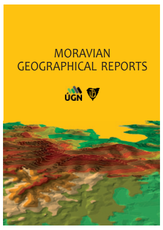

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Effects of policy changes in the last 80 years on LU/LC and ecosystem services: A case study of the Odra River floodplain (Czech Republic)

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Abstract

Riverscapes are degraded and threatened by human activities. We investigated the spatiotemporal dynamics and trends of land use/land cover (LU/LC) and ecosystem services (ES) in the floodplain of the Odra River in the Czech Republic over the last 80 years. Our focus was on: (i) the effects of changing political regimes and environmental policies on changes in LU/LC and ES (agricultural potential, natural flooding, and water provision and quality), and (ii) the effects of the establishment of a protected landscape area (Poodří PLA) on ES over the last 30 years. To assess LU/LC changes, we performed vectorization and categorization using aerial images. For ES assessment, we analyzed the spatial distribution of LU/LC and other characteristics in our study area. Potential agricultural ES showed a decreasing trend, similar to neighboring countries, while natural flood mitigation and water ES increased due to the decline in arable land. Policy assessments revealed significant changes in LU/LC. The Poodří PLA significantly enhanced ES by preserving the riverscape. This research demonstrates the under-researched long-term monitoring of ES, including before and after evaluation of the PLA, and highlights the importance of practical nature conservation for the riverscape ecosystem benefits to human society.

Keywords: Land Use/Land Cover, Ecosystem Services, Trend, Protected Landscape Area, Environmental Policy

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1. Introduction

Rivers and their floodplains are an essential part of the landscape (Tockner & Stanford, 2002; Wohl, 2021). These areas are perceived as multifunctional landscapes (Funk et al., 2019; Jakubínský et al., 2021; Schindler et al., 2014), where the functions of the river landscape depend on the river pattern (and its various characteristics, e.g., width and sinuosity) and human interventions through policies that change land use/land cover (LU/LC) and river channel alterations (Thorp et al., 2010). Ecosystem services can be used to assess all these changes.

Costanza et al. (2017) defined ecosystem services (ES) as "ecological characteristics, functions, or processes that directly or indirectly contribute to human well-being, that is, the benefits that people derive from functioning ecosystems." ES are divided into four main categories: provisioning services, regulating services, cultural services and supporting services (Haines-Young & Potschin, 2018; Keele et al., 2019). The variety and quality of ES depend on environmental conditions and ecosystem functions. All types of ES categories (provisioning, regulation, cultural services and supporting) are represented in a river landscape. Firstly, supporting services represent the natural foundation for other ES. Provisioning services include fisheries (aquaculture), agriculture, water (for nondrinking purposes), and raw (biotic) materials. Regulation services include flood protection, water purification, carbon storage, and erosion control, among others. Cultural services include recreation, spirituality, and symbolic appreciation (Grizzetti et al., 2015; Haines-Young & Potschin, 2018).

According to Opperman et al. (2010), rivers and their floodplains are among the most productive ecosystems on Earth. In a literature review, Hanna et al. (2018) identified more than 33 services from 89 relevant studies on the ES of riverscapes. Floodplains are often flat, accessible and fertile areas (Jakubínský et al., 2021); due to these characteristics, these lands have been settled by societies since prehistoric times (Munoz et al., 2014; Petřík et al., 2019). Humans have gradually altered the dynamics of floodplains, with the intensification of agriculture in the 19th century accelerating these changes (Hooftman & Bullock, 2012). In Europe, it is estimated that 70–90% of floodplains are in a degraded eco-hydromorphological state (European Environment Agency, 2018); the situation is similar in North America (Tockner & Stanford, 2002). Floodplain degradation is most evident in urban areas (Jakubínský et al., 2021); river adjustments (changing sinuosity, embankments, or fragmentation by horizontal barriers) have reduced ecosystem functions and ES (Large & Gilvear, 2015). Previous research, however, rarely studied ES of riverscape in large longitudinal scale or assess ES from historical data of aerial images. In our study, we focused on the part of the lowland with continuous floodplain of the river corridor of the Odra River in the Czech Republic (a corridor between the cities of Odry and Ostrava) to demonstrate:

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1. How changing political regimes and policies have affected LU/LC, as reflected in the provision of ES at two different spatial scales (the scale of the whole river corridor and individual river segments) over the last 80 years?
2. How have ES, namely agricultural potential, natural flooding, and water (water quality and supply) changed?
3. How the establishment of a landscape protected area under the Ramsar convention, based on changed environmental policy, has affected ecosystem services over the last 30 years?

River corridors provide a wide range of ES, encompassing provisioning services such as biomass production, regulating services like carbon capture and habitat provision or cultural services including recreation and heritage (Jakubínský et al., 2021). The selection of ES was made based on their representative characteristics, which reflect the characteristics of the broader territory. Emphasis was placed on the identification of potential agricultural ES, which are crucial for understanding land-use dynamics and productivity, as well as river-related services, which play a significant role in hydrological processes, biodiversity conservation, and the provision of ecosystem functions associated with water bodies. We provide a unique insight into the river landscape of Central Europe, which, in contrast to less detailed scales, shows the tangible results of policy changes. This study provides a compelling case for advocating the establishment and protection of protected areas, and for conducting assessments that sensitively reflect the policy changes of the last 80 years in Central Europe. We aim to understand how political shifts and policy changes have modified LU/LC and ES and to contribute to a comprehensive understanding of landscape evolution.

2. Theoretical and institutional background

In assessing the transformation of LU/LC, the chosen scale is an integral part of the assessment process. Study authors typically use a less detailed scale, such as a planetary scale (Costanza et al., 2017) that focuses on the evolution of the ES and estimates its value, or a national scale (e.g., Bičík et al., 2015; Aziz, 2021; Schirpke et al., 2023). The former approach is less commonly used (Burkhard et al., 2009; Requena-Mullor et al., 2018), and only a limited number of studies have been conducted at a more detailed scale. Examples of such studies include Peterson et al. (2003), Keele et al. (2019), and Stammel et al. (2021). Nevertheless, research conducted at this level of detail may be more sensitive to the actual consequences of policy changes and LU/LC. At the national or regional scale, only extreme manifestations can be observed (Schirpke et al., 2023).

Another key element in assessing changes in LU/LC is the analysis of the drivers of these changes. The provision of ES can be affected by changes in LU/LC as consequences of societal dynamics (Aziz, 2021; Hasan et al., 2020; Schirpke et al., 2023). In addition, disasters or climate change can act as a catalyst for change. In Central Europe, society has been an important driver of LU/LC change over the last 80 years (Aziz, 2021; Bičík et al., 2015; Schirpke et al., 2023). There were several political and social changes in Europe during the 19th and 20th centuries that affected LU/LC. These included the Industrial Revolution, World War I and the fall of the Austro-Hungarian monarchy, the establishment of new republics, the Great Depression, World War II, the rise and fall of communism, and the establishment of democratic regimes in the post-Soviet republics. These events affected the landscape in various forms and intensity. While some changes manifested in form reformation of local policies, others changed it dramatically, such as the nationalization of the lands (Grešlová Kušková, 2013). In the Czech Republic, this resulted in the creation of large agricultural plots, while in neighboring Austria the land remained much smaller and more fragmented (Schirpke et al., 2023). The consequences of land nationalization became evident over time through various adverse effects, including diminished water retention capacities of the land and watercourse regulations. Additionally, the intensive agricultural practices involved the extensive use of chemical fertilizers, resulting in negative impacts on biodiversity and soil quality (Kupková et al., 2021; Schirpke et al., 2023).

The identification of these issues was the initial step towards mitigating and potentially reversing the damage. The alteration of the political regime and other sociopolitical structures were major steps that led to the establishment of the Poodří protected landscape area (PLA). However, this was not an uncomplicated process, as the first proposals for its establishment appeared as early as the 1980s (Jarošek, 2021). The advantage of our research is that we observe the situation before and after the establishment. Kaiser et al. (2021) criticize that most of the studies evaluating river restoration and its impact on the ES in her case struggle with drawing conclusions based only on 'after' revitalization data. There is a complete lack of data before the restoration. Overall, it is important to protect and improve the condition of the river. As an improvement can be small or large river restoration or complex adjustments (Large & Gilvear, 2015). Stammel et al. (2021) evaluated ES of river corridors in the question of construction of flood control measures. Keele et al. (2019) evaluated pairs of rivers, one with and one without nature conservation designations. Both showed that the river landscape with more natural river provides better ecosystem services. So, it is important to support conservation. Several laws and directives have been established to prevent the degradation of river corridors, such as the European Water Framework Directive, the Habitats and Birds Directives, EU Biodiversity Strategy for 2030, Natura 2000 and the Ramsar Convention. In addition, there is much more to be done on the issue of river landscape protection and conservation.

3. Methodology

The methodology consists of several steps, starting with a description of the study area and its environmental and socio-economic characteristics. This is followed by a description of LU/LC assessment. The following chapter describes the assessment of each ES. The methodological framework (Fig. 1) is based on the availability of data and the spatial coverage of the study area (blue color). The results of the assessment of LU/LC and ES (green color) are placed in the context of political and social changes (purple color) to understand the trends and overall results (orange color) of the Odra River floodplain.

