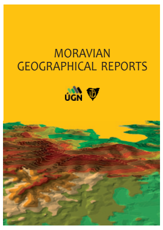

MORAVIAN GEOGRAPHICAL REPORTS

Czech Academy of Sciences, Institute of Geonics
Palacký University Olomouc, Faculty of Science

journal homepage: **www.geonika.cz/mgr.html**

doi: **https://doi.org/10.2478/mgr-2025-0008**

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Natura 2000 sites as a crucial part of nature conservation? An analysis of landscape development in selected areas of the Czech Republic

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Abstract

The Natura 2000 network is the key tool for preserving biodiversity in the EU. However, such a system of territorial protection is under increasing anthropogenic pressure and sites with no national designation are managed rather insufficiently across Europe. Therefore, we investigated six selected large areas consisting of Natura 2000 sites in the Czech Republic, which are not designated as national large-scale protected areas, analysed their landscape development over the last 70 years, and considered their suitability for establishment as national protected areas. All studied Natura 2000 sites have suitable conditions to become national protected areas; lower anthropogenic pressure than in current nationally protected areas and also natural and close-to-natural land cover in the vast majority of the areas. Moreover, designation of these areas as nationally protected areas could contribute significantly to ensuring connectivity between protected areas and could enhance proper management of the areas, which is especially needed in some valuable but vulnerable regions.

Keywords: Natura 2000, Czech Republic, protected areas, land cover, landscape fragmentation and connectivity, anthropogenic pressure

Article history: Received 30 January 2024, Accepted 15 March 2025, Published 30 June 2025

1. Introduction

Protected areas (PAs) are a cornerstone of protecting nature around the world. PAs are designated as a tool to halt biodiversity loss and enhance the ecological functions of landscape and conditions of habitats (Watson et al., 2014). In the European Union (EU), the Natura 2000 network is the largest ecological network and a key part of the EU´s Biodiversity strategy (European Commission, 2021). Natura 2000 is based on the Birds Directive from 1979 (79/409/EEC; European Council, 1979), with designation of Special Protection Areas (SPA), and the Habitats Directive from 1992 (92/43/EEC; European Council, 1992), spatially defined as Sites of Community Importance (SCI) by member states and, after European Commission approval, designated as Special Areas of Conservation (SAC). Natura 2000 sites are established to protect selected species and habitats and to be coherent across the EU. This framework stresses sustainability and effective and careful management to achieve goals regarding the subject of protection, but no strict conservation measures are needed (European Environmental Agency, 2012). Now, the Natura 2000 network covers around 19% of the EU (European Environmental Agency, 2024).

However, despite their aims to protect habitats, Natura 2000 sites are experiencing negative changes, which are similar to the surrounding landscape. Indeed, it was found that Natura 2000 sites are dynamic parts of the landscape with change recorded on 20% of their area between 1990 and 2012 (Guerra et al., 2019; Hermoso et al., 2018). Generally, artificial or intensively used areas (e.g. buildings, roads) in Natura 2000 sites have increased (Kubacka & Smaga, 2019) but at a lower rate than outside of the Natura 2000 sites (Kallimanis et al., 2015). In order to halt this negative trend, suitable and sustainable management is crucial for finding appropriate measures, which can vary over time (Kovac et al., 2018). Thus, one of the important research topics deals with monitoring the rate and type of landscape changes caused by different management regimes in and around Natura 2000 sites.

In the Czech Republic, 14% of land is protected as Natura 2000 sites (European Environmental Agency, 2024). Like in other parts of Europe, Central European and Czech Natura 2000 sites have experienced anthropisation (an increase of man-made structures) and land-use intensification (Concepción, 2021; Hermoso et al., 2018; Mammides et al., 2024). This is in accordance with

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general trends in Czech landscape recorded over the past century and has been driven in particular by political and socio-economic events (Kupková et al., 2013).

In some EU countries, and also in Czech environmental law, Natura 2000 sites do not have such strict protection status as nationally designed Protected Landscape Areas (PLA) or even National Parks (NP). Management in Natura 2000 sites allows economic activities except those harmful for the purpose of protection. As documented by Křenová and Kindlmann (2015) and Miklín and Čížek (2014) implementation of Natura 2000 in Czech Republic can be suboptimal due to unstable political conditions and the weak position of state representatives. The success of management and protection also largely depends on ownership of property and common agreement of all stakeholders. The protection of Natura 2000 sites is rather focused on certain species and habitats, not on the ecosystem or landscape as a whole (European Commission, 2015). Natura 2000 sites also sometimes lack clear management plans (Martínez-Fernández et al., 2015). Management of Czech Natura 2000 sites is not zoned and management plans are relatively brief in comparison with PLA and NP management plans (Czech National Council, 1992). In addition, there currently exists no EU-wide regulation strictly preventing new infrastructure from being built inside Natura 2000 sites. Prevention of new infrastructure within Natura 2000 sites is thus left to regulation and enforcement at the local and national level (Kenig-Witkowska, 2017).

2. Theoretical background

Land cover changes in the Natura 2000 sites around the EU have been widely examined (e.g. Mücher et al., 2009; Mallinis et al., 2011). Natura 2000 sites experienced higher urbanisation (and lower landscape stability) than nationally designated PAs in Spain (Martínez-Fernández et al., 2015). A study researching Natura 2000 sites across the EU revealed that more than 20% of the landscape in these sites has changed in the last two decades (Hermoso et al., 2018). Moreover, older and steeper Natura 2000 sites were transformed towards natural land cover, whereas recently established and flatter ones were changed to more artificial cover and the landscape structure of all sites has become homogenised (Hermoso et al., 2018). The threat of homogenisation is related to land-use intensification on the one side and abandonment on the other (Anderson & Mammides, 2020).

However, changes are still larger and management of farmland worse in the surroundings of Natura 2000 sites than within them (Anderson & Mammides, 2020; Hermoso et al., 2018). More than half of Natura 2000 sites in Europe (58.5%) are less fragmented than their surroundings (especially in remote and mountainous regions). In contrast, within EU countries, France, Belgium, the Netherlands, Luxembourg, Germany, and the Czech Republic show the highest level of fragmentation inside and around Natura 2000 sites (Lawrence at al., 2021); moreover, landscape fragmentation in the Czech Republic has been increasing (Romportl, 2017). Furthermore, smaller Natura 2000 sites are more vulnerable to change (Concepción, 2021; Hermoso et al., 2018). Therefore, larger and fewer, rather than more and smaller, Natura 2000 sites covering underrepresented species should be preferred during the designation process (Concepción, 2021; Gruber et al., 2012).

