

LANDSCAPE CHANGES OF RURAL PROTECTED LANDSCAPE AREAS IN CZECHIA: FROM ARABLE LAND TO PERMANENT GRASSLAND – FROM OLD TO NEW UNIFICATION?

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ABSTRACT

The Czech rural landscape is a subject of research because it is affected by both intensification and extensification of land cover. This landscape was influenced in recent decades by political and socio-economic changes; we studied how these changes were reflected in the land cover development in protected areas. We selected ten Protected landscape areas (PLAs) with a significant share of open agricultural landscape and focused on land cover changes from the 1950s till the present with four milestones (1950s, 1990, 2004–2006, 2016–2019). Based on vectorised land cover data, analyses of land cover changes, land cover flows and landscape structure were performed.

More than one third of the studied area had changed. Forests dominated and enlarged its extent (from 39 % to 47 %); land cover flow (LCF) from arable land to permanent grassland was the largest process during study period (17% of study area) and it expanded after 1990. Other major LCF is forest spreading on permanent grassland (5 %) and arable land (3 %).

Trends of landscape metrics describing landscape structure are ambiguous and differ between PLAs. In total, Shannon's diversity index (*SDI*), Shannon's evenness index (*SEI*), and Mean Patch Size (*MPS*) increased and Number of Patches (*NumP*) decreased. *SDI* and *SEI* show improvement through time; however increasing anthropogenic areas are considered as factor contributing to this positive trend, despite the negative role of these categories in ecological stability. *MPS* and *NumP* show ongoing homogenization and unification of the landscape; however it differs between PLAs, with some having more favourable conditions and trends towards higher landscape heterogeneity.

To conclude, homogenous landscape structure remains present in Czech rural PLAs; however, there has been a huge shift to more extensive agricultural land cover, which is similar to some European protected areas.

Keywords: Land cover change; Landscape structure; Land cover flows; Protected landscape area; Czechia

INTRODUCTION

Since 1950s, land cover changes have occurred on a significant part of Czechia (Feranec *et al.*, 2010; Kupková *et al.*, 2021). After World War II, urbanization, afforestation, and a decrease in arable land took place (Kupková *et al.*, 2021). Basically, changes have resulted from two opposite processes – (sub)urbanization around built-up areas (Pazúr *et al.*, 2017) and extensification of land cover in the form of grassing over and an increase in forest area (Kupková & Bičík, 2016; Skokanová *et al.*, 2016), especially in more peripheral areas (Antrop, 2005). These landscape changes are caused by several driving forces affected by political and economic transformations (HAMPL & Müller, 2011; Sýkora & Bouzarovski, 2012; Skokanová *et al.*, 2016), which are connected with regimes and their changes: socialism and communism during the second half of the 20th century (1948 – 1989), the collapse of communist regimes in Central Europe (1989/1990), emerging democracy and capitalism in the 1990s, and EU accession (2004) and membership (Žoncová, 2020).

Besides overall categorical changes in the extent of land cover, the Czech landscape also experienced change in landscape structure. This change is expressed as a shift from a small-scale heterogeneous landscape, typical for the pre-socialist period, to a more homogenous large-scale landscape as a legacy of the socialist era and agricultural collectivization (Sklenička *et al.*, 2014). This is true for vast areas of the country, despite the fact that more than 15 % of Czechia is protected by large protected areas (protected landscape areas and national parks) and the majority of them were established during the socialist era (Pešout, 2010). Protected landscape areas (PLAs) are characterized by “harmonious landscape development” and a “significant share of natural ecosystems” (Act No. 114/1992). Thus, not only natural but also anthropogenic values are objects of protection, such as architecture, urbanism, and landscape composition, i.e. landscape structure (Pešout, 2010). Protection status should therefore provide better landscape functionality based on landscape structure, as was explored in some examples (Skokanová & Eremiášová, 2013).

The extent of protected areas has significantly increased worldwide in recent decades (Naughton-Treves *et al.*, 2005) and in Czechia as well. Protected areas are crucial for ensuring ecosystem services and biodiversity, as well as other natural values (Lehtomäki & Moilanen, 2013). However, nature and landscape protection is not the only public interest in the protected areas. There is also interest in regional development, but this contradiction brings conflicts to the protected areas (Brandon & Wells, 1992; Pietrzyk-Kaszynska *et al.*, 2012). Therefore, protected areas also face land cover change (Žoncová, 2020), which can worsen the provision of ecosystem functions and can contribute to biodiversity loss (Brooks *et al.*, 2002; Romportl, 2017).