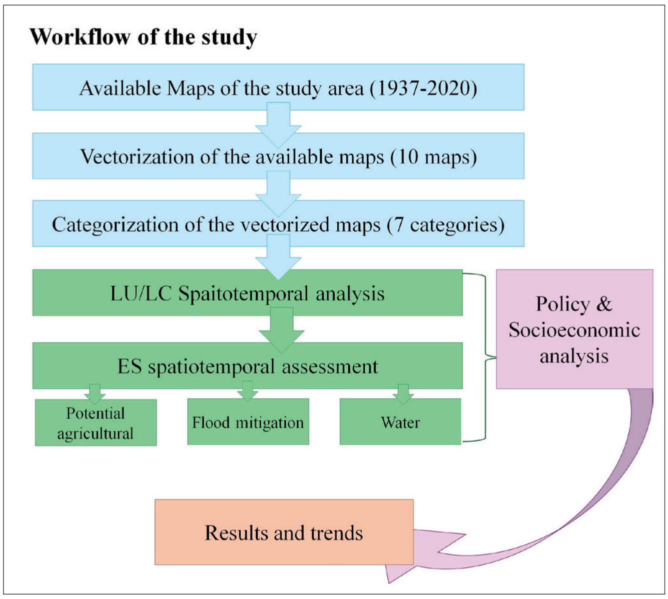

Fig. 1: Workflow of the research
Source: Authors' conceptualization

3.1 Study area

3.1.1 Geographical characterization of the study area

The study area is located in Central Europe, in the north-eastern part of the Czech Republic (Fig. 2). The study area is a river floodplain flanked by two urban areas: the smaller town of Odry and the city of Ostrava, which was one of the most developed regions of the Austro-Hungarian Empire, characterized by large factories and extensive coal mining areas. Land use and land cover changed rapidly over the years as the city expanded due to urbanization, agricultural and industrial demands (Bičík et al., 2015). In the midst of urban growth, woodlands, grasslands, and watercourses were preserved, creating a unique natural landscape between these urban centers. The water bodies are artificial ponds with normal (fish farming) and special management (natural ecosystem protection combined with fish farming) (Bartoš, 2011). The central part of the study area is part of the Poodří PLA, which was established in 1991 and includes 10 Small Spatially Protected Areas. It is part of the Ramsar Convention and Natura 2000 network. A free meandering river is the uniqueness of the European scale. Man-made and natural water bodies create biodiversity hotspots for fauna and flora.

It is a nesting place for more than 400 bird species, including the white-tailed eagle (*Haliaeetus albicilla*) (Bartoš, 2011). Arable land, orchards, and small urban areas can be found throughout the study area. The dominant element in the whole area is the Odra River. The Odra River is a major European river that rises in Oderské Vrchy (Czech Republic) and flows northeast through the Moravská Brána plain to the border with Poland. The river is 854 km long: 113 km flows in the Czech Republic and 742 km in Poland. The total area of the river basin is 118,861 km^2 (Brosch, 2005).

The Odra River originates as a torrential channel at an altitude of 632 m a. s. l. and downstream it develops into an extensive floodplain with typical phenomena such as oxbow lakes and abandoned channels, which are the target features of the Poodří Protected Landscape Area. Due to the dominant influence of the right tributaries (gravel-bed rivers), the sediment delivered to the Odra River channel mainly consists of gravels. Therefore, gravel bar formations are common in the Odra River and its tributaries (Eremiášová & Skokanová, 2014; Holušová & Galia, 2020). The Odra River is mainly regulated (managed) by straightening, embankment or weir construction and nearby cities such as Ostrava or Odry. In the 1960s, intensive regulations were implemented in Ostrava due to subsidence problems in the undermined area (Brosch, 2005).

3.1.2 Characterization of political and socio-economic changes in the study area

The beginning of our study period was in 1937, characterized by a market-oriented and democratic economy with a strong focus on agriculture and land development (industrialization and urbanization (Grešlová Kušková, 2013)). This development was interrupted from 1938 to 1948 by the German occupation, the Second World War and the post-war period (Kupková et al., 2021). From 1948 to 1989, the political regime was communist, characterized by totalitarian rule and a centrally planned economy. The Communists carried out the nationalization and collectivization of agriculture and industry, which destroyed private property (Bičík et al., 2001; Kupková et al., 2021). The effects of LU/LC were noticeable, before 1948 the land was characterized by small farms with fields, after 1948 small farms were replaced by a large agricultural cooperatives and fields were transformed into a large productive block (Grešlová Kušková, 2013).

In the 1970s, the first attempts were made to protect and preserve the landscape. In our study area, two small, protected areas were established: Polanský Les (1975) and Polanská Niva (1985). However, natural resources were exploited, rather than protected (Bičík et al., 2001). In 1989, the communist regime collapsed, a market-oriented and democratic economy was re-established, and the legal rights of landowners were respected

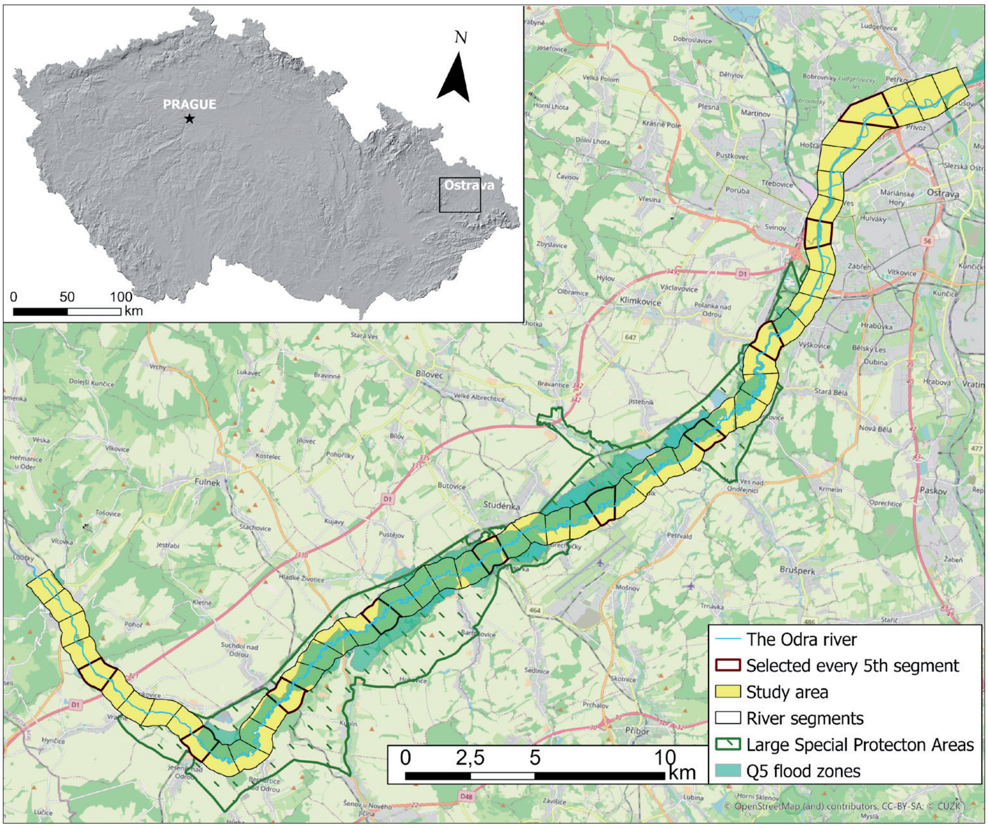

Fig. 2: Map of the studied river (Map inspired by Stammel, 2020)
Source: Authors' conceptualization based on the Base map of the Czech Republic and DEM map of the Czech Republic provided by State Administration of Land Surveying and Cadastre (Czech Republic)

(Bičík et al., 2001). Land protection and conservation became an important issue, and the Ministry of Environment was established in 1989. The Poodří Protected Landscape Area was established in the study area in 1991 (Jarošek, 2021). In 2004, Czech Republic became a member of the European Union, and the corresponding legislation and policies were implemented. The year 2020 was considered as the end of the assessment period, without any significant political or social changes. The following timeline (Fig. 3) illustrates the implementation of each policy and significant historical milestones.