From a landscape change point of view, the Czech landscape shows different developments in the periphery and core areas. Peripheral parts of mainly mountainous regions along the border in the south, west, and north of the Czech Republic were abandoned after World War II due to the expulsion of Czech Germans. Furthermore, the communist regime restricted entry to the border areas. These facts subsequently led to afforestation and extensification of agriculture (Kupková et al., 2021). On the other hand, in more fertile core regions, agriculture was collectivised and intensified with consequences for land use and landscape structure (Bičík & Jančák, 2001; Sklenička et al., 2014). After the fall of communism in 1989, less favoured areas for agriculture, mostly found in the periphery, experienced ongoing extensification in the form of afforestation and grassing over (Feranec et al., 2010; Kupková & Bičík, 2016), while ongoing intensification of agriculture and urbanisation is present in lowlands and surroundings of large cities, representing core areas (Kupková & Bičík, 2016; Kupková et al., 2021; Pazúr et al., 2017).

In this study, our aim was to focus on landscape changes (land cover and anthropogenic structures) and landscape fragmentation that occurred during the past 70 years in selected larger Natura 2000 sites without any additional national protection to analyse landscape stability and anthropogenic pressure. Studying landscape changes together with fragmentation in these sites can help in deciding whether these sites a) can strengthen ecological stability and landscape connectivity across the Czech landscape, thus helping in preserving biodiversity and increasing gene flow, and therefore b) are good candidates for national designation with stricter protection, like national parks and protected landscape areas. Although studied sites were declared in 2005, we studied landscape changes since 1950s in order to capture long-term landscape stability, which can be used as a proxy for capturing the level of habitat quality, and subsequently to host biodiversity (Fraser & Pouiliot, 2009).

We evaluated selected study localities, which so far have not been assessed in more detailed way, based on whether they have experienced similar changes as other Natura 2000 sites in the EU or not, focusing on: changes of land cover, land-use intensification, and anthropisation.

Based on this, we hypothesised that:

1. The studied Natura 2000 sites have been more affected by urbanisation and land-use intensification according to European findings (Anderson & Mammides, 2020; Concepción, 2021; Hermoso et al., 2018; Martínez-Fernández et al., 2015) than Czech PLA and NP (Janík et al., 2024).
2. Selected study localities within Natura 2000 sites are, regarding the past 70-year period, rather favourable for national PA designation as they have similar characteristics as current PLAs and NPs (Janík et al., 2024) and due to their location (Feranec et al., 2010; Kupková & Bičík, 2016) they can serve as crucial stepping stones for increasing ecological connectivity and biodiversity; however, we expect that nationally designated PAs (PLAs and NPs) are more ecologically stable (stability of natural and close-to-natural land cover categories) without significant negative changes (see e.g. Martínez-Fernández et al., 2015).

3. Data and methods

3.1 Study area

We grouped the selected Natura 2000 sites into six localities and excluded parts that are already inside a PLA or NP (Tab. 1). The framework of Natura 2000 does not exclude human activities from the landscape. Paradoxically, it can lead to a more diverse landscape; for example, Boletice, Doupovské hory Mts., and Libavá, which are situated in mid and higher elevations, have been military areas (established after World War II) since the beginning of our study period. Bzenecká Doubrava – Strážnické Pomoraví and Soutok are located in South Moravia in the lowlands and combine forests and agricultural land along large rivers. Krušné hory Mts. is a mountainous locality affected by depopulation after World War II and significant air pollution from coal-fired power stations. On the other hand, Krušné hory Mts. can be depicted as a large piece of landscape with ecologically valuable sites.

Study localities range from lowlands (Bzenecká Doubrava – Strážnické Pomoraví, Soutok) to mountainous ridges (Boletice, Krušné hory Mts.) and are situated across the whole of the Czech Republic (Fig. 1)

3.2 Land cover

Land cover data were created by manual vectorisation in ArcGIS 10.x (ESRI, 2020) using available georeferenced and scanned topographic maps and aerial imagery to capture the most significant events of landscape development in the last seventy years. They were created for four periods and made it possible to detect changes between them:

1. 1950 dataset represents period of changes in open agricultural land, such as the expansion of arable land in more fertile regions based on land reforms from the beginning of the 20th century, as well as the introduction of new technologies (Kupková et al., 2021) and abandonment of mostly border areas formerly inhabited by Czech Germans, who were expelled after the Second World War (Havlíček et al., 2022), predominantly resulting into afforestation (Lipský, 2001). Land cover from this period was based on 1:25,000 Czechoslovak military maps from 1952–1956 (General Staff of the Czechoslovak Army 1952–1956).
2. 1990 dataset shows a time of change from communism with large-scale landscape exploitation, ranging from intensified agriculture and destruction of small landscape features caused by socialist collectivisation (Sklenička et al., 2014; Skokanová et al., 2016), to industrialisation and the spread of large open mines (Kupková et al., 2021) and to democracy and capitalism with rapid suburbanisation and extensification (in the form of afforestation as well as grassing over) of less favourable regions, mainly the mountainous ones (Grešlová et al., 2023). The land cover layer from this period was based on 1:25,000 Czechoslovak military maps from 1988–1995 (General Staff of the Czechoslovak Army 1988–1995).
3. 2004 dataset shows the year of accession into the EU, accompanied with changes in agricultural subsidies and other restrictions, such as restricted land purchases and land quotas on various types of cultivated crops, which led to a decrease in agricultural production, extensification, and land abandonment (Kupková et al., 2021) on one hand, and spread of specific types of crops (e.g. vineyards) before this date (Skokanová et al., 2020) on the other. Land cover data from this period were vectorised from a 1:10,000 base map originating between 2002 and 2006 (Czech Office for Surveying, Mapping and Cadastre 2002–2006) and aerial imagery from 2003 and 2005 with pixel size 0.5 m (Czech Office for Surveying, Mapping and Cadastre 2003–2005).
4. 2016–2020 dataset represents the current state, with ongoing urbanisation and growing pressure from recreational use (Janík et al., 2021). Land cover data are based on aerial imagery with pixel size 0.2 m (Czech Office for Surveying, Mapping and Cadastre 2016–2020) and supported by LPIS (Land Parcel Information System – Soil registry; Ministry of Agriculture 2016–2020).

