

Will the Soutok/Confluence protected area fit in with other Moravian lowland riverine protected areas? Comparing landscapes, values, pressures, and effective protection

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ABSTRACT

Lowland riverine protected areas in Czechia are relatively rare and threatened by anthropogenic pressure. In the Moravian region, two protected landscape areas (PLAs), Litovelské Pomoraví and Poodří, were established in the early 1990s. In 2025, the Soutok (Confluence) PLA was designated. This article compares these three areas based on landscape characteristics (land cover, watercourse length, landscape fragmentation and connectivity, anthropogenic pressure, and priorities for protection) to evaluate how Soutok compares to the established two. The analysis includes a 3km buffer area. A marked contrast exists between the PLAs and their buffers; while the PLAs are largely natural or semi-natural with an increasing proportion of forests (especially Litovelské Pomoraví and Soutok) or permanent grasslands, arable land and built-up areas dominate adjacent areas. This land-use intensification causes landscape fragmentation, creating a crucial limitation for landscape connectivity. Therefore, nature protection priorities are concentrated along the watercourses, which remain relatively natural in the PLAs (with a slight decrease in naturalness in Litovelské Pomoraví and Soutok, and an increase in Poodří), but channelized, regulated, and shortened in adjacent areas. Positive changes are evident within the two PLAs designated in the 1990s; Soutok shares similar traits with Litovelské Pomoraví, which may indicate a relatively positive future for this new PLA.

KEYWORDS

Soutok/Confluence of the Morava and Dyje Rivers; protected landscape area (PLA); landscape change; anthropogenic pressure; Czechia

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1. Introduction

Riverine landscapes are a vital part of natural processes. The landscape around rivers is connected to the water streams and fluvial processes transporting material and energy through the landscape (Montgomery and Wohl 2003). These parts of the landscape are dynamic and important for broader surroundings from a biological and ecological point of view because they are acknowledged as biodiversity hotspots (Tockner et al. 2000).

In Central Europe, there are few areas with a natural hydrological regime and a preserved, close-to-nature landscape. The rivers in Czechia have been negatively affected by channelization (Grygar et al. 2010) and by high anthropogenic impact, such as intensification of agriculture and construction (Kiliánová et al. 2017). Despite these changes, floodplain forests and close-to-nature habitats persist in some localities, making these localities highly naturally valuable (Miklín et al. 2014).

In the Morava region, three lowland protected areas of high merit in this regard can be found: Litovelské Pomoraví, Poodří, and Soutok.

Protected areas (PAs) are used as a key tool for preserving natural values. They are established to face biodiversity loss and enhance ecosystem conditions (Watson et al. 2014). Natura 2000 is a significant network of protected sites for selected species and habitats in the European Union (European Commission 2021). However, implementation of the Natura 2000 can be suboptimal in the case of Czechia (Křenová and Kindlmann 2015; Miklín and Čížek 2014). Moreover, Natura 2000 sites are more concentrated on protecting certain species and habitats, not ecosystems or landscape (European Commission 2015). On the other hand, Protected Landscape Areas (PLAs) have zonation, detailed management plans, and other tools for better fulfilment of their objectives (Czech National Council 1992).

Many studies have been published for specific sites (e.g. Mácha et al. 2023; Miklín and Čížek 2014; Miklín and Hradecký 2016; Poledniková et al. 2025); however, there is no comparison of three similar areas regarding landscape characteristics. This article, therefore, focused on comparing landscape development and the qualities of three areas to highlight their strengths, weaknesses, opportunities, and threats, as well as the similarities and differences between them. The aim was to analyze landscape changes, anthropogenic pressure on the landscape, landscape connectivity, fragmentation, and spatial natural conservation prioritization to detect key phenomena of the PLAs and their surroundings (Kubacka et al. 2022; Mingarro and Lobo 2023). Litovelské Pomoraví and Poodří have been protected as nationally designated PLAs since the early 1990s, but Soutok has been protected only as Natura 2000 sites since 2005 and became a PLA recently (2025).

We concentrated on comparing long-term nationally non-protected Soutok with the other two older PLAs to evaluate whether Soutok has similar landscape features as the others.

Generally, we hypothesized that:

- the PLAs have similar landscape characteristics, with natural land cover and preserved natural and semi-natural habitats, mainly floodplain forests along unregulated rivers;
- the adjacent areas are vastly transformed, which can be a threat for protection and landscape functioning;
- high prioritization rankings within PLAs than buffers;
- Soutok is like the two older PLAs regarding presence of natural habitats and their species;
- inside the PLAs, anthropogenic pressure on the landscape (including traffic intensity) is lower than in the 3km buffer and that anthropogenic pressure was more pronounced in the 3km buffer;
- the three areas serve as important links for migration routes of various animal species on a regional scale.

2. Materials and methods

We compared key landscape features in three PLAs and their buffers (Fig. 1) to show strengths and weaknesses of the landscape as well as opportunities and threats. We analyzed land cover changes, water stream change, anthropogenic pressures, associated landscape fragmentation, and functional connectivity. In addition, priorities regarding the values for each area were examined.

2.1 Study area

Litovelské Pomoraví mainly consists of persistent forests and meadows. The PLA was designated in 1990, covering 93.3 km² with a 248.6 km² buffer. This differs from other parts of the landscape along the Morava River with a larger portion of increasing arable land and settlements (Kiliánová et al. 2017). The Morava divides into many natural anastomosing channels, together with man-made channels (Máčka 2016). Veteran trees are crucial havens for biodiversity (Nakládal et al. 2022). The average annual flow of the Morava River in the Soutok PLA is around 20 m³s⁻¹ (ISVS CHMI.CZ).

Poodří PLA was designated in 1991, covering 81.5 km² with a 273.5 km² buffer; the average annual flow of the Odra River is 7 m³s⁻¹ (ISVS CHMI.CZ); close to Ostrava, it is an area formerly glaciated by a continental ice sheet. The Odra River flows through the flat terrain, where many branches originated. They have been used by human to build ponds and channels, but the river has remained relatively unaffected and meanders still exist (Hradecký et al. 2016;

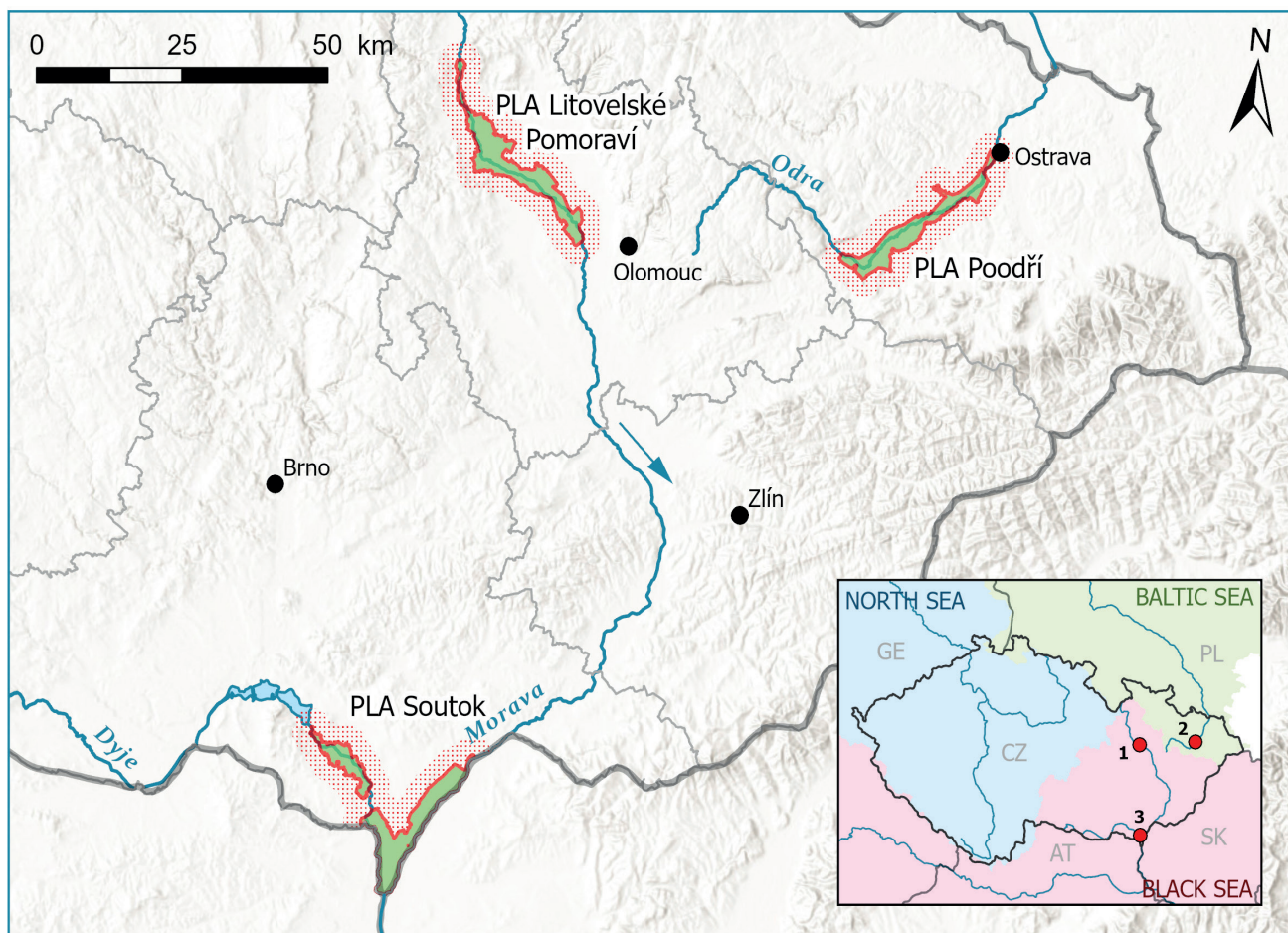


Fig. 1 Study area. (1) Litovelské Pomoraví, (2) Poodří, (3) Soutok PLAs and their buffers.

