Transformation of Czech cultural landscapes over the past two centuries: typology based on model areas

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ABSTRACT Central European landscapes have undergone massive changes since the mid 19th century. Various driving forces including industrialization and different political decisions led to the processes that have profoundly influenced society, landscape character, and also heritage. This article focuses on thirty model areas across Czechia that were selected as typical representatives of various types of landscape changes. Based on land use/cover data covering the mid-19th century and the present time (2018–2020), a cluster analysis was carried out and model areas grouped into types/clusters. The results show that the main dividing line runs between intensively and extensively used landscapes. The current data show this division in a very clear manner and add one more type – anthropogenic landscapes. This differs from the expert typology based on key landscape features. They are often not big enough to play a significant role in the analysis of land use/cover change.

KEY WORDS nature-society interaction – land use/cover changes – Czech landscapes, transformation of functions – cluster analysis

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1. Introduction

1.1. Milestones of human-nature interaction and main driving forces and processes of landscape change in Czechia over the last two hundred years

Within the long history of mankind and human-nature interaction there are two key periods that brought far reaching and large-scale changes of natural landscapes. First of all, Neolithic Revolution that started about 10,000 years ago. Original untouched natural landscapes were altered into cultural landscapes that could secure basic needs for growing population.

Second, Industrial Revolution has influenced landscapes since early 19th century. Industrial Revolution also became a catalyst for changes in many other fields including agriculture, demographics, transportation, social structure, etc. In general, modernization was taking place – that is why some scholars talk about "complex revolution of modern time" (Purš 1973, 1980). Fast population growth resulted into dynamic landscape changes – these changes, however, had different face in different territories (Antrop 2008; Hampl, Müller 2011; Kupková, Bičík, Jeleček 2021).

Mather (2002) discusses different levels of landscape changes and different effects of human activities on landscapes. He defined three types of factors that cause landscape changes. First, there are "proximate" factors, i.e. driving forces that can be quantified and that have a direct relation (statistical correlation) to landscape, land use/cover change. Second, directions and intensity of proximate factors change over time and depend on "intermediate" factors. These are economic and technological tools used by humans to alter the environment. Third, intermediate factors, however, are not fully stable either; their changes, according to Mather, are caused by changing "underlying" factors, i.e. by political, institutional, and cultural conditions.

Proximate factors can be quantified and are related to small territorial units like plots or municipalities. On the contrary, intermediate and underlying factors have rather qualitative nature and are related to large areas (national, global levels).

Landscape changes, however, take place at all spatial levels as the above mentioned factors act simultaneously and in complexity. Political changes usually take place within days or weeks. Resulting economic changes last months or a few years, demographic and social changes require a longer time – usually many years. So-called complex changes that include also landscape changes come last (Hampl, Müller 2011; Sýkora, Bouzarovski 2012). That is why land use/cover data reflect changes with a considerable delay.

Past research defined the following main driving forces of landscape changes in Czechia (Bičík et al. 2015; Kupková, Bičík, Jeleček 2021):

1. Revolution of 1848/49: e.g., the end of feudalism.

2. Completion of Industrial Revolution (industrialization, urbanization, railways, etc.) and Agricultural Revolution.
3. Transition into Technological-Scientific Revolution under conditions of protracted agrarian crisis in 1880s and 1890s.
4. World War I: war economy, controlled market, lack of male workforce in agriculture.
5. 1918–1938: birth of Czechoslovakia, land reform (1920–1937), Great Depression (1929–1933).
6. World War II: war economy, Nazi regime, population decrease.
7. Impacts of World War II: transfer of Czech Germans (1945–1947), depopulation of borderland, agricultural boom in the interior of Czechia.
8. 1948–1989: nationalization, centrally controlled economy, collectivization of agriculture, industrialization, special system of subsidies.
9. From 1990 onwards: reintroduction of market economy, property restitution, privatization, accession to the European Union, new system of agricultural subsidies, urban and sub-urban boom.

The above-mentioned driving forces led to diverse changes and different processes that altered Czech cultural landscapes over the past two hundred years. Based on available data sources, different sub-periods with different landscape changes can be defined (see Bičík et al. 2015; Kupková, Bičík, Jeleček 2021):

- The period 1845–1896 was the only one when arable land was expanding (i.e. agricultural intensification); afforestation just started.
- Diverse changes were taking place between 1896 and 1948. Afforestation and early stages of urbanization were important.
- The Communist period 1948–1990 was characterized especially by urbanization, afforestation, and significant decrease of arable land.
- The period 1990–2010 is the only one with increase of permanent grasslands. It was also a time of afforestation and rapid urbanization.

Looking at the period 1848–2010 as a whole, one can say that the following processes prevailed: agricultural extensification (marked decrease of arable land), afforestation, and urbanization.

1.2. Land use/cover as an indicator of human impact on landscape, heritage of traditional and transformed landscapes

Changing character of land use/cover patterns reflects human impact on landscape (OECD 1993). Historical materials containing land use/cover "data" (old maps and accompanying texts) are invaluable sources of information that contribute to

understanding of landscape heritage and ancient landscape structures (Bičík et al. 2015; Cousins 2001; Fuchs et al. 2015; Lipský 1992; Skokanová et. al. 2012). These sources have been used by a number of scholars over the past decades in order to study landscape changes on local level (cadastral areas, plots; Balej 2011; Bičík et al., eds. 2012; Bucala 2015; Kolejka, Krejčí, Nováková 2020; Kupková, Bičík 2016, Kupková, Bičík, Boudný 2019; Masný, Weis, Boltižiar 2016; Popelková, Mulková 2018; Sklenička et al. 2014; and many more). Historical sources help to assess the intensity of landscape changes in the past.

So-called traditional landscapes are often praised for relative stability, long-term historical continuity, and preservation of landscape heritage. Traditional landscapes contribute to the formation of regional identity. Each region is unique – depending on landscape character, culture, and traditions. Different types of cultural landscapes usually contain a certain degree of historical landscape structures, even under circumstances of ongoing and often far-reaching changes. These historical structures reflect the past patterns of cultivation and landscape utilization (e.g. rests of vanished artificial lakes, field boundaries, ancient farm tracks, abandoned fortifications, diverse sacral structures). Landscapes with high presence of the above-mentioned structures bear an outstanding historical and cultural heritage and often boast high aesthetic and ecological values (Kolejka, Krejčí, Nováková 2020; Renes et al. 2019; Skaloš, Kašparová 2012; Tappeiner et al. 2021).

Many regions throughout Europe (including Czechia), however, contain landscapes that have been significantly altered during the last two centuries, when their functions and character (land use/cover etc.) were significantly changed, then they were called disappeared (or lost, extinct) landscapes. Such landscapes usually include just a handful of historical landscape structures; landscape heritage has been badly damaged and original land use/cover patterns fundamentally changed.

We have analysed thirty small regions across Czechia that represent various processes of significantly transformed landscapes. Old maps (so called "Stable Cadaster"), orthoimages, and ancient photographs have been used in order to identify, reconstruct, and make available the heritage of disappeared- and transformed landscapes (see also www.zaniklekrajiny.cz). The project aims at vanished landscape heritage as preserved in historical files. It also has the ambition to identify chief types of changes that were in progress and led to disappearance of the original landscapes, including main driving forces.

1.3. Czech cultural landscapes and transformation: typology

Scholars have produced several typologies of Czech cultural landscapes over the past decades. Chuman, Romportl (2010) used multivariate analysis based on seven groups of topographical, meteorological, soil, vegetation, and land cover variables

and defined eleven current landscape types in Czechia. Romportl, Chuman, Lipský (2013) also focused on current landscapes using statistical approach combining natural landscape types and so-called functional landscape types; land cover classes were also taken into consideration. The result was 79 types of current landscapes. Kolejka, Krejčí, Nováková (2020) defined pre-industrial landscapes based on secondary landscape structure. There are also approaches using expert knowledge, e.g. Meeus (1995) stressing diversity of European landscapes. This can be applied as a tool for assessing landscape character (Vorel et al. 2004).

1.4. Hypothesis and aims

According to literature research, any kind of typology that would address sorting of intensively transformed landscapes and take into consideration historical processes has not yet been carried out. Analysis of thirty small regions can serve as a suitable laboratory for creating typology and generalization of landscape processes (Mücher et al. 2006). This typology of significantly transformed landscapes includes sorting into types that were based mainly on (1) main driving force that have influenced the development of landscape, or (2) on feature of landscape heritage arising from specific use, or (3) on specific land use/cover development.