Name of area	Type and number of included Natura 2000 site	Area [km^2]
Boletice	1 SAC, 1 SPA	101.25
Bzenecká Doubrava – Strážnické Pomoraví	1 SPA	117.23
Doupovské hory Mts.	1 SAC, 1 SPA	620.12
Krušné hory Mts.	3 SAC, 2 SPA	573.54
Libavá	1 SAC, 1 SPA	327.24
Soutok	2 SAC, 1 SPA	128.39

Tab. 1: Study localities
Source: AOPK ČR / NCA (Nature Conservation Agency of the Czech Republic)

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

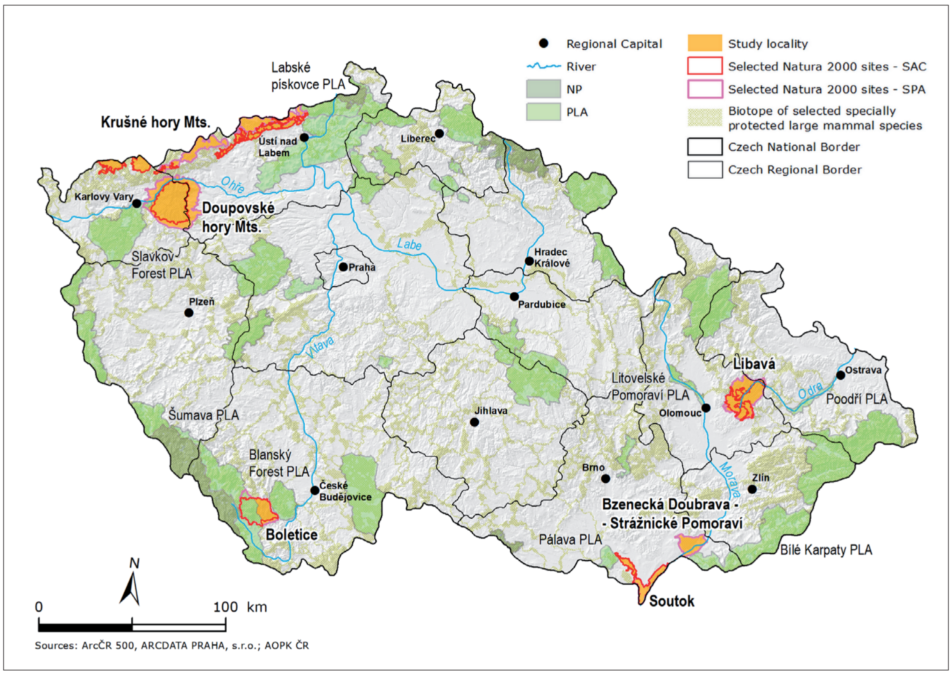

Fig. 1: Study localities and other large-scale nationally designed PAs and Biotope of selected specially protected large mammal species. Study localities are situated between current PLAs and NPs (Krušné hory Mts. and Doupovské hory Mts. are between Labské pískovce and Slavkov Forest, Boletice is between Šumava and Blanský Forest, Libavá is between Litovelské Pomoraví and Poodří and Soutok with Bzenecká Doubrava are between Pálava and Bílé Karpaty, see the description in the map) and their names are stated in larger bold font
Source: ArcČR 500 ARCDATA PRAHA, s.r.o.; AOPK ČR / NCA (Nature Conservation Agency of the Czech Republic)

comparable, only nine main land cover categories were identified (Tab. 2), based on the combination of used map keys and legends (Mackovčin, 2009; Skokanová, 2009).

Arable land is defined as a land used mainly for agricultural production of cereals, legumes, oil crops, root crops, and technical crops. It also includes a mosaic of arable fields with small vineyards, trees and meadows, and fallow land. Permanent grassland includes all types of permanent herbaceous vegetation, regardless of their composition. As such, this category includes also wetlands, which, while potentially distinguishable in orthophotos, are usually depicted in the maps as grasslands. Gardens and orchards include mainly extensive as well as intensive orchards in the landscape. However, some orchards can be close to settlements and might therefore be seen as large gardens, especially in orthophotos. Unfortunately, the maps used have the same symbol for both large gardens and orchards, making them undistinguishable from each other. Therefore, they are grouped together. Vineyards and hop-fields are included in a separate category in order to capture this specific, and rather unique, land cover class. The forest category includes all larger wooded plots, regardless their type and stage.

Water areas are represented by all types of water bodies, i.e. with a permanent level of above-ground water.

Built-up areas include all types of residential, industrial, commercial, agricultural, transportation, administrative or military structures and social facilities with adjacent small gardens and other forms of green plots. Recreational areas are categorised as areas used mainly for recreation and tourism outside settlements with distinct man-made features, such as sheds and wooden structures (in the case of garden allotments and campsites), playgrounds (for sport resorts), cages (zoological gardens), holes, sand features and rocks (golf courses) or distinctive and dense paths in, for example, wooded plots (in the case of spas). In the maps, they are usually marked by abbreviation (e.g. golf, rekre, zoo, etc.). Other areas are anthropogenic features in the form of mining areas, usually as open mines, or dump sites, i.e. features of unused land.

While forest and permanent grassland represent natural and close-to-natural and more ecologically stable land cover categories, built-up areas, recreational areas and other areas can be seen as anthropogenic categories, with arable land, gardens and orchards, and vineyards and hop-fields being grouped into agricultural use. Water areas could be both natural and artificial, so they were excluded from this distinction of aggregated natural and anthropogenic land cover categories (see Tab. 2).

Polygon layers capturing land cover distribution in each period enabled calculating shares of land cover categories and selected landscape metrics, namely edge density (ED) and Shannon diversity index (SHDI). Both landscape metrics can capture simplification of the landscape caused by different processes and driving forces behind them. ED highlights change of patch shape while SHDI illustrates diversity of represented land cover categories and their relative distribution (Rempel et al., 2008). Both landscape metrics as well as shares of land cover categories were calculated in Patch analyst extension for ArcGIS (Elkie et al., 1999).

To capture main processes of change in the terms of largest growths and decreases, as well as stability, of land cover (i.e. if the land cover class of a given patch did not change in any given period), the polygon layers were overlaid, resulting in a GIS database. The main processes or land cover flows (European environmental agency, 2006; Feranec et al., 2010; Martínez-Fernández et al., 2015; Zbierska, 2022) were calculated between two adjacent periods (e.g. 1950 and 1990) as transitions of land cover classes to arable land, permanent grassland, forest or built-up areas.

To compare differences between selected land cover characteristics, in particular area of individual land cover categories and their stability calculated for NATURA 2000 sites and average values of these characteristics calculated for 4 NP and 26 PLA and to test significance of these differences, Wilcoxon signed rank, a non-parametric, test in R (R core team, 2023) was used.