Poředníková et al. 2025). The area is less forested than other Czech PLAs (Janík et al. 2024a). Landscape changes are relatively dynamic, including non-forest woody vegetation as an important habitat for some species (Mácha et al. 2023).

Soutok consists mainly of floodplain forests and meadows (this new PLA covers 127 km², with a buffer in Czechia of 223.6 km²). However, it is surrounded by an increasing share of arable land. Forestry has intensified alongside agriculture, threatening open woodlands and other valuable habitats (Miklín and Čížek 2014). The main water streams were affected by anthropogenic changes to the hydrological regimes, but some other streams have remained more natural (Miklín and Smolková 2011). The average annual flow of the main streams in the PLA Soutok is the largest of the three areas of interest, the Morava River 52 m³s⁻¹ and the Dyje River 34 m³s⁻¹ (ISVS CHMI.CZ).

2.2 Data

2.2.1 Land cover

Land cover data were processed manually by vectorization in ArcGIS 10.x (ESRI 2020) software. Using topographic maps and aerial imagery, we captured

land cover in four periods for the three areas, including their buffers. Datasets cover the last seventy years (1950–2020).

The 1950s represent the beginning of modern nature conservation in Czechia, as well as large changes in landscape caused by agricultural collectivization. The dataset was based on 1:25,000 Czechoslovak military maps from 1952–1956 (General Staff of the Czechoslovak Army 1952–1956).

The 1990 dataset is a milestone for changes in political, economic, and social regimes; it is also a reference point because Litovelské Pomoraví PLA was designated in 1990 and Poodří in 1991. The dataset from this period was based on 1:25,000 Czechoslovak military maps from 1988–1995 (General Staff of the Czechoslovak Army 1988–1995).

The 2004 dataset represents EU accession and changes associated with agricultural policy and transposing other legislation into national law. Land cover data was vectorized from a 1:10,000 base map (Czech Office for Surveying, Mapping and Cadastre 2002–2006) and aerial imagery with a pixel size 0.5 m (Czech Office for Surveying, Mapping and Cadastre 2003–2005).

The last period is a contemporary dataset (2016 to 2020) based on aerial imagery with pixel size 0.2 m (Czech Office for Surveying and Cadastre 2016–2020)

Tab. 1 Land cover categories.

Land cover category	Description
Other area	Mining areas, dump sites, dams
Arable land	Arable fields, mosaics of fields and trees and small vineyards, fallow land
Permanent grassland	Meadows, pastures, steppes, wetlands
Garden and orchard	Intensive and extensive orchards, large gardens adjacent to built-up areas
Vineyard and hop field	Small and large scale, facility included
Forest	Forest, non-forest woody vegetation, mountain pine, shrubs, forest nurseries
Water body	Ponds, lakes, reservoirs, pools, flooded mining areas
Built-up area	Continuous and dispersed built-up areas, industrial, agricultural and military sites, cottages, cemeteries
Recreational area	Garden allotments, spa resorts, zoological gardens, golf courses, camps

and supported by LPIS (Land Parcel Information System – Soil registry; Ministry of Agriculture 2016–2020).

Land cover data were captured as polygons larger than 0.8 ha and wider than 40 m. This ensured the same level of generalization from sources of different spatial scale (1:10,000 to 1:25,000 topographic maps and aerial photographs with pixel sizes from 0.5 m to 0.2 m). Given the different sources that capture land cover types in different detail, and to make corresponding maps comparable, nine land cover categories were identified (Tab. 1).

2.2.2 Natural habitat mapping data

Natural habitat data were provided by the Nature Conservation Agency of the Czech Republic (©AOPK) as vector data for the whole of Czechia at 1:10,000. This dataset was developed during NATURA 2000 establishment and is continuously updated.

2.2.3 Water streams

Length of the water streams were analyzed from manually vectorized line spatial data based on maps of the second military survey from the 19th century (1836–1852) and the current Fundamental Base of Geographic Data of Czech Republic (ZABAGED®). It is expected that significant modifications of water streams began in 19th century and continued in the 20th century.

2.2.4 Anthropogenic pressure

Anthropogenic pressure is composed of structures such as built-up and recreational areas (camping sites, golf courses, sport fields, etc.) and communications (roads, dirt roads, and streets). Polygon structures are more detailed than within land cover. The minimum polygon size is 0.2 ha. It follows a similar temporal period as for land cover:

The 1960 dataset was created by vectorization from a 1:10,000 topographic map (Central Administration of Geodesy and Cartography 1957–1971) and aerial images from the 1950s.

The 1990 dataset is based on a 1:10,000 base map (Central Administration of Geodesy and Cartography 1986–1995).

The 2004 dataset is vectorized from a 1:10,000 base map (Czech Office for Surveying, Mapping and Cadastre 2002–2006) and aerial imagery with a pixel size 0.5 m (Czech Office for Surveying, Mapping and Cadastre 2003–2005).

The 2016–2020 dataset represents the current situation; it was obtained and edited from ZABAGED® and aerial imagery with a pixel size 0.2 m (Czech Office for Surveying, Mapping and Cadastre 2016–2020).

We also extracted buildable areas from current municipal spatial planning documents.

To analyze landscape fragmentation, we also used data on traffic intensity. This is expressed using annual average daily intensity measured during regular (usually every five years) National Transport Censuses provided by the Directorate of Roads and Motorways on all motorways, Class I and II roads, and selected Class III roads. For our study, results from 1950, 1990, 2005, and 2021 were used.

2.2.5 Landscape connectivity

Landscape connectivity analysis was built on previous research by Romportl et al. (2021), which created a set of habitat suitability models for the Czech environment for various protected animal species. Therefore, there was no need to prepare additional spatial data. In the map representation of landscape connectivity analysis, we used data on planned construction of the road and railway network and buildable areas.

2.2.6 Prioritization

Data about landscape quality can evaluate the PLAs and their buffers to highlight priorities for protection. We divided the data into four groups:

- Biodiversity – the inputs were habitat suitability models of animals selected by our experts and PLA administrations. Habitat suitability models were calculated from records on the National Database of Fauna-Flora Records [NDOP] (Nature Conservation Agency 2022a) and predictors characterizing landscape features (altitude, slope, precipitation, temperature, land cover, etc.). Predictors were selected individually for each species based on its requirements. Then, the MaxEnt approach was used (Phillips et al. 2006), which enables

habitat suitability modelling with presence-only data (Elith et al. 2011). MaxEnt is based on maximum entropy, which estimates the probability of species' distribution from occurrence data and environmental predictors (see selected species in Appendix 1). Habitat suitability models (HSM) were created by the MIAMaxent tools (Vollering et al. 2019; Romportl et al. 2021). Plants were represented by maps of richness of native and Red List species for grassland and forest vegetation modelled by Divíšek and Chytrý (2018).

- Natural qualities of the landscape are composed of seven individual features:
 - Geodiversity layer – based on abiotic factors of topography, climate, soil, and geology.
 - Habitat diversity – computed as the number of habitats in defined surroundings (cell of 10 × 10m and 500m buffer) from the Consolidated layer of ecosystems of the Czech Republic (Nature Conservation Agency 2013; Romportl et al. 2021).
 - Number of species – recorded in regular square net from NDOP (Nature Conservation Agency 2022a).
 - Quality of habitats – derived from the habitat mapping layer (Nature Conservation Agency 2022b).
 - Presence of habitats – from the habitat mapping layer (Nature Conservation Agency 2022b); less-represented habitats in Czechia were weighted more to better represent all habitats.
 - Length of edges – from the Consolidated layer of ecosystems of the Czech Republic (Nature Conservation Agency, 2013) to analyze landscape structure.
 - Natural forests and primeval forests layer (Vrška et al. 2023).
- Cultural qualities of landscape data are reflected by the map of potential presence of historical cultural landscapes (Šantrůčková et al. 2023). This map shows, in a 1 × 1 km grid, several types of historical small-scale cultural landscapes (extensive agriculture, forests, permanent grasslands, vineyards, hop fields, orchards, ponds, spas, mining, and religious landscapes). We extracted information on whether the cultural landscape was present in the current cell and how many landscapes were present.
- Anthropogenic transformation is scaled into nine classes, ranging from densely built-up areas to pristine forests, from the Consolidated layer of ecosystems of the Czech Republic (Nature Conservation Agency 2013; Romportl et al. 2021).