Along with non-linear changing landscapes theory (Antrop 2008, Lipský 2000), we chose relatively long period, which captures the change during the industrial and post-industrial age in Czechia. Moreover, we are aware of complexity of the phenomenon of the cultural landscape containing past and presence, environment and also its values or heritage (Harvey 2001; Selman 2006; Howard, Thompson, Waterton, eds. 2013; Kolejka et al. 2011). Therefore, both expert and statistical typologies were investigated to reveal variability in landscape processes, changes and their perception.

We hypothesised that outputs of both typologies will be different and will stress different features because the statistical approach used objective data and the expert approach rather worked with perception of the landscape.

Land use/cover data based on cadastral maps from mid 19th century and also current data were analysed in order to quantify the changes within model areas. This quantification of changes of land use/cover structure allows to elaborate a new typology based on statistical comparison (cluster analysis).

The primary goal of our study is to evaluate whether expert-based expectations of landscapes changes (typology) correspond with real land use/cover development and processes of landscape changes, i.e. with statistical typology based on historical data sources. In addition, similarities / differences among trends of land use/cover changes in significantly transformed landscapes in model areas on one hand and general trends of land use/cover changes on the national level on the other hand were studied.

2. Data and methods

2.1. Model areas and expert typology

Thirty model areas across Czechia that have undergone significant landscape changes (land use/cover changes) between mid 19th century (Stable Cadastre) and early 21st century have been selected. Model areas were selected to capture diversity of functional transformation within the Czech landscape, e.g. landscapes with historical mining, industrial, military, agricultural or other activities and functions. These model areas were sorted on the base of transformed and disappeared landscape typology. Geographical position of all model areas is shown in Figure 1; Table 1 contains main features of them.

In a way the expert typology is based on a subjective point of view of experts depending on their experience with Czech cultural landscape. Detailed evaluation of land use/cover changes was not a base for this typology; it is rather based on main use / function / transformation or main driving forces that have influenced landscape changes (land use/cover). The presence of specific activities / landscape features / landscape heritage arising from specific use / development of the model area was also taken into consideration. Then, the most significant features were discussed and according to them, typology and names of types were given: Aristocratic landscapes as examples of cultural landscapes around residences of aristocracy, Border landscapes as examples of landscapes along the state borderline; Extensively used agricultural landscapes in the interior of Czechia as rather peripheral agricultural landscapes; Intensively used agricultural landscapes as the landscapes with favoured conditions for agriculture; Military training landscapes as landscapes with former or ongoing military activities; Mining landscapes as landscapes with former or ongoing mining activities; Urban-industrial landscapes as landscapes affected by urbanization and industrialization; and Artificially flooded landscapes as landscapes of significant changes of water bodies. Table 2 shows how model areas were sorted into different types of expert typology. The combined extent of model areas is 613.44 km² ranging from the smallest one (3.45 km²) up to 112.33 km².

2.2. Data

Landscape (land use/cover) data containing information on land use patterns by cadastral units collected in two different periods (1826–1843 and 2018–2020 respectively) in each model area were used in this study. The mid 19th century data were acquired from old maps – Imperial imprints of the Stable Cadastre. These were obtained in the form of scanned images from the Czech Office of Surveying

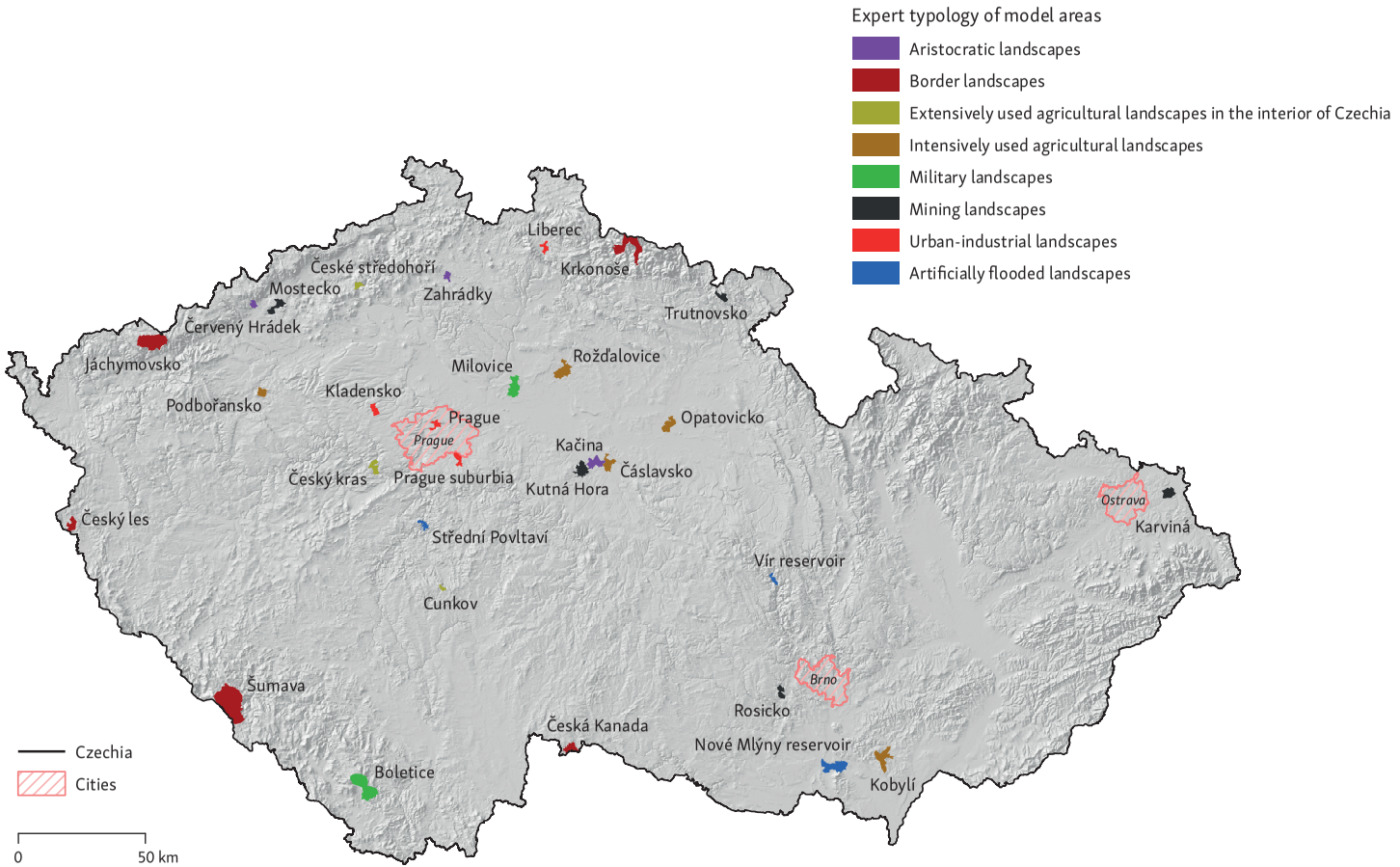


Fig. 1 – Model areas

Table 1 – Description of Model Areas

Model Area	Main Functions and Changes	Main Driving Forces
Boletice	Former extensive agriculture in mountainous setting, dotted by small villages, was replaced by military training area.	Political decisions led to destruction of human settlements, military training area was established.
Cunkov	Extensification of agriculture due to less-favoured conditions. Grasslands prevail at the present time. Diverse recreational use.	Farming was no longer viable (high altitude, remote location). Much of the area was turned into grasslands and is used for leisure time activities.
Čáslavsko	Artificial lakes were built in the 17th century and drained in the 19th century due to agricultural intensification.	Artificial lakes were drained as part of agricultural intensification – arable land brought better profits.
Červený Hrádek	Castle with adjoining park. The park was later abandoned and transformed into forest after WWII.	The property was nationalized after 1945 and partly abandoned. Castle has been renovated after 1990 and serves for recreational activities and education. Park is much smaller now, the rest was taken by forest.
Česká Kanada	Gradual extensification of original agricultural landscape based on family farms. Landscape was influenced by significant depopulation, especially after 1948.	Negative effects of border especially due to creation of iron curtain. Destruction of many villages after 1945, upsurge of leisure time activities after 1990.
České středohoří	Agriculture based on family farms, specialized in fruit production. Extensification was taking place under Communism due to depopulation.	Fruit farming diminished after WWII, depopulation took place (transfer of Czech Germans, migration to new industrial centres with better standards of living).
Český kras	Agriculture was originally based on family farms. Traditional agricultural methods were abandoned under Communism. Limestone quarries worked till 1960.	Traditional agricultural methods disappeared after 1948 as did mining. The proximity of Prague brings many visitors to the area to practice various leisure time activities (e.g., climbing).
Český les	Traditional subsistence farming and glass industry based on charcoal till WWII.	Transfer of Czech Germans after 1945 and creation of military areas and no-go border zone changed land use patterns profoundly. At the present time, the area enjoys legal protection. Modest leisure time activities.
Jáchymovsko	Mining since the Middle Ages, small industrial enterprises (wood, textile, timber) in the 19th century. Uranium ore mining between 1947 and 1960. Extensification, leisure time activities after 1990.	Transfer of Czech Germans after 1945. Access was restricted in the time of uranium mining. The area became part of UNESCO World Heritage (mining landscape).
Kačina	Part of aristocratic landscape that included extensive park and various bodies of water. Many of these features survived. Agriculture dominates in the area now.	Agricultural intensification based on large cooperatives during the period 1948–1990.
Karviná	Coal mining has transformed the original traditional agricultural landscape into urbanized industrial area since the second half of the 19th century. Post-mining landscape has been emerging recently.	Industrialization led to complete change of land use patterns. Some human settlements made way for mines. Nowadays, industrial activities are gradually diminishing.