3.3 Anthropogenic structures and landscape fragmentation

Anthropogenic pressure is a threat for biodiversity and landscape resilience. Therefore, we analysed it separately in more detail. Anthropogenic pressure is defined for this study as physical anthropogenic structures and their impact on landscape fragmentation. We prepared data of anthropogenic structures in the selected study areas for similar temporal milestones using the following historical sources:

1. 1960 dataset: 1:10,000 topographic map from 1957 to 1971 (Central Administration of Geodesy and Cartography 1957–1971) with support of aerial images from the 1950s;
2. 1990 dataset: 1:10,000 base map originating between 1986 and 1995 (Central Administration of Geodesy and Cartography 1986–1995);
3. 2004 dataset: 1:10,000 base map originating between 2002 and 2006 (Czech Office for Surveying, Mapping and Cadastre 2002–2006) with support of aerial imagery from 2003 and 2005 with pixel size 0.5 m (Czech Office for Surveying, Mapping and Cadastre (2003–2005);
4. 2016–2020 dataset: current data was obtained and edited from ZABAGED® (The Fundamental Base of Geographic Data of Czech Republic) and aerial imagery with pixel size 0.2 m (Czech Office for Surveying, Mapping and Cadastre 2016–2020).

As for land cover, data for analysing anthropogenic pressure were derived manually in ArcGIS 10.x (ESRI, 2020) based on the above-mentioned data sources. Built-up and recreational areas were processed as polygon layers with a minimum mapping unit of 0.2 ha (higher resolution than in land cover data). Built-up areas consisted of buildings, urban areas, fenced estates, and gardens around houses. Recreational areas were recognised as camp sites, golf courses, playgrounds, ski slopes, shooting ranges, tracks for motocross and cyclocross, and recreational areas along water bodies. Furthermore, linear features of roads and dirt roads were recorded.

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

Tab. 2: Land cover categories
Source: Authors' elaboration

Finally, we included anthropogenic structures data in one layer of fragmentation geometry and calculated the index Effective Mesh Size (EMS; Jaeger, 2000; Moser et al., 2007; Girvetz et al., 2008) for all study localities and also for NPs and PLAs for comparison. The input data was composed of fragmentation geometry, a mask of the selected study areas, and a regular square grid (500 × 500 m). Fragmentation geometry was assembled from built-up areas, roads and dirt roads. Fragmentation geometry enters the calculations as a polygon layer; therefore, roads features have been provided with a buffer that expresses their estimated occupation area of land. The radius of the buffer corresponds to the categories of the road network based on the following expert evaluation: motorway – 13 m; first class road – 8 m; second class road – 5 m; third class road – 4 m; maintained dirt or forest road – 3 m; unmaintained dirt or forest road and purpose-built road – 2 m. The expert evaluation was based on an estimate of the average road width of the given category. Two versions of fragmentation geometry (FG) were included in the calculations, namely (FG-a) only built-up areas and roads and (FG-b) built-up areas with roads, dirt and forest roads and purpose-built roads. The result of composing the fragmentation geometry is that we prepared two versions (FG-a and FG-b) for the four mentioned milestones (1950, 1990, 2004, 2020) for our study localities in the Czech Republic.

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

$$\mathrm{m}_{\mathrm{eff}}^{\mathrm{CBC}}(\mathrm{j}) = \frac{1}{A_{tj}} \sum_{i=1}^{n} A_{ij} A_{ij}^{cmpl}$$

The resulting variable m_{eff}^{CBC} *(j)* represents the EMS value (calculated in square kilometres) for the given unit (a square 500 × 500 m), where n is the total number of patches extending into one square, A_{tj} is the total area of the square, A_{ij} is the partial area of the patch that extends into the square, and A_{ij}^{cmpl} is the total area of the patch. The values of EMS express in a figurative sense the probability of mutual connection of two randomly located points in the landscape. This means that the higher the value of EMS is, the higher the probability of connecting and, at the same time, the lower the level of landscape fragmentation.

Like in case of land cover, also here the Wilcoxon signed rank, a non-parametric, test in R (R core team, 2023) was used for comparing distribution of anthropogenic structures in selected Natura 2000 sites with average values for all Czech PLAs and NPs and testing the significance of these differences.

4. Results

4.1 Land cover

The six selected localities varied in land cover changes, main processes, and stability as well as anthropogenic pressure. Generally, regardless of protection status (Natura 2000 sites, PLA, NP), all protected areas and studied localities experienced forest area growth, especially those at a higher altitude. The share of stable forest was not significantly different from PLAs or NPs (Tab. 5); however, the share of stable permanent grassland was significantly higher than in PLAs and NPs. Stable arable land was represented less than in PLAs and more than in NPs (Tab. 3). In the Bzenecká Doubrava – Strážnické Pomoraví and Soutok (areas situated in the lowland of South Moravia), intensification of agriculture took place and also the metrics SHDI and ED rose, indicating higher diversity, whereas in other areas both metrics decreased. This was true mainly in Krušné hory Mts. with its large stable forest area, which was enlarged during the study period (Fig. 2). The share of natural and close-to-natural land cover categories was high in all studied Natura 2000 sites and steadily grew, with the exception of the Bzenecká Doubrava – Strážnické Pomoraví and Soutok where the intensification of agricultural use was dominant (Fig. 3).

4.2 Anthropogenic structures and landscape fragmentation

Anthropogenic pressure and the presence of anthropogenic structures are negligible across all areas. Built-up areas were significantly less represented in the selected Natura 2000 sites

Landscape or anthropogenic feature in Natura 2000 localities	PLA	NP	Explanation
Built_up_1960 (less)	**p = 0.016**	**p = 0.031**	In 1960, built-up areas in Natura 2000 study localities were significantly less represented than in PLAs and NPs on average.
Built_up_2016 (less)	**p = 0.016**	**p = 0.016**	In 2016, built-up areas in Natura 2000 study localities were significantly less represented than in PLAs and NPs on average.
Recreation_1960 (less)	**p = 0.017**	**p = 0.045**	In 1960, recreational areas in Natura 2000 study localities were significantly less represented than in PLAs and NPs on average.
Recreation_2016 (less)	p = 0.109	**p = 0.031**	In 2016, recreational areas in Natura 2000 study localities were significantly less represented than in NPs on average.
Roads_1960 (less)	**p = 0.047**	p = 0.344	In 1960, roads in Natura 2000 study localities were significantly less represented than in PLAs on average.
Roads_2016 (less)	**p = 0.031**	p = 0.281	In 2016, roads in Natura 2000 study localities were significantly less represented than in PLAs on average.
Dirt roads_1960 (less)	p = 0.078	p = 0.656	In 1960, dirt roads in Natura 2000 study localities were not significantly less represented than in PLAs and NPs on average.
Dirt roads_2016 (less)	p = 0.219	p = 0.109	In 2016, dirt roads in Natura 2000 study localities were not significantly less represented than in PLAs and NPs on average.
Stable arable land (less)	**p = 0.016**	p = 0.219	Stable arable land during the study period was significantly less represented in Natura 2000 study localities than in PLAs on average.
Stable permanent grassland (greater)	**p = 0.031**	**p = 0.031**	Stable permanent grassland during the study period was significantly more represented in Natura 2000 study localities than in PLAs and NPs on average.
Stable forest (whether differ – less or greater)	p = 1.000	p = 0.063	Stable forest during the study period was not significantly different in Natura 2000 study localities from PLAs and NPs on average.
Stable land cover (whether differ – less or greater)	p = 0.438	**p = 0.031**	Stable land cover during the study period was significantly different in Natura 2000 study localities from NPs on average (NPs are more stable).