2.3 Methods

We compared the three areas and their buffers regarding land cover changes, changes in water stream length, natural habitat stability, landscape fragmentation and connectivity, and priorities for protection.

This identified strengths, weaknesses, opportunities, and threats for these riverine landscapes.

2.3.1 Land cover

We analyzed changes and stability of land cover categories and landscape structure from 1950s to today for the areas and their buffers to evaluate differences between protected and non-protected landscapes and between the three areas.

2.3.2 Natural habitat assessment

Information about land cover changes was used to evaluate individual natural habitats and their formation groups in areas with different land use. The groups of natural habitats used in the analysis are as defined by Chytrý et al. (2010): streams and water bodies; wetlands and riverine vegetation; springs and mires; cliffs and boulder scree; secondary grasslands and heathlands; scrub and forests. Habitats heavily influenced or created by humans were not included. Polygons containing mosaics of different habitats were assigned to the dominant habitat type, provided it covered at least 51% of the polygon's area. If no single habitat type exceeded 51% of the area in a mosaic polygon, that polygon was excluded from the analysis.

2.3.3 Water streams

The density of water streams (km per km²) and the index of change between the 19th century and today were calculated.

2.3.4 Anthropogenic pressure

The density of communications (roads, dirt roads, and streets) and the proportion of built-up, recreation, and buildable areas were counted for every time horizon. Differences between the areas and their protected and non-protected parts were then evaluated.

2.3.5 Landscape fragmentation

Selected anthropogenic structure data were merged into one layer of fragmentation geometry and the Effective Mesh Size (EMS; Jaeger 2000; Moser et al. 2007; Girvetz et al. 2008) was computed. Analysis consisted of fragmentation geometry, a mask of the selected areas, and a regular square grid (500 × 500 m).

In the first fragmentation geometry version (FGa), built-up areas and roads were merged with a buffer that expresses their estimated land area. The buffer radius corresponds to road network categories based on the following expert evaluation: motorway – 13 m; first class road – 8 m; second class road – 5 m; third class road – 4 m. The second version (FGb) again merged built-up areas and roads, but road buffers were expressed by traffic intensity with a conversion factor of 1 vehicle = 1 cm of buffer radius. Fragmentation geometry resulted in two versions (FGa and FGb) for the four milestones (1960, 1990, 2004, 2020).

The EMS method works on simple mathematical calculations of the size of the areas remaining after cutting fragmentation geometry from the layer of the interested area. These remaining areas are then intersected with a square grid, with resulting EMS calculated according to the formula (Girvetz et al. 2008):

$$m_{\text{eff}}^{\text{CBC}}(j) = \frac{1}{A_{tj}} \sum_{i=1}^n A_{ij} A_{ij}^{\text{cimpl}}$$

The resulting variable $m_{\text{eff}}^{\text{CBC}}(j)$ represents the EMS (in km²) for the given unit (500 × 500 m square) where: n is total number of patches extending into one square; A_{tj} total area of the square; A_{ij} partial area of the patch that extends into the square; and A_{ij}^{cimpl} total area of the patch. The EMS values express, figuratively, the probability of mutual connection of two randomly located landscape points. Thus, the higher the EMS, the higher the connecting probability and, simultaneously, the lower the landscape fragmentation level.

2.3.6 Landscape connectivity

Landscape connectivity analysis was carried out for the whole country. From this, we prepared individual PLA maps. The analysis was based on the abovementioned HSM of protected species. From these HSM for dozens of different rare fauna species, seven functional animal groups were created (Tab. 2). Analysis was done for each functional group.

When analyzing landscape connectivity, we used least cost path modelling, where input data were resistance surface and the system of core areas. The resistance surface was created from the habitat model for each functional group by a simple mathematical operation (1 – habitat model); a larger value means greater resistance of the given species to movement through the landscape. Core areas were based on expertly determined parameters of habitat suitability and minimum area size.

Core areas were linked using Linkage Mapper Toolbox 3.0 (McRae and Kavanagh 2011). The resulting line network was expertly verified to ensure that modelled paths were not mis-defined (e.g. passing through built-up areas). A buffer zone was added to the edited line network, with which the connectivity

raster was subsequently trimmed, as one of the outputs of the tool used. This step gave the migration corridors a changing riverbed that better matches the environmental conditions than simple lines. For clarity, the results for individual functional groups were combined according to prevailing and relevant environmental preference into forest, meadow, water (and wetland).

2.3.7 Prioritization

We utilized Zonation software, a conservation planning and prioritization tool, working with raster layers (Moilanen et al. 2005; Moilanen and Kujala 2006). All input data were transformed into a 100 × 100 m grid, a resolution corresponding with the most input layers and suitable for management planning. Zonation software works iteratively and hierarchically, removing cells from the landscape according to their priorities. We chose the algorithm of Additive benefit function, emphasizing richness and diversity and count average values of all inputs, which can represent a wider group of phenomena not included in the analysis (Lehtomäki and Moilanen 2013; Moilanen 2013; Moilanen et al. 2011).

Biodiversity data and natural qualities layers are then run separately. Biodiversity data were treated with weights for habitat suitability models from 1 to 5 according to how endangered a species is based on expert knowledge and the Red List for Czechia (2017; Appendix 1). Finally, aggregated outputs for animals and plants were given equal weight. Priorities for natural qualities were calculated separately with the same weight for each input.

To sum up, all four groups of data were run with the same weight, with final prioritization of the result.

3. Results

3.1 Land cover

Litovelské Pomoraví PLA is mostly forested, which increased during the study period. Before 1990 arable land increased while permanent grassland decreased; after 1990 (and PLA designation), the opposite processes began. Built up areas grew

Tab. 2 Parameters of landscape connectivity analysis used.

Functional groups	Parameters of landscape connectivity analysis		
	Minimum habitat suitability (%)	Minimum size of core area (ha)	Buffer zone of migration path (m)
Forest mollusks	40	1	500
Forest butterflies	50	5	1000
Wetland butterflies	40	5	1000
Open landscape amphibians	75	10	500
Forest birds	40	50	2500
Waterfowl and wetland birds	50	10	2500
Forest mammals	25	100	2500

throughout the whole period. The buffer is dominated by arable land, but coverage declined; there is less permanent grassland now than at the beginning, but it grew from 1990. Forest increased slightly and built-up areas hugely. The PLA and its buffer experienced increasing landscape fragmentation. Both parts remained relatively unchanged; the buffer has been predominantly used for agricultural and is more stable than the PLA. Most of the stable arable land areas within the PLA buffer are currently characterized by large fields. Remnants of small-scale arable land patterns, including former water bodies, are located mainly in the northern part of the buffer area. In the eastern part, the remnants of former water bodies are still visible, although most have been drained by several artificial watercourses.

Poodří shows two different regimes. Before 1990 (PLA designation), arable land grew, together with forest, water bodies, and built-up areas. After 1990, arable land decreased with ongoing forest expansion. Built-up areas and water bodies remained stable after 1990, while permanent grassland decreased and then increased. The buffer is dominated by arable land, but it decreased and built areas grew significantly. Forests steadily expanded and permanent grassland remained relatively stable – decreasing and then increasing again to the same level. We can see relatively contrasting landscapes. Permanent grassland and forests are increasing in the PLA with arable land decreasing; there is a stable share of waterbodies and built-up areas. The buffer has a large portion of arable land and built-up areas, with a stable share of permanent grassland and increasing forest area. Both parts experienced increasing landscape fragmentation; the buffer, with predominantly agriculture use, remained more stable than the PLA with more environmentally favorable changes. In the PLA buffer, traditional and

continuously used agricultural land is currently dominated by larger plots, while in several municipalities, historical agricultural landscape structures have been preserved near built-up areas.

Soutok shows slightly different development. Arable land grew in the proposed PLA until 2004 (three Natura 2000 sites were established there in 2005) and then decrease between 2004 and today. Permanent grassland decreased during the whole period and built-up areas are negligible. The buffer is mainly arable land with a moderate reduction, and permanent grassland decreased too. The buffer is relatively diverse with increasing water bodies and built-up areas, plus gardens, orchards, and vineyards. Both the PLA and buffer experienced increasing landscape fragmentation. The PLA is slightly more stable, although both parts experienced relatively large change. Several areas with small plots of vineyards, fields, orchards and water bodies in the vicinity of the Soutok PLA preserve historically valuable agricultural landscape structures.