Model Area	Main Functions and Changes	Main Driving Forces
Kladensko	Mining and heavy industry from ca. 1850 till 1970. Mines now defunct. New industrial and commercial companies. Many people commute to Prague on a day basis.	The area provided supply of coal and steel for Prague, manufacturing became important. At the present time, Kladno is part of Prague Metropolitan Area.
Kobylí	Until 1920 one big farm dominated the local agriculture, supplemented with a number of small family-type farmers. Agricultural intensification was taking place during the 20th century including a steady increase of wine, fruit, and vegetable production.	Agricultural intensification due to fertile soils, favourable climate and well developed transport lines.
Krkonoše	Originally extensive farming (pastures) prevailed. At the present time, the area enjoys legal protection, many converted farmhouses are used as hotels and guest houses.	Transfer of Czech Germans and unprofitable subsistence agriculture led to post-war depopulation. Creation of National Park in 1959; nowadays the area is annually visited by ca. 10 million people.
Kutná Hora	In the Middle Ages this was a famous mining district. Later, mines were abandoned, residential and commercial functions prevailed. Important tourist region after 1990.	The intensity of mining fluctuated in the past. Tourists are drawn to Kutná Hora due to the UNESCO Heritage status. There are new residential districts and industrial plants around the town. Intensive agriculture in the environs.
Liberec	Industrialization and residential development has changed the original extensively used farming landscape. After WWII increase of built-up and recreational areas.	Liberec boomed due to industrialization and influx of newcomers. Green areas in the immediate surroundings of the town are used as recreational areas.
Milovice	The original farming landscape was converted from 1900 onwards into a military area. Recently, the area has been changed into a sort of post-military landscape.	Political decisions were behind the major changes: creation of the military area, during the WWII used by Germans, after 1968 by Soviets. Military area was abolished after 1990 and replaced by residential development and "new wilderness".
Mostecko	Several changes in landscape functions took place: intensive agriculture – mining – industry – land reclamation – leisure time and/or agriculture, transformation into post-industrial landscape.	Open pit mining and heavy industry, arrival of working class, creation of new city (destructionof the old one), land reclamation after 1990, new functions (outdoor activities).
Nové Mlýny reservoir	Intensively farmed fields and Mušov village have been submerged by water reservoir in the 1980s. Water is used for irrigation, lake is visited by tourists.	Intensification of agriculture, leisure time activities (wine tourism, fishing).
Opatovicko	Artificial lakes created in the 17th century were drained due to agricultural intensification in the end of the 19th century. Sand pits replaced ponds in places.	Intensification of agriculture due to fertile soils since the 19th century. Some former sand pits are used for recreational activities and irrigation.

Model Area	Main Functions and Changes	Main Driving Forces
Podbořansko	Original farming landscape with traditional hop gardens was changed into extensively used agricultural landscape. Strong depopulation.	Traditional hop gardens were abandoned after the post-1945 transfer of Czech Germans. Proximity to coal mines led to depopulation from 1970 onwards.
Prague suburbia	Traditional agricultural landscape was transformed into commercial suburbia. Creation of Prague Metropolitan Area.	Many new infrastructural and commercial structures have been built along the principal Czech motorway D1 and in Prague's environs since 1980s, especially after 2000.
Prague	From open landscape towards an important urban and industrial centre. Creation of Prague Metropolitan Area.	Gradual industrialization and concentration of business and social activities. In the present time transformation from industrial to residential function, gentrification.
Rosicko	Industrialization and mining in the 19th century. Agricultural extensification and afforestation since the 1960s.	Industrialization of Brno suburbia in the 19th century, nowadays part of Brno Metropolitan Area. Commuting distance of Brno, boom of service sector, tourism.
Rožďalovice	No major changes of spatial functions. The structure of farming landscape has changed.	Politically motivated changes in agriculture during the period 1948–1990. Most small fields ceased to exist, cooperatives reorganized the landscape.
Střední Povltaví	Valley submerged under the waters of reservoir in the 1950s. Hydroelectric power plant, various recreational activities along the lake.	Need to generate electricity, measures to protect Prague against flood water. Increase of tourism and leisure time activities.
Šumava	Small-scale farming, forestry, glass industry, transfer of Czech Germans after 1945.	Political decisions transformed the formerly relatively densely inhabited region to military area (after 1945). National Park, established in 1991, supported increase of tourism.
Trutnovsko	Former mines were closed. Landscape was gradually abandoned, extensificitation and depopulation is going on.	Mining as part of industrialization became important in the 19th century. Agricultural extensification was taking place after 1945. The importance of mining and agriculture has significantly decreased, recreational use increased.
Vír reservoir	Part of Svratka Valley has been submerged under the waters of reservoir. Peripheral location and high proportion of sloping land led to agricultural extensification.	Farming has diminished due to creation of drink water supply reservoir and afforestation.
Zahrádky	Man-made aristocratic landscape from the 16th century is surrounded by agricultural landscape.	The structure of farming landscape has changed during the period 1948–1990. No major land use changes.

Mapping and Cadastre (ČÚZK 2010, for detailed characteristics of the maps see Bičík et al. 2015). These maps serve as a unique data source reflecting the state of landscape just before the main phase of Industrial Revolution. The maps have been georeferenced, mosaiced, and vectorized in ArcGIS 10 software (ESRI 2011). Land use/cover database was created for each area.

The latter data reflect the current state of landscape (2018–2020). Cadastral maps from the Registry of Territorial Identification, Addresses, and Real Estate (RÚIAN) were used. In many cases, however, land use/cover categories are assigned in a wrong way in these maps. Therefore, it proved necessary to correct such errors using recent aerial imagery connected via WMS (Web map service) into the ArcGIS.

In order to secure comparison between both datasets, simplified legend was used (current cadastral maps distinguish only basic land cover classes). As a result, the legend contains the following classes: arable land, built-up areas, forests, permanent cultures, permanent grasslands, water bodies, and so-called remaining areas. In specific cases of selected model areas more classes were applied, e.g., abandoned land, ecological succession, sludge ponds and working / abandoned quarry / mine.

2.3. Methods

Spatial overlay has been used in order to evaluate land use/cover changes between mid 19th century and the present time. Shares of land use/cover categories for each model area and for both periods were calculated.

In order to compare the mentioned expert-based typology with the statistical land use/cover typology in both periods separately and to compare changes based on the shares of land use/cover categories between mid 19th century and at present, cluster analysis has been used. This analysis provides statistically determined units (also known as typological classes, groups, or clusters; Everitt et al. 2011; Kolejka, Lipský 2008; Romportl, Chuman, Lipský 2013). Statistical typology was based on K-means clustering in R software (R Core Team 2019). K-means clustering is the robust and fast commonly used unsupervised non-hierarchical classification method with the aim to create clusters with the highest intra-class similarity and the lowest inter-class similarity (MacQueen 1967; Navin, Agilandeeswari 2019), where shares of land use/cover categories for each model area were the inputs.

K-means clustering for land use/cover data from mid 19th century and 2018–2020 were first computed separately. Second, K-means clustering was created together from mid 19th century and current data using the optimal number of clusters derived from elbow method determination (R cluster and factoextra packages). This allows to outline similarities of the land use/cover state in the beginning

and in the end of the study period and its change within the model areas as well. Furthermore, model areas were sorted into eight clusters so that they could be compared with the same number of the expert-based types.