While during the socialist era, the Czech countryside (and especially less-favoured areas) obtained politically motivated agricultural subsidies to intensify agricultural use (Bičík & Jančák, 2001; Kümmerle *et al.*, 2008), after 1990, agro-environmental programmes, especially from the EU Common Agricultural Policy (CAP), were used to replace intensive agriculture with extensification activities, such as grassing over (Bičík & Jančák, 2005; Skokanová *et al.*, 2016; Havlíček *et al.*, 2018).

The aim of this article is to analyse the development of land cover and landscape structure in the selected PLAs in Czechia, characterized by a large share of agricultural land. In particular, it will focus on the following questions: 1) was land use intensification and homogenization of the landscape structure typical for the socialist era present in PLAs? 2) have these processes continued towards the present, despite establishing new protected areas and improved environmental policy since the 1990s? 3) and, if so, in what form?

MATERIAL AND METHODS

Study area

Ten PLAs were selected for the analyses (Tab. 1, Fig. 1). They were characterized as rural and were defined by the following criteria:

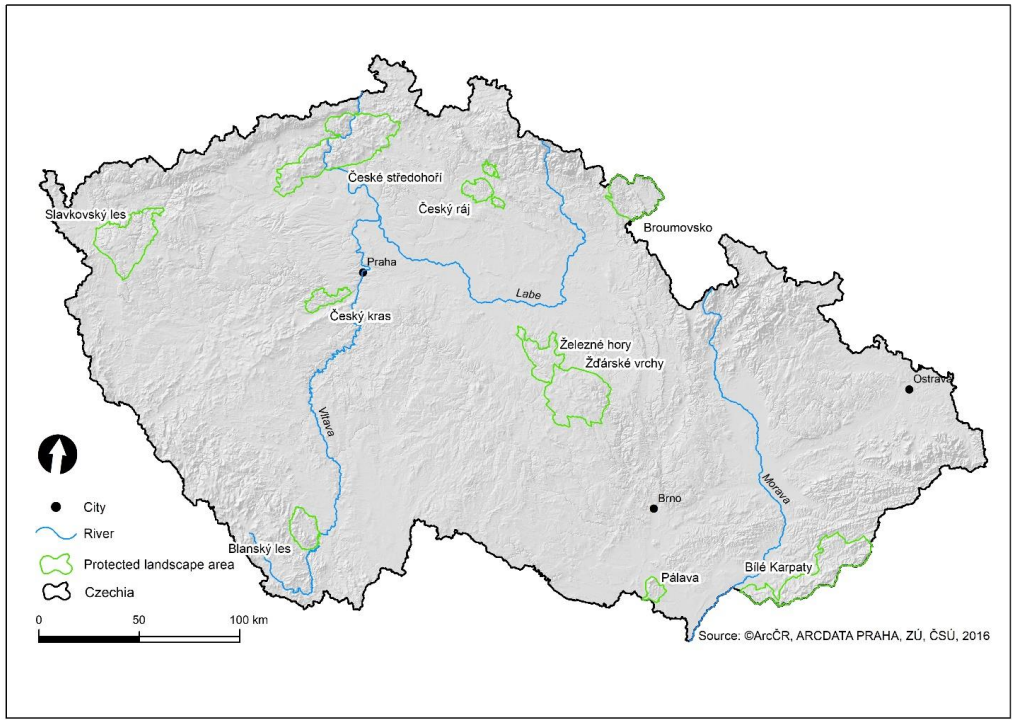
- 1) forests occupy less than 60 % of the area in each time horizon,
- 2) arable land, permanent grassland, vineyards and hop gardens, gardens and orchards together make up more than 30 % of area in each time horizon,
- 3) exclusion of mountainous PLAs and National Parks (NPs) with the highest point over 1100 m a.s.l.,
- 4) the total extent of a PLAs is larger than 85 km².

