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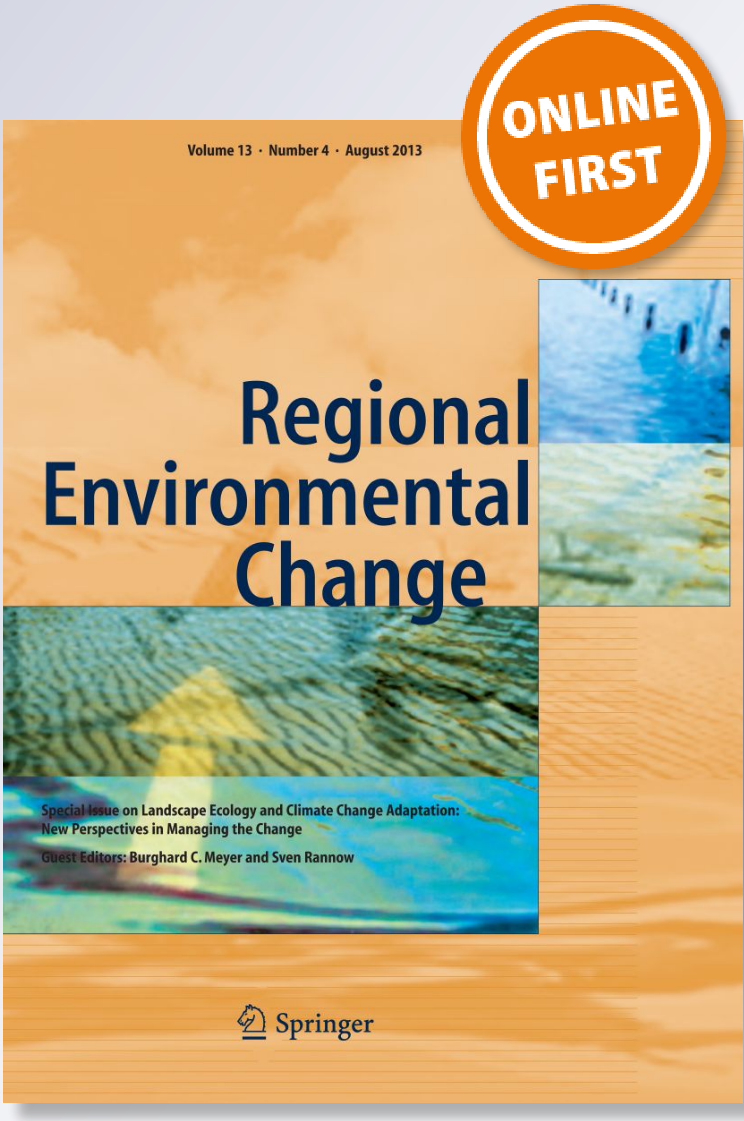

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Spatio-temporal dynamics of wood-pastures in lowland and highland landscapes across Czechia

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Abstract
Wood pastures represent grasslands, managed by grazing and characterised by scattered woody vegetation, recognised for their ecological, agricultural and socio-cultural roles, and are among the oldest land-use types in Europe. Rapid decline in their area all across Europe has been observed recently, sparking the appearance of a number of related studies. But these trends differ for each country and period, and more detailed analyses are needed to distinguish the character, drivers and the consequences of the changes on a general and local scale, Thus, the present study was aimed at analysis of spatio-temporal dynamics of wood pastures in Czechia between the beginning of the nineteenth century and the present moment, and of the importance of integrated influence of natural factors as a driver. For this purpose, 30 cadastral districts from five types of natural landscapes (GTNL) of Czechia were analysed for changes between the beginning of the nineteenth century and the present, using ArcGIS tools and statistical analysis. Upon the conducted analysis, the general decrease of area of wood pastures was observed, but the dynamics differed depending on the integrated natural characteristics of each group. Sinks of lost and sources of gained wood pastures were defined. Persistent patches had a small share within both present and historical areas. Trends in this dynamic differ statistically for each GTNL. The scale of these changes also depends on this factor. However, the character of overall changes appeared to be defined more by political circumstances in many cases.

Keywords Land cover change · Change trajectories · Habitat continuity · Agroforestry

Introduction

Wood pastures combine livestock grazing with scattered trees and shrubs (Plieninger et al. 2015) and have been widespread in Europe since the middle ages (Forestry Commission Scotland 2009; Jørgensen and Quelch 2014). Many current wood pastures (e.g. in Transylvania) have developed from woodland grazing, which was common up to the nineteenth century, and further separated into forestry and pasturing due to demand for timber and agricultural products (Hartel et al. 2013, 2016).

Recently, wood pastures have been getting increasing attention due to recognition for their high ecological, cultural and economic values (Hartel and Plieninger 2014). The first is caused by diversity of land structure and use, and the presence of scattered trees, as keystone structures, which may be 'ancient' or 'veteran', of which the first are those which have reached a great age in comparison with others of the same species and are characterised by a low, fat and squat shape, a wide trunk compared with others of the same species and hollowing of the trunk, whereas the second can be any age, but with similar ancient characteristics, which can be the result of management, or the tree's environment. They can reach a large size, increase biodiversity and create a unique vegetation structure (Read 2000; Gibbons and Lindenmayer 2002; Quelch 2002; Garbarino and Bergmeier 2014; Jakobsson and Lindborg 2015; Moga et al. 2016). Together with the traditional low-intensity pasture management, this results in a unique

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vegetation structure (Manning et al. 2006; Rosenthal et al. 2012) and biodiversity potential (Hartel et al. 2013, 2014), creating 'biodiversity reservoirs' in the landscape (Hartel et al. 2016). Wood pastures help with buffering against wind and dryness, controlling nutrient cycling and soil erosion (Manning et al. 2009; Hartel et al. 2016) and adaptation to anthropogenic climate change (Manning et al. 2009). At the same time, wood pastures have traditionally been serving as a source of tree products (tree hay, fruits, timber, etc.) (Hartel 2012; Hartel et al. 2016), creating shelter, pasture and fodder for livestock, crops for pannage (Szabó 2013; Szabó and Hédl 2013) and have been an important socio-cultural component for local people and especially farmers due to their aesthetic qualities, e.g. wood pastures of Romania (Sutcliffe et al. 2014) and Estonia (Roellig et al. 2015), or montados of Portugal (Surová et al. 2014), and related to the history and culture of local societies (Plieninger et al. 2015).