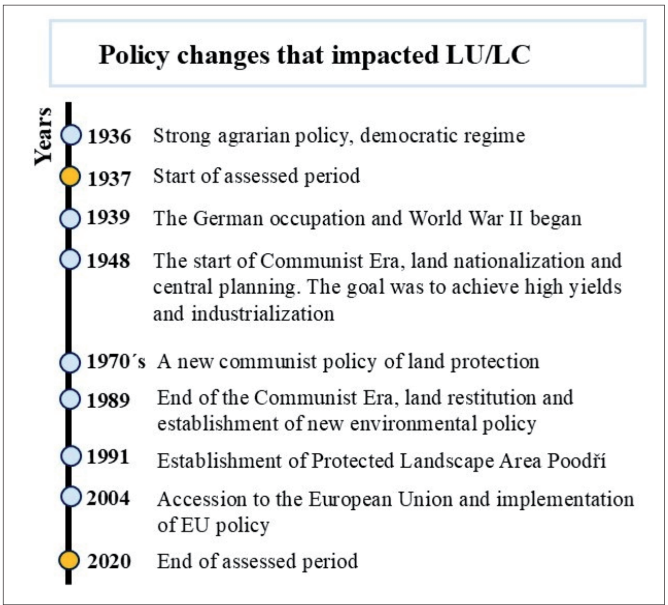

Fig. 3: A timeline of policy changes that impacted LU/LC
Source: Authors' conceptualization

3.2 LU/LC analysis and assessment

In order to achieve both objectives, it was necessary to carry out vectorization and LU/LC categorization of the study area. The vectorization was based on aerial images from 1937, 1949, 1955, 1966, 1973, and 1990 provided by the Military Geographical and Hydrometeorological Office in Dobruška (Czech Republic) and orthophotos from 2003, 2012, and 2020 provided by the State Administration of Land Surveying and Cadastre (Czech Republic). Historical aerial images were georeferenced and combined into raster mosaics using Geomatica 2014 software (PCI Geomatics). The root mean square error (RMS) of the georeferencing varied between 0.02 to 1.5. The highest RMS value was caused by the lower quality of the older aerial images (i.e., 1937). The 1937, 1949, 1966, and 1973 datasets do not fully cover the study area. We defined this map as uncomplete that corresponds to aerial photographs in certain years that cover only a portion of the study area.

The entire study area (river corridor, RC) was divided into 53 river segments (RS) of 1 km length (Fig. 2) (Stammel et al., 2021). The dimensions of the river corridor were based on the Q5 active floodplain area, representing the area inundated by a five-year return period flow, as this reflects the frequent and geomorphologically significant flood events shaping the river corridor, while also keeping the segments manageable in size and aligning with similar studies (Keele et al., 2019; Stammel et al., 2021). Therefore, each segment was approximately 1 km wide. This method resulted in a consistent study area covering the majority of the active floodplain.

For the manual vectorization of the study area, we used ArcGIS Pro (ESRI). We defined seven generalized LU/LC categories for the whole study period (1937–2020): arable land, permanent grassland, green area with floodplain forest, water bodies, river corridor, urban (built-up) area, and orchards (Fig. 4). These categories were applied to both black and white and colored versions of the aerial images (Fig. 5).

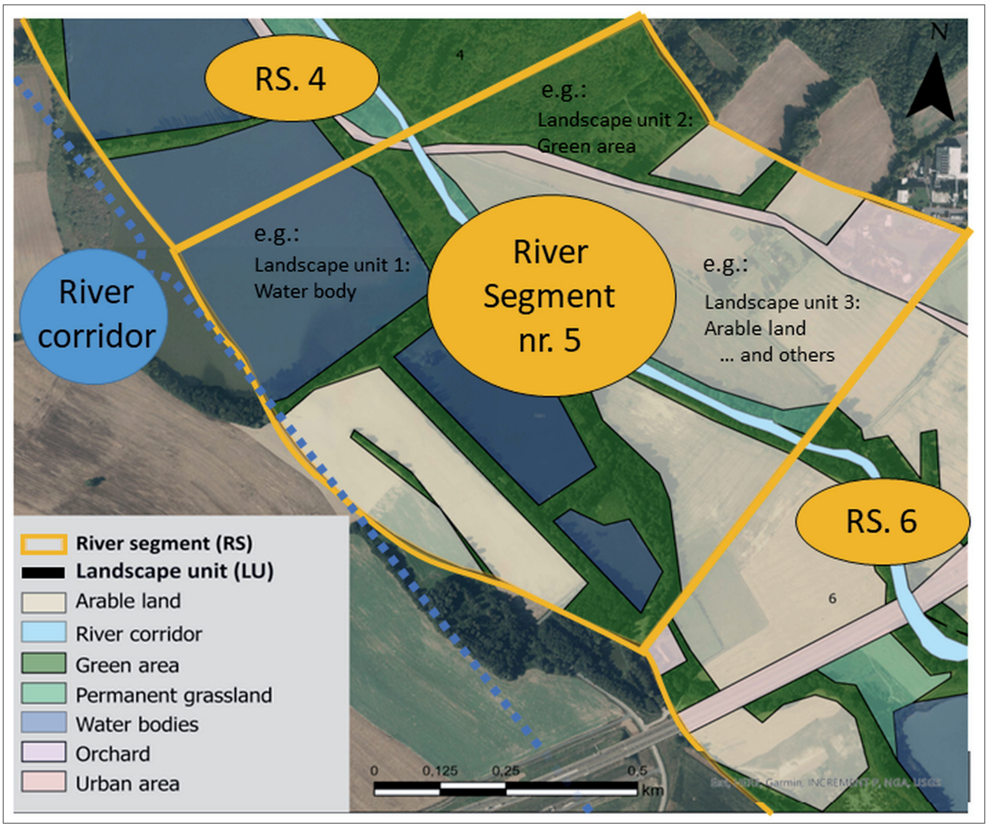

Fig. 4: Division of the study area of the river corridor (RC, blue dot line) into river segment (RS, orange line), and landscape unit (LU, black line), consisting of land use/land cover categories
Source: Authors' conceptualization and based on base map of the Czech Republic provided by State Administration of Land Surveying and Cadastre (Czech Republic)

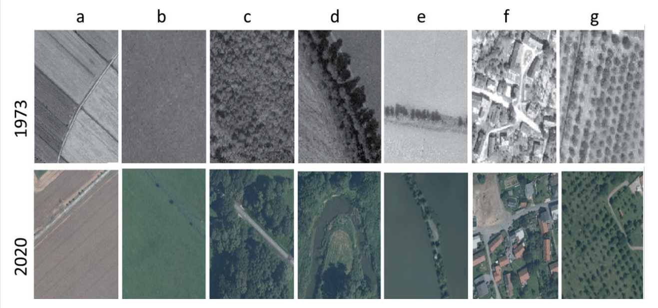

Fig. 5: All land use/land cover categories in 1973 (black and white version) and 2020 (color version): (a) arable land, (b) permanent grassland, (c) floodplain woods and green areas, (d) river channel corridor, (e) water bodies, (f) urban area, and (g) orchards
Source: Authors' conceptualization based on aerial images provided by Military Geographical and Hydrometeorological Office in Dobruška (Czech Republic) and orthophoto maps provided by State Administration of Land Surveying and Cadastre (Czech Republic)

The LU/LC categories were chosen to accurately reflect each type of LU/LC during the study period. Seven categories were used as the main types. Due to the variable quality of the maps, we have utilized a limited number of LU/LC categories. The selected categories encompass the key characteristics of the area; however, we acknowledge that, for instance, the 'water bodies' category could be further divided into natural water bodies, including wetlands, and artificial water bodies, such as ponds. Generalizing in this way reduced potential bias and allowed for more effective manual vectorization. Each identified category was manually outlined and classified into the corresponding vector layer (Głosińska & Lechowski, 2014). The vectorized and categorized maps were cross-checked by at least two researchers to minimize potential bias. We analyzed the LU/LC trend of the entire river corridor (1937 to 2020).

3.3 Ecosystem Services Assessment

Each river segment of the river corridor was analyzed to obtain more detailed information on ES. This process followed the framework of Burkhard et al. (2009), who developed a method to assess ES based on the LU/LC categorization. Keele et al. (2019), Podschun et al. (2018) and Stammel et al. (2021) created an assessment tailored for riverscapes that analyzes ES by land cover type and other relevant river characteristics (e.g., river width and channelization). We adjusted this approach to achieve higher precision. The ES assessed were considered typical and noteworthy for this study area and included all categories: potential agricultural ecosystem services and yield, natural flood mitigation, and water (including water purification, quality and provision). Each ES was analyzed separately according to the workflow (Fig. 1). Each analysis is discussed in detail. The results of LU/LC categorization and ES assessment were analyzed and visualized using Microsoft Excel and the R programming language.

The ES assessment was based on manually vectorized maps of the study area from 1937 to 2020 (n = 10) (see Section 3.2). A spatiotemporal and non-monetary ES valuation was chosen. Willemen (2020) noted that the limitation of this approach is that not all landscape features, qualities, and rarities relevant for ES assessment can be expressed by maps. To circumvent this limitation, we conducted fieldwork in the study area to verify the current state of the river, to understand the historical dynamics of the river and to gain deeper knowledge of the sociocultural relevance of the PLA. We used different indicators for each ES assessment (Appendix 1) We are aware that the list of ES assessed could be longer; however, we selected those that were considered key to our study area.

3.3.1 Potential Agricultural Ecosystem Services

We assessed the potential crop production and average agricultural yield (t/ha) for the river corridor and for each segment from 1937 to 2020. The potential agricultural ES were obtained from the RESI manual (Podschun et al., 2018). The river corridor was divided into arable land (AL) and permanent grassland land (PL).