Table 1: Characteristics of studied protected landscape areas (PLAs)

PLA	year of establishment	area [km ²]	elevation range [m a.s.l.]	mean elevation [m a.s.l.]
Bílé Karpaty	1980	747	171 – 970	439
Blanský les	1989	220	420 – 1087	634
Broumovsko	1991	432	357 – 880	516
Český kras	1972	132	208 – 499	345
Český ráj	1955	182	235 – 744	330
České středohoří	1976	1069	122 – 837	366
Pálava	1976	85	153 – 544	254
Slavkovský les	1974	610	374 – 983	668
Žďárské vrchy	1970	709	490 – 836	644
Železné hory	1991	285	268 – 668	502

Data

We used land cover data derived from topographical maps and aerial imagery that capture milestones for land cover and land use development in recent history, as well as for nature protection. These milestones are: a) 1950s as the beginning of the socialist era and also the founding of the first PLAs, b) around the year 1990 as a transformation from socialism and communism to a free market economy, capitalism, and democracy, as well as new environmental legislation (Act No. 114/1992), c) around 2004 as EU accession, together with requirements of EU legislation, and d) 2016-2019 as the present state. Nine categories of land cover (Tab. 2) were distinguished according to various sources (topographical maps, aerial imagery) which were used. Data were manually vectorised in ArcGIS 10.5 software (ESRI) with a minimum area of 0.8 ha and a minimum width of 40 m for each patch from the mentioned sources. These criteria were set with regard to output scale.

Fig. 1: Studied protected landscape areas (PLAs) in Czechia**Table 2: Description of land cover categories**

Land cover category	Description
Other area	Mining area, dump sites, development areas
Arable land	Arable fields, mosaics of fields, trees and small vineyards, fallow land
Permanent grassland	Meadows, pastures, steppes, moors, grasslands
Garden and orchard	Intensive and extensive orchards, large gardens adjacent to built-up areas
Vineyard and hop garden	Small and large scale, facility included
Forest	Forest, non-forest woody vegetation, mountain pine, shrubs, forest nurseries
Water area	Ponds, lakes, dams, pools, flooded mining areas
Built-up area	Continuous and dispersed built-up area, industrial and military areas
Recreational area	Cottages, recreational objects, golf courses, camps

Methods

General trends in the total share of land cover categories for all PLAs together and for all four time horizons were analysed. For visualising land cover change, a principal component analysis (PCA) in R software (R Core Team 2019) was used.

To evaluate and define changes among land cover categories, the concept of so-called land cover flows (LCF) was used (EEA, 2006; Feranec *et al.*, 2010; Martinez-Fernandez *et al.*, 2015). Only overall changes above 1 % were considered. Furthermore, LCF areas for both the whole group and for each PLA were compared in two periods: 1950s-1990 and 1990-present. In these two periods, stable and changed land cover were also evaluated for the whole group as well as individual PLAs. Wilcoxon signed rank test in R was used for evaluation of differences between areas of LCF in the two periods.

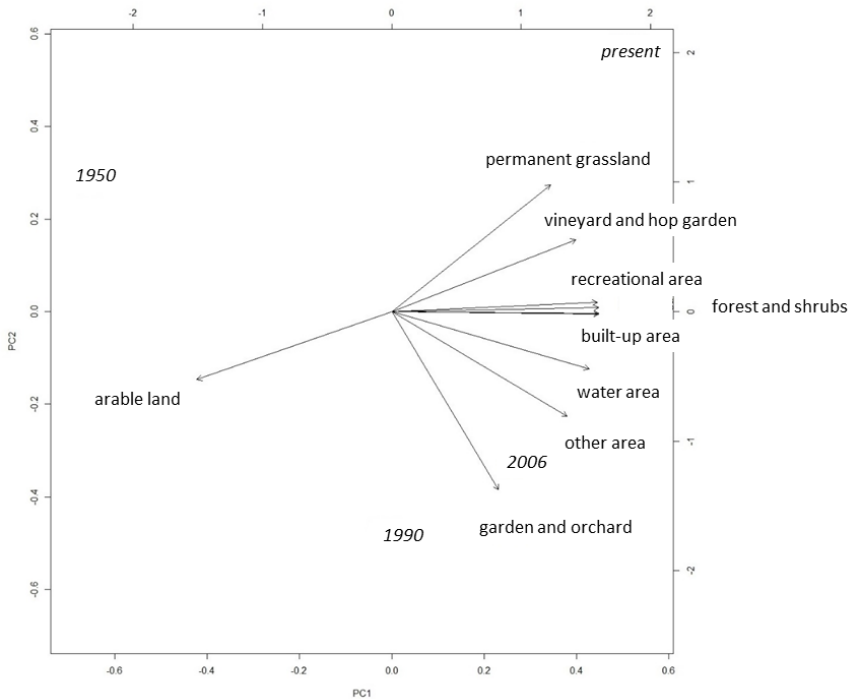
To compare changes in landscape structures, several easy-to-evaluate landscape metrics were chosen: Shannon's diversity index (*SDI*), Shannon's evenness index (*SEI*), number of patches (*NumP*), mean patch size (*MPS*), and edge density (*ED*). *SDI* assesses land cover diversity by the number of land cover categories and number of patches, while *SEI* is an index showing evenness of distribution of patches in individual land cover categories. *NumP* and *MPS* are metrics demonstrating whether homogenization and unification of the landscape is taking place. Finally, *ED* evaluates the complexity of shape of the patches and is comparable between landscapes of varying size (McGarigal & Marks, 1994; Uemaa *et al.*, 2009). For computation of landscape metrics, Patch Analyst (Elkie *et al.*, 1999), extension for ArcGIS, was used.