The existing studies on spatio-temporal changes of wood pastures at the international level have demonstrated major negative changes of these areas over the past decades. A sharp decline over the past 300 years left only relicts of wood pastures in Western and Northern Europe, primarily maintained for nature conservation purposes (Bergmeier et al. 2010). This has often been attributed to abandonment of traditional management, particularly in developed countries (Rackham 1998), reflected in discontinuation of livestock husbandry, and in wood pasture transformation into commercial forests and properties (Forestry Commission Scotland 2009). As a result of these developments, e.g. many fires have been occurring due to increased uncontrolled and often illegal burning, even in protected areas, which damages large trees (oak and hornbeam) and harms wood pastures, as was the case in Transylvania in 2012 (Hartel et al. 2013). A considerable role has also been attributed to socioeconomic changes during industrialisation, the shift of higher income yield towards off-farm vocations and expansion from local to globalised markets (Hartel and Plieninger 2014). Ross et al. (2016) points out the importance of the interaction system between such factors of industrial development as numbers of grazing animals, carrying capacity of the vegetation, physical environment, changing economic conditions and agricultural subsidy systems, stressing the need for a balance between economic gain and prevention of environmental degradation through the use of a proper management regime. The Age of Enlightenment had an effect, where peasant forestry and agricultural practices were often being transformed into more 'modern' types, such as common land enclosure advocated by land reformers, with a strict separation of forestry and agriculture and elimination of many wood pastures up until the twentieth century (Hartel and Plieninger 2014).

Thus, economically advanced countries should have fewer wood pastures and a less 'wood-pasture-friendly' management. Domination of modern, more productive land use types makes traditional links between people, nature and historic ecological knowledge weaker (Forestry Commission Scotland 2009). Centuries of intensive grazing in the uplands have left many open landscapes with few old trees. In Czechia, ancient wood pastures have mostly disappeared (Vojta 2012), though similar habitats of diverse origin and management can be found in Central, Western and Northern Bohemia and Southern Moravia.

More detailed works upon dynamics of wood pastures (Seabrook et al. 2007; Huzui et al. 2012; Spanò and Pellegrino 2013; Khromykh and Khromykh 2014) upon trajectories of changes of wood pastures and their drivers have appeared, such as one by Roellig et al. (2015), providing comparative analysis of the structure of grazed wood pastures of recent ungrazed forest stands and abandoned wood pastures, stressing again the effects of management and the position of the society. Overall, the landscape preservation dimension may best address management of these spaces, as well as potentially conflicting land uses (Grădinaru et al. 2017). A multi-scale long-term change has been reflected in a study of non-forest woody-vegetation dynamics in the Eastern German agricultural landscape by Plieninger et al. (2012), who demonstrated an increase in the number of trees in the period of 1964–2008, while Costa et al. (2014) described a constant decline in density and cover of characteristic tree species in a study of the wood pastures of south-western Iberia (dehesas and montados), attributed to an interplay of technological factors. Many recent studies on wood pastures, based on such tools as Geographic Information System (GIS) software (Boltiziar 2001; Hreško and Boltiziar 2001; Hreško et al. 2003; Olah et al. 2006; Turner et al. 2007; Seabrook et al. 2007; Khromykh and Khromykh 2014), have demonstrated success in combining satellite image processing with other cartographic materials, GIS-mapping, analysis of remote sensing data and digital elevation models. Old maps can serve well as a source of historical data, like they did for the forests and built-up areas of Romanian Carpathians (Pătru-Stupariu et al. 2016).

The situation with wood pastures in Czechia has been described insufficiently. One of the related interesting studies by Bičík et al. (2001) described dynamics of land use and land cover (LULC) in Czechia during the period of 1845–2000, showing the sharpest decline during 1845–1948, and the highest rise during 1990–1999 for grasslands in comparison to other categories. Demková and Lipský (2015) described a decline in non-forest woody vegetation in the East of the country during the socialist period, which was followed by an increase. However, despite a number of studies conducted in Central and Eastern European countries (Hartel 2012; Plieninger 2012; Vojta 2012; Vojta and Drhovská 2012; Hartel et al. 2013), detailed information on the spatio-temporal dynamics of wood pastures at the landscape level for Czechia is missing. At the same time, a clear systemised vision of the spatio-temporal changes of wood pastures and their relation to different drivers is needed to approach their sustainable management, not only allowing maintenance of vegetation, soil and animal components of these systems, but also socioeconomic functioning while maintaining environment. Thus, the current paper describes spatio-temporal changes of wood pastures in Czechia and continues the study reported by us earlier (Forejt et al. 2017). This time, a larger number of studied sites were covered, which improves statistical reliability of the results. Additionally, besides the general spatio-temporal changes of wood pastures, these dynamics were observed in correspondence to the character of natural factors expressed here in the general types of natural landscapes (GTNLs) (as defined by Romportl et al. 2013). GTNLs were chosen as the basic way of delimiting the study area and are characterised by a specific combination of natural conditions (geomorphology, climate, altitude). At the same time, natural conditions are the most important factors influencing the changes in the landscape (and therefore changes in wood pastures), and thus provide a substantial framework for the definition of the area of interest. In addition, community structure and ecosystem processes often vary along elevational gradients (which is one of the components of the classification), and those can also be useful for understanding community and ecosystem responses to global climate change at much larger spatial and temporal scales than is possible through conventional ecological experiments (Sundqvist et al. 2013). Methodological changes included exclusion of data sources for the period of the 1950s, as our first study could not prove them to be fully reliable, but more modern interactive sources were used for the current time horizon.