Tab. 3: Wilcoxon signed rank test testing significance of difference between selected Natura 2000 sites (n = 6) and PLAs (n = 26) and NPs (n = 4) on average. Selected anthropogenic features were analysed for the beginning (1960) and the end of the period (2016), and landscape features for the whole period (regarding 'stable' land cover and its categories). Testing whether they are less, greater, or testing difference – less or greater (see in brackets). Bold means significant difference
Source: Authors' calculations

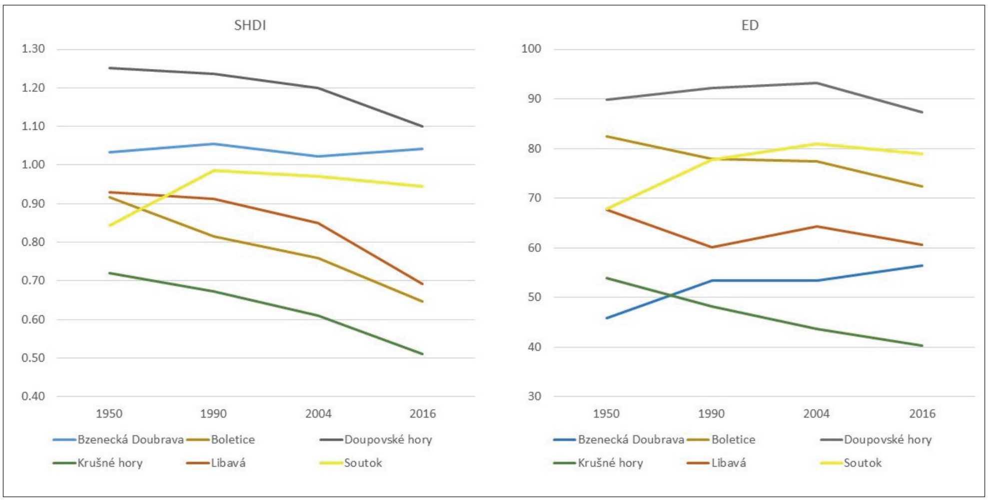

Fig. 2: Development of the selected landscape metrics (Shannon diversity index, edge density) for studied Natura 2000 sites
Source: Authors' calculations

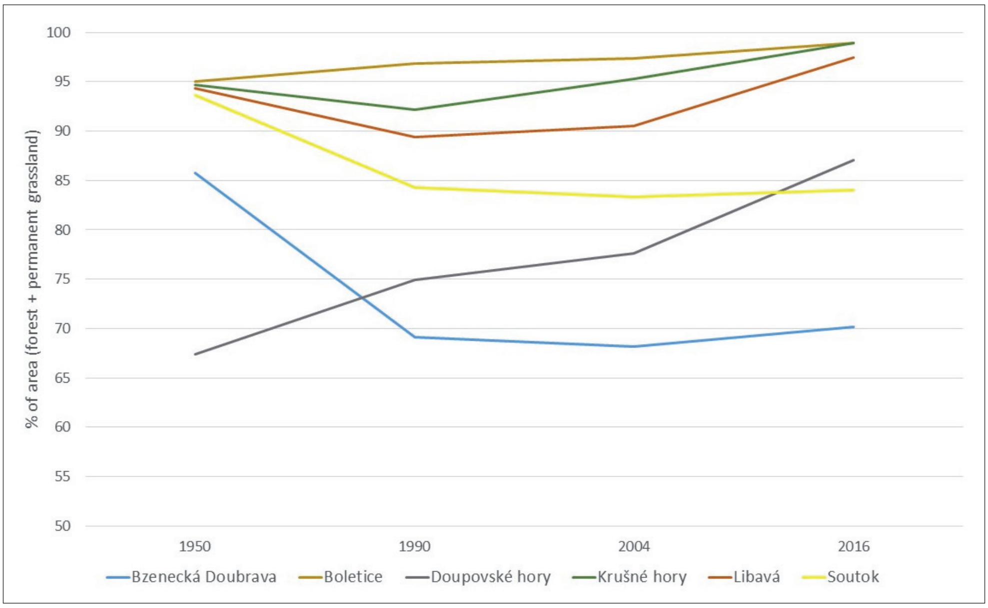

Fig. 3: Share of natural and close-to-natural land cover categories (forest and permanent grassland) in study localities during the study period
Source: Authors' calculations

than in PLAs and NPs. Recreational areas are significantly less represented in Natura 2000 sites than in NPs at the beginning and the end of the study period, whereas in comparison with PLAs, there were significantly less recreational areas in Natura 2000 sites at the beginning and no significant difference is recorded in the most recent period. Road density is significantly lower in Natura 2000 sites than in PLAs and not-significantly but lower than in NPs. There is no significant difference between dirt road density in Natura 2000 sites, NPs, and PLAs (Tab. 3).

The analysis of the level of landscape fragmentation showed that the average EMS values for roads and built-up areas (FG-a) in the Natura 2000 sites were higher by several tens of square kilometres for all years than the average EMS values in NPs and PLAs (Tab. 4.). This significant difference was mainly caused by the different use of the landscape, where three of the six areas of interest have been military training areas with specific landscape management. The average EMS values for built-up areas and roads (FG-a) reached 50.94 km^2 for Natura 2000 sites and 43.98 km^2 for NPs and PLAs at the beginning of the study period (1960). Currently, average EMS values reach 58.76 km^2 for Natura 2000 sites, and 39.95 km^2 for NPs and PLAs. By including dirt and forest roads in the analyses (FG-b), the level of landscape fragmentation will significantly increase to 1.41 km^2 for Natura 2000 sites and 2.01 km^2 for NPs and PLAs (Tab. 4).