RESULTS

Land cover change

In total, area of 4471.3 km² of the landscape within the ten PLAs was investigated. There is a clear shift from arable land and more intensive agriculture to less intensive agriculture land cover with an increased share of permanent grassland as well as forest area during the study period. On the other hand, built-up and recreational areas increased as well. In 1950s, forest was the most widespread category (39.2 %), followed by arable land (36.8 %) and permanent grassland (18 %). It has gradually changed: from 1950s to 1990 forested area increased with a share of 44 % in 1990 and arable land decreased to 30.8%, while permanent grassland remained almost same (17.2 %). After 1990, forest still dominated (45.3% in 2006 and 47.3 % at present), permanent grassland grew (22.1 % in 2006 and 27.8 % at present), and arable land shrunk (24.1 % in 2006 and 15.8% at present). Also, built-up areas increased gradually (4.1 % - 5.5 % - 5.9 % - 6.5 %); it is approximately 0.5 % of the whole study area per 10 years. The landscape development described above is clearly visible from Fig. 2, especially the change from arable land to permanent grassland.

Fig. 2: PCA analysis showing land cover change. The trends of changes of land cover categories are shown by arrows, especially shift from arable land in the past to permanent grassland nowadays is visible.



Land cover flows

In total, land cover flow (LCF) from arable land to permanent grassland is the largest (16.7 % of the area of all PLAs for whole study period, i.e. 1950-present). The second and third largest LCF for the whole study period were forest increases from permanent grassland and arable land. LCF larger than 1 % of the study area in whole study period are also represented by LCF from arable land to built-up area and LCF from permanent grassland to arable land (Tab. 3).

The comparison of LCF in the period from 1950s to 1990 and from 1990 to present (which are similar in duration and the year 1990 is a main breaking point in our study period) reveals the following (Tab. 3): The main LCF from arable land to permanent grassland increased extensively; on the other hand, LCF from permanent grassland and LCF from arable land to forest decreased. Other LCF were smaller than 1% in the 1990-present period, showing a reducing number of significant LCF to only a few processes. For example, LCF from permanent grassland to arable land was 5 % in 1950s-1990 period and only 0.7 % after 1990; furthermore LCF from arable land to built-up area was 1.2 % in 1950s-1990 period and only 0.6 % in 1990 present period. Despite the differences between these two periods in the largest LCFs, the areas of all individual LCF are not significantly different (Wilcoxon signed rank test, p -value= 0.0909, sig. level 0.05).

Table 3: Land cover flows larger than 1% of study area in all PLAs for selected time periods

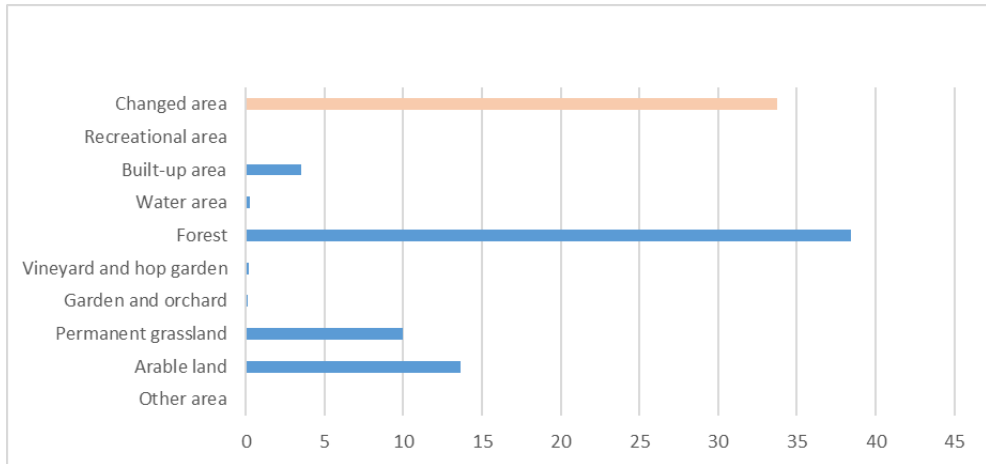
Land cover flows larger than 1% of study area	Whole study period (%)	1950s-1990 (%)	1990-present (%)
Arable land to permanent grassland	16.7.0	7.5	13.9
Permanent grassland to forest	5.2	3.5	3.2
Arable land to forest	3.4	2.1	1.1
Arable land to built-up area	1.8	1.2	
Permanent grassland to arable land	1.6	5.0	