This analysis reveals that Litovelské Pomoraví and Soutok PLAs are continuously forested, whereas Poodří PLA has a larger portion of arable land, permanent grassland, and water bodies. The buffers are strongly agricultural in all cases with higher urbanization (Fig. 2).

3.2 Natural habitats

Land cover stability results were assessed in relation to the presence of natural habitats (Tab. 3). In Litovelské Pomoraví PLA, alluvial and oak-hornbeam forests dominate continuous forests. Alluvial forests are the most extensive habitats in the buffer, with two-thirds in continuously forested areas and one-third in areas that underwent land use changes. Meadows

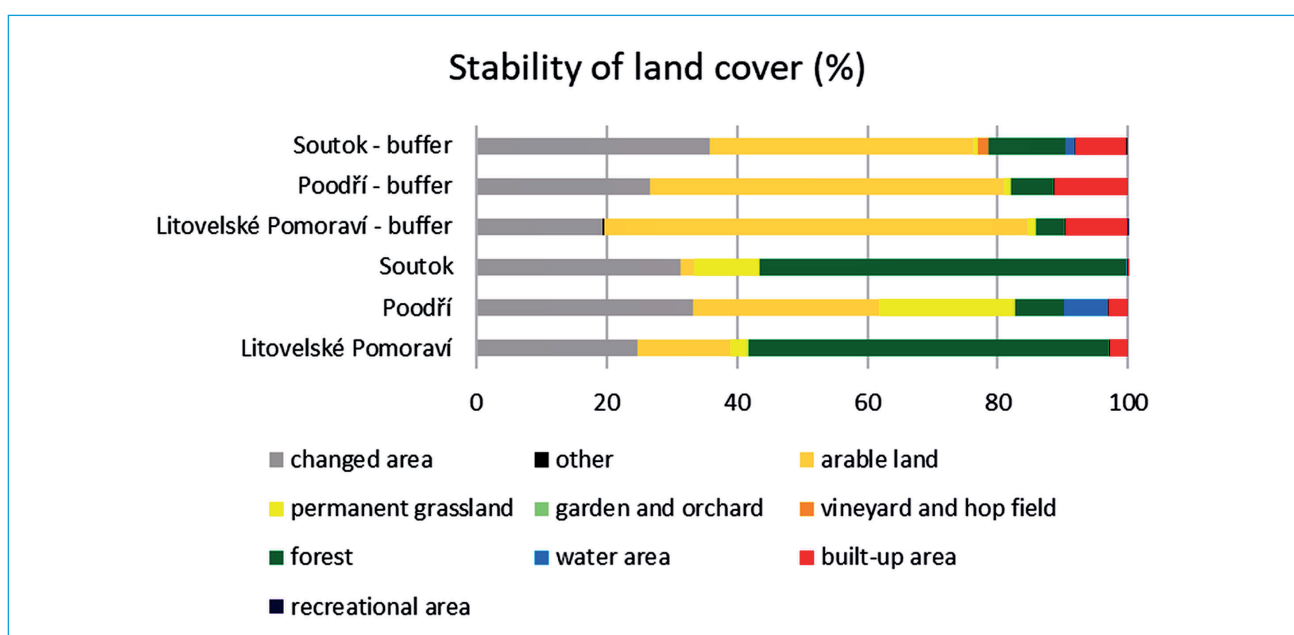


Fig. 2 Stable land cover categories in the PLAs and buffers for the whole study period (1950–2020).

and pastures are more prevalent in the buffer than the PLA, mainly present in areas where land cover has changed. The PLA was established to protect the river environment; therefore, macrophyte vegetation of water streams is present there. It is mostly found in unchanged areas, but one-quarter occurs in areas where land cover has changed.

Poodří PLA differs in that its most extensive habitats are meadows and pastures. Within the PLA, they prevail in unchanged areas, but they are also significantly present in areas where land cover has changed. Meadows and pastures are also important in the buffer, primarily in areas with land cover changes. The second most extensive habitats within the PLA are alluvial forests, found in both unchanged and changed areas. In contrast, oak-hornbeam forests dominate the buffer, where alluvial and beech forests are also significantly present. Within the PLA, habitats associated with the river environment are particularly important, including macrophyte vegetation of naturally eutrophic and mesotrophic still waters, macrophyte vegetation of water streams, and reed and tall-sedge beds. These habitats are predominantly found in unchanged areas but also occur in areas of land cover change.

Soutok is the most forested area, with alluvial forests as the dominant habitat, particularly within the PLA. These forests are primarily found in unchanged areas but have also developed in areas with land cover change. The buffer is significantly less forested,

with oak-hornbeam forests present alongside alluvial forests in both changed and unchanged areas. Within the PLA, meadows and pastures, macrophyte vegetation of naturally eutrophic and mesotrophic still waters and reed and tall-sedge beds are also present. Notably, reed and tall-sedge beds are concentrated in the southern part of the PLA, at the confluence of the Morava and Dyje.

3.3 Water streams

The highest density is in Poodří PLA, which increased in the study period. Litovelské Pomoraví and Soutok PLAs had a slight decline. The PLAs and buffers together experienced a decrease, reflecting higher water stream regulation in the buffers (Tab. 4).

3.4 Anthropogenic pressure and Landscape fragmentation

The average EMS in Litovelské Pomoraví PLA, based on built-up area and road network (FGa), is currently 20.7 km². In 1960, it was 21.6 km², representing a 6% decrease in landscape fragmentation over time. The average EMS in the buffer is significantly lower, but this is largely due to methodological limitations (specifically, the fixed 3 km boundary). It is therefore essential to monitor the development of

Tab. 3 Natural habitat groups (in %) in the Protected Landscape Areas (PLA) and buffer zones (3 km surrounding the PLA). LC – Land cover (stable or changed during the whole study period 1950–2020).

Groups of habitats	Litovelské Pomoraví				Poodří				Soutok			
	PLA		Buffer		PLA		Buffer		PLA		Buffer	
	Plots with stable LC	Plots with changed LC	Plots with stable LC	Plots with changed LC	Plots with stable LC	Plots with changed LC	Plots with stable LC	Plots with changed LC	Plots with stable LC	Plots with changed LC	Plots with stable LC	Plots with changed LC
Streams and water bodies	0.90	0.36	0.01	0.02	4.88	1.13	0.03	0.08	2.00	1.19	0.16	0.37
Wetlands and riverine vegetation	0.13	0.12	0.01	0.09	0.71	0.73	0.02	0.04	1.44	0.40	0.11	0.39
Secondary grasslands and heathlands	1.00	1.81	0.46	0.59	12.37	5.69	0.38	0.67	4.30	1.50	0.25	0.38
Scrub	0.07	0.09	0.01	0.04	0.15	0.26	0.04	0.08	0.01	0.01	0.01	0.02
Forests	44.23	1.64	1.14	0.61	7.76	6.66	2.64	1.90	44.52	5.62	4.19	0.79
<i>Total</i>	<i>46.33</i>	<i>4.02</i>	<i>1.63</i>	<i>1.35</i>	<i>25.87</i>	<i>14.47</i>	<i>3.11</i>	<i>2.77</i>	<i>52.27</i>	<i>8.72</i>	<i>4.72</i>	<i>1.95</i>

Tab. 4 Length of water streams.

Period	1840		2020		Index of change
	Water streams (km)	Density (km /km ²)	Water streams (km)	Density (km /km ²)	
CHKO Litovelské Pomoraví	307	2.87	286	2.67	0.93
CHKO Litovelské Pomoraví – including buffer	894	2.16	691	1.67	0.77
CHKO Poodří	269	3.32	335	4.13	1.24
CHKO Poodří – including buffer	698	1.96	681	1.92	0.98
CHKO Soutok	453	3.56	425	3.35	0.94
CHKO Soutok – including buffer	681	1.94	596	1.69	0.88

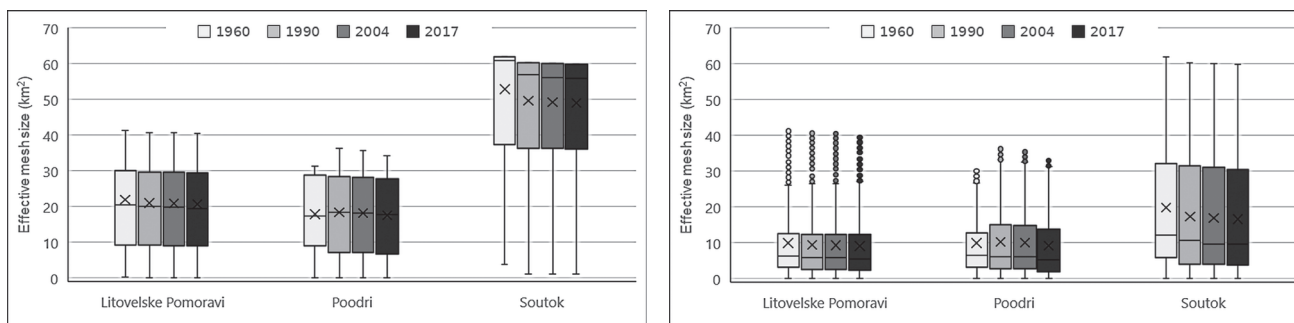


Fig. 3 Effective Mesh Size for built-up area and roads (FGa) in the PLAs (left) and buffers (right). The values should be compared relatively, with emphasis on trends over time. The absolute values in the buffers are influenced by the chosen methodology.

landscape fragmentation, as it has deteriorated by 8% since 1960, which is more than in the PLA itself. When traffic intensity (FGb) is included, the EMS decreases gradually with increasing traffic intensity; the EMS is now 3% lower in the PLA and 7% lower

in the buffer. Increasing landscape fragmentation is primarily caused by the expanding built-up area and increasing road network density in both areas since the 1950s (Tab. 5). The built-up area is currently 3 times higher in the buffer than the PLA. While the

Tab. 5 Changes in anthropogenic structures in the PLAs and their buffers since the 1950s.