3. Results

3.1. Overview of land use/cover changes in model areas

The results based on vectorization of model areas land use/cover in mid 19th century and in the present time allow to summarize that arable land dominated in most model areas (20 out of 30) in the second quarter of the 19th century. Forest was the major land use/cover type in eight model areas; permanent grasslands and water bodies in one model area each. Nowadays, forest is the largest category by size in 14 out of from 30 areas, followed by arable land (nine), permanent grasslands (two), and water bodies (one model area).

Such changes correspond with general trends seen on the national level, i.e. afforestation (Bičík et al. 2015). In comparison to Czechia as a whole, afforestation is even more pronounced in some model areas. Figure 2a shows some of the areas with especially intensive afforestation – on average, the proportion of land covered by forests has increased from 27.28% to 38.27%. On the other hand, some model areas show different trends: Nové Mlýny reservoir and Střední Povltaví (in both cases valleys have been intentionally submerged by reservoirs) lost a good deal of forests (minus 17.37% and minus 5.44% respectively). At present permanent grasslands cover smaller area in all model areas combined (13.43% of the total area currently) than it used to in mid 19th century (18.95%) though there are cases when arable land has been gradually transformed into grassland (e.g. Cunkov, Trutnovsko). In these areas, intensive agricultural has been replaced by other functions and the proportion of permanent grasslands increased rapidly (up to 24.53%, 15.09% respectively). Elsewhere, however, original permanent grasslands have been turned into forests or used for other purposes. The decrease of permanent grasslands have been more intensive across the model areas than in Czechia as a whole (Fig. 2b).

The average share of arable land on the total area has decreased from 43.97% (mid 19th century) to 20.9% (present) in all model areas combined. Such a change is bigger than that in Czechia as a whole (Fig. 2c). Arable land has expanded only in the most fertile areas suitable for intensive farming (Čáslavsko +11.98%, Kačina +14.52%, and Opatovicko +12.44%).

There has been a huge expansion of built-up land and so-called remaining areas in general. That reflects growing anthropogenic influence on the landscape. Urbanization, industrialization, mining etc. has contributed to the increase of

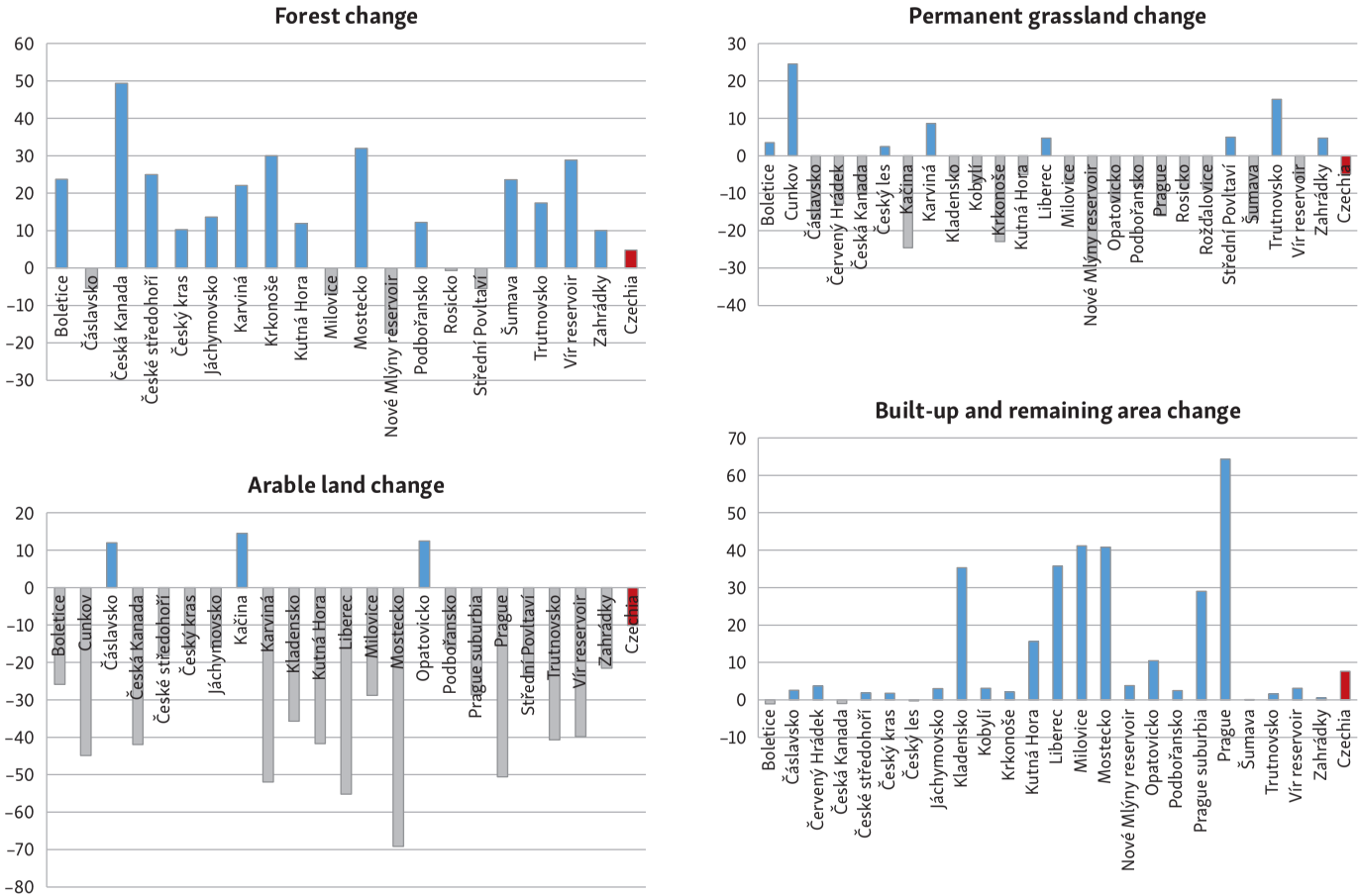


Fig. 2 – Changes of main land use/cover categories in selected model areas in comparison with Czechia as a whole; 2a) Change of forest areas, 2b) Permanent grasslands change, 2c) Arable land change, 2d) Built-up and "remaining" areas change (in percentage points). Changes are assessed over the period from the mid-19th century (based on stable cadastre mapping) to the present (2018–2020).

Table 2 – Categorization of model areas into expert landscape types. This typology is based on perception and specific landscape features.

Aristocratic landscapes	Border landscapes	Extensively used agricultural landscapes in the interior of Czechia	Intensively used agricultural landscapes	Military training landscapes	Mining landscapes	Urban-industrial landscapes	Artificially flooded landscapes
Červený Hrádek Kačina Zahrádky	Český les Jáchymovsko Krkonoše Česká Kanada Šumava	Cunkov České středohoří Český kras	Čáslavsko Kobylí Opatovicko Podbořansko Rožďalovice	Boletice Milovice	Karviná Kutná Hora Mostecko Rosicko Trutnovsko	Kladensko Liberec Prague Prague suburbia	Nové Mlýny reservoir Střední Povltaví Vír reservoir

Table 3 – Clustering results (optimal number of clusters) for 19th century, Stable Cadastre data; current data (2018–2020) and their combination.

Extensively afforested landscapes	Intensively used agricultural landscapes	Anthropogenic landscapes
Clustering based on data from stable cadastre (19th century)		
Boletice, Červený Hrádek, Český kras, Český les, Jáchymovsko, Krkonoše, Nové Mlýny reservoir, Opatovicko, Střední Povltaví, Šumava, Trutnovsko	Čáslavsko, Česká Kanada, České středohoří, Cunkov Kačina, Karviná, Kladensko, Kobylí, Kutná Hora, Liberec, Milovice, Mostecko, Rožďalovice, Podbořansko, Prague, Prague suburbia, Rosicko, Vír reservoir, Zahrádky	—
Clustering based on current data (2018–2020)		
Boletice, Červený Hrádek, Česká Kanada, České středohoří, Český kras, Český les, Cunkov, Jáchymovsko, Karviná, Krkonoše, Střední Povltaví, Šumava, Trutnovsko, Vír reservoir	Čáslavsko, Kačina, Kobylí, Kutná Hora, Nové Mlýny reservoir, Rožďalovice, Opatovicko, Podbořansko, Prague suburbia, Rosicko, Zahrádky	Kladensko, Liberec, Milovice, Mostecko, Prague
Clustering based on stable cadastre (19th century) and current data		
Boletice, Červený Hrádek, Český kras, Český les, Cunkov, Jáchymovsko, Krkonoše, Střední Povltaví, Šumava, Trutnovsko	Čáslavsko, Česká Kanada, České středohoří, Kačina, Karviná, Kladensko, Kobylí, Kutná Hora, Liberec, Milovice, Mostecko, Nové Mlýny reservoir, Rožďalovice, Opatovicko, Podbořansko, Prague, Prague suburbia, Rosicko, Vír reservoir, Zahrádky	—

built-up areas' share from 0.4% to 2.0%; the share of "remaining" areas has increased from 3.39% to 12.65% (figures are for all model areas combined). These trends correspond with general trends in Czechia (Bičík et al. 2015). However, one can see that such a significant increase is driven by just a handful of model areas with strong anthropogenic influence (Fig. 2d). On the other hand, some model areas show a decline of anthropogenic activities – this is the case of regions situated along the border that used to be populated by ethnic Germans until 1945. After the transfer of original population access was restricted to these zones and military zones were established. This is the case of Boletice (built-up land and remaining areas combined minus 1.08 percentage points), Česká Kanada (minus 1.00 p.p.) and Český les (minus 0.25 p.p.).