4.3 Overview of study localities

There are some differences and similarities between the studied Natura 2000 sites. We point out the most significant features in more detail below (see Tab. 5 and Tab. 6):

Fragmentation geometry	Protected areas	1960	1990	2004	2016
FG-a	Natura 2000	50.94	83.08	61.17	58.76
	NPs/PLAs	43.98	41.50	43.82	39.95
FG-b	Natura 2000	2.54	2.59	1.97	1.41
	NPs/PLAs	3.36	2.04	1.90	2.01

Tab. 4: The average EMS values for roads and built-up areas (FG-a) and built-up areas with roads, dirt and forest roads and purpose-built roads (FG-b) in Natura 2000 sites and NPs/PLAs during selected time milestones
Source: Authors' calculations

- Bzenecká Doubrava – Strážnické Pomoraví experienced intensification of agricultural use and urbanisation, especially before 1990; thus, arable land (from 12% to 26%) and built-up areas grew, whereas permanent grassland declined rapidly from 29% to 9%. Afforestation also took place with an increase in forest from 57% to 61%. Landscape structure stayed relatively diverse, with an increasing number of patches and edge density. Land cover was stable at 66% of the area during the study period, with stable forest being the main part of the area. The rate of built-up area growth is the largest in comparison with other areas (from 0.4% to 1.3%). Also, road density increased slightly, whereas dirt road density decreased. This area also has the largest share of recreational areas in comparison with other study localities. The average value of EMS (FG-a) decreased from 64.04 km^2 in 1950 to 54.52 km^2 in 2016 (Fig. 4). On the other hand, the average value of EMS with dirt and forest roads (FG-b) gradually increased from 1.54 km^2 to 2.1 km^2.
- Change in another Natura 2000 site – Boletice – could be defined as afforestation; arable land almost vanished (from 3%) and permanent grassland decreased (53% to 27%), resulting in forest increase from 42% to 72%. Therefore, permanent grassland together with forest created the vast majority of the area. Landscape structure was unified and land cover remained stable at 61% of the area. The area is almost without anthropogenic structures with an increase in small built-up areas, while road and dirt road density shrank. Recreation areas were presented only negligibly. For the EMS, we observed a significant increase from 109.4 km^2 to 145.1 km^2 in 2016 (Fig. 4), reducing the fragmentation rate by almost 50%. For forest and dirt roads, this increase was only slight (from 1.41 to 1.68 km^2).
- Doupovské hory Mts. was, during the whole period, covered largely by permanent grassland, which ranged from 30% to 40% with a decrease from 40% to 36%. Afforestation caused a growth of forest from 27% to 51%. Arable land shrank from 28% to 9%. The area went through a large change as only half of the area retained the same land cover with unifying of landscape structure occurring especially in the central and western part of the area, where forest covered the former landscape mosaic of meadows, fields, forests, and settlements. The area had the largest portion of built-up areas; despite the decrease before 1990, it grew from 1.5% to 1.8%. Roads and dirt roads were slightly shortened. Recreational areas continuously increased but only covered a negligible area. Due to the increase in anthropogenic structures, especially on the edges of the study locality, the average value of EMS (FG-a) decreased from 53.12 km^2 to 45.16 km^2 and this led to an increase in the degree of landscape fragmentation. In the case of forest and field roads (FG-b), the EMS value dropped from 2.41 to 1.57 km^2.
- Krušné hory Mts. was predominantly forested and characterised with ongoing forest area growth (from 76% to 83%). Arable land grew from 4% to 7% between 1950s and 1990s and then almost vanished from the study locality. The landscape is stable (land cover remained stable on 82% of the area) but experienced homogenisation of landscape structure. Built-up areas increased slightly, especially after 1990. Roads were reduced, whereas dirt road density increased. Recreational areas were newly developed, which was in particular caused by the construction of ski slopes. The degree of landscape fragmentation by built-up areas and roads stagnated, and in 2016 the average EMS value was 12.8 km^2. In the case of forest and dirt roads, the value of EMS decreased to 0.88 km^2, and thus there was an increase in the degree of landscape fragmentation.
- Libavá mainly experienced afforestation, with forest area growth from 50% to 73%. Permanent grassland (45% to 24%) and arable land (4% to 2%) generally decreased during the whole period, but an increase from the 1950s to 1990 was

Study localities	Main changes of selected land cover categories areas during the study period (%)						Stable land cover (%)			
	1950 – arable land	2016 – arable land	1950 – permanent grassland	2016 – permanent grassland	1950 – forest	2016 – forest	stable arable land	stable permanent grassland	stable forest	overall stability of land cover
Bzenecká Doubrava – Strážnické Pomoraví	12.23	26.16	28.80	9.32	56.98	60.82	7.07	5.00	53.43	66.34
Boletice	2.74	0.03	52.70	26.52	42.30	72.37	0.00	20.41	40.70	61.46
Doupovské hory Mts.	28.48	8.92	40.11	36.49	27.32	50.57	6.93	16.51	25.21	50.17
Krušné hory Mts.	4.10	0.01	18.76	16.2	75.92	82.73	0.00	7.03	74.27	81.50
Libavá	3.68	1.58	44.63	24.4	49.70	73.07	0.28	13.34	48.39	62.26
Soutok	5.82	13.63	29.22	16.54	64.39	67.46	4.15	9.82	56.66	71.03
Czech NPs	7.85	1.76	19.76	15.95	70.08	79.13	1.32	8.75	68.44	79.75
Czech PLAs	24.79	9.70	17.01	21.78	53.67	61.30	7.71	5.98	51.86	68.51

Tab. 5: Overview of study localities with the most important studied land cover features and comparison with NP and PLA
Data source: Authors' calculations