Study area	Period	Density of communications (km/km ²)							
		Road network		Street network		Dirt-road network		Total	
		Buffer	PLA	Buffer	PLA	Buffer	PLA	Buffer	PLA
Litovelské Pomoraví	1960	1.04	0.33	1.48	0.28	3.71	5.54	6.23	6.15
	1990	1.15	0.40	1.49	0.34	2.30	4.93	4.94	5.67
	2004	1.23	0.41	1.56	0.38	2.51	4.84	5.30	5.63
	2017	1.26	0.45	1.71	0.47	2.43	4.68	5.40	5.60
Poodří	1960	1.05	0.32	1.37	0.26	3.84	5.18	6.25	5.76
	1990	1.16	0.39	1.47	0.30	2.54	4.56	5.16	5.25
	2004	1.24	0.41	1.53	0.35	2.78	4.43	5.55	5.19
	2017	1.29	0.44	1.71	0.43	2.69	4.29	5.69	5.16
Soutok	1960	0.72	0.11	0.90	0.03	3.95	3.60	5.58	3.75
	1990	0.87	0.15	1.01	0.03	3.46	3.55	5.34	3.74
	2004	0.88	0.15	1.06	0.03	2.85	2.87	4.79	3.06
	2017	0.88	0.17	1.63	0.01	2.81	3.44	5.32	3.62

Study area	Period	Proportion of recreational areas (%)		Proportion of built-up area (%)		Proportion of buildable area (%)	
		Buffer	PLA	Buffer	PLA	Buffer	PLA
		Buffer	PLA	Buffer	PLA	Buffer	PLA
Litovelské Pomoraví	1960	0.11	0.13	11.80	3.26	–	–
	1990	0.20	0.16	13.97	4.19	–	–
	2004	0.20	0.19	14.34	4.58	–	–
	2017	0.20	0.20	15.26	4.90	3.59	0.94
Poodří	1960	0.07	0.00	14.92	3.62	–	–
	1990	0.22	0.06	17.45	3.65	–	–
	2006	0.31	0.06	18.06	3.77	–	–
	2019	0.32	0.06	19.26	3.96	3.17	1.45
Soutok	1960	0.00	0.00	10.6	0.14	–	–
	1990	0.01	0.01	14.07	0.23	–	–
	2004	0.01	0.02	15.23	0.24	–	–
	2017	0.03	0.03	16.11	0.19	4.11	0.04

density of dirt roads has gradually declined, the overall density of all types of communications is comparable in both areas. Tab. 5 also shows that recreational areas in the PLA have increased steadily, whereas the buffer has remained stable since 1990s. Today, the proportion is the same in both areas (0.2%). Buildable area is nearly 4 times larger in the buffer than the PLA.

The current average EMS for built-up areas and roads (FGa) is 17.6 km² in Poodří PLA and 9.2 km² in the buffer. Like Litovelské Pomoraví, a gradual increase in landscape fragmentation can be observed – 1.3% in the PLA and 7.3% in the buffer compared to 1960. The influence of traffic intensity is particularly evident in the PLA, where the current average EMS (FGb) is 16.5 km² (8.2 km² in the buffer). Compared to 1960, this is a 7.7% and 17.5% deterioration in the PLA and buffer, respectively. This substantial difference in landscape fragmentation is largely due to the high proportion of built-up areas in the buffer, which increased from 15% in 1950s to nearly 20% today (Tab. 5). In contrast, the proportion in the PLA is 5 times lower, increasing by only 0.3% over the same period. In addition, road density has increased in the buffer but slightly decreased in the PLA. Street length has grown in both areas, although very minimally in the PLA. In contrast, dirt road density has declined in both areas and is now comparable. Like built-up area, the proportion of recreational areas in the PLA is 5 times lower than the buffer. While stable in the PLA since the 1990s, recreational areas in the buffer have expanded continuously. The proportion of buildable area in the PLA is more than 2 times lower than the buffer (Tab. 5).

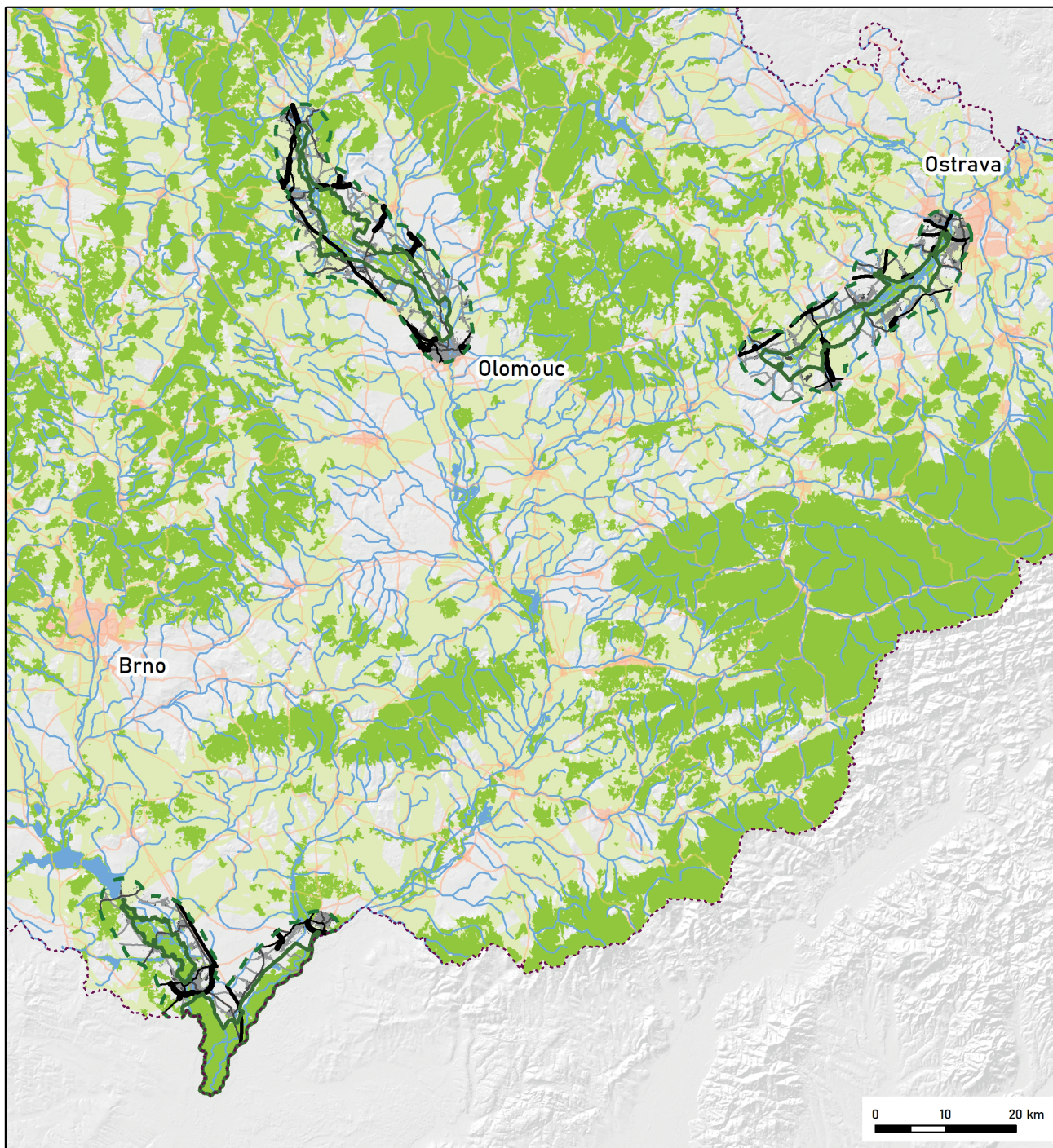
In Soutok, the current average EMS for built-up areas and roads is 49 km² in the PLA, and 16.7 km² in the buffer. Compared to EMS values in Litovelské Pomoraví and Poodří PLAs, Soutok is 2–3 times higher, indicating a lower degree of landscape fragmentation (Fig. 3). Since 1960, the average EMS in the PLA has decreased by 7.4%, which is similar to the reduction observed in the other PLAs. However, the buffer experienced a 16.3% decrease, indicating a fragmentation rate twice as high as the PLA. This decline is likely due to the presence of larger unfragmented areas in Soutok PLA; thus, the split of these areas has a significant effect on overall fragmentation. Traffic intensity in the PLA is similar to that in the other PLAs and contributes only slightly to the degree of landscape fragmentation. Low fragmentation in the PLA can be attributed to its very low population density, reflected by the small proportion of built-up area (0.2%) which contrasts with its surroundings where it is 16% (Tab. 5). While road density has continuously increased in both areas, dirt road density has declined, except for a slight increase in the most recent period in the PLA. A substantial difference is also evident in the proportion of buildable area – 0.04% in the PLA and 4% in the buffer (Tab. 5).