3.2. Cluster analysis

The cluster analysis based on mid 19th century data with optimal number of clusters divides the model areas into two types. The first one can be labelled Extensively afforested landscapes with high proportion of land covered by forests and permanent grassland. The second one is Intensively used agricultural landscapes with prevalence of arable land (Table 3).

Regarding the analysis of the current state of land use/cover within model areas, optimal number of clusters have increased – model areas were clustered into the three types. Extensively afforested landscapes feature high proportion of land covered by forests (higher than in mid 19th century) and also a high proportion of permanent grasslands. The second type, Intensively used agricultural landscapes, has the highest share of arable land. The third type, called Anthropogenic landscapes, has a significant share of urban and industrial areas including mines (Table 3).

Considering both datasets, only two clusters corresponding to Extensively afforested landscapes and Intensively used agricultural landscapes were created (Table 3).

Extensively afforested landscapes with the highest share of forests show some increase of land covered by forests between mid 19th century and the present time. On the other hand, there has been a decrease of arable land. Similarly, in Intensively used agricultural landscapes arable land decreased and forest increased – however, on a different scale. There is a difference concerning the so-called remaining areas (affected by human activities): their share has increased, which led to the formation of third cluster (Anthropogenic landscapes) based on current data (Table 4).

3.3. Statistical clustering and expert-based determination

The above-mentioned expert-based typology emphasizes main features of the model areas, e.g., intensive agricultural land use, new water bodies, new urban, industrial, and mining areas, abandoned or extensively used land, military areas, aristocratic landscape etc. However, the expert-based typology was not based on a precise statistical evaluation of land use/cover changes over time.

The chief question was whether the use of statistical approach (cluster analysis) would group model areas into clusters similarly or differently. Statistical approach means that the shares of land use/cover categories in model areas from mid 19th century and the present time would be used as inputs into the cluster analysis. The other precondition is that the final number of clusters would be set to 8 like in the expert-based typology.

Results show that K-means clustering shows a rather different distribution (compare Table 2 and 5) of the model areas:

The first type of cluster called *Urbanized landscapes with significant agricultural function* includes Kutná Hora and Prague suburbia model areas. These were originally farming regions with a very high share of arable land in mid 19th century (77.83%); however, arable land had decreased rapidly since then (down to 42.68% nowadays). Built-up land has expanded namely in the vicinity of cities and towns and along the motorways (from 0.79% to 6.68%). Also the so-called remaining areas have grown significantly (from 6.32% to 22.74%). Commercial and residential (sub)urbanization has changed the character of landscape which was originally dominated by agriculture or mining (Kutná Hora).

Anthropogenic landscapes have experienced a lot of crucial changes. Kladensko, Liberec, Milovice, Mostecko, and Prague model areas have been transformed by urbanization, industrialization, mining, and also by military presence. The originally farming landscapes have seen a steep decline of arable land (from 57.77% to 9.89%) that has been replaced by built-up areas (from 0.74% to 7.98%) and so-called remaining (anthropogenic) areas (from 4.29% to 40.51%).

As mentioned above, extensification and afforestation are processes that appear in many model areas. Therefore, three "extensification" types of model areas were created. *Landscapes of agricultural extensification with anthropogenic activities* is a type that includes a diverse set of model areas with extensification processes and significant human footprint. The stories are somewhat different: České středohoří and Česká Kanada have gone through agricultural extensification and have seen the transfer of Czech Germans after 1945. Karviná has experienced a period of industrialization and later extensification. Vír reservoir was built in time when agricultural extensification and afforestation had already been under way. These areas have in common decrease of arable land (from 51.00% to 13.02%) together with forest growth (from 16.87% to 48.17%).

Table 4 – Average shares (in %) of land use/cover categories in clusters for 19th century and present

	Clustering based on data from Stable cadastre		Clustering based on current data		
Average share of land cover category	Extensively afforested landscapes	Intensively used agricultural landscapes	Extensively afforested landscapes	Intensively used agricultural landscapes	Anthropogenic landscapes
Built-up areas	0.24	0.50	0.64	2.37	7.98
Remaining areas	2.53	3.88	4.91	9.84	40.51
Water bodies	4.32	3.40	4.07	7.29	1.52
Forests	47.50	15.57	59.14	18.61	23.01
Arable land	21.98	56.71	5.72	45.25	9.89
Permanent grasslands	22.56	16.85	20.24	6.63	9.37
Permanent cultures	0.88	3.08	3.04	8.78	7.73
Abandoned land	0.00	0.00	1.02	0.95	0.00
Working quarry and mine	0.00	0.00	0.35	0.00	0.00
Abandoned quarry and mine	0.00	0.00	0.29	0.00	0.00
Ecological succession	0.00	0.00	0.26	0.29	0.00
Sludge ponds	0.00	0.00	0.31	0.00	0.00

Table 5 – Landscape types and model areas grouped as a result of K-means clustering. Cluster names were chosen on the base of main landscape change between mid 19th century and the present time. Colours of names refer to expert typology (Table 2).

Urbanized landscapes with significant agricultural function	Anthropogenic landscapes	Landscapes of agricultural extensification with anthropogenic activities	Landscapes of agricultural extensification and afforestation	Landscapes of strong agricultural extensification with increasing permanent grasslands	Landscapes with permanent agricultural function	Afforested landscapes	Landscapes artificially flooded by water or with high share of water areas
Kutná Hora Prague suburbia	Kladensko Liberec Milovice Mostecko Prague	Česká Kanada České středohoří Karviná Vír reservoir	Český kras Střední Povltaví Trutnovsko	Boletice Cunkov	Čáslavsko Kačina Kobylí Podbořansko Rosicko Rožďalovice Zahrádky	Červený Hrádek Český les Jáchymovsko Krkonoše Šumava	Nové Mlýny reservoir Opatovicko

Landscapes of agricultural extensification and afforestation are similar to the previous type. However, the share of arable land has always been lower and that of forest somewhat higher (increase from 47.21% to 54.62%). Český kras, Střední Povltaví, and Trutnovsko belong to this type.

Landscapes of strong agricultural extensification with increasing permanent grasslands contain Boletice and Cunkov model areas. This type has the highest share of permanent grasslands (increase from 33.89% to 47.91%). On the other hand, arable land has almost disappeared (from 35.82% down to 0.45%). There are no vast forests due to specific reasons. Boletice is a military training area and Cunkov, a typical example of "inner periphery", has seen development of different recreational facilities including bison farm, golf course, and ski slopes.

Intensively used agricultural landscapes are grouped into one type called *Landscapes with permanent agricultural function*. It includes model areas of Čáslavsko, Kačina, Kobylí, Podbořansko, Rosicko, Rožďalovice, and Zahrádky. Most of these model areas are located in lowlands or mid-altitudes. Arable land has decreased slightly, but it still covers more than half of the total area (54.73% and 51.12%). Such a change marks the smallest decrease of arable land between mid 19th century and present; the current share of arable land is the highest one among all types.

Afforested landscapes are characterized by ongoing afforestation. These areas have the highest proportion of land covered by forests which has even increased (from 60.43% to 77.14%). Model areas that belong to this type are largely located in the border mountains: Červený Hrádek, Český les, Jáchymovsko, Krkonoše, and Šumava.