We defined the site-specific yield potential for agricultural use (scale 0–94-points) for AL and PL separately. The data are open access and available from the Ministry of Agriculture as GIS layers (Ministry of Agriculture of the Czech Republic, 2021). Yield potential for agricultural use is based on many indicators, such as soil classification, climate, and slope. We have chosen to use a constant value of yield potential for the assessment period. According to Dolek (1990), the site specific agricultural yield potential based on field survey data from 1970 to 1980. In most cases, these data have not changed or been replaced by new data. We also checked the data on possible wind and water erosion in the study area, which could affect the agricultural yield potential. We found that our study area was not affected by soil erosion; therefore, we did not include this risk in our calculations. We did not include data from flood risk maps because data from 1937 to 1991 were not available or did not exist.

We then calculated the value for each RS based on the area of AL or PL and site-specific yield potential. The results were then classified into five categories (1 = very low, 2 = low, 3 = average, 4 = good, and 5 = very good). For detailed statistics and the following discussion, we also used results in percentages to increase the sensitivity to changes and the ability to interpret the data correctly.

We assessed the yield of AL based on the average yield of wheat and barley from the same year, specifically in the study area. We collected data on permanent grassland crops based on the average hay yield for the whole country, as it was difficult to find data specific to the region. National statistical books (from 1937 to 2020) were the sources of AL and PL. The yield for the river corridor was calculated as the sum of the product of the average yield and the areas of arable land and PL.

3.3.2 Natural Flood Mitigation

Our method for assessing natural flood mitigation ES was based on Keele et al. (2019) and Large and Gilvear (2015), with significant adjustments. We used four main indicators: roughness (R), palaeochannels and oxbow lakes (P_{ch}), riverbed sinuosity (S), and the coefficient of ecological stability (ES_{coef}), and A_{lu} corresponds to one land unit in the river segment (A_{RS}). It was calculated using the following formula (Equation 1 – Equation of Natural Flood Mitigation):

$$NFM_{RS} = \sum_{i}^{n} 0.5\frac{R_1 A_{lu_1} + \cdots}{A_{RS_1}} + 0.3P_{CH} + S + 0.4ES_{coef}$$

Roughness (Manning's roughness coefficient) was determined for the following individual LU/LC classes and varied between 0.03 and 0.12 (Chow, 1988). Palaeochannels and oxbow lakes had a positive effect on ES due to water retention, which enhances the natural dynamics in the lateral dimensions (Large & Gilvear, 2015). Sinuosity (index) is an important parameter of channel morphology that describes river patterns (from straight to meandering) (Wilzbach & Cummins, 2019). A meandering river has a greater capacity for flood mitigation than a channelized riverbed because a meandering river is connected to the floodplain; consequently, floodwater can be stored in the floodplain during overflow (Acreman et al., 2003; Kline & Cahoon, 2010), which is important for protecting downstream urban settlements (Watson et al., 2016).

The sinuosity for each RS was automatically calculated using the Meander Statistic toolbox (MSaT) to analyze the meander characteristics for each segment and study year (Ruben et al., 2021). The coefficient of ecological stability is the ratio of stable (natural) to unstable (artificial) landscape units in the RS. Stable landscape units include permanent grassland, green areas, water bodies, river channels, and orchards; unstable units include arable land and urban areas. Appendix 2 describes the equation and full procedure for the assessing natural flood mitigation, and we also describe the differences between Keele's et al. (2019) and our approach.

3.3.3 Water Ecosystem Services

Water ES include water purification (water quality) and water provision. We have chosen to use these two categories to provide a broader view, as there was insufficient data to identify a single category (as we have been looking at ES since 1937). Brauman et al. (2007) emphasized that water quality is an indicator of water purification and not of ES. Similar to previous ES analyses, the methodology was based on Large and Gilvear (2015) and Keele et al. (2019), with significant modifications as described in the Natural Flood Mitigation chapter. The used parameters for the calculation were the channel width (W_R), presence of palaeochannels (P_{ch}), ecological stability coefficient (ES_{coef}), green area coefficient of (GA_{coef}), and gravel bar coefficient (B_{coef}) and the formula is described in Equation 2 – Equation of Water Ecosystem Services:

$$W_{ES_{RS}} = \sum_{i}^{n} 0.5W_R + 0.3P_{CH} + 0.5ES_{coef} + 0.2GA_{coef} + 0.3B_{coef}$$

In Appendix 3 is available detailed description of calculation. River width (RW) is an important hydromorphological parameter that describes the area of the riverbed in contact with the flowing water and provides better potential for water purification. Since most of the study area belongs to a free meander section, we expect water purification potential to be high. The smaller regulated section still includes tributary inputs of mixed sediment and formations of gravel bars that could potentially play a role in the process. A wider channel indicates a greater volume of water supply in the bankfull state. In normal to minimal flows, wide channels are often associated with sediment deposition and gravel bar formations and heterogeneity of the river channel morphology (Witkowski, 2020). Paleochannels (Pch) and the ecological stability coefficient (EScoef) were characterized in the previous section. The green area coefficient (GAcoef) is the ratio of green area to the total area. The river bar coefficient (Bcoef) is the ratio of the area of the river bar to the area of the river channel. Gravel bars are accumulations of sediment of varying sizes that are typical of gravel-bed rivers and provide important habitat for many species, including riparian vegetation. The final categories (1 = very low, 2 = low, 3 = average, and 4 = high) were based on the quartiles of the values calculated for the whole river corridor and all the years assessed.

4. Results

4.1 General LU/LC patterns

The analysis of the trends of the representative LU/LC for each year showed that the dominant LU/LC in 1937 and 1949 was permanent grassland (Tab. 1). In 1955, arable land dominated, followed by permanent grassland and green areas. In 1985, the dominant type of LU/LC shifted to permanent grassland. The last change in the prevailing LU/LC type was in green areas, which changed in 2012. The trend of urban areas was increasing in all years considered, except in 1990 when there was a decrease of 9% in urban areas compared to the previous year. The reason for this change is discussed below. From 1937 to 1955, the coverage of urban areas was less than 300 ha; in 1985, it was 499.6 ha, and in 2020, it reached 876 ha. Other types of LU/LC, i.e., orchards, rivers, and water bodies, did not show any major changes. The first two types remained constant at 0.3% and 3% respectively.

Figure 6 shows the cumulative distribution of each LU/LC type in each segment. In this section, we describe the trends for each river segment (RS 1 to 53). In all assessment years, RS 1–9 were arable land with urban areas, and RS 10–16 were dominated by a mixture of arable land and permanent grassland, with additional green and urban areas. RS 17–34 were very dynamic, with the dominant arable land (1937–1955) being almost completely replaced by permanent grassland (1966–2020). In addition, the green area in these segments has increased significantly since 1990. RS 35–44 were dominated by water bodies and had low dynamics; since the 1970s, the protected landscape areas in these segments have been dominated by grassland and green areas. Finally, RS 44–53 were dominated by urban areas, which increased since 1949 and have remained stable since 2012.

4.2 Spatiotemporal variations in ecosystem services

4.2.1 Potential Agricultural Ecosystem Services

We assessed the potential agricultural ES of arable land and permanent grassland (Tab. 2). The potential agricultural ES of arable land was 1 (very low) in 1937, 1.5 in 1949, 2 (low) in 1955, and 1 (very low) in 1966–2020. In the case of permanent grassland, the category was 1.5 in 1937 and 1 (very low) in 1949–2020. The sum of the yields showed that there was no trend. Yields varied from year to year depending on climate and fertilizer use. The potential agricultural ES and the average yield (t/ha) of arable land showed a decreasing trend (especially from 1937 to 1973). Based on the potential agricultural ES of permanent grassland, the average value for the river corridor has fluctuated by about 15% since 1949.

Figure 7 shows the river segments in 1955, 1990, 2003 and 2020 that covering the whole study area. RS 1–9 achieved the highest potential values of all selected. In 1955, the category of RS 4–9 was 3 (average potential); segments 17–35 were classified as higher value segments. The trend of RS 35 was decreasing.