Analyses of LCF in individual PLAs revealed the dominance of LCF from arable land to permanent grassland, with the exception of Pálava PLA. In Pálava, arable land was predominantly changed to vineyards. The second most spread LCF in five PLAs (Bílé Karpaty, Blanský les, České středohoří, Slavkovský les, Žďárské vrchy) was from permanent grassland to forest, while in three (Broumovsko, Český kras, Český ráj) it was from arable land to forest. Other LCF larger than 1% of the area represented in all PLAs are LCF from arable land to forest and from arable land to built-up area.

Comparing the periods 1950s-1990 and 1990-present shows an increase in LCF of arable land to permanent grassland. The only exception is Broumovsko PLA where this process was bigger during the 1950s-1990 period than in 1990-present. Generally, there is a shift from many relatively large LCF during 1950s-1990 to dominant LCF from arable land to permanent grassland in period 1990-present (see appendix A).

Stability and change in land cover

In the studied PLAs, approximately one third of the area had changed, while 38.4 % of the area remained as forest, 13.7 % as arable land, 10.0 % as permanent grassland, and 3.5 % as built-up areas (Fig. 3). During the first period (1950s-1990), about a quarter of the area changed, which means that less than 1 % (0.7 %) of the area changed per year on average. In the second period, from 1990 to 2006, about 17.3 % changed, leading to a change of 1.1 % of the total area per year. The same change rate per year occurred in the last and most recent period (2006-present). However, considering the period 1990-present, the change is almost the same (24.41 %) as in the 1950s-1990 period (24.40 %).

Fig. 3: Stability of the land cover categories (%) for all PLAs in total and the whole study period (1950s – present)

The proportion of changed and stable land cover varied between PLAs. The minimum area with stable land cover was noted in České středohoří (49.6 %), followed by Pálava (56.7 %), Broumovsko (57.1 %), Bílé Karpaty (57.7 %), and Slavkovský les (58.0 %). A PLA with higher stable land cover is represented by Český ráj (63.5 %), while the stability of land cover is the highest in Železné hory (66.9 %), Blanský les (68.6 %), Žďárské vrchy (69.8 %), and Český kras (72.3 %).

Landscape structure and metrics

The development of landscape structure was analysed with several metrics (Table 4). Shannon's diversity and evenness index increased over the first study period and mean patch size in the whole period. On the other hand, the number of patches and edge density decreased. Changes in the indices varied between categories; for example, mean patch size of arable land increased in the period 1950s-1990 and then decreased, while edge density and number of patches in this category steadily decreased over time. On the other hand, both mean patch size and edge density of permanent grassland increased (*ED* was the lowest in 1990), especially after 1990. The number of patches as well as edge density of forest increased, while mean patch size is almost similar throughout the time. Built-up area experienced increased edge density, mean patch size, and number of patches (see appendix B).

Table 4: Selected landscape metrics for all PLAs, whole landscape, and time periods. SDI – Shannon's diversity index, SEI – Shannon's evenness index, ED – edge density, MPS – mean patch size, NumP – number of patches

Time horizon	SDI	SEI	ED	MPS	NumP
1950s	1.27	0.58	97.27	26.86	16646
1990	1.31	0.60	93.58	27.72	16131
Present	1.31	0.60	88.33	29.78	15015

An overview of changes in landscape structure measured by landscape metrics in individual PLAs is shown in Table 5. In five of ten PLAs, the number of patches steadily decreased (Blanský les, Broumovsko, České středohoří, Slavkovský les, Železné hory), while in three there was a continuous increase (Bílé Karpaty, Pálava, Žďárské vrchy) and in two the peak of number of patches was noted in 1990 (Český kras, Český ráj). Similarly, edge density increased in four PLAs (Bílé Karpaty, Český kras, Český ráj – but the highest was in 1990, Pálava) and decreased in six (Blanský les, Broumovsko, České středohoří, Slavkovský les, Žďárské vrchy, Železné hory). Shannon's diversity and evenness indexes increased in all areas except Blanský les (*SDI* increased with peak already in 1990 and *SEI* decreased), Broumovsko (both increased with peak already in 1990) and Slavkovský les (both *SDI* and *SEI* decreased).