The current paper tries to fill in the following research gaps:

- The lack of information on spatio-temporal dynamics of wood pastures in a longer temporal scale (typically, only changes from the 1950s onwards are reflected) and the exact trajectories of these changes on Czech territory;
- Relation of these changes to the GTNL.

The study aims to answer the following research questions:

(1) What are the spatio-temporal changes and trajectories in wood pastures at the landscape level in the lowland and highland landscapes of Czechia?
(2) What are the major sinks of the old wood pastures and the sources of the new ones?
(3) Are spatio-temporal changes of wood pastures correlated to the GTNL and how?

Materials and methodology

Study area

The current research covers a total area of 756.573 km^2, with samples from each of the six GTNL of Czechia (Romportl et al. 2013), which implies categorisation by climatic and geomorphologic characteristics (Table 2, Fig. 1). For the current research, moderately cold and cold mountain landscapes were united into one category, as they often appear within similar areas and have close natural characteristics.

The sampling was based on administrative division of the country into cadastral districts and initially 57 of those were selected in such a way that all GTNLs would be equally represented and presumably contain enough wood-pastures. Further, neighbouring wood pastures were merged, and parcels of an area of < 3000 m^2 were excluded from the analysis, as well as districts with less than 0.5% of wood pastures by area in their current state (see 2.2.2). As a result, 30 districts were left for the final analysis, with areas ranging from 1.94 to 80.58 km^2. Original historic borders of the studied districts were chosen for the measurements at both time horizons, due to the consistency and accessibility of data on land use at the historical time horizon.

Data sources and acquisition

We ran analysis of two temporal horizons, based on such data sources as old maps, orthoimages, aerial images, publicly available online interactive sources (Google Earth 2015) and field trips.

First half of the nineteenth century

Scanned images of old Franciscan cadastral maps, acquired from the Czech Office for Surveying, Mapping and Cadaster (2015), served as the main source of data for the first time horizon (first half of the nineteenth century), which consists of a series of maps that cover the whole former Habsburg monarchy and are widely used for LULC studies in Czechia (Lipský 1995; Bičík et al. 2001; Raška et al. 2016). The images ("Imperial imprints", at the scale of 1:2880) show parts of Czechia in the form of map sheets created in 1824–1843. Here, we label this long period "1st half of the 19th century". Besides ordinary LU classes, the images reflect pastures, arable land with various woody vegetation and meadows with or without woody vegetation (Krčmářová and Jeleček 2017).

Each map sheet was manually georeferenced using ArcGIS software (ESRI 2015) by matching control points on current cadastral maps to distinct corners of parcel boundaries or intersections with the presumption that they have not changed shape. For some of the maps, first-order polynomial transformation was used, where the mean square error (RMSE) was 1.4 on average per map sheet, while for most, second-order transformation was applied with average RMSE = 1.6 per map sheet. The method was chosen to best fit the current cadastral map. Throughout the entire analysis, the S-JTSK coordinate system was used.

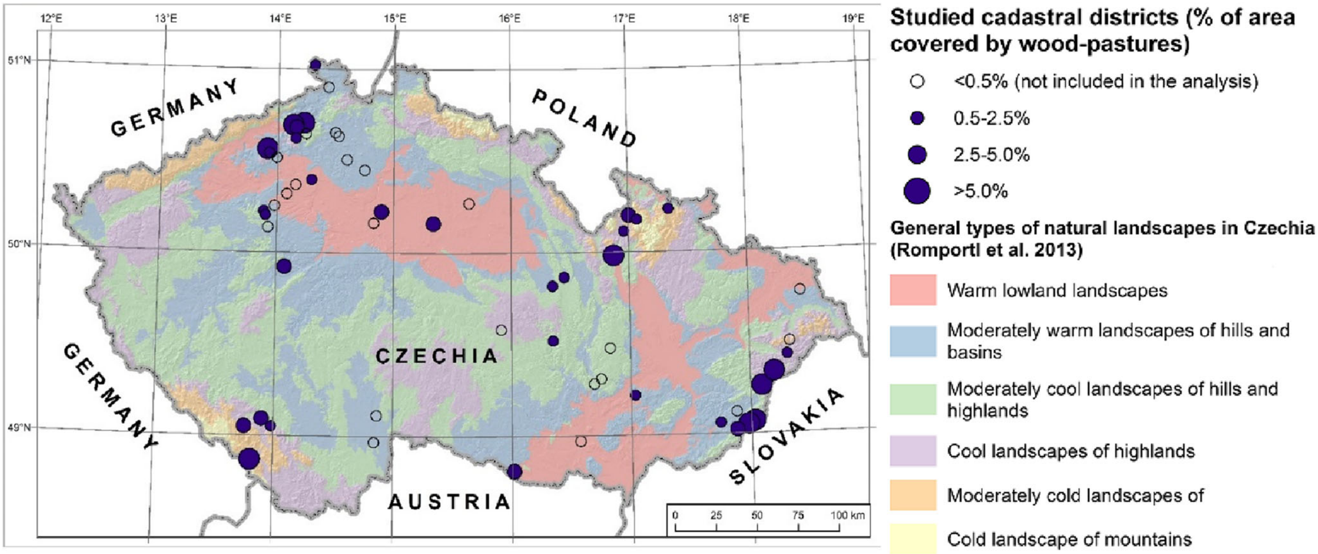


Fig. 1 Localisation of the studied cadastral districts according to the general types of natural landscapes (Romportl et al. 2013)

2015–2017

For the current time horizon, several complementary sources were used. The current orthophotomap at the Czech Office for Surveying, Mapping and Cadastre served as the basis. The Land Parcel Identification System (LPIS) was applied to distinguish agricultural land-use (Ministry of Agriculture of the Czech Republic 2016). The basic map of the Czech Republic (scale 1:10,000) served as an additional source of such details as occurrence of watercourses and routes, etc. Publicly available Google Earth for desktop (Google Earth 2015) was used to double-check the areas of concern quickly at a closer scale and in a sequence of several years (e.g. the stability/rotation of the land). Multiple trips to the study sites between August 2015 and September 2017 helped to confirm previous conclusions.