	Arable Land	T	Permanent Grassland	T	Green Area	T	Orchards	T	Urban Area	T	River	T	Water Bodies	T
1937*	1,364.9	-	1,904.3	-	373.7	-	6.2	-	228.9	-	94.7	-	193.2	-
1949*	935.3	-	949.5	-	397.7	-	2.3	-	224.6	-	101.9	-	47.4	-
1955	2,455.8	-	1,826.0	-	644.0	-	21.9	-	292.4	-	152.4	-	322.4	-
1966*	701.8	-	1,770.3	-	546.9	-	21.5	-	362.6	-	141.0	-	272.0	-
1973*	1,227.6	-	1,952.9	-	963.5	-	33.0	-	427.9	-	139.0	-	376.4	-
1985	1,197.8	↘	2,064.5	↗	1,225.7	↗	32.7	↘	658.2	↗	161.0	↗	381.1	↗
1990	1,271.5	↗	2,209.1	↗	1,136.5	↘	18.2	↘	499.6	↘	157.7	↘	424.0	↗
2003	1,171.0	↘	1,685.2	↘	1,503.8	↗	18.5	↗	785.4	↗	166.6	↗	389.5	↘
2012	1,131.7	↘	1,520.1	↘	1,604.1	↗	19.4	↗	873.6	↗	166.1	↗	400.7	↗
2020	1,137.7	↗	1,523.3	↗	1,586.8	↘	20.0	↗	876.3	↗	186.1	↗	400.7	↗

Tab. 1: Sum of each area (ha)
*Notes: T – trend, *year with uncomplete map cover*
Source: Authors' calculations

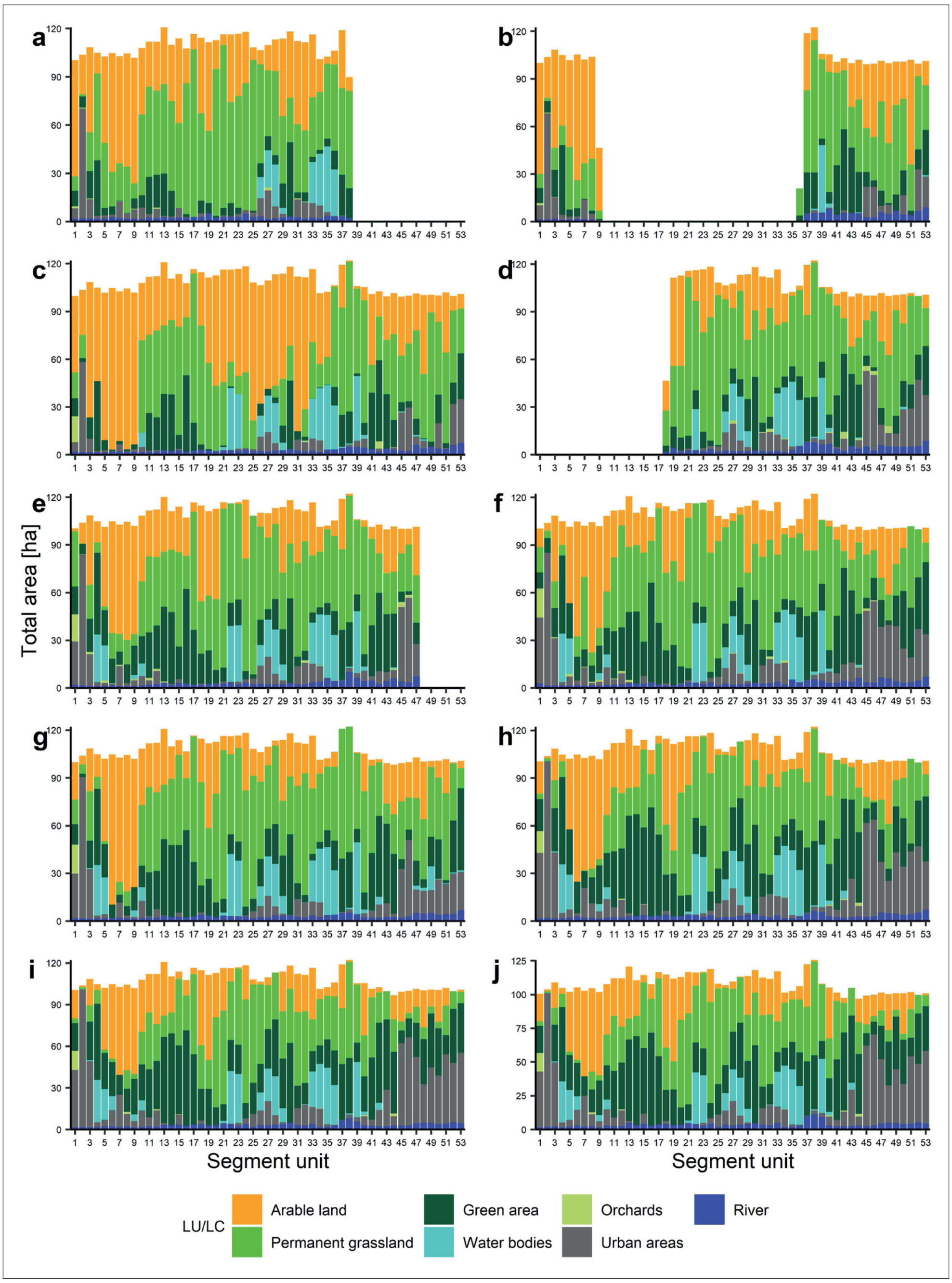

Fig. 6: Cumulative distribution of each land use/land cover type by river segment from 1937 to 2020. (a) 1937, (b) 1949, (c) 1955, (d) 1966, (e) 1973, (f) 1985, (g) 1990, (h) 2003, (i) 2012 and (j) 2020
Source: Authors' calculations

	1937*	1949*	1955	1966*	1973*	1985	1990	2003	2012	2020
Arable land										
Average category for the entire river corridor	1	1.5	2	1	1	1	1	1	1	1
Average % of river corridor	15%	28%	21%	8,8%	11.2%	9.3%	11%	9,6%	10%	10%
Average yield (t/ha)	1.98	2.18	2.52	2.51	3.60	4.99	5.58	3.87	4.25	5.66
Sum of yield (t/ha)	2,622	2,293	6,188	1,762	4,429	5,954	7,206	4,638	4,956	6,360
Permanent grassland										
Average category for river corridor	1.5	1	1	1	1	1	1	1	1	1
Average value for river corridor	19.4%	7.5%	14%	13%	15%	16%	17%	13%	12%	12%
Average yield (t/ha)	3.57	4.20	3.22	3.42	3.71	5.35	4.89	2.41	3.22	3.15
Sum of yield (t/ha)	6,798	3,949	5,877	5,970	7,167	11,040	10,802	4,060	4,895	4,820

Tab. 2: Results of potential agricultural ecosystem services
*Notes: *Year with uncomplete map cover*
Source: Authors' calculations

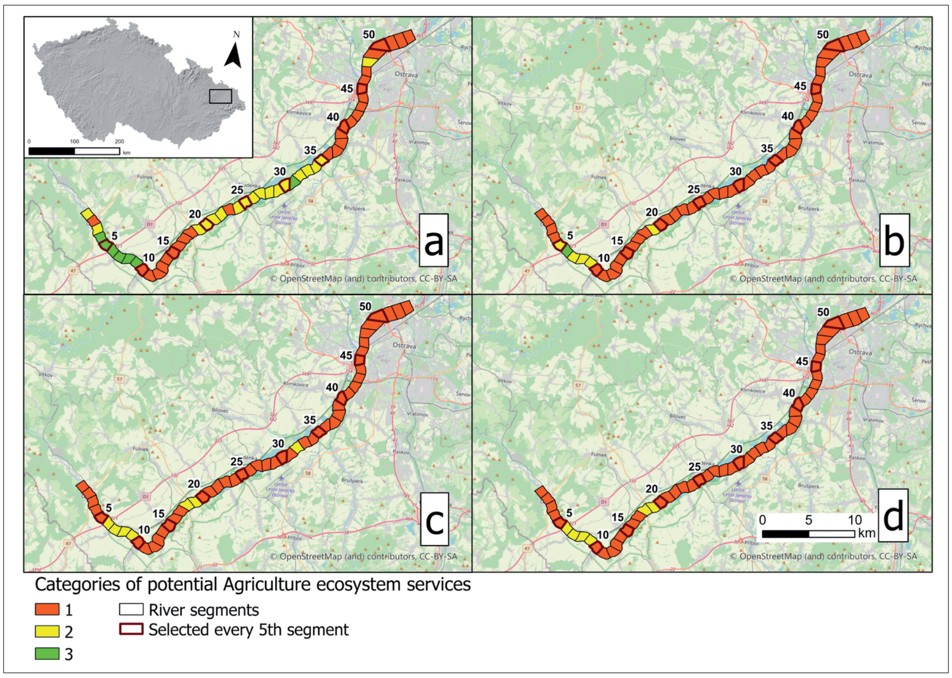

Fig. 7: Map of categories of potential agricultural ecosystem services in (a) 1955, (b) 1990, (c) 2003 and (d) 2020. Each category is based on the area values of AL and site-specific potential. Results range from 1 (very low) to 3 (average). From segment 8 to segment 44, PLA is placed
Source: Authors' conceptualization based on a base map and DEM of the Czech Republic provided by State Administration of Land Surveying and Cadastre (Czech Republic)

Figure 8 illustrates the potential agricultural ES on permanent grassland with a decreasing category trend in RS 10–15 and 47–51. In the middle of the study area, a few RS (e.g., 21–22, 31) showed category improvements from very low to low.

4.2.2 Natural flood mitigation ecosystem services

Natural flood mitigation ES increased from 1955 to 2003 and decreased slightly in 2020 (Tab. 3). Indicators of roughness and the coefficient of ecological stability showed increasing trends, and the trend of palaeochannels decreased after 1973. Sinuosity has been stable since 1973. An interesting trend can be seen when river segments are evaluated separately for each year (Fig. 9).

In all the years studied (1955, 1990, 2003, and 2020), the upstream (RS 1–10) and downstream (44–53) segments of the river had lower values (category very low – low) than the segments in the middle (RS 10–44) of the river reach (category average or high).