Table 5: Landscape metrics and their development in time horizons 1950s-1990-present for all study areas and PLAs. SDI – Shannon’s diversity index, SEI – Shannon’s evenness index, ED – edge density, MPS – mean patch size, NumP – number of patches

Landscape metrics	Bílé Karpaty	Blanský les	Broumovsko	České středohoří	Český kras	Český ráj	Pálava	Slavkovský les	Žďárské vrchy	Železné hory
SDI	increase	increase - peak in 1990	increase - peak in 1990	increase	increase	increase	increase	decrease	increase	increase
SEI	increase	decrease	increase - peak in 1990	increase	increase	increase	increase	decrease	increase	increase
ED	increase	decrease	decrease	decrease	increase	increase - peak in 1990	increase	decrease	decrease - minimum in 1990	decrease
MPS	decrease	increase	increase	increase	decrease - minimum 1990	decrease - minimum in 1990	decrease	increase	decrease - but peak in 1990	increase - peak in 1990
NumP	increase	decrease	decrease	decrease	increase - peak in 1990	increase - peak in 1990	increase	decrease	increase	decrease

DISCUSSION

Land cover trends

The analyses presented here revealed trends typical for the majority of regions with less favourable conditions in Europe (Munteanu *et al.*, 2014), including Czechia (Havlíček *et al.*, 2018), especially during the past 30 years. These trends are afforestation/landscape abandonment connected with an increase in woody vegetation (e.g. Pazúr & Bolliger, 2017; Kolečka *et al.*, 2017) and agricultural extensification expressed by expansion of permanent grassland to the detriment of arable land (Lieskovský & Lieskovská, 2021). Afforestation in the PLAs was more widespread during 1950-1990 and forest spread both on arable land and permanent grassland (see Table 3). This could be a result of establishing PLAs during the second half of the 20th century, but also of expulsion of Czech Germans after 1945 in Sudeten PLAs such as Blanský les, Broumovsko, České středohoří, or Slavkovský les (Kupková *et al.*, 2013). On the other hand, agricultural extensification was more pronounced after 1990. It was driven by changed agricultural policy to less intensive management supported by agri-environmental schemes, mainly by grassing former arable land (Havlíček *et al.*, 2018). Similar trends were typical for all areas with less favourable conditions, not only in Czechia (Štych *et al.*, 2019) but also in Slovakia (Bezák & Mitchley, 2014).

Agricultural intensification during the socialist era (Bičík & Jančák 2001; Kümmerle *et al.*, 2008), demonstrated as an increase in the area of arable land and other agricultural land cover categories like vineyards and orchards, was typical mainly for lowland and mid-altitudes regions of Czechia (Havlíček *et al.*, 2014). In our study, it was absent even in the studied PLAs that can be considered as agriculturally more-favoured regions (Český ráj, Český kras, and České středohoří). The exception was Pálava PLA, where the amount of agricultural land remained more or less the same during this period. This was due to agricultural specialization focusing on wine production thanks to favourable abiotic conditions. Because of these conditions, this trend also continued after 1990 and was even the most widespread one in the PLA. In the more upland PLAs, agricultural intensification was largely absent, which corresponds with general trends captured for this type of landscape (Kupková *et al.*, 2021) and are affected by less favourable biophysical factors (Opršal *et al.*, 2016).

All PLAs were affected by increased anthropogenic pressure in the form of expansion of built-up and recreational areas. It differentiated between periods as well as between the PLAs (see appendix A). In general, it was higher during the socialist period thanks to the spread of built-up areas, despite the protection status. This trend was common for the whole of Czechia (Štych *et al.*, 2019; Kupková *et al.*, 2021); however, it was less pronounced in PLAs than in non-protected areas (Jačková *et al.*, 2011). Pressure in the form of recreational areas was not as pronounced as in mountainous PLAs (Janík *et al.*, 2019; Janík *et al.*, 2020).