Categorisation of LULC, accepted for the analysis and based on density/canopy cover of woody vegetation and presence of specific land use types, is reflected in Table 1.

Each open and semi-open landscape was divided this time into two groups to observe the influence of cultivation status. Wood pastures were not included into any of those groups, but regarded as a separate group.

Data processing and analysis

All wood pastures were vectorised according to the above-mentioned sources, for both time horizons using the ArcGIS 10.4 environment (ESRI 2015). First, all data was filtered according to the chosen minimal spatial criteria to exclude cadastral districts with cover of wood pastures of < 0.5% of the total area, and individual wood pastures smaller than 0.3 ha. We interpreted former LULC of current wood pastures in the first half of the nineteenth century and LULC of wood pastures from the first half of the nineteenth century in 2015/2017.

Overlay analysis was performed using the Intersect and Union tools. The results were checked by the Repair Geometry tool to eliminate sliver polygons. All wood pastures were then classified into persistent, lost and gained. The lost and gained groups were analysed for sinks and sources, respectively. All the three groups were categorised by their location within different GTNLs using Overlay analysis.

Statistical calculation

To analyse the data, two separate ANOVAs were performed. GTNL type and former/new LULC-type were used as predictors. As the response variables, areas of previous/acquired LULC and area of shared gained/lost wood pastures were used, respectively. Since both response variables were in percentage rate, the data were arcsin transformed to meet the normal distribution of the variables. The Tukey test was then used as the post hoc comparison to find the differences among particular LULC categories.

Data for the statistical analysis was exported from ArcMap 10.3 into a Microsoft Excel 2013 sheet, organised and analysed using the Excel 2007 and R programs.

Results

Overall changes

From the 30 cadastral districts, which were included into the final analysis, total area of wood pastures amounted to 2128.12 ha for the time horizon of 2015/2017 (4.7% of the total area of the cadastral districts), versus 4910.66 ha for the

Table 1 Categorisation of former/new land use and land cover types of the areas of gained/lost wood pastures

LULC code	General name	Description
1	Open non-cultivated landscapes	All open habitats, excluding arable lands, and with less than 7 trees/ha. In the old map, those depicted as open dry/wet grasslands with no woody vegetation.
2	Semi-open non-cultivated landscapes	Habitats with at least 7 trees/ha and maximally 80% tree canopy cover, similar to Garbarino et al. 2011; Grossman & Mladenoff, 2007. From old maps, wet/dry grasslands with trees mostly were included to this group.
3	Closed landscapes	Habitats with minimum 80% tree canopy cover. For old maps they include all forests.
4	Other areas	All areas not mentioned in the other categories, such as urban and industrial areas and water streams and bodies, etc.
5	Open cultivated landscapes	Cultivated habitats with less than 7 trees/ha (arable or rotational lands).
6	Semi-open cultivated landscapes	Habitats with at least 7 trees/ha used for agricultural purposes (gardens within/in close vicinity of urbanised areas).
7	Wood-pastures	Semi-open habitats where grazing is the dominant management of semi-open grassland.

Here and further in the text: *former LULC category* is the category of land use and land cover that was characteristic for the same area, which is currently covered by a newly formed (gained) wood pasture. Thus, it is the LULC that a gained wood pasture has substituted; *new LULC* is the category of land use and land cover that is characteristic for the area, where a wood pasture was present at the historical time horizon (first half of nineteenth century), but does not exist anymore. Thus, it is the LULC, which has substituted a lost wood pasture

first half of the nineteenth century (10.89% of the total area of the cadastral districts). Thus, their decrease in area more than doubled. Considerable differences between the districts should be mentioned, e.g. the Babetin (moderately cool landscapes of hills and highland landscape type) district had a 23.84% increase in wood pasture area of large wood pasture, while Horni Becva (cool landscapes of highland landscape type) lost 19.14% of them.

Habitat continuity

Only 263.08 ha of wood pastures is present in both time horizons (persistent wood pastures) (Table 3), which equals 5.36% of the area of original historical wood pastures and up to 12.36% of the area of all the current ones. Table 3 and Fig. 2 demonstrate the differences between temporal changes depending on GTNL, which reflects major relatively stable natural characteristics. Since total areas of districts taken for

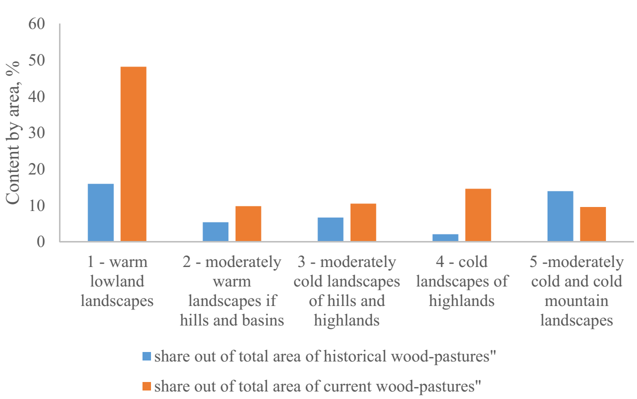


Fig. 2 Relative content of the persistent wood pastures by total area of all historical and current wood pastures within each general type of natural landscapes

the analysis within each GTNL differed initially, here we reflect relative values (shares of areas of persistent wood pastures by total areas of the districts within each of the GTNL). These values were the highest for the districts of 1—warm lowland landscapes—and 3—moderately cold landscapes of hills and highlands (0.997 and 0.801%, respectively)—and the smallest in 2—moderately warm landscapes of hills and basins (0.20%) (Table 2 and Fig. 2). However, in general, this number was very low for all GTNLs. Figure 2 and the last two columns of Table 3 demonstrate the relative abundance of the persistent wood pastures, as compared to the total areas of all historical or current wood pastures of the same GTNL. For both periods, they have maximum presence within the type 1—warm lowland landscapes (48.16 and 15.96%, respectively)—whilst the minimum differs between the time horizons. It corresponds to type 4—cold landscapes of highlands (2.09%) for the historical period—and to 2—moderately warm landscapes of hills and basins—and 5—cold highland landscapes (9.82 and 9.58%, respectively) for the present.