3.5 Landscape connectivity

Litovelské Pomoraví PLA is an extensive complex of floodplain and lowland forests, representing a significant remnant of natural habitats within an otherwise intensively managed agricultural matrix. Although fragmented by the town of Litovel and its deforested surroundings, they remain a crucial element for forest connectivity and wetland habitat integrity in the broader region. The connectivity model identified several well-preserved and more extensive floodplain areas as important for amphibian populations. Migration corridors along watercourses are vital for dispersing these species. Similarly, for aquatic and wetland-dependent species, corridors along the Morava River constitute the most important landscape linkages.

Poodří PLA and its buffer exhibit low forest cover. Consequently, existing forest fragments are critical stepping stones for forest-dwelling faunal species in the transitional zone between the Western Carpathians and the Oder Mountains. However, the functioning of these ecological corridors is endangered by major anthropogenic barriers, namely the D1 motorway and the international railway line. For amphibians, migration pathways towards the south are particularly important. Here, the D48 motorway presents a fundamental barrier, as does, to some extent, the natural watershed dividing the Baltic and Black Sea drainage basins. Northward amphibian dispersal along the Oder River is conceivable. The PLA itself is a significant wetland complex. In this area, transportation infrastructure, coupled with numerous settlements and intensively cultivated agricultural land, constitutes major barriers that limit wetland habitat connectivity.

Soutok PLA also provides high-quality habitat for forest-dependent terrestrial fauna (Fig. 4); however, its connectivity is severely compromised. The entire central portion is fenced within Obora Soutok Game Reserve (the impact of this fence could not be incorporated into the landscape fragmentation analysis due to methodological constraints). The northeastern part of the PLA is isolated by the D2 motorway and the Brno–Bratislava railway corridor. Additional significant barriers include the town of Břeclav and its immediate urban periphery. This area also possesses high conservation value for amphibian populations. Numerous channels, pools, and coarse woody debris create valuable microhabitats, while the channels and floodplains themselves function as natural dispersal corridors. There are floodplain mounds (locally called 'hrúdy') – elevated, treeless remnants of aeolian sand dunes, dating from Pleistocene epochs prior to forest establishment, which have great ecological and biodiversity importance. These features support rare relict communities of organisms. Unfortunately, a significant portion of these unique habitats has already been degraded or lost due to conventional forestry practices.



Fragmentation geometry

Roads network

- highway
 - I. class
 - II. class
 - III. class
- built-up areas

Planned constructions

- roads network
- buildable areas

Landscape connectivity

forest mollusks, butterflies,
birds and mammals

core areas corridors

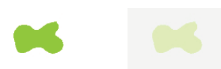
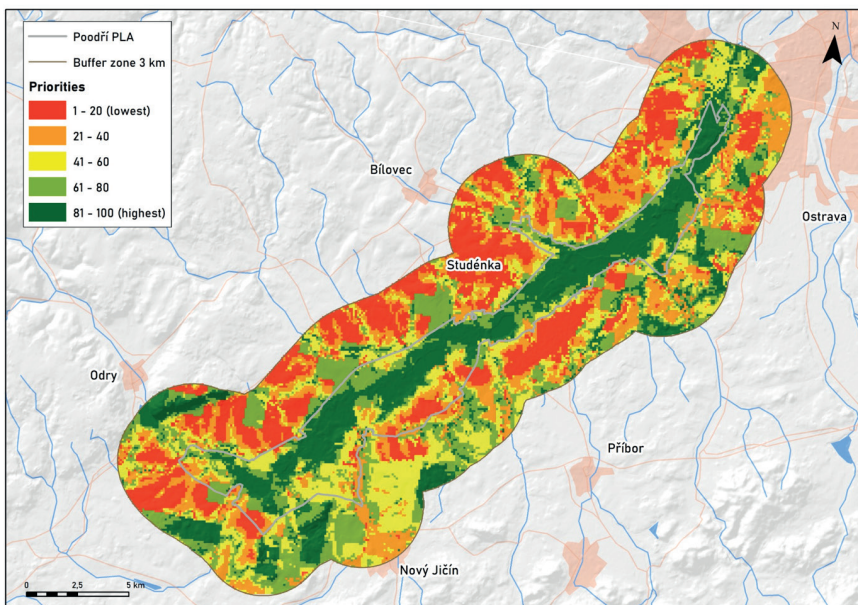
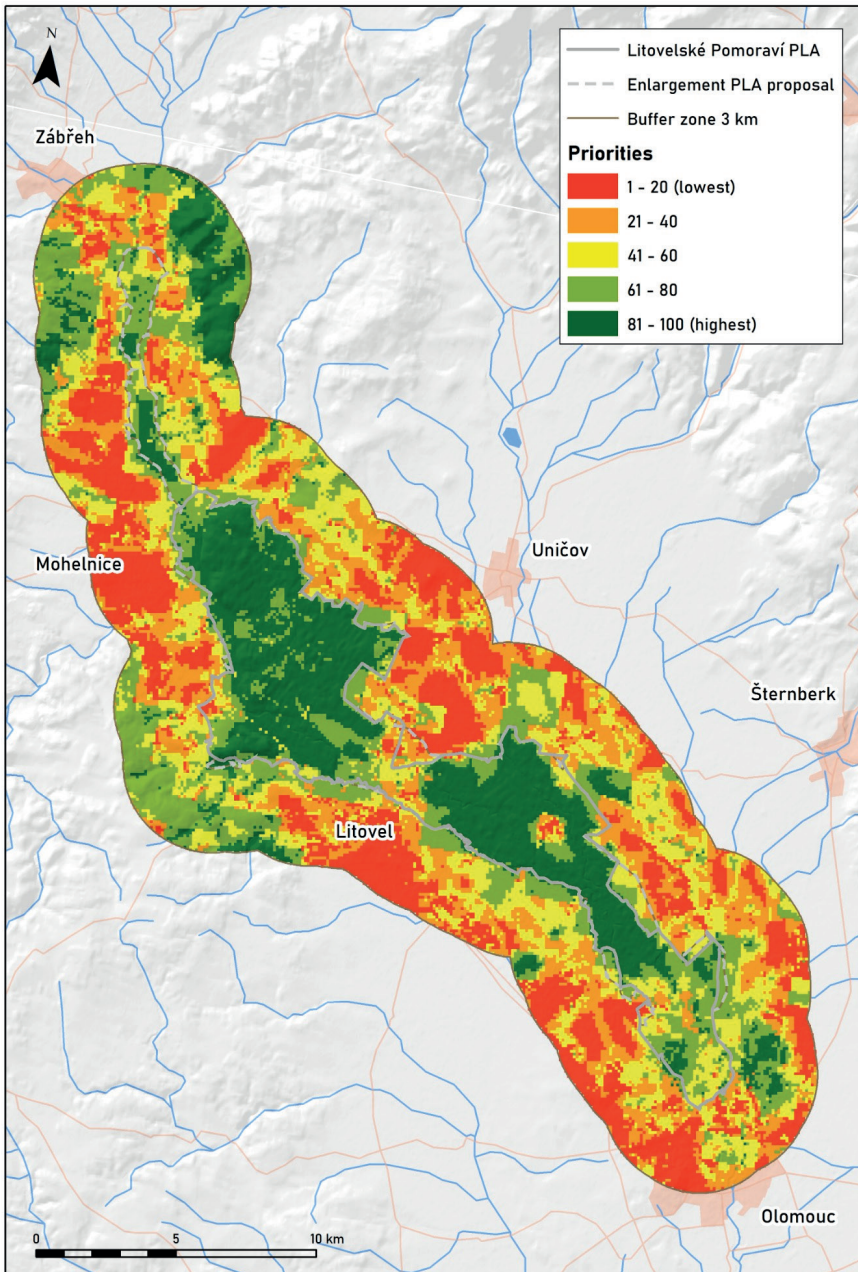


Fig. 4 Landscape connectivity of all three PLAs and buffers for forest habitat.