The trends described did not affect the whole area of the PLAs but occurred on more territory even in Central Europe. For example, the dominance of stable forest areas and their increase were typical not only for the studied PLAs but also for other regions in Czechia, as well as Slovakia, from the mountains (Janík *et al.*, 2019; Janík *et al.*, 2020; Skokanová & Havlíček, 2018) to the lowlands (e.g. Havlíček *et al.*, 2014; Kilianová *et al.*, 2017). Generally, extensification of land cover in the form of forest expansion was also observed in Slovakian (Žoncová, 2020; Olah & Boltžiar, 2009) and other European protected areas (Hellwig *et al.*, 2019). It should be stressed that the main process in the studied rural PLAs is change from arable land to permanent grassland. This fact can be attributed to the prevailing agricultural character of the PLAs being more prone to change than forested landscape. Indeed, PLAs with higher forest cover have larger stable areas, which are usually formed by forested land (Fig. 3).

Land cover structure

There is an overall increase in *SDI* and *SEI*, showing a more heterogeneous landscape in terms of various land cover categories (Table 4, 5). However, this fact was highly affected by the introduction of an increase in anthropogenic categories – recreational as well as built-up areas, i.e. categories that usually have a negative impact on biodiversity and ecological stability (Kuussaari *et al.*, 2020; Michaeli *et al.*, 2015).

Landscape metrics representing homogenization of the landscape structure (i.e. decreasing number of patches (*NumP*), increasing mean patch size (*MPS*), and decreasing edge density (*ED*) show a rising trend for the landscape as a whole (Table 4), confirming steady homogenization of the landscape from 1950 onwards. This is clearly a result of socialist agricultural policy during the 1950-1990 period (Sklenička *et al.*, 2014) and productivist agriculture that was introduced after 1990 (Skokanová *et al.*, 2016). Changes in the metrics of individual land cover categories show that, despite significant decrease in arable land (and consequent changes in landscape metrics of the category) after 1990, homogenization of the landscape has continued, with permanent grassland replacing arable land.

There are obvious differences between PLAs (Table 5). With the exception of České středohoří and Slavkovský les, PLAs established during 1955-1980 show a trend towards larger heterogeneity of the landscape, especially during the 1950-1990 period, while the youngest PLAs (Blanský les, Broumovsko, and Železné hory), together with České středohoří and Slavkovský les, show a trend towards landscape homogenization. Homogenization in the youngest PLAs during the socialist era is not so surprising as these PLAs were not protected at the time and therefore no protection restrictions were applied. A certain trend towards homogenization after 1990 can be seen not only in the mentioned PLAs but also in Český kras and Český ráj. This is in contrast with the initial assumption that improved environmental policy after 1990 contributes to higher landscape heterogeneity. This trend of change to ecological more stable land cover categories but also to homogenization can be seen in other PLA as well, e.g., mountainous as Jeseníky and it can be insufficient for preserving biodiversity (Dostál *et al.*, 2020).

We can say that the results presented here correspond with Jačková *et al.* (2011) who, when comparing landscape structure development inside and outside protected areas, found increasing homogenization of the landscape regardless of its protection status. However, as with her findings, it must be stressed that the results regarding landscape structure might be somewhat biased due to the spatial parameters of the data and sources used, which cannot capture detailed landscape microstructure.

CONCLUSION

Our results show a relatively big land cover change, especially from arable land to permanent grassland and forest. It implies that protection status might affect land cover changes to some degree and lessen anthropogenic pressure in the form of intensive agriculture in selected rural PLAs. General trends in forest increase and expansion of permanent grassland, typical for less favourable areas, played a significant role in the land cover changes of the studied PLAs. In particular, LCF from arable land to permanent grassland, which is even more pronounced after 1990, characterizes the given study period.

While the landscape composition of PLAs largely changed towards more ecologically stable land cover categories, such as forests and grasslands, landscape structure in the larger part of the studied PLAs still remains homogenous and this situation has even worsened since 1990. Despite these ongoing general processes, which show signs of simplification of landscape even after improved environmental policy after 1990, there are also PLAs with

favoured land cover and landscape structure development. Landscape change continues, and by using suitable legislative tools we can improve the rest of our landscape as well.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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APPENDIX A: land cover flows for selected time period and each PLA.