Sinks of wood pastures from the past

As follows from the Fig. 3a, the major direction of change trajectories of historical wood pastures was towards closed areas (mainly forests). As mentioned above, only 5.36% of the original area of wood pastures kept the same LULC in the current time horizon, though some of that could have had intermediate changes of LULC and overgrown back in. Interestingly, only 14% of historical area transformed to semi-open areas (wooded grasslands (13%) or gardens (1%)); thus, only land use, but not land cover, changed. Only 2% of historical area changed into open-cultivated lands (arable lands) due to both land use and cover changes, and 8% turned into other open landscapes (grasslands, pastures, cut-outs, etc.).

Table 2 Description of study areas—general types of natural landscapes (Novotný et al. 2017)

Study area (GTNL)	GTNL description	Landscape unit characteristics
1	Warm lowland landscapes	A landscape unit with a character of intensively agriculturally used landscape
2	Moderately warm landscapes of hills and basins	A landscape unit that represents a mosaic of forestry, agricultural and pond landscape
3	Moderately cool landscapes of hills and highlands	A landscape unit with a character of extensively agriculturally used landscape
4	Cool landscapes of highlands	A landscape unit with a forestry and extensive agriculture using
5	Moderately cold landscapes of mountains	A landscape unit with forests and extensively agriculturally used grasslands
6	Cold landscape of mountains	A landscape unit with predominating forests and ecosystems above the forests

A closer look at the character of changes by separate GTNLs (Fig. 3b, Apendix1) reveals that these are moderately warm landscapes of hills and basins, and especially in moderately cold and cold landscapes of hills and highlands, where most of the lost wood pastures converted into closed areas. However, in the case of moderately cold and cold mountain landscapes, more transformations were happening in the direction of semi-open areas (wooded grasslands), and the majority of lost wood pastures of warm lowland landscapes transformed into open non-cultivated landscapes (open grasslands and pastures).

Sources of gained wood pastures

As seen in Fig. 4a, the majority of the wood pastures, present in 2015/2017 (50.96% by total area of current wood pastures or 60.65% by total area of gained wood pastures), appeared from former open cultivated areas (arable and rotational lands). A comparable and relatively small amount of gained wood pastures appeared from open non-cultivated and semi-open landscapes (grasslands with woody vegetation) (13.66 and 12.16% by total area of current wood pastures, respectively), having changed either only land cover or use type. Only 5.54% of the total present area of wood pastures within the studied districts appeared from the previously forested areas.

Considering the role of the GTNL (Fig. 4b, Appendix 2), it is seen that open cultivated landscapes served as the major source of gained wood pastures in the case of all these types, ranging between 35.85% of total area of gained wood pastures in moderately cold and cold mountain landscapes to 91.75% in warm lowland landscapes. These areas were the main source for the gained wood pastures in the case of all the GTNL except for warm lowlands, where former open non-cultivated areas were prevalent. Former forested areas had a considerable role as sources input only in the case of moderately cold and cold mountain landscapes, whereas for the rest, their input was insignificant. Former open pastures and grasslands gave birth to a notable share of gained wood pastures in most cases, with the exception of warm lowlands, showing that quite a lot of wood pastures appeared due to overgrowing of open areas.

Analysis of the impact of environmental factors on spatio-temporal changes of wood pastures using statistical tools

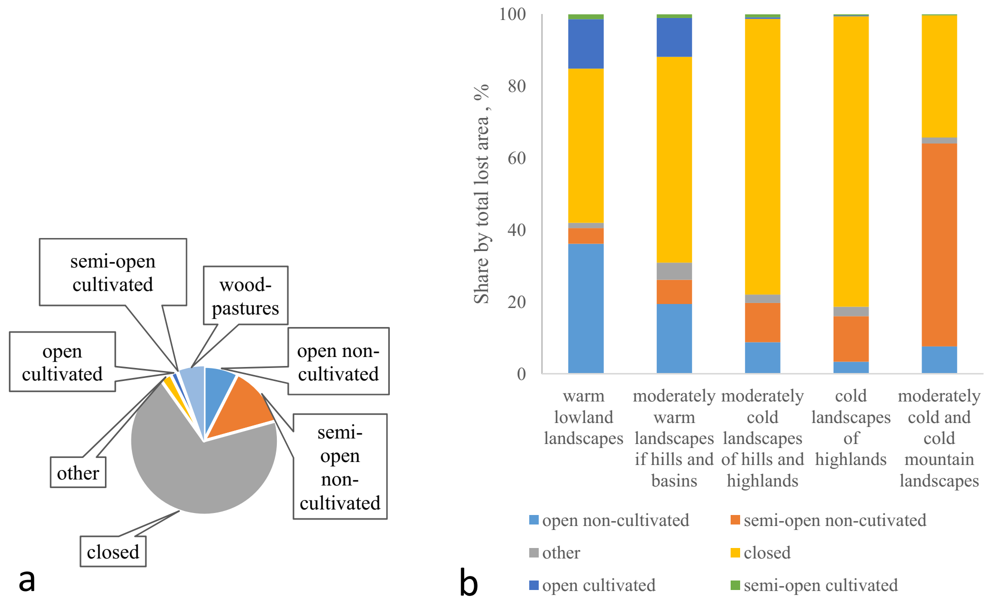
As the results of the two-factor ANOVA test for the dataset of gained wood pastures (Table 4) have shown F = 13.39, $P < 0.01$, for the factor of the LULC categories, which they were transformed from (Table 6: rows), the null hypothesis 1A

Table 3 Presence of persistent wood pastures within each general type of natural landscapes