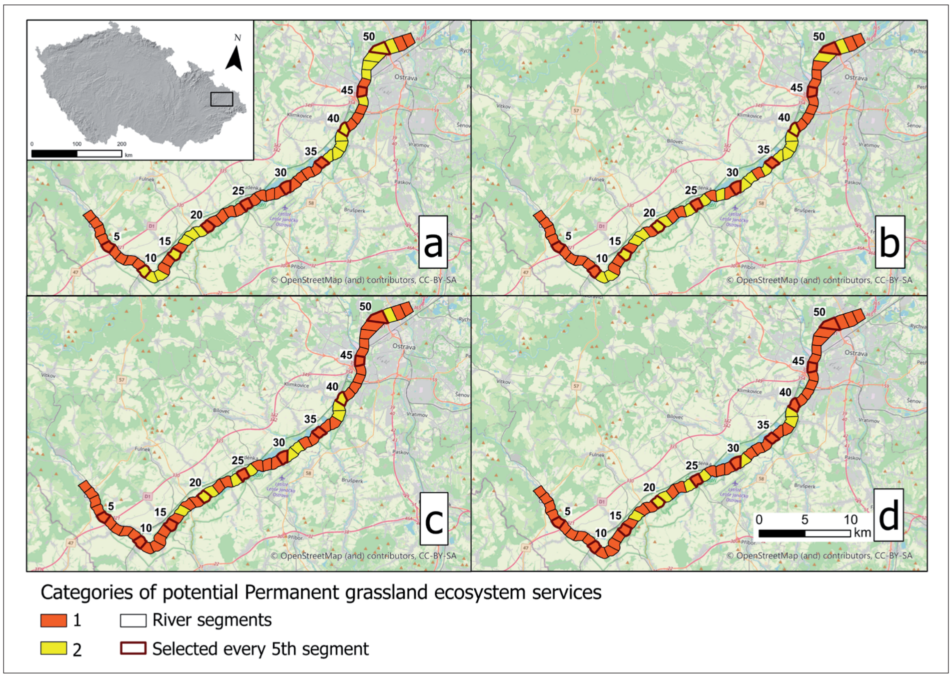

Fig. 8: Map of categories of potential agricultural ecosystem services on permanent grassland in (a) 1955, (b) 1990, (c) 2003 and (d) 2020. Each category is based on the area values of PL and site-specific potential. Results range from 1 (very low) to 2 (low). From segment 8 to segment 44, PLA is placed
Source: Authors' conceptualization based on a base map and DEM of the Czech Republic provided by State Administration of Land Surveying and Cadastre (Czech Republic)

Indicators	1937*	1949*	1955	1966*	1973*	1985	1990	2003	2012	2020
Roughness	60	50	91	71	96	128	116	194	197	199
Sinuosity	29.5	11	38	24	28.5	30	30	28	29.5	28.5
Paleochannels	53	27	87	72	93	91	85	58	74	71
Coefficient of ecological stability	149	95	180	156	195	218	220	214	215	212
Sum of final value°	135	89.1	181.6	143.5	182.4	208.5	201.5	228	236.2	234.1
Average category	2	2	2	3	3	3	3	3	3	3

Tab. 3: Results of natural flood mitigation service
*Notes: *Year with uncomplete map cover; °with added weight for each category*
Source: Authors' calculations

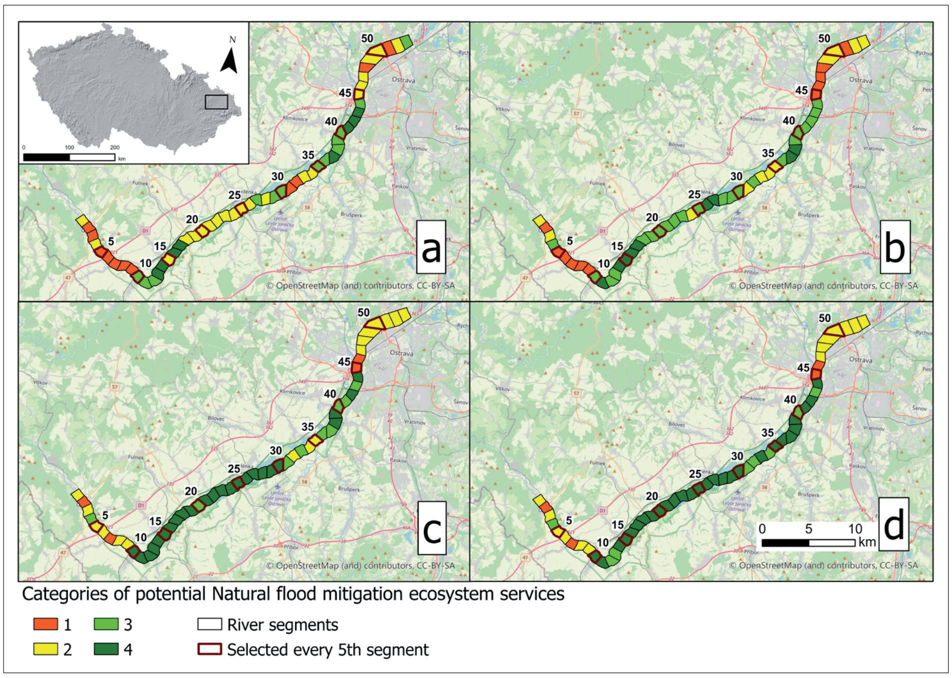

Fig. 9: Map of categories of natural flood mitigation in (a) 1955, (b) 1990, (c) 2003 and (d) 2020 (Notes: Each category represents a quartile of calculated ES values, ranging from 1 (very low) to 4 (high). From segment 8 to segment 44, PLA is placed)
Source: Authors' conceptualization based on base map and DEM of the Czech Republic provided by State Administration of Land Surveying and Cadastre (Czech Republic)

4.2.3 Water ecosystem services

Water ES exhibited an increasing trend from 1937 to 2020 (Tab. 4).

Figure 10 shows the trends of the river segments for each year. In 1955, the whole river corridor had a category of only 2 (low). The exception was RS 40–43, which had a category of 4 (high). These segments have been part of the Small Special Protection Area since the 1970s. The category was lower in the upstream segments of the river corridor (1–10) than in the downstream segments (RS 45–53); there could be several reasons for this. However, we assumed that the location of these upstream and downstream river segments in urban areas reduced the naturalness of the river reach.

5. Discussion

The data presented in this study show spatiotemporal trends in LU/LC and ES changes over the last 80 years, reflecting policy and societal changes. The dominant LU/LC reflects these policy shifts, namely agricultural and environmental protection. Until 1955, the dominant type was arable land, in 1985, permanent grassland and in 2012 green areas and floodplain forest.

5.1 LU/LC trends and policy in the last 80 years

In the assessed period from 1937 to 2020, we observed gradual changes in LU/LC. The dominant types were arable land (peak in 1955), permanent grassland (peak in 1985), and green areas, including floodplain forest (peak in 2012). We compared complete maps (representative, 1955, 1985–2020) and incomplete maps as additional data (1937, 1949, 1966 and 1973).

To understand the reasons for the change in LU/LC, it is necessary to look at the history of Europe and the Czech Republic and its landscape policies (namely, agricultural, urban, and environmental protection policies). Before the Second World War, this period was characterized by the capitalist model and democratic political parties (Grešlová Kušková, 2013). Maps from 1937 are characterized by the dominance of permanent grassland, followed by arable land, and small farmlands and orchards can be seen as a result of the agrarian reform (the reform had started in 1918 after the disintegration of Austrian Hungarian monarchy) focused on high and rational yields. The map of 1949 shows the beginning of the Communist Era. The easiest way to observe the expropriation of private land (Grešlová Kušková, 2013; Kupková et al., 2021) as state-owned arable land is through aerial images (Fig. 11).

The development of agriculture during the study period was related to mechanization. Human and animal labor was gradually transferred to machines; e.g., tractor performance doubled in just two decades after 1948 (Grešlová Kušková, 2013). The same trend can be observed in other Central European countries. Even in Austria, which was not part of the socialist bloc, Schirpke et al. (2023) noted that mechanization led to more dynamic changes in land use. Mechanization of processes led to cost-effective methods that accelerated yields but damaged the meadow ecosystem

Indicators	1937*	1949*	1955	1966*	1973*	1985	1990	2003	2012	2020
River width	56	57	95	88	88	108	100	115	109	105
Paleochannels	53	27	87	72	93	91	85	58	74	71
Coefficient ecological stability	149	95	180	156	195	218	220	214	215	212
Coefficient of Green Areas	41	43	67	65	104	136	127	165	174	172
Coefficient of river bars	67	68	63	60	68	97	76	106	79	92
Sum of final value°	146.7	113.1	195.9	174.6	209.1	246.6	233.7	246.7	242.7	241.8
Average category	2	3	2	3	3	3	2	3	3	3

Tab. 4: Results of water ecosystem service
*Notes: *Year with uncomplete map cover; °with added weight for each category*
Source: Authors' calculations