Study localities	Built-up areas (%)				Recreational areas (%)				Roads (km/km^2)				Dirt roads (km/km^2)			
	1960	1990	2004	2016	1960	1990	2004	2016	1960	1990	2004	2016	1950	1990	2004	2016
Bzenecká Doubrava – Strážnické Pomoraví	0.36	0.75	1.05	1.31	0.01	0.18	0.38	0.39	0.13	0.13	0.14	0.15	4.44	4.35	4.10	4.05
Boletice	0.34	0.58	0.58	0.56	0.00	0.00	0.01	0.00	0.34	0.45	0.38	0.29	5.19	3.40	3.61	3.96
Doupovské hory Mts.	1.48	1.43	1.63	1.81	0.01	0.02	0.03	0.03	0.70	0.63	0.65	0.65	3.35	3.02	3.13	3.30
Krušné hory Mts.	0.37	0.40	0.45	0.54	0.00	0.03	0.06	0.07	0.49	0.48	0.42	0.42	4.29	4.51	4.57	4.71
Libavá	0.69	0.59	0.57	0.54	0.00	0.00	0.00	0.00	0.44	0.31	0.38	0.38	5.09	4.04	3.85	4.21
Soutok	0.16	0.27	0.41	0.39	0.00	0.03	0.02	0.05	0.13	0.17	0.16	0.19	3.20	3.45	2.98	3.38
Czech NPs	1.01	1.34	1.52	1.64	0.01	0.25	0.36	0.45	0.41	0.44	0.42	0.40	4.20	4.10	4.04	4.24
Czech PLAs	2.50	3.32	3.57	3.89	0.02	0.08	0.15	0.19	0.58	0.61	0.60	0.60	4.85	4.20	4.18	4.10

Tab. 6: Overview of study localities with the studied anthropogenic features and comparison with NP and PLA
Data source: Authors' calculations

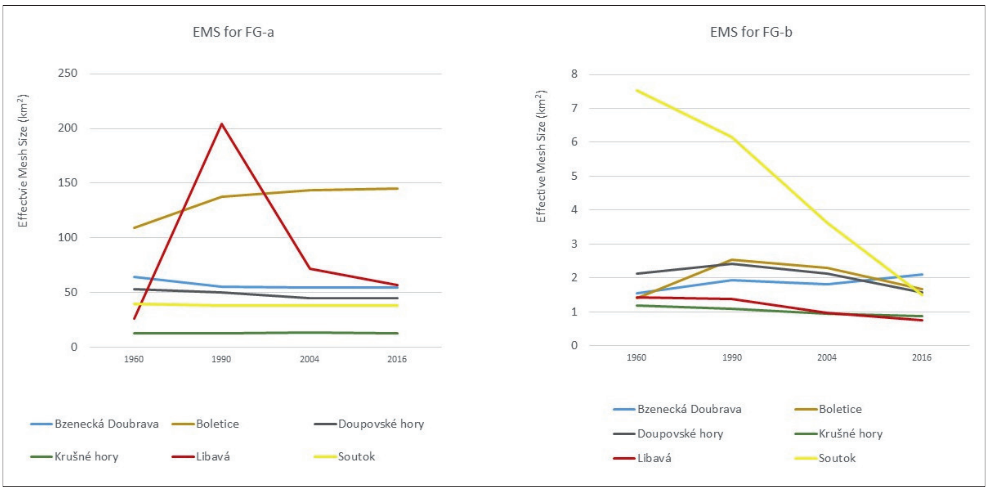

Fig. 4: Development of average Effective Mesh Size for the studied Natura 2000 including built-up areas and roads (FG-a) and built-up areas, roads, dirt and forest roads, and purpose-built roads (FG-b)
Source: Authors' calculations

recorded. Landscape structure was unified and land cover remained stable at 62% of the total area. Built-up areas slightly declined. Roads and dirt roads were shortened. Recreation was barely present in the area. The average value of EMS (FG-a) increased significantly from 26.51 km^2 to 56.78 km^2 during the monitored period. A massive increase in the EMS value was recorded in 1990 due to the missing part of the road section in the road network (Fig. 4). In contrast, the average value of EMS (FG-b) halved from 1.43 km^2 to 0.75 km^2 in 2016.

- Soutok was affected by agricultural intensification, with a growth of arable land from 6% to 14%, especially before 1990, whereas permanent grassland declined from 29% to 17%. Forest increased slightly from 64% to 67%. Landscape increased its diversity with the stable forest area and overall stability of 71% of the total area. Built-up areas had the smallest share among all studied localities, but they grew. Roads and dirt roads enlarged their network. Recreation areas emerged from the garden allotments. The average value of EMS (FG-a) decreased only slightly from 39.57 km^2 to 38.23 km^2. A significant decrease in the average value of EMS was observed in the case of forest and dirt roads (FG-b), from 7.53 km^2 to 1.51 km^2 in 2016 (Fig. 4).

5. Discussion

As our results show, selected areas protected as Natura 2000 sites can, from the landscape perspective, be regarded as valuable parts of the Czech landscape without significant presence of anthropogenic structures and with the prevalence of natural or close-to-natural land cover categories. This fact confirms their uniqueness and justification for inclusion in the Natura 2000 network, but also for national designations, at least as PLAs. If done so, they would contribute to fulfilling improvement of the conservation status to reach 30% of sufficiently protected areas (European Commission, 2021). This is also stressed because the selected Natura 2000 sites more or less overlap the "Biotope of selected specially protected large mammal species", a GIS layer delimiting key parts of the Czech Republic for functional landscape connectivity, which creates obligatory data for spatial planning (Hlaváč et al., 2021). Furthermore, low fragmented large PAs are of high ecological quality because they accommodate species movement and, at the same time, boost climate change resilience (Lawrence & Beierkuhnlein, 2023).

The majority of the selected Natura 2000 sites are located in the peripheral regions of the Czech Republic, with specific landscape development. Also, Jepsen et al. (2015) mention that drivers and the timing of these changes are identical for wider area of the former Soviet bloc of European countries. Our study localities experienced relatively large land cover change (except Krušné hory Mts.) in accordance with other EU Natura 2000 sites (Guerra et al., 2019; Hermoso et al., 2018). In our study localities it was caused in particular by ongoing abandonment and extensification of land use (Feranec et al., 2010; Kupková & Bičík, 2016); for example, afforestation is present in all study localities, which is a trend common for PAs across Europe (Ameztegui et al., 2021; Žoncová, 2020).

Our hypothesis regarding higher anthropogenic impact (urbanisation and land use intensification) occurring in the Natura 2000 sites across Europe (e.g. Mammides et al., 2024) was not confirmed and only partly concerned two smaller, lowland localities (Bzenecká Doubrava – Strážnické Pomoraví and Soutok). Both sites are threatened in particular by agricultural intensification as suitable areas for agriculture (Kupková & Bičík, 2016; Kupková et al., 2021) and by unsuitable management of valuable forests (Miklín & Čížek, 2014). These findings are in accordance with results from the studies by Hermoso et al. (2018) and by Concepción (2021).