GTNL[a]	Area of studied cadastral districts within the GTNL, ha	Area of persistent wood-pastures, ha (share in total area of cadastral districts within the GTNL)	Share in total area of persistent wood pastures, %	Share in area of historical wood pastures within the GTNL, %	Share in area of current wood pastures within the GTNL, %
1	4140.66	41.29 (0.10)	15.70	15.96	48.16
2	7536.76	15.17 (0.20)	5.77	5.39	9.82
3	13,946.69	111.67 (0.8)	42.45	6.68	10.52
4	12,361.41	49.69 (0.4)	18.89	2.09	14.62
5	7918.27	45.27 (0.57)	17.21	13.92	9.58
Total	45,903.79	263.08 (0.57)	N/A	5.36	12.44

[a] See Fig. 1

Fig. 3 Share of the current land use and land cover categories in **a** total area of original (historical) wood pastures, **b** areas of the lost wood pastures by general types of natural landscapes (sinks)



(Materials and methodology: Statistical Calculation) can be rejected (Table 5). Thus, at a 95% level of confidence, we conclude that there is a significant difference in the areas of gained wood pastures depending on the LULC category they appeared from. Results for the factor of GTNL in the case of gained wood pastures (Table 6: columns) show $F = 0.09$, $P = 1$ so null hypothesis 2A for the case of gained wood pastures cannot be rejected. Thus, we cannot state that there is a significant difference in the areas of the gained wood pastures for the different GTNLs they were appearing in. However, we may still suppose that there is a less significant dependence on this factor.

Similarly, testing areas of lost wood pastures (Table 5) has resulted in $F = 1.61$, $P < 0.01$; thus, null hypothesis 1B (Materials and methodology: Statistical Calculation) can be rejected (means are different). So, at a 95% level of confidence, we can conclude that there is a significant difference between the areas of lost wood pastures, which were transformed into different (Table 7: rows). At the same time for the null hypothesis 2B $F = 0.19$, $P = 0.94$ (case of lost wood pastures (Table 5: columns). So, the same as for the case of the gained wood pastures, it is not possible to make a statement about significant difference in the areas of the lost wood pastures for the different GTNLs.

The Tukey test for the case of gained wood pastures (Table 8) confirms the outstanding role of the former open cultivated area category as the main source of them, as the pairwise comparisons of this category with all the source-LULC types have shown significant difference with $P < 0.05$. The most significant difference observed is the input of open cultivated areas with former closed, semi-open cultivated landscapes and the category of "other" areas. For the case of lost wood pastures, our conclusion about the closed areas as the most common sink of those has also been confirmed with the $P < 0.05$ for all the pairwise comparisons with other LULCs (Table 9). The most significant difference of impacts was observed between this group and those of open-cultivated, semi-open cultivated and "other" landscapes.

Fig. 4 Share of the former land use and land cover categories in **a** total area of current wood pastures, **a** areas of gained wood pastures by general types of natural landscapes (sources)

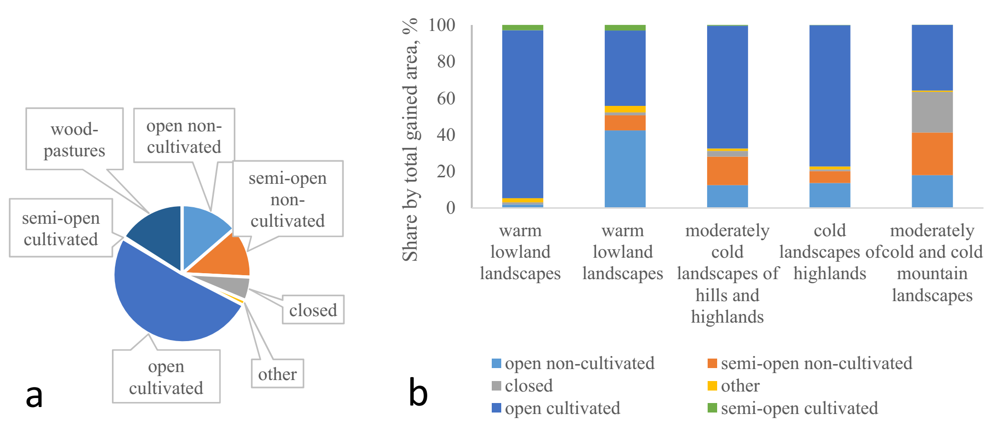


Table 4 Share of areas of gained wood pastures by the former land use and land cover categories

Former LULC category[a]	GTNL**				
	1	2	3	4	5
1	1.92	42.4	12.51	13.63	17.99
2	< 0.01	8.16	15.54	6.53	23.26
3	1.19	1.68	3.16	0.97	22.21
4	2.27	3.56	1.34	1.58	0.69
5	91.75	41.23	67.07	77.18	35.85
6	2.87	2.96	0.37	0.11	0.01

[a] See Table 1

**General types of natural landscapes

Discussion

Character of long-term spatio-temporal changes of wood pastures with relation to environmental factors

General decrease of total area of wood pastures in time corresponds to our expectations, as well as to the trends described in the majority of previous research studies concerning agroforestry dynamics in Czechia and Europe (Plieninger 2006; Costa et al. 2011; Garbarino et al. 2011; Plieninger et al. 2015; Schaich et al. 2015; Varga et al. 2015; Krčmářová and Jeleček 2017). It also confirms the suggestion from our previous research (Forejt et al. 2017) that the increase in the area of wood pastures demonstrated that there might refer to the small selection, which included only districts with currently significant cover of wood pastures and only within warm landscapes of hills and basins. Even though areas with fractions of current wood pastures < 0.5% of the areas of cadastral districts were excluded, results fit the general flow well. Decrease of wood pastures with time was observed for all GTNL, except for moderately cold and cold mountain landscapes. However, the increase for the latter was relatively small, as well as the total area of wood pastures of this GTNL for both time horizons. Plus, according to field-trip observation, many wood pastures there have seasonal rotation of land use. Namely, some slopes are used for tourism (skiing) in winter and as pastures in summer. From our previous study (Forejt et al. 2017), most changes took place in the second part of the twentieth century, supposedly due to the faster changing political situation, leading to collectivisation, large open fields and heavy mechanisation. This is especially valid for warm lowland landscapes. Additionally, according to many authors, rapid loss of wood pastures was prompted by intensification of land use and intensive grazing (Plieninger 2006; Schaich et al. 2015; Varga et al. 2015). Another factor is invasion of woody vegetation following extensification and abandonment of farming (Plieninger 2006), related depopulation of former farming areas and abandonment of traditional management.