Land cover flows larger than 1% of study area (whole study period) in %	Bílé Karpaty	Blanský les	Broumovsko	České středohoří	Český kras	Český ráj	Pálava	Slavkovský les	Žďárské vrchy	Železné hory
Arable land to permanent grassland	20.73	12.33	24.20	18.83	12.99	12.26	2.92	14.54	12.33	15.12
Permanent grassland to forest	4.64	4.63	3.18	6.16	3.00	2.91	1.88	10.65	3.35	2.52
Arable land to forest	4.63	1.61	3.31	4.76	4.77	3.49	2.74	2.03	1.76	2.26
Arable land to built-up area	2.57	1.43	1.10	2.11	1.56	2.05	2.47		1.73	1.78
Permanent grassland to arable land	1.70	3.10	2.06	1.06		1.52			2.97	2.77
Forest to permanent grassland							1.74			
Arable land to garden and orchard	1.78			1.53		1.92				
Permanent grassland to built-up areas				1.37						
Garden and orchard to arable land				1.24						

Garden and orchard to permanent grassland	1.13									
Arable land to vineyard	17.86									
Vineyard to arable land	1.12									
Arable land to recreational area	1.18									
Land cover flows larger than 1% of study area (1950s-1990) in %	Bílé Karpaty	Blanský les	Broumovsko	České středohoří	Český kras	Český ráj	Pálava	Slavkovský les	Žďárské vrchy	Železné hory
Arable land to permanent grassland	7.26	7.14	14.25	8.79	6.69	6.44	1.99	5.29	5.06	7.33
Permanent grassland to forest	2.91	3.65	2.30	3.86	1.37	1.99	1.27	7.52	2.44	1.89
Arable land to forest	2.68	1.23	2.31	2.86	1.52	2.61	1.09	1.53	1.28	1.57
Arable land to built-up area	1.79			1.48		1.34	1.57		1.26	1.41
Permanent grassland to arable land	3.17	5.20	3.61	5.42	1.36	4.31		7.64	5.99	4.91
Forest to permanent										

grassland										
Arable land to garden and orchard					2.17			2.46		
Permanent grassland to built-up areas										
Garden and orchard to arable land					1.85					
Garden and orchard to permanent grassland										
Arable land to vineyard									6.91	
Vineyard to arable land									2.98	
Arable land to recreational area										
Built-up area to permanent grassland					1.14					
Forest to arable land									2.71	
Land cover flows larger than 1% of study area (1990-present) in %										
	Bílé Karpaty	Blanský les	Broumovsko	České středohoří	Český kras	Český ráj	Pálava	Slavkovský les	Žďárské vrchy	Železné hory

Arable land to permanent grassland	17.22	8.22	13.45	16.35	7.03	9.08	2.90	16.54	11.29	11.21
Permanent grassland to forest	3.33	2.14	2.44	4.63	3.76	2.15	1.49	4.61	1.64	1.80
Arable land to forest	1.62			1.22	1.41	1.17	2.11			1.07
Arable land to built-up area							1.01			
Permanent grassland to arable land			1.27							1.01
Forest to permanent grassland		1.02		1.37				1.12		
Arable land to garden and orchard										
Permanent grassland to built-up areas			1.17	1.02		1.03				
Garden and orchard to arable land										
Garden and orchard to permanent grassland										
Arable land to vineyard							14.06			
Vineyard to arable land							1.31			

Arable land to recreational area
Built-up area to permanent grassland
Forest to arable land

APPENDIX B: landscape metrics for all land cover classes and selected time horizons

	1950s			1990			Present		
	ED	MPS	NumP	ED	MPS	NumP	ED	MPS	NumP
Other area	0.28	2.91	159	0.28	6.08	117	0.23	8.48	82
Arable land	33.50	46.41	3548	25.04	52.39	2628	12.67	36.25	1945
Permanent grassland	30.40	13.10	6126	29.48	12.76	6021	33.02	25.79	4822
Garden and orchard	2.12	4.98	947	2.25	5.89	960	2.33	4.30	1174
Vineyard and hop garden	0.55	6.99	218	0.45	23.90	85	0.60	29.05	92
Forest	22.00	60.14	2917	25.68	60.41	3255	27.59	60.29	3509
Water area	0.46	6.65	205	0.72	6.84	311	0.79	6.02	370
Built-up area	7.86	7.46	2480	9.34	9.59	2585	10.56	10.32	2749
Recreational area	0.10	4.18	46	0.35	4.06	169	0.55	5.22	227