Landscapes artificially flooded by water or with high share of water areas include two model areas: Nové Mlýny reservoir and Opatovicko. Processes, however, have been different. In the case of Nové Mlýny reservoir, the share of water bodies on total area has increased (from 2.85% to 50.50%), much of the rest is farming land. Opatovicko has lost a number of water bodies (from 32.25% down to 14.42%); on the other hand, arable land has increased (from 19.64% to 32.08%).

Typical representatives of individual types are presented in Figure 3(a–d). It shows land use/cover in the times of Stable Cadastre (mid 19th century) and the current state of land use/cover in different model areas.

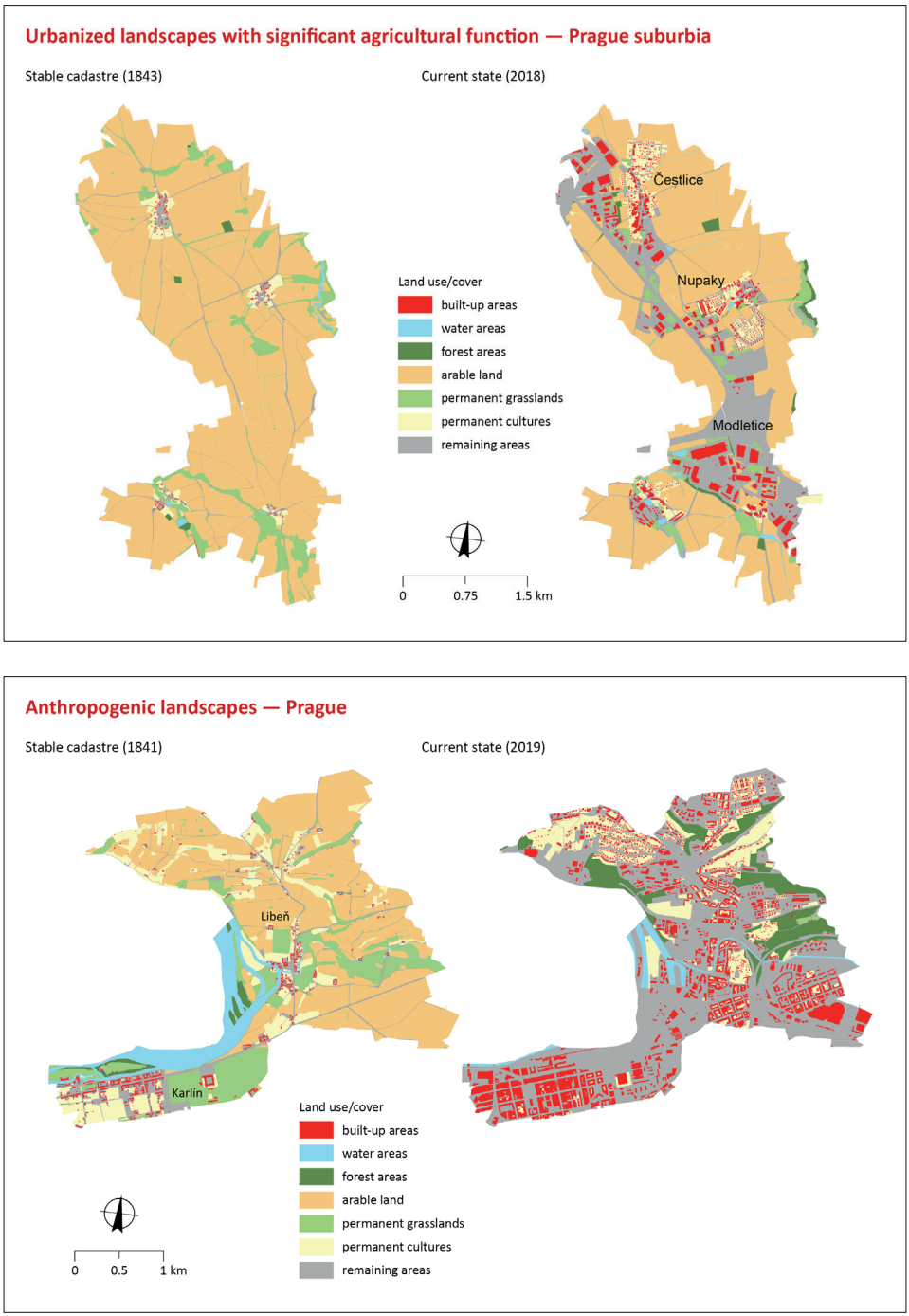
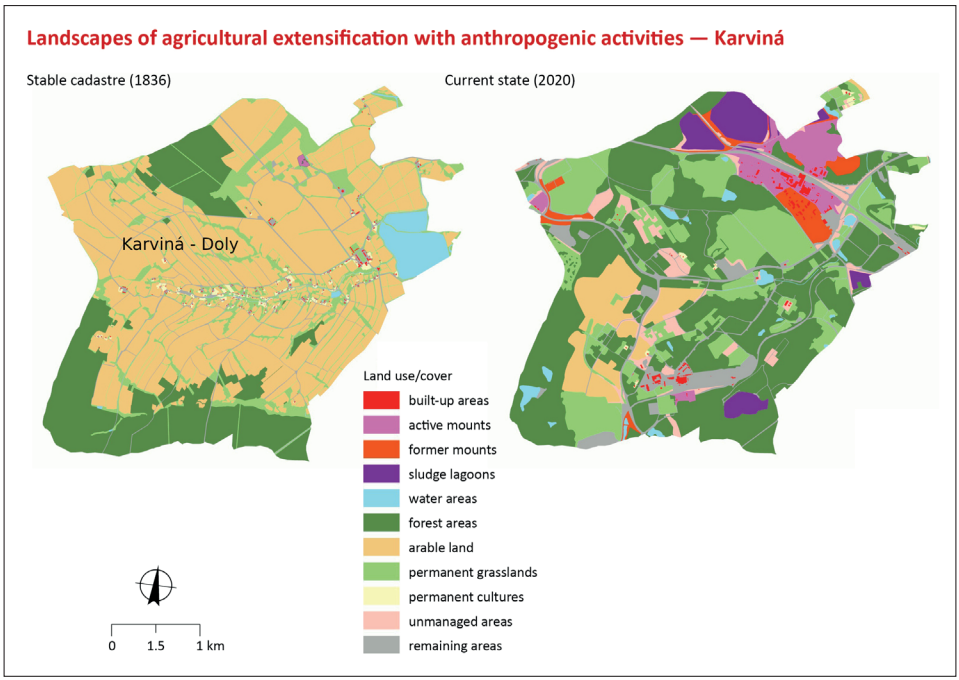