Table 5 Share of areas of lost wood pastures by the new land use and land cover categories

New LULC category[a]	GTNL **				
	1	2	3	4	5
1	36.21	19.46	8.84	3.39	7.67
2	4.39	7.85	10.9	12.66	56.42
3	42.88	66.41	76.65	80.75	33.96
4	1.43	5.53	2.35	2.66	1.67
5	13.78	12.55	0.46	0.22	< 0.01
6	1.32	1.02	0.81	0.31	0.27

[a] See Table 1

**General types of natural landscapes

Table 6 Results of two-factor ANOVA test for relation of the area of gained wood pastures to former land use and land cover category and general types of natural landscapes

Source of variation	F	*P* value	F crit	*df*
Rows	13.39	< 0.01	2.71	5
Columns	0.09	1	0.98	4

From the relatively small area of current wood pastures, only 12.44% (5.36% of the total area of historical wood pastures) could be persistent. Considering GTNLs, warm lowland landscapes show a large proportion of persistent wood pastures of their total current area, but calculation was based on small absolute numbers, thus is low if compared to the other types. In several cases, moderately cold landscapes of hills and highlands and of cold landscapes of highlands are present within the same cadastral districts. Both these types show comparable and high content of persistent wood pastures, which proves significance of socio-cultural characteristics and local policies. Local people confirm this fact through non-formal conversations and describe wood pastures as a local tradition. Economy of those districts with a stronger connection to pastoralism was less affected by political changes in the second half of the twentieth century. Structurally, wood pastures in these types are also more "integrated" into villages and "scattered across" them, forming a part of the local lifestyle.

From all the lost wood pastures, the dominant proportion turned into closed areas, which, firstly, could be related to

Table 7 Results of two-factor ANOVA test for relation of the area of lost wood pastures to new land use and land cover category and general types of natural landscapes

Source of variation	F	*P* value	F crit	*df*
Rows	12.61	< 0.01	2.71	5
Columns	0.19	0.94	2.87	4

Table 8 Results of Tukey HSD test for significance of former land use and land cover categories in relation to the area of gained wood pastures

LULC pair	Lower value	Upper value	p adj	
f-d	− 2.51	− 24.07	19.05	1.00
d-c	− 3.91	− 25.47	17.65	0.99
c-b	− 5.15	− 26.70	16.41	0.97
f-c	− 6.42	− 27.98	15.14	0.93
b-a	− 6.52	− 28.08	15.03	0.93
d-b	− 9.06	− 30.61	12.50	0.77
f-b	− 11.57	− 33.12	9.99	0.56
c-a	− 11.67	− 33.23	9.89	0.55
d-a	− 15.58	− 37.14	5.98	0.25
f-a	− 18.09	− 39.65	3.47	0.13
e-a	30.08	8.53	51.64	< 0.01
e-b	36.61	15.05	58.16	< 0.01
e-c	41.75	20.20	63.31	< 0.01
e-d	45.66	24.11	67.22	< 0.01
f-e	− 48.17	− 69.73	− 26.62	< 0.01

abandonment, but also to the steady increase of commercial forests in the last decades (Postulka 2008) (FERN 2008). This prevalence is less expressed in moderately cold and cold landscapes, where closed areas share a leading position with semi-open non-cultivated areas, which could again be partly attributed to development of tourism.

Most current wood pastures appeared recently on open landscapes, mainly arable lands, which reflects again the processes of abandonment of less accessible lands during communism and extensification of agriculture in the 1990s (Bičík et al. 2001; Feranec et al. 2010). A comparable area of wood

Table 9 Results of Tukey HSD test for significance of new land use and land cover in relation to the area of lost wood pastures

LULC pair	Lower value	Upper value	p adj	
e-d	0.60	− 20.66	21.87	1.00
b-a	2.00	− 19.26	23.27	1.00
f-d	− 4.47	− 25.74	16.79	0.98
f-e	− 5.08	− 26.34	16.19	0.97
e-a	− 11.61	− 32.87	9.65	0.54
d-a	− 12.21	− 33.47	9.05	0.48
e-b	− 13.61	− 34.87	7.65	0.37
d-b	− 14.22	− 35.48	7.05	0.33
f-a	− 16.69	− 37.95	4.58	0.18
f-b	− 18.69	− 39.95	2.57	0.11
c-b	27.81	6.54	49.07	0.01
c-a	29.81	8.55	51.07	< 0.01
e-c	− 41.42	− 62.68	− 20.16	< 0.01
d-c	− 42.02	− 63.29	− 20.76	< 0.01
f-c	− 46.50	− 67.76	− 25.23	< 0.01

pastures appeared from semi-open (woody grasslands) or open non-cultivated landscapes (pastures, grasslands). Some of these cases could be explained even by periodical rotation of land use and/or slow successional overgrowing (in the second case) of grazed areas and observed in most GTNL.

Structurally, wood pastures in Czechia at the current time horizon form either large areas (with oak, pine or birch in lowlands, protected for their dry grasslands on slopes with southern exposition; with maples, spruce or rowan in highlands, often in former military areas) or small patches with fruit trees anywhere with sheep, goats and horses. Depending on the location within different GTNLs and local management traditions, bigger plots with more deciduous trees can be seen around some villages, or smaller plots, mostly with fruit trees, are found scattered across the villages (mostly in highlands). Old oaks and silver spruce are still present, but need more recognition and protection. Veteran trees have been disappearing gradually. From the perspective of conservation value, as persistent wood pastures are scarce, one can expect a few old, but more relatively young trees in the current wood pastures, which was confirmed in the field. Yet, some authors talk about possibility of restoring former wood pastures from the currently overgrown closed areas (Roellig et al. 2015) if these patches are not registered as forestland in the Czech cadastre. The old trees which still are found today (Krčmářová 2016) are becoming endangered if they get overgrown by younger strong trees, which is risky for the whole particular ecosystems around these trees (Hartel 2015, personal communication).