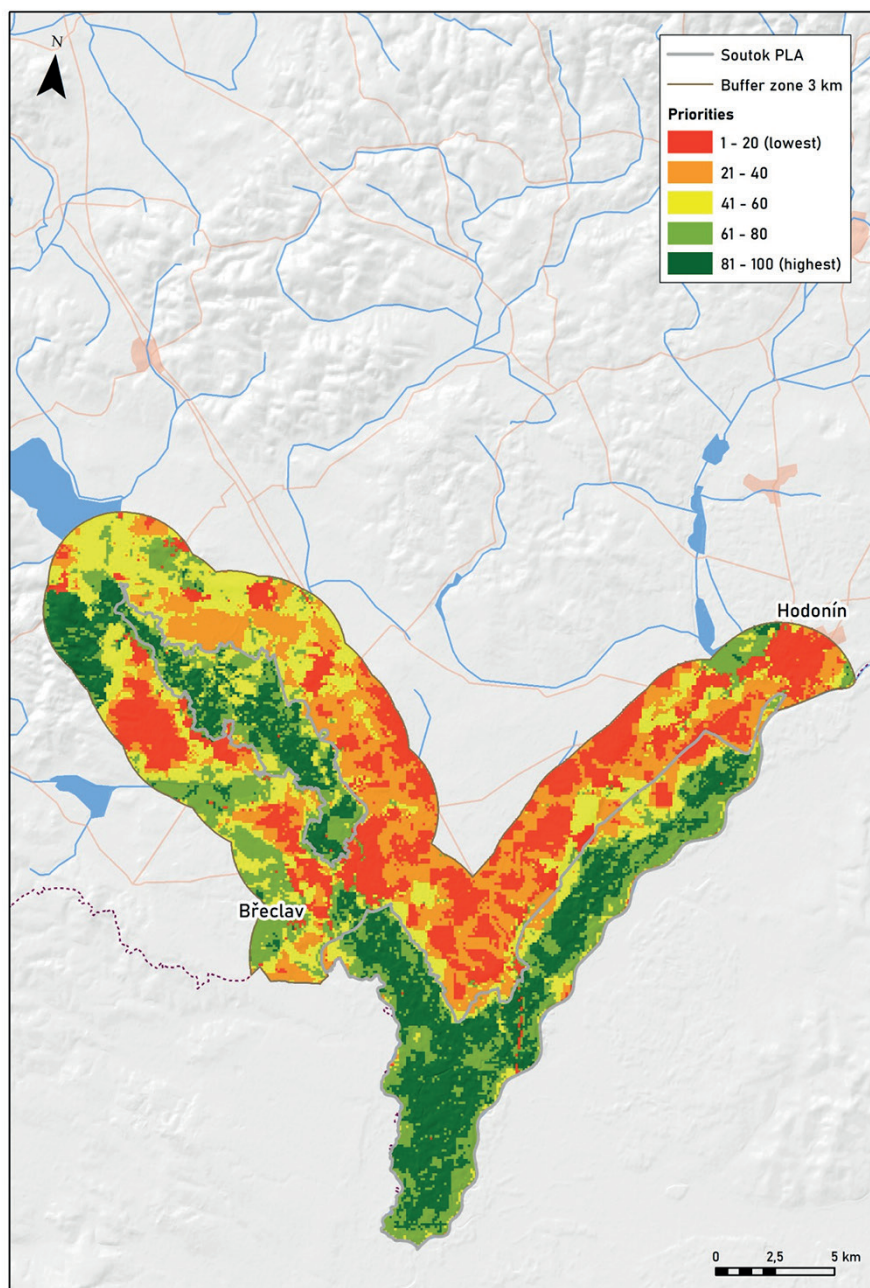


Fig. 5 Prioritization of three study areas – PLAs and 3km buffers.

3.6 Prioritization

In the study areas, priorities are concentrated especially on areas along the rivers. In Litovelské Pomoraví PLA, the core areas are in the south in the forested part, along the Morava River. If we consider the buffer, it has rather lower prioritization because of its intensively used landscape (agriculture and settlements); some areas along the river and forested areas are favorable. Similar priorities are found in Poodří PLA, with the values concentrated along the Odra River and associated ponds. The buffer is predominantly agriculture and settlements with intensively used infrastructure (motorways, railways, airport). Soutok has the highest priority in the core area with a dense network of water streams, but not along the borders and the largest rivers (Dyje and Morava) because of their

regulation (an exception is the Dyje around Lednice, with high natural and cultural values). The surroundings are intensively agriculture, therefore there are no priorities, only around ponds and in forested areas and areas continuing into Pálava PLA (Fig. 5).

4. Discussion

The study areas are important parts of relatively large and persistent riverine landscapes within Morava, with similar features as well as differences (Tab. 6). Valuable nature conservation parts are concentrated along the rivers. Litovelské Pomoraví and Soutok are rather forested in contrast with Poodří, which is more open with prevalent meadows and a large share of

ponds although, since PLA designation, its ecosystem services have improved (Mácha et al. 2023; Poedniková et al. 2025). However, landscape structure changes and management were negative for natural values in Soutok, so PLA designation may improve the situation (Miklín and Hradecký 2016). In the buffers, the analysis reveals intensification of land use along the Morava and Odra rivers, as elsewhere. Therefore, it is crucial to protect valuable forests with natural habitats. A positive trend of increasing permanent grassland is visible in the PLAs, despite the general decrease within the floodplain (Kiliánová et al. 2017). Land use intensification in the buffers is common for all three areas. Stability in arable land use and increased built-up areas cause limitations for landscape connectivity and potential threat of intensification of the land use within the protected areas as well.

The PLAs have a significant share of valuable natural and semi-natural habitats, providing evidence that they are an important component of both regional and

global biodiversity conservation strategies (e.g. Jackson and Gaston 2008; Hoffmann 2022). Thus, they fulfil the fundamental role of protected areas, which is primarily to preserve a representative sample of biodiversity, especially rare and threatened features (typically habitats or species), and to isolate or buffer them from external pressures (Margules and Pressey 2000). In Litovelské Pomoraví and Soutok, natural habitats (mainly alluvial and oak-hornbeam forests) cover more than half of the PLAs. Macrophyte vegetation of still waters and water streams are important despite their relatively small areas. In Poodří, natural habitats cover less than half of the area, but there are significantly alluvial, oak-hornbeam, and beech forests, meadows and pastures, plus macrophyte vegetation of still waters and water streams. Soutok is comparable with the older PLAs and this newly designated PLA complements the Czech system of protected areas with its rare and endangered riverine landscapes.

Tab. 6 Results as a SWOT analysis for the study areas, individually and combined.

Study area	Strengths	Weaknesses	Opportunities	Threats
Litovelské Pomoraví	Stable forested PLA. Valuable natural habitats in unchanged areas (mainly alluvial and oak-hornbeam forests). Lengthening of water streams. Landscape connectivity along the river. Valuable parts of landscape along rivers.	Weak presence of natural habitats in buffer. Shortening of water streams. Increasing landscape fragmentation. Urban areas (Litovel, Olomouc), TEN-T railway, D35 motorway and agricultural intensive land use disrupt landscape connectivity.	Valuable natural habitats (mainly meadows and pastures but also macrophyte vegetation of water streams) in both changed and unchanged areas (potential for restoration).	Intensive land use and landscape fragmentation influencing the PLA and its connectivity from buffer, including potential buildable areas.
Poodří	Increasing share of natural and close-to-nature land cover categories. Valuable natural habitats in unchanged areas (mainly macrophyte vegetation connected with water streams and still water). Lengthening of water streams. Valuable parts of landscape along rivers. Valuable natural habitats of meadows and pastures.	Increasing landscape fragmentation. Urban areas (Ostrava), D1 motorway, TEN-T railway and agricultural intensive land use disrupt landscape connectivity.	Valuable natural habitats (mainly meadows and pastures but also forests) in both changed and unchanged areas (potential for restoration).	Intensive land use and landscape fragmentation influencing the PLA and its connectivity from buffer, including potential buildable areas. Railway to be upgraded to high-speed line.
Soutok	Stable forested PLA with minimal built-up areas. Valuable natural habitats in unchanged areas (mainly alluvial forests). Lower landscape fragmentation within PLA. Valuable parts of landscape along rivers.	Weak presence of natural habitats in PLA buffer. Shortening of water streams. Urban areas (Břeclav), TEN-T railway line, D2 motorway and fenced Game reserves disrupt landscape connectivity.	Relatively diverse and forested PLA's surrounding suitable for enhancing connectivity in the broader region.	Intensive land use of surroundings (arable land, built-up areas) and worsening of landscape connectivity due to potential future activities (e.g. buildable areas).
All	Valuable natural habitats in PLAs. Lower landscape fragmentation within PLAs. Valuable parts of landscape along rivers.	Weak presence of natural habitats in the PLA buffers. Urban areas, motorways, and agriculturally intensively used land in the buffers disrupting landscape connectivity and increasing landscape fragmentation. Lower quality of landscape in the buffers from the nature conservation point of view.	Valuable natural habitats in changed and unchanged areas (potential for restoration).	Intensive land use of surroundings (arable land, built-up areas) and worsening of landscape connectivity due to potential future activities (e.g. buildable areas).