It should be stressed that by using our data and analyses, we were not able to characterise the ecological quality of the habitats or ecosystems, only land cover categories and their dynamics. However, we evaluated stability and the share of natural and close-to-natural land cover categories as a proxy of quality (Guerra et al., 2019). In this manner, despite detecting relatively large changes, these changes were predominantly represented by increasing share of natural and close-to-natural land cover categories (Fig. 3), leading to the presumption of increased ecological quality of habitats. However, recent study showed that Czech Natura 2000 sites protect sufficiently mainly critically endangered habitats but not natural habitats in general (Pechanec et al., 2018).

Increase in the share of natural and close-to-natural land cover categories are mainly result of landscape abandonment, especially in steeper (and more remote) regions, and general simplification of landscape structure. This was not only in the last two decades or so, as found by Hermoso et al. (2018), but these processes started even as early as the 1950s (Figs. 2 and 3) and were recorded also elsewhere (Lasanta et al., 2017). All mountainous Natura 2000 sites were affected by the expulsion of Czech Germans after World War II, leading to depopulation and afforestation (Janík et al., 2022), and these landscapes are now still relatively abandoned, as also stated by Mareš et al. (2013).

Boletice, Doupovské hory Mts., and Libavá have similar landscape trajectories and drivers. These localities overlap significantly with military training areas, which were established on previously inhabited areas with a large share of open landscape (Skokanová et al., 2017; Havlíček et al., 2018). Logically, the typical development of built-up areas and road networks could not occur here, as happened in the normally accessible countryside, but current land cover composition and biodiversity could be positively influenced by the former military management (Svenningsen et al., 2019). Landscape abandonment caused growth of forest area in particular and a significant decrease in the area of permanent grassland. However, this land cover type was maintained in some parts with military activities (Havlíček et al., 2018; Janík et al., 2022; Lipský et al., 2022). Similar changes were also detected elsewhere across Europe, especially in peripheral and mountainous regions (Feranec et al., 2010; Fuchs et al., 2013). Many authors point out wilderness and high biodiversity in military training areas. Parts of these areas were transferred into the Natura 2000 network or into national networks of protected areas because of their high conservation values (Seidl & Chromý, 2010; Schumacher & Johst, 2015; Ellwanger & Reiter, 2019). To preserve biodiversity, it is necessary to manage landscape structure, which is on the decline and is now maintained as a side effect of military activities. Specific restoration and management measures need to be implemented in order to maintain endangered habitats, for example against succession, which is often a major problem (Šíbl & Klimová, 2011). Moreover, the current situation regarding Russian invasion of Ukraine has led to an increased focus on national defence and we are unlikely to see the transformation of military training areas into nature PAs in the foreseeable future.

Krušné hory Mts., on the other hand, has been a predominantly forested mountainous area with high stability of land cover and low human presence (Janík et al., 2020), with similar landscape features as other already protected mountain ridges across the Czech Republic (e. g. Český les, Jizerské hory, Jeseníky). However, the mountains were previously inhabited by the mining industry (Bastian, 2013; Janík et al., 2022). The increase in the forest landscape category that we found coincides with the results of Palmero-Iniesta et al. (2020) who showed that afforestation related with forest patch coalescence occurs in European forested areas. The high conservation value of Krušné hory Mts. has also been documented by Bastian et al. (2010) and Bastian (2013). They also suggest appropriate management of habitats and ecosystems in order to maintain biodiversity and the ecosystem services that they provide as well as to create job opportunities by implementing management plans.

National designation of all the studied Natura 2000 sites in this article (or even with their surroundings) could strengthen the connectivity of the Czech landscape between current PLAs and NPs: Boletice would connect Šumava PLA with Blanský Forest PLA; Doupovské hory Mts. and Krušné hory Mts. are situated between Slavkov Forest PLA and Labské pískovce LPA; Bzenecká Doubrava – Strážnické Pomoraví and Soutok are located between Bílé Karpaty PLA; and Pálava PLA and Libavá would fill the gap between Litovelské Pomoraví PLA and Poodří PLA (see Fig. 1). Moreover, the majority of the study localities are less fragmented (by roads and built-up areas) than the rest of Czech Republic (Romportl, 2017). On the other hand, landscape fragmentation by dirt and forest roads is relatively high in Natura 2000 sites. However, dirt and forest roads, which we included in the analyses, have different effects on landscape functions and it is necessary to evaluate them individually (Zielińska, 2007; Lindenmayer, 2018). Further protection of critical points outside the areas would be necessary, but national designation with appropriate management of these relatively natural areas with minimum human presence could enhance landscape functional connectivity (Hlaváč et al., 2021).

Doupovské hory Mts., Soutok, and Krušné hory Mts. have been discussed for national designation as PLAs for a long time (Pelc, 2018). While the process of declaring Soutok as PLA has been completed and the declaration of Krušné hory as PLA has been initiated, discussed in depth with local, stakeholders, and could be seen as being finalised in the coming years, declaration of Doupovské hory Mts. as a PLA is rather academic due to its strategic role in military training (NCA, 2023).

6. Conclusion

Selected localities within Natura 2000 sites are valuable for preserving ecological stability and connectivity from a landscape point of view. They are less affected by anthropogenic pressure than other Czech PLAs and NPs and also than Natura 2000 sites across Europe. The study localities are predominantly covered by natural and close-to-natural land cover categories – they are largely forested or covered by permanent grassland with significant cultural and natural heritage – and the share of these categories have increased in the majority of the localities.

Therefore, national designation of these areas as protected landscape areas (or even national parks) could prevent them from intensification of land use, help to set suitable management and, via these steps, secure landscape connectivity between already protected areas and contribute to the better coherence and functionality of the Czech PA network.

The further research steps will focus on the comparison of PAs and their surroundings in terms of land cover and anthropogenic pressure changes and development. Moreover, connectivity and conservation priorities will be analysed in the PAs and their surroundings for landscape planning addressing the issues of nature conservation.

Data are visible on website: https://experience.arcgis.com/experience/b948109ec019412882a4734c8303bbce/.

Acknowledgements

This work was funded by the Ministry of the Environment of the Czech Republic. The project of Landscape monitoring (Biological research and monitoring in Czech Republic – providing scientific support for Environment 2018–2022 (contract No. 0113/17/900), part D – Changes in landscape and trends in landscape changes). This work was also supported by the Faculty of Science, Charles University, grant SVV 260694.

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Please cite this article as:

Janík, T., Zýka, V., Havlíček, M., Borovec, R., Demková, K., Skokanová, H., …, & Romportl, D. (2025). Natura 2000 sites as a crucial part of nature conservation? An analysis of landscape development in selected areas of the Czech Republic. Moravian Geographical Reports, 33(2), 106–116. https://doi.org/10.2478/mgr-2025-0008