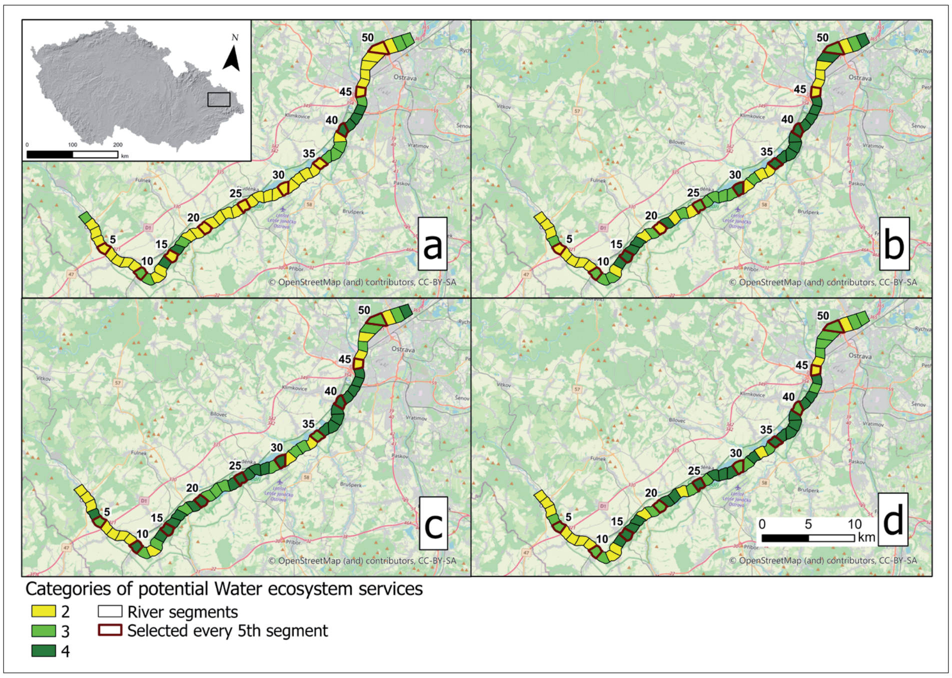

Fig. 10: Map of categories of water ecosystem services in (a) 1955, (b) 1990, (c) 2003 and (d) 2020 (Notes: Each category represents a quartile of calculated ES values, ranging from 2 (low) to 4 (high). From segment 8 to segment 44, PLA is placed)
Source: Authors' conceptualization based on base map and DEM of the Czech Republic provided by State Administration of Land Surveying and Cadastre (Czech Republic)

Fig. 11: Aerial images before (1937) and after (1955) collectivization during the Communist Era
Source: Authors' conceptualization based on aerial images provided by Military Geographical and Hydrometeorological Office in Dobruška (Czech Republic)

(Bartoš, 2011). The year 1955 is considered to be a peak of arable land, followed by a decline. According to Kupková et al. (2021), more than 90% of the Czech Republic has experienced a decrease in agricultural land. A comparison of LU/LC types between 1955 and 1985 (Fig. 6c and 6f) shows that production peaked in the 1980s, after which local agriculture was unable to compete with imported products (Grešlová Kušková, 2013). During this period, there was a steady decline in the emphasis on agriculture, and heavily cultivated areas were transformed into grasslands and forests and green areas. A similar trend was reported by Dolejš et al. (2019) for northern part of the Czech Republic (assessed from 1843 to 2013), and it is applicable to the whole of Central Europe, including Poland, Slovakia, which has a similar Communist Era (Bičík et al., 2001; Moravcova et al., 2022; Schirpke et al., 2023) In Austria, the decreasing trend started after the Second World War and in 1995, when the country joined the European Union, it escalated due to the inability to deal with imported products (Schirpke et al., 2023).

In the Czech Republic a landscape protection policy was established in the 1970–1980s (Kupková et al., 2021). In the study area, this was demonstrated by the establishment of the first natural reserves. In 1989, the political regime changed to a democratic one and global capitalism was applied (Bičík et al., 2001). Environmental protection started to be an important issue of the new political regime, which was concluded by the establishment of the Ministry of Environment (1989, including landscape policy and protection) (Kupková et al., 2021); however the power for a more progressive policy was gradually lost (Jehlička, 1999). In 1990, permanent grassland started to decrease in favor of green areas. In 1991, the Poodří PLA was established to specifically manage RS 7 to 43, and permanent grassland is still dominant in this part.

Urbanization is another important driver of change due to population growth and migration from small villages to cities. In particular, the city of Ostrava expanded throughout the 20th century. The same pattern can be found in the Austria, especially around larger cities undergoes strong urbanization (Schirpke et al., 2023). The results showed that the urban area in the study area gradually increased until 1990, when the growth started to decrease; however, the upward trend continued in 2003. The Communist Era boosted the urbanization process, especially around the city of Ostrava (the end of the study area) (Bičík et al., 2001; Kupková et al., 2021). Today, urbanization in the study area is not very high compared to other regions of the Czech Republic (Kupková et al., 2021), due to the formation of the Poodří PLA and the policy of the master plan and PLA zoning. The dynamic shifts in LU/LC types of the Odra River landscape were undoubtedly influenced by the country's policies and societal decisions. Schirpke et al. (2023) noted that urbanization and population growth is one of the main drivers of LU/LC change that can affect the provision of ES.

The assessment of historical changes in LU/LC faced certain limitations. The primary issue was the incomplete availability of aerial images for specific years (1937, 1949, 1966, 1973). Additionally, the quality of some images varied, that made detailed identification of LU/LC categories possible only on certain number of images. Consequently, the study was restricted to seven LU/LC categories. With complete datasets the number of categories would be larger.

5.2 Ecosystem services trends and challenges

The potential agricultural ES were calculated based on Podschun et al. (2018) and were highest in 1955 (21%; low category). In the following years, the category rapidly decreased to 9.3% (1985), and from 1990 to 2020, the values fluctuate around 10%. This corresponds to the trend in the whole country: agriculture expanded from the 1930s to the 1980s (Kupková et al., 2021). One of the reasons for the decrease in the ES score for agriculture is that the average area of floodplain forest and green areas has increased over the last 80 years. Watson et al. (2021) reported a peak in Dorset, southern England, in 1955 and a decreasing trend thereafter. Intensification of agriculture in Austria has also led to a decline of ES (Schirpke et al., 2023). The yield of arable land depends on many factors, including climate, the amount of fertilizer, and the use of pesticides. Fertilizer use increased from the 1950s to the 1990s in the Czech Republic (Grešlová Kušková, 2013) and from the 1950s to the 1980s in the UK (Watson et al., 2021). Thus, the trends were similar despite differences in political systems and agricultural policies. The potential agricultural ES in permanent grassland were highest in 1937, with a value of 19.4% (category 2, low), although this was assessed on an incomplete map (15 segments were missing). The value between 1955 and 2020 was approximately 14% (complete maps of the study area).

The ES of natural flood mitigation were assessed based on the Large and Gilvear (2015) and Keele et al. (2019). Similar to Grizzetti et al. (2015), we believe that assessing the ES of the river and its surrounding floodplain based on hydromorphological and landscape indicators is an effective method. In section 4.3, we list the differences between our study and the aforementioned studies (Keele et al., 2019; Large & Gilvear, 2015). Thorp et al. (2010) noted that different river patterns can provide different functions and ES. Our study area had two dominant river patterns: a straightened (channelized) and a meandering river. Generally, meandering rivers provide low to moderate benefits and services, whereas straightened rivers provide low benefits only. We have used Thorp's et al. (2010) constricted river pattern as a reference for a straightened river; thus, we assume that artificially adjusted rivers can provide less benefits and ES than natural rivers. Applying this approach to the study area, it is easy to detect which part of the river is meandering (middle part) and which part is channelized (beginning and the end of the study area). This pattern was not easy to detect in the 1955 water ES, but was detectable in the other years (1990, 2003 and 2020). The reason for the reduced detectability of water ES is that the sinuosity indicator was not included. There is a strong relationship between sinuosity and river patterns (Bravard & Petit, 2009).

The assessment of natural flood mitigation revealed that the very low (1) and low (2) categories were dominant at the beginning and end of the study period, whereas in the intervening years, the category was average to high. In 1955, segments 18–26 were in the low category due to the dominance of arable land. In the following years, the arable land was replaced by permanent grassland and green areas, which improved the category to average (3) and high (4), respectively. The same pattern was shown in Austria where the change of LU from arable land to grassland and forest increased the ES flood mitigation and erosion protection (Schirpke et al., 2023). The dominant category of water ES in 1955 was low (2), mainly because the prevailing category of LU/LC was arable land in the whole area. The exceptions were RS 36–37 and 40–44, where the category was average to high because these RS are the core area of the Poodří PLA. As the LU/LC types shifted towards more natural areas, the ES for water improved (Fig. 10). In 2020, the prevailing category of water ES was average to high.

5.3 Poodří Protected Landscape Area: protection success?

The creation of the Poodří Protected Landscape Area was proposed in 1975 but was rejected by the political regime (Jarošek, 2021). Partial success was achieved in the 1970s and 1980s with the creation of smaller protected landscape areas (Natural Reservation Polanský Les (1975) and Polanská Niva (1985)). The object of protection is the natural and near-natural ecosystems of the Odra River and its floodplain, including the lower sections of its tributaries and river terraces, and the associated flora and fauna of river floodplains and wetland biotopes (Nature Conservation Agency of the Czech Republic, 2009).