Existing threats are motorways, which cross Soutok PLA (to a length of 4 km) and Litovelské Pomoraví PLA (5 km). They can have a negative impact on biodiversity, including habitat loss, barrier effect associated with landscape fragmentation, or disturbances such as noise, air and light pollution (e.g. Forman et al. 2003; Gimmi et al. 2011; Hlaváč et al. 2020). Litovelské Pomoraví PLA is the only PLA with a slightly higher density of communications compared with its buffer. Dirt road network density here is higher than the average value for all Czech PLAs – 4.13 km per km² (Janík et al. 2024b). Soutok PLA shows a lower density of dirt roads than the PLA average value, according to Janík et al. (2024b).

From the anthropogenic structure point of view, Soutok PLA has the lowest proportion of built-up and recreational areas. Nevertheless, the current proportion of built-up area in its buffer (16%) is very similar to Litovelské Pomoraví (15.3%) and Poodří (19.3%). Similar values for built-up areas around protected areas were published by de la Fuente et al. (2020) in European countries (e.g. Belgium 18.9%, the Netherlands 15.6%); however, they used a 10-km unprotected buffer at the country level. Furthermore, part of Soutok's buffer lies in neighboring countries whose effect was not taken into consideration. Conversely, opportunities to cross the rivers from Austria and Slovakia are limited, which reduces accessibility and intensity of anthropogenic activities within the Soutok PLA. Limited anthropogenic pressure in the western part of Soutok PLA is largely due to the strictly guarded border zone between 1950 and 1990 (part of the "Iron Curtain"). Densely built-up areas around protected areas can be seen as threat because it can be more problematic to acquire additional land for protected area extension (Turner et al. 2006). On the other hand, Jones et al. (2018) found that built-up structures in protected areas do not expand significantly with time. This was documented in both Poodří and Soutok PLAs. Recreational areas have a very low proportion in Soutok PLA and its buffer (both 0.03%) – lower than the other two PLAs and much lower than the average (0.19%) for Czech (Janík et al. 2024b).

5. Conclusions

The three selected PLAs are similar, and they protect rare landscapes of relatively non-regulated floodplain forests or meadows along anastomosing rivers in Czechia. We can see similar traits in all study areas; conversely some differences can be found as well, e.g. Poodří PLA with a lower portion of forest and higher share of water areas, namely ponds. In Litovelské Pomoraví and Poodří we reveal positive effects after designation as PLAs; therefore we can expect similar positive development for Soutok PLA. On the other hand, the contrast between PLAs and their

surroundings is evident, which could be a threat for landscape connectivity due to increasing landscape fragmentation.

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Appendix 1

Group	Species	Red List	Weight	Litovelské Pomoraví	Poodří	Soutok
molluscs	<i>Cochlodina orthostoma</i>	NT	2			
molluscs	<i>Daudebardia brevipes</i>	VU	3			
molluscs	<i>Discus perspectivus</i>	NE	1			
molluscs	<i>Euconulus praticola</i>	NT	2			
molluscs	<i>Vertigo antivertigo</i>	NE	1			
butterflies	<i>Apatura ilia</i>	NE	1			
butterflies	<i>Arethusana arethusa</i>	EN	4			
butterflies	<i>Brenthis daphne</i>	NE	1			
butterflies	<i>Erebia medusa</i>	NT	2			
butterflies	<i>Euphydryas maturna</i>	CR	5			
butterflies	<i>Glaucopsyche alexis</i>	VU	3			
butterflies	<i>Hamearis lucina</i>	EN	4			
butterflies	<i>Hesperia comma</i>	VU	3			
butterflies	<i>Hipparchia fagi</i>	VU	3			
butterflies	<i>Hipparchia semele</i>	CR	5			
butterflies	<i>Limenitis camilla</i>	NT	2			
butterflies	<i>Lycaena alciphron</i>	VU	3			
butterflies	<i>Lycaena dispar</i>	NE	1			
butterflies	<i>Lycaena hippothoe</i>	NT	2			
butterflies	<i>Lycaena virgaureae</i>	NT	2			
butterflies	<i>Melitaea athalia</i>	NT	2			
butterflies	<i>Melitaea aurelia</i>	EN	4			
butterflies	<i>Melitaea cinxia</i>	VU	3			
butterflies	<i>Minois dryas</i>	VU	3			
butterflies	<i>Parnassius mnemosyne</i>	EN	4			
butterflies	<i>Phengaris arion</i>	EN	4			
butterflies	<i>Phengaris nausithous</i>	NT	2			
butterflies	<i>Phengaris teleius</i>	VU	3			
butterflies	<i>Plebejus argus</i>	NT	2			
butterflies	<i>Polyommatus bellargus</i>	VU	3			
butterflies	<i>Polyommatus coridon</i>	VU	3			
butterflies	<i>Polyommatus damon</i>	CR	5			
butterflies	<i>Polyommatus daphnis</i>	VU	3			
butterflies	<i>Polyommatus thersites</i>	VU	3			
butterflies	<i>Pseudophilotes vicrama</i>	CR	5			
butterflies	<i>Satyrrium ilicis</i>	EN	4			
butterflies	<i>Satyrrium w-album</i>	NT	2			
butterflies	<i>Zerynthia polyxena</i>	NT	2			
amphibians	<i>Bombina bombina</i>	EN	4			
amphibians	<i>Bufo viridis</i>	EN	4			
amphibians	<i>Lissotriton vulgaris</i>	VU	3			
amphibians	<i>Pelobates fuscus</i>	NT	2			
amphibians	<i>Rana arvalis</i>	EN	4			
amphibians	<i>Rana dalmatina</i>	NT	2			

Group	Species	Red List	Weight	Litovelské Pomoraví	Poodří	Soutok
amphibians	<i>Triturus cristatus</i>	EN	4			
amphibians	<i>Triturus dobrogicus</i>	CR	5			
reptiles	<i>Lacerta agilis</i>	VU	3			
reptiles	<i>Natrix natrix</i>	NT	2			
reptiles	<i>Zootoca vivipara</i>	NT	2			
birds	<i>Acrocephalus arundinaceus</i>	VU	3			
birds	<i>Actitis hypoleucos</i>	EN	4			
birds	<i>Alcedo atthis</i>	VU	3			
birds	<i>Anas crecca</i>	CR	5			
birds	<i>Anas querquedula</i>	CR	5			
birds	<i>Aquila heliaca</i>	CR	5			
birds	<i>Ardea alba</i>	NE	4			
birds	<i>Botaurus stellaris</i>	CR	5			
birds	<i>Bucephala clangula</i>	EN	4			
birds	<i>Ciconia ciconia</i>	NT	2			
birds	<i>Columba oenas</i>	VU	3			
birds	<i>Crex crex</i>	VU	3			
birds	<i>Dendrocopos medius</i>	VU	3			
birds	<i>Dendrocopos minor</i>	VU	3			
birds	<i>Falco cherrug</i>	CR	5			
birds	<i>Ficedula albicollis</i>	NT	2			
birds	<i>Gallinago gallinago</i>	EN	4			
birds	<i>Grus grus</i>	CR	5			
birds	<i>Haliaeetus albicilla</i>	EN	4			
birds	<i>Charadrius dubius</i>	VU	3			
birds	<i>Ixobrychus minutus</i>	CR	5			
birds	<i>Locustella luscinioides</i>	EN	4			
birds	<i>Luscinia svecica cyanecula</i>	EN	4			
birds	<i>Milvus migrans</i>	CR	5			
birds	<i>Milvus milvus</i>	CR	5			
birds	<i>Nycticorax nycticorax</i>	EN	4			
birds	<i>Pernis apivorus</i>	EN	4			
birds	<i>Picus canus</i>	VU	3			
birds	<i>Porzana parva</i>	CR	5			
birds	<i>Rallus aquaticus</i>	VU	3			
birds	<i>Remiz pendulinus</i>	VU	3			
birds	<i>Riparia riparia</i>	NT	2			
birds	<i>Saxicola rubetra</i>	LC	1			
birds	<i>Saxicola rubicola</i>	VU	3			
birds	<i>Sterna hirundo</i>	EN	4			
birds	<i>Tringa glareola</i>	NE	5			
birds	<i>Tringa ochropus</i>	EN	4			
birds	<i>Vanellus vanellus</i>	VU	3			
mammals	<i>Castor fiber</i>	LC	1			
mammals	<i>Lutra lutra</i>	NT	2			