Fig. 3a – Changes of land use/cover categories in selected model areas



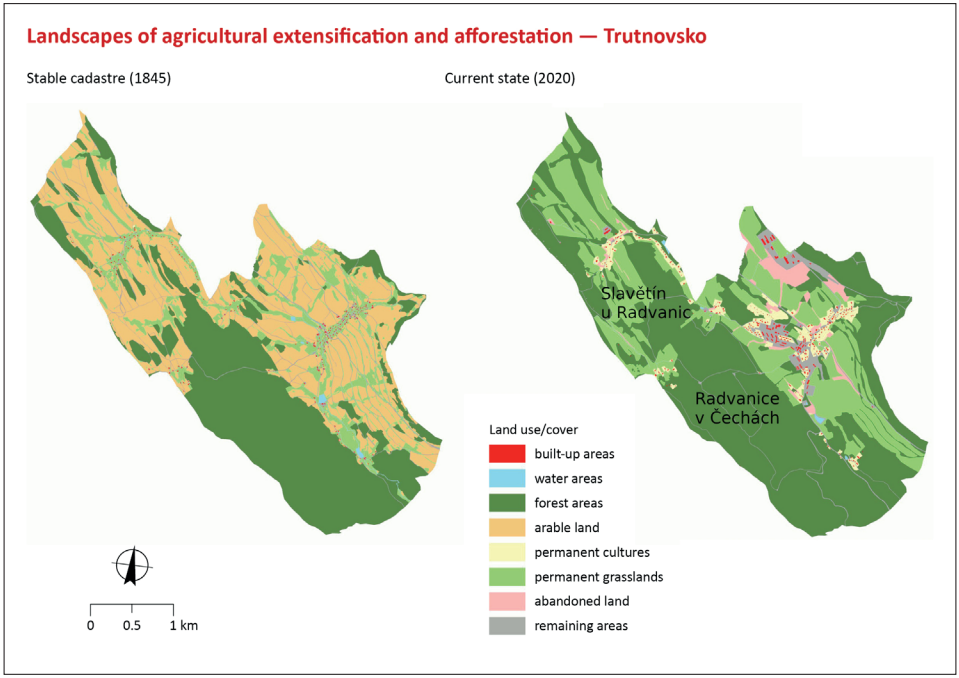
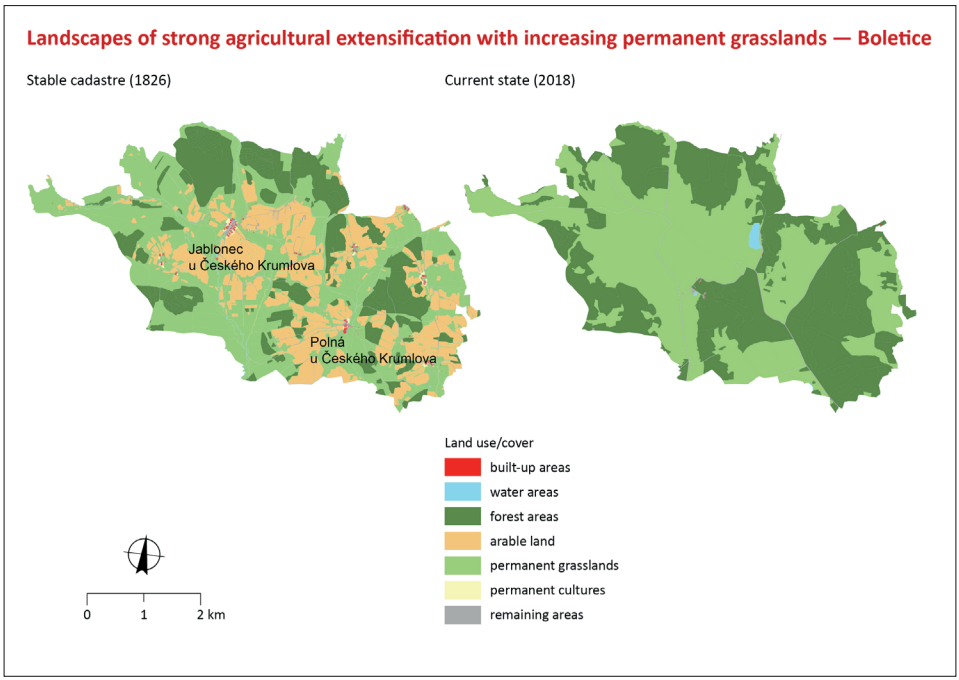


Fig. 3b – Changes of land use/cover categories in selected model areas



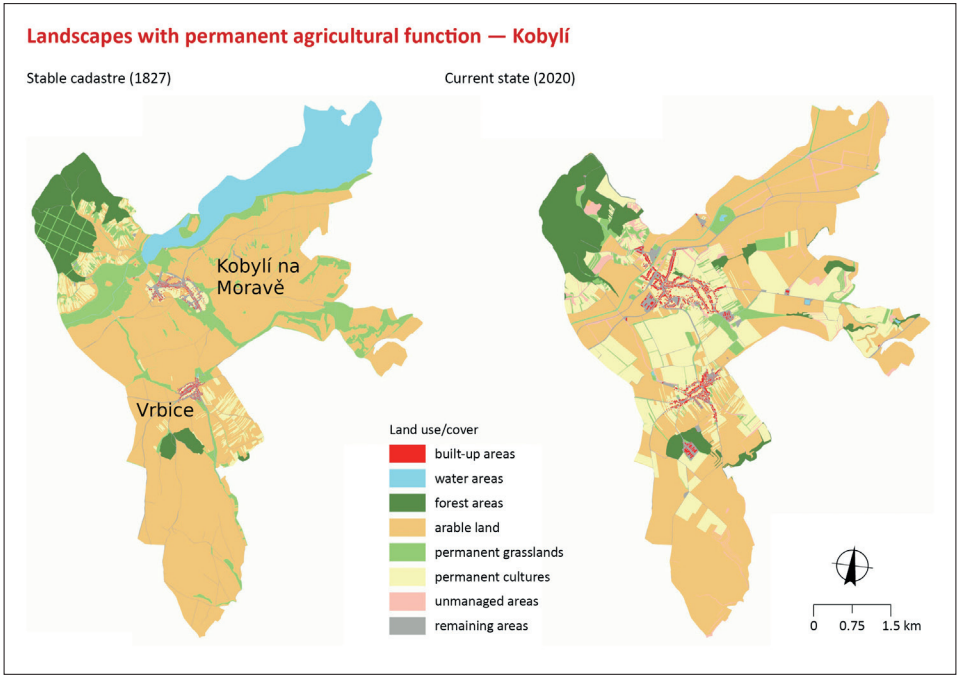


Fig. 3c – Changes of land use/cover categories in selected model areas

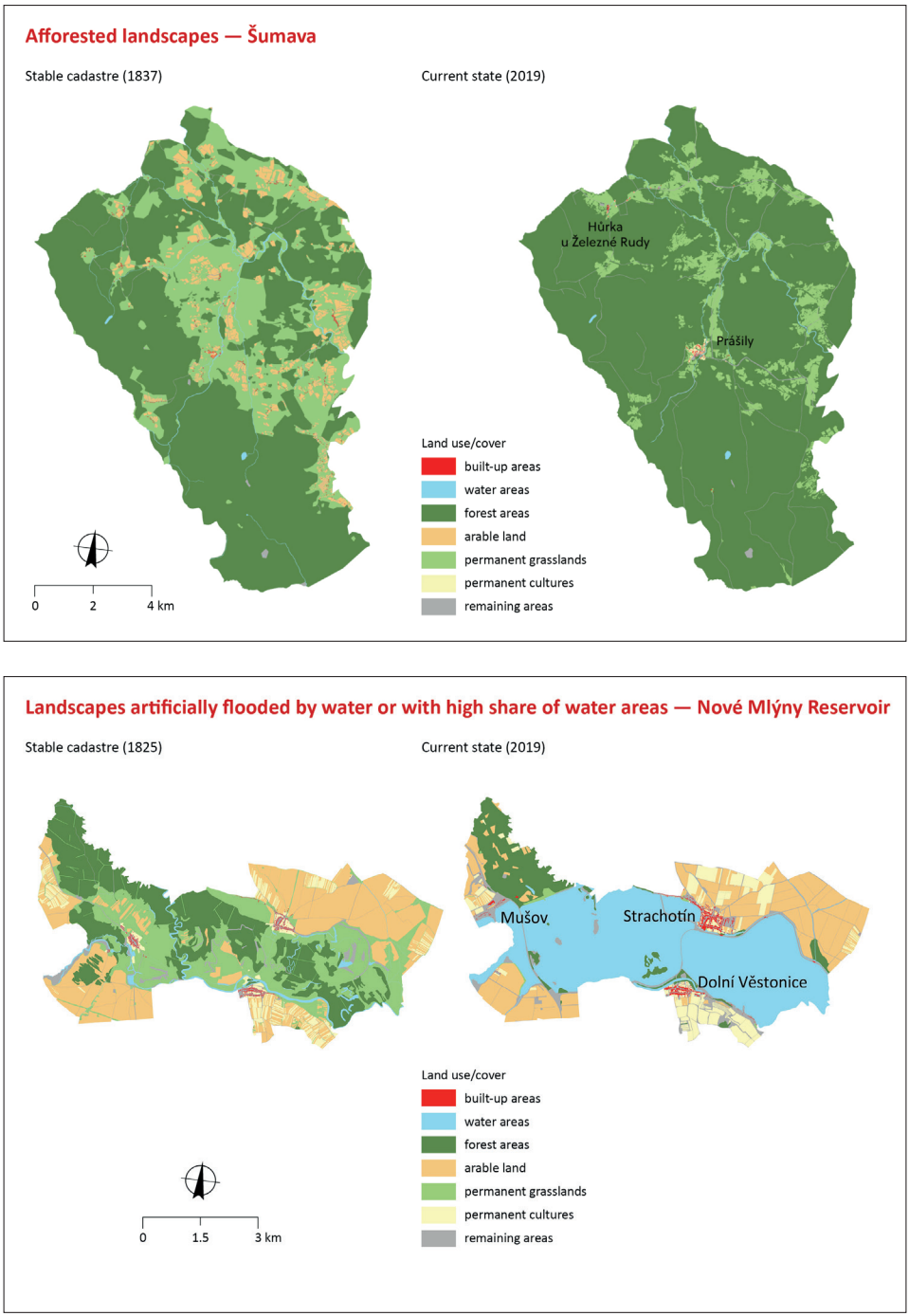


Fig. 3d – Changes of land use/cover categories in selected model areas

4. Discussion

4.1. Results in the context of general landscape changes in Czechia

The results show that land use/cover changes and processes in model areas mostly correspond to contemporary trends in the broader spatial context of Czechia and Central Europe (Feranec et al. 2010; Kupková, Bičík 2016; Kupková, Bičík, Jeleček 2021). These processes and trends (afforestation, increase of permanent grassland, extensification, urbanization) are present in most model areas, usually with a greater intensity than in Czechia as a whole. Some model areas show opposite trends and different trajectories of land use/cover changes than those recorded in Czechia as a whole (Fig. 2, Kupková, Bičík 2016).