Spatial-temporal changes of wood pastures described for the studied sites in general appear more dynamic than in most of the other European countries and are lacking traditional land use (Krčmářová and Jeleček 2017).

Statistical analysis, firstly, confirms general dependence of area of the wood pastures on the GTNL according to comparison of wood pastures at historical and current moments (Pearson correlation coefficient), but shows that it is low. However, it can be influenced by the fact that most of current wood pastures are gained and most of the historical wood pastures have been lost. At the same time, the Pearson coefficient proves that occurrence of gained wood pastures is much more significantly dependent on GTNL, than of the lost wood pastures. The last fact may mean that the loss was related to economic and political changes across the country more than on the GTNL. However, as gained wood pastures were reappearing mostly in certain GTNLS, which was mostly happening in the second half of the twentieth century, and under less pressure from political and economic circumstances, it allows concluding that presence of wood pastures does depend on GTNL, but this factor is less strong.

Relation of gained wood pasture area to the precedent LULC was confirmed statistically by ANOVA test as significant, whereas the impact of GTNL is much lower, which agrees with the discussion on sources above. Similarly, ANOVA shows stronger relation of area of lost wood pastures to their new LULC categories, than to GTNL, which can be proof of the bigger influence of industrialisation and political regime, leading to either forest plantations or overgrowth of wood pastures.

Constraints and solutions in working with geographical data over large spatial and temporal scale

The current study is a continuation of our previous research (Forejt et al. 2017), and similar methodology was applied at the first step with some improvements. First, results of the current work are more informative and reliable in general, as more districts have been considered. Moreover, districts from all six GTNLs of Czechia were included this time. Applying minimum thresholds of 3000 m^2 to the areas for wood pasture patches and of 0.5% of wood pasture content by the total district area (see Materials and methodology: Study area) reduced the amount of manual work, and guaranteed each area is large enough to be included into detailed analysis of the GTNL impact. Certain concern, though, could be brought by different proportion of cadastral districts for each separate GTNL after this selection was applied.

Differently from our previous research (Forejt et al. 2017), only two time horizons were described this time, as one demonstrated that data on LULC from the sources used for the 1950s were not reliable. Still, results of the current study reflect the changes between relatively distant time horizons, unlike most other studies (Plieninger 2006; Garbarino et al. 2011; Schaich et al. 2015). In addition, the goal of this paper was rather to observe the relation of different character of changes to more factors, than to see continuity as such on a detailed time scale. At the same time, combination of the conclusions from our above-mentioned previous study with a smaller selection of districts, but more detailed historical scale, and the data collected for current spatially broader work, allow making more detailed conclusions on the change trajectories within the whole country throughout the history. However, not all of the outcomes could be included due to the limited capacity of the article.

The fact of excluding wood pastures of the area < 3000 m^2 could affect results, in the cases where, due to different character of "mosaic" structure within certain cadastral districts, they contained more smaller patches scattered across the district area as opposed to bigger "merged" patches. The structure may depend on relief, type of woody vegetation, local tradition of land use and management. We tried to minimise this effect by merging the bordering small wood pastures at initial steps of analysis.

Talking of the use of the data sources, the risk of mistakes could be higher in the current research than in the previous, as we needed to process a larger amount of data. However, we tried to improve the accuracy using additional data sources. The same method as previously was applied to describe the period of the beginning of the nineteenth century, based on Franciscan cadastral mapping, as the most informative data source for that period, which covers the whole current area of the Czech Republic. The same as in previous research, obstacles exist, firstly, for georeferencing and digitising old maps, and they were eliminated by transforming the vector layer into a raster with a 5-m cell size. Also, old maps are limited in the possibility of precise judging of their cover, especially due to the fact that they do not clearly reflect the density of woody vegetation, which makes it less reliable when applying the threshold that we have chosen to define wood pastures. These limitations, however, are easily solved for the current time horizon. Additional sources, such as the Google Earth program, help confirm stability of the patches on a shorter-time scale, within the period of as much as 10–15 years (depending on the district), create polygons directly within this software and easily convert them into a form suitable for the further analysis within ArcGIS environment.

Another limitation, relevant to both time horizons, is the large amount of manual work, needed especially during vectorising all data, which can be especially difficult to solve in the case of old maps.

In contrast to our previous research, the ArcGIS analysis was done by the same researcher, to minimise the possible effect of personal work-style on the results for different cadastral areas.

Conclusion

The results of the research are helpful for answering the research questions posed in the introduction. Firstly, it can be concluded that the net area of wood pastures in Czechia decreased at the present moment as compared to the first half of the nineteenth century. Only a small part of the present wood pastures can be characterised as persistent; thus, the general situation with presence of wood pastures in Czechia has been less stable than in the majority of other European countries, where similar studies have been executed, which can serve as a confirmation of significant impact of the political situation on the dynamics of wood pastures, especially considering the major changes in political division of Czechia, and the related influence of different neighbouring countries through this period. It can be assumed with high probability that most of the gained wood pastures were formed during the second part of the twentieth century.

Sources of the gained wood pastures and sinks of the old ones have been analysed; the relation of the character of those to GTNL was confirmed. This could be partly attributed to natural reasons, but can be an indirect confirmation of the role of socio-cultural factors, as those often depend on location within certain GTNL. Moreover, according to statistical analysis, the role of GTNL initially has an impact on presence of wood pastures. But this relation is less significant in comparison to other purely anthropogenic factors (political, economic, etc), which can also be confirmed by the fact of a higher relation to the former/new LULC categories of the gained/lost wood pastures. However, relative significance of each of those in more detail was not a subject of the current study and needs a separate investigation, though it still reflects the importance of appropriate management, with support of the state/local government, to counteract the decline of wood pastures in Czechia.

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