dominant levels of vegetation, the connectivity within and between the analysed spatial-landscape units, and the variety of plant communities and species, valuable insights into the ecological value of each unit were obtained.

The results from the ecological assessment of the agricultural units reveal distinct patterns and characteristics helpful to determine suitable activities to supplement the natural structure. Linear corridors and dispersal (stepping stone) corridors are very useful and relatively easier to introduce in the agricultural landscape at the local level of planning.

In conclusion, relevant improvement of the ecological structure in man-transformed landscape, with emphasis on natural refuges (e.g. forests) and the increase of ecological corridors concerning their share, number, size, and rank, as well as the enhancement of plant communities, are vital steps towards conserving and restoring biodiversity across the whole area.

The evaluation method of rural areas presented herein could be implicated by the local government for landscape planning and management.

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ULEPSZENIE SYSTEMU KORYTARZY EKOLOGICZNYCH NA OBSZARACH WIEJSKICH ORAZ IMPLIKACJE DLA PLANOWANIA I ZARZĄDZANIA KRAJOBRAZEM GMINY LESZNO W CENTRALNEJ POLSCE

ABSTRAKT

Cel badań

W artykule przedstawiono badania mające na celu rozpoznanie, ocenę i poprawę powiązań ekologicznych na obszarze gminy Leszno, ze szczególnym uwzględnieniem doskonalenia istniejących i tworzenia nowych korytarzy ekologicznych na obszarach wiejskich sąsiadujących z ekosystemami leśnymi, wchodzącymi w skład Puszczy Kampinoskiej, na terenie Kampinoskiego Parku Narodowego, w centralnej Polsce, pośrodku Niziny Środkowoeuropejskiej.

Materiał i metody
Badania źródłowe składały się z dwóch etapów: przed przeprowadzeniem badań w terenie i po ich zakończeniu. W trakcie badań terenowych obserwowano i dokumentowano obszar badawczy, położony w Polsce, w środkowej i południowej części gminy Leszno. Zastosowano autorskie podejście metodyczne, wykorzystujące podział obszaru badań na jednostki krajobrazowe w celu przeprowadzenia dalszej szczegółowej analizy i umożliwienia precyzyjnego sformułowania zaleceń. Oceniwszy pokrywę roślinną, dominujące poziomy roślinności i ich ciągłość w obrębie jednostek rolniczych i poza nimi, uzyskano ważne informacje na temat wartości ekologicznej poszczególnych jednostek krajobrazowych.

Wyniki i wnioski
Za główne wyzwanie uznano negatywny wpływ dróg na korytarze ekologiczne. Uznano znaczenie roślinności wzdłuż dróg i wewnątrz pasaży siedliskowych dla łagodzenia izolacji ekologicznej. Zaproponowano: zwiększanie szaty roślinnej i tworzenie różnego rodzaju korytarzy zielonych – liniowych, ostojowych i krajobrazowych – łączących lasy, a także umiejscowionych wzdłuż dróg, przy jednoczesnym zachowaniu strefy wolnej od roślinności wysokiej bezpośrednio przy drodze (ze względu na wymóg widoczności dla kierowców) jako środki mające na celu łagodzenie skutków ruchu drogowego, zachowanie łączności i promowanie przemieszczania się gatunków.

Słowa kluczowe: korytarze ekologiczne, łączność ekologiczna, ochrona różnorodności biologicznej