In general, the communist period and agricultural policies changed and damaged the landscape of the Czech Republic, including Poodří (Grešlová Kušková, 2013; Kupková et al., 2021). Before 1948, meadows were grazed by livestock or mown by hand, but after 1948, some were converted to arable land or mown by machine. This led to a decline in species-rich ecosystems. The species-rich alluvial meadows of the Odra floodplain were replaced by arable land or by more progressive grass species occupying the open niches (Jarošek, 2021). Flynn et al. (2009) pointed out that simplified agricultural ecosystems lead to a loss of species richness and most endanger unique species. The smaller areas of arable land were connected to create larger productive blocks (Fig. 8), and large amounts of fertilizer were used (Bartoš, 2011). All of these changes affected the hydrological regime and water quality.

The challenge of the last 30 years has been to restore these species-rich floodplain meadows through specific management, e.g., manual mowing at least twice a year or different mowing dates (Jarošek, 2021). At present, the landscape and its ecosystem are threatened by changing climate (heavy rainfall on the one hand and low flow on the other hand) and the expansion of alien species such as Reynoutria sp. or Helianthus tuberosus, which could damage the Poodří ecosystem without human intervention (Bartoš, 2011).

In terms of ES from 1937 to 2020, natural flood mitigation and water showed increasing trends; in contrast, the trend of potential agricultural ES of arable land and permanent grassland decreased after 1949. The categories of ES varied from very low to low for potential agricultural ES and from low to high for natural flood mitigation and water ES. Compared to similar studies, we monitored the study area at a more detailed scale and over a longer period. Understanding the historical patterns that lead to the declines in ES can help identify problems. This allows environmental managers to address the situation more quickly and policies can be changed or adopted accordingly.

Figure 12 shows the changes in natural flood mitigation and water ES after the creation of the Poodří PLA. These ES remained the same or increased in the following years due to the natural shift of the LU/LC.

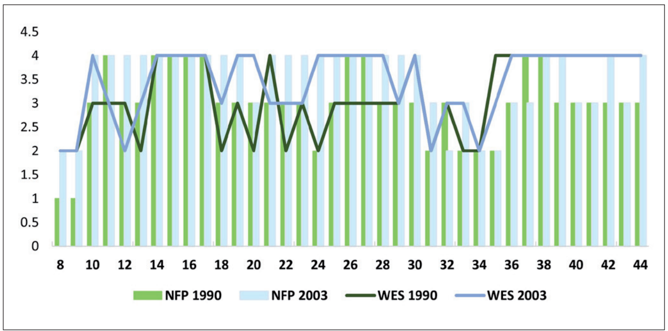

Fig. 12: Categories of natural flood mitigation (NFP) and water ecosystem services (WES) before and after the establishment of the Poodří PLA. Source: Authors' calculations

6. Conclusions

Over the past 80 years, political changes and implementation of environmental policies have been the main drivers of LU/LC change in the study area. Initially, from 1937 to 1955, arable land dominated, with negative impacts on ecosystem services. The Communist Party's agricultural intensification and collectivization efforts, starting in 1948, exacerbated this trend, a pattern observed throughout Central Europe. By 1985, the decreasing competitiveness of the agricultural sector had anticipated the political transformations of 1989. These transformations subsequently resulted in advancements in environmental policies, which preceded improvements in ecosystem services, particularly regarding natural flood protection and water-related services. The establishment of the Poodří PLA in 1991 preserved the Odra River in its natural state and improved the quality of ES.

In this respect, the study provides valuable data on the continuous monitoring of ES in the Poodří PLA, illustrating the positive impact of landscape protection policy. The comparison between 2012 and 2003 highlighted the effects of urbanization pressure and natural grassland overgrowth. Our results underline the importance of the Poodří PLA in stabilizing the region's landscape and improving ES and serve as a compelling example for advocating new protected areas. Future efforts should focus on maintaining these high ES levels in the face of political change, extreme weather, urbanization.

Future research should focus on understanding the combined effects of land-use change, urbanization, and climate change on the dynamics of ES in protected areas. In particular, investigating how changes in agricultural practices, natural grassland cover and extreme weather events affect flood protection and water provision, and quality services would provide valuable insights. Furthermore, studying the socio-economic drivers of land use change in different policy contexts could help predict future trends and inform policy decisions for better land management and conservation strategies.

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Data accessibility

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Appendices

Appendix 1: Indicators used for the ecosystem services assessment
*Notes: # = number of ordinal classes, * = will be discussed separately, RS = river segment*

Name of indicator	#	Description of ordinal classes of RS
Area of the segment	none	Classes defined by number and extent of different categories
Channel width	10	Classes defined by measured width
Sinuosity	3	Classes defined by calculation of sinuosity
Paleochannels	4	Classes defined by calculation quantity of paleochannels
Coefficient of Green Areas	10	Classes defined as a proportion to the total segment area
Coefficient of river bars	10	Classes defined as a proportion to the total segment area
Roughness of area	4	Classes defined by number and extent of different categories
Ecological stability ratio	4	Classes defined by area of ecological stable stage
Yield potential	96	Classes defined by categories
Cultural elements	5*	Classes defined by number and extent of different categories

Appendix 2: Process of calculation of Natural Flood Mitigation ES

Name of Ecosystem Service	Abbr.	Description		
Natural Flood Mitigation Provisioning category	NFM	Natural flood protection based on the river and floodplain LU/LC characteristics		
Indicator	**Abbr.**	**Unit**	**Variable description**	**Data basis**
Roughness of the segment	R	Manning's value	Roughness of each LU/LC unit	Tables Calculation
Paleochannels	P_{ch}	-	Number and size of P_{ch} at each segment	Map analysis
Sinuosity	S	-	Calculated sinuosity for each segment	Map analysis Calculation
Coefficient of ecological stability	ES_{coef}	-	Calculated sinuosity for each segment	Statistical Office

Equation of Natural Flood Mitigation: $$NFM_{RS} = \sum_{i}^{n} 0.5\frac{R_1 A_{lu_1} + \cdots}{A_{RS_1}} + 0.3P_{CH} + S + 0.4ES_{coef}$$

The resulting service is the product of the sum of four variable. The numbers 0.3, 0.4 and 0.5 are weights for each variable determined by expert estimation for the study area. The final categories of Natural Flood Mitigation (1 = very low, 2 = low, 3 = average, and 4 = high) were based on quartiles of the values calculated for the entire river corridor and all assessed years (see Table below).

Category			
very low <2.7	low 2.7 to 3.8	average 3.8 to 4	high >4
1	2	3	4

Roughness (Manning's roughness coefficient) was determined for the following individual LU/LC classes: arable land (0.04), permanent grassland (0.035), green areas (0.12), water bodies (0.03), river channel (0.03), orchards (0.1), and urban area (0.05) (Chow, 1988).

Compared to Keele et al. (2019) and Large and Gilvear (2015), we (i) used ArcGIS Pro instead of the Google Earth platform; (ii) measured each landscape unit instead of estimating the percentage cover in the defined river corridor; (iii) used less detailed land cover types because some categories in our study were missing and precision of work can be affected by aerial image quality (more than 50% of aerial images are black-white); (iv) used Manning's value to describe the roughness of different landscape units to achieve more accurate data; (v) used ecological stability; and (vi) based the final categories on quartiles of the values calculated for the whole river corridor and all assessed years. The final score of ES Natural Flood Mitigation is the sum of all listed parameters corresponding to the equation (Tables 3 and 4) for each river segment.

The sinuosity for each RS was automatically calculated using the Meander Statistic toolbox (MSaT) to analyze the meander characteristics for each segment and studied year (Ruben et al., 2021). This software provides a comprehensive analysis of the input river centerline in the form of point coordinates.

Appendix 3: Equation of Water Ecosystem Service

Name of Ecosystem Service	Abbr.	Description
Water Ecosystem Services Provisioning category	NFM	Natural flood protection based on the river and floodplain LU/LC characteristics

Indicator	Abbr.	Unit	Variable description	Data basis
River width	WR	Manning's value	Roughness of each LU/LC unit	Tables Calculation
Paleochannels	P_{ch}	-	Number and size of P_{ch} at each segment	Map analysis
Coefficient of ecological stability	ES_{coef}	-	Calculated sinuosity for each segment	Statistical Office
Coefficient of Green Areas	GA_{coef}	-	Ratio stable and unstable landscape unit in segment	Map analysis Calculation
Coefficient of river bars	B_{coef}	-	Ratio of area of river bar to river segment length and width	Map analysis

Equation of Water Ecosystem Services: $$W_{ES_{RS}} = \sum_{i}^{n} 0.5W_R + 0.3P_{CH} + 0.5ES_{coef} + 0.2GA_{coef} + 0.3B_{coef}$$

The resulting service is the product of the sum of four variable. The numbers 0.2, 0.3 and 0.5 are weights for each variable determined by expert estimation for the study area.

Category			
very low <3.2	low 3.2 to 4.1	average 4.1 to 4.9	high >4.9
1	2	3	4