One can see that afforestation is more intensive throughout the model areas, especially in the type of Afforested landscapes, e.g. in Český les and Šumava. Political changes and installation of the iron curtain were important there (Kupková, Bičík, Najman 2013). In addition, extensification has been taking place in many model areas (Kupková, Bičík, Boudný 2019). This process has multiple drivers: abandonment of countryside (Latocha 2009) together with population decline after the transfer of Czech Germans (Kupková, Bičík, Najman 2013) which was followed by changes in agriculture and transformation of areas in less favoured areas (mountains) that had been used in a non-effective way. The latter process has been taking place since 1990 and has accelerated after 2004 when Czechia joined the EU (Bičík, Jančák 2001, 2005).

(Sub)urbanization is another process that plays a major role in some model areas like in Prague suburbia (type Urbanized landscapes with significant agricultural function). The nature of urbanization and suburbanization is examined in detail in many other publications (Pazúr et al. 2017; Kupková, Ouředníček, 2013).

Some areas show agricultural intensification (Kupková, Bičík 2016). The model areas belonging to the type Landscapes with permanent agricultural function have almost equal share of arable land in mid 19th century and nowadays, but landscape composition and structure were changed.

In general, the cluster analysis based on optimal number of clusters reveals a sort of dichotomy. Extensively used landscapes and intensively used ones are distinguished. Basically, due to selection of model areas with more dynamic changes in comparison with average changes in Czechia one can see:

1. peripheral areas in higher altitudes with afforestation, increase of permanent grasslands, and extensification
2. lowlands and urban areas dominated by intensification of agricultural land use and (sub)urbanization (Kupková, Bičík 2016).

4.2. Comparison of expert-based and statistical typology

Types based on expert approach and those purely statistical ones show some similarities but also differences regarding landscape perception and classification. Different perceptions of model areas and dissimilarities within expert and statistical typologies are explained in the following text.

Model areas Čáslavsko, Kobylí, Podbořansko, and Rožďalovice belong to the same type in both typologies: *Intensively used agricultural landscapes* (expert-based typology) and *Landscapes with permanent agricultural function* (cluster analysis type). Kačina and Zahrádky belong to *Aristocratic landscapes* (expert-based typology); however, "real" aristocratic landscapes cover only small parts of the model areas. Both of them consist of small aristocratic compounds that include buildings like manors, castles etc.; these are largely surrounded by farmland. However, elements of *Aristocratic Landscapes* form an important feature in the broader landscape and therefore it has been decided to incorporate them into the research. The owners' intentions are clearly visible in the landscape and one can see how it has developed over the past 200 years.

In addition, Rosicko was added to the statistically created type *Landscapes with permanent agricultural function*. The expert-based type *Mining landscapes*, where Rosicko belongs to, was temporally and spatially limited and the share of arable land remains high (54.89% and 50.96%).

The expert-based type *Border landscapes* is similar to the statistical type *Afforested landscapes*. Only Česká Kanada (statistically belonging to *Landscapes of agricultural extensification with anthropogenic activities*) was replaced in this type by Červený Hrádek (*Aristocratic landscapes* in the expert-based typology) with higher forest cover.

New water bodies are significant phenomena in the landscape. Talking about the expert-based typology, Nové Mlýny reservoir, Střední Povltaví, and Vír reservoir belong to *Artificially flooded landscapes*. In statistical typology, Nové Mlýny reservoir and Opatovicko were assigned to the same type called *Landscapes artificially flooded by water or with high share of water areas*. As there have been also other important processes of landscape change in Střední Povltaví and Vír reservoir in addition to the creation of water reservoirs, the latter two model areas were assigned to different statistical types: *Landscapes of agricultural extensification with anthropogenic activities* (Vír reservoir) and *Landscapes of agricultural extensification and afforestation* (Střední Povltaví). Opatovicko, on the other hand, belongs to the expert-based type *Intensively used agricultural landscapes*.

Military training and *Mining landscapes* (expert-based typology) are based rather on specific landscape functions than on land use/cover change. Therefore, they belong to different statistically created types. In Boletice, the military still use parts of the region and much of the area is without forest cover, though with no or little

agricultural use. Consequently, in terms of statistical typology Boletice belongs to *Landscapes of strong agricultural extensification with increasing permanent grasslands*, and Milovice to *Anthropogenic landscapes* (due to increase of "remaining" areas).

Moreover, in some areas military training or mining were conducted just over a limited period of time and nowadays there are different activities and also different land use/cover changes. Therefore, Karviná (Mining landscapes in expert-based typology) was assigned to the statistical type of *Landscapes of agricultural extensification with anthropogenic activities*, Trutnovsko (*Mining landscapes* in expert-based typology) belongs statistically among *Landscapes of agricultural extensification and afforestation*, and Kutná Hora among *Urbanized landscapes with significant agricultural function*. The latter type is characterized by switch from predominantly agricultural use to largely urban landscape.

Model areas labelled as *Extensively used agricultural landscapes in the interior of Czechia* (expert-based typology) belong to "extensive" statistical types, there is still some variety – České středohoří belongs among *Landscapes of agricultural extensification with anthropogenic activities*, Český kras among *Landscapes of agricultural extensification and afforestation*, and Cunkov among *Landscapes of strong agricultural extensification with increasing permanent grasslands*.

The statistically created *Anthropogenic landscapes* type contains model areas with the largest anthropogenic transformation (Kladensko, Liberec, Milovice, Mostecko, Prague), which reflects anthropogenic features mentioned in expert-based typology as well.

When comparing the differences between expert-based and statistical typologies, one can see that expert-based typology rather focuses on the most important features, phenomena, and functions of model areas (new water bodies, aristocratic landscape, mining, urbanization, industrialization) while statistical typology emphasizes the most important land use/cover changes and processes (extensification, urbanization, etc.) over the examined period of time (Antrop 2008; Kupková, Bičík, Jeleček 2021). Both types of landscape evaluation, sorting, and perception are crucial for understanding of the landscape. When both perspectives are taken into consideration, one gets quantitative and qualitative information on landscape (Kolejka 2013). It can help us to interpret landscape characteristics, changes, and heritage more precisely (Harvey 2001).

5. Conclusion

Thirty model areas have been examined. Their selection aimed at capturing specific trajectories of landscape changes during the past 200 years. Model areas have been classified on the base of changes into several clusters using expert-based and statistical approaches. The assignment of model areas into different types has

been compared. The rate of land use/cover changes recorded in different model areas has been compared to general trends in Czechia as well.

Both expert-based and statistical approaches allow to enhance knowledge of the landscape and its changes. As regards the expert-based typology, significant landscape features like new water bodies or relatively small aristocratic-style landscapes were stressed. In order to view changes from a more complex perspective, land use/cover data and cluster analysis were used to create statistical typology based on land use/cover changes within the period of last 200 years. In many cases, the same model area was classified differently in expert-based and statistical typologies, which gives us a more precise information on the landscape, its change and heritage. On the other hand, some model areas were grouped into the same type in both typologies, especially when land use/cover changes were significant in the expert-based typology.

Model areas reflect great variations of landscape processes across different regions throughout Czechia. Regarding the current state of the landscape, the statistical analysis shows a sort of dichotomy between extensively and intensively used landscapes. This reflects change of functions and driving forces that can differ region by region, e.g. abandonment of unprofitable agricultural land, creation of new water bodies, transfer of the Czech Germans, agricultural intensification and collectivization, mining, and (sub)urbanization.

In most cases, land use/cover changes in model areas that represent some of the most transformed landscapes in Czechia correspond to the general trends and have usually been more intensive than in Czechia as a whole. However, only land use/cover data from mid 19th century and 2018–2020 have been used which provides information on changes from the whole period of 200 years. A more detailed insight focused on shorter intermediate periods of time and the role of different driving forces could be a next research step that would offer a closer look at landscape dynamics.

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