Czech University of Life Sciences Prague
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Wood-pastures in the Czech Republic: change trajectories, proximate causes and underlying driving forces

Pastviny s dřevinami České republice: změna trajektorií, nejbližší příčiny a základní hnací síly

Doctoral Thesis

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Statement

I hereby declare that I have independently elaborated the thesis with the topic of: “Wood-pastures in the Czech Republic: change trajectories, proximate causes and underlying driving forces” and that I have cited all the information sources that I used in the thesis and that are also listed at the end of the thesis in the list of used information sources. I am aware that my thesis is subject to Act No. 121/2000 Coll., on copyright, on rights related to copyright and on amendment of some acts, as amended by later regulations, particularly the provisions of Section 35(3) of the act on the use of the thesis. I am aware that by submitting the thesis I agree with its publication under Act No. 111/1998 Coll., on universities and on the change and amendments of some acts, as amended, regardless of the result of its defence. With my own signature, I also declare that the electronic version is identical to the printed version and the data stated in the thesis has been processed in relation to the GDPR.

The work presented in Chapter 5.1 was previously published in the scientific journal “Applied Geography” as Changes and continuity of wood-pastures in the lowland landscape in Czechia” in collaboration with co-authors, which is specified in the sections of Methodological structure and References of this work.

In Prague on 10. 10. 2020 …………………………………..............

Ing. Anna Pereponova

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Abstract

This thesis addresses the subject of historic changes in wood-pastures as one of the oldest land use types in Europe. Wood-pastures are landscape segments with trees scattered across an open area, mainly grasslands, which are managed as pastures. Despite their high ecological, cultural, and agricultural importance, these landscapes have recently experienced rapid decline all over Europe due to intensive tree cutting, changes in land use, and lack of regeneration. Although wood-pastures are currently sparse in Czech landscapes, their traces can still be observed. Despite some recent studies, information on their historic change patterns is missing. The main goal of this work is to assess long-term change patterns of wood-pastures in Czechia at the landscape level and to identify the driving factors behind them, which will also increase knowledge about long-term change of land use and land cover in Czechia generally. Identifying and understanding causalities between change patterns and the present state of wood-pastures can serve as a foundation to support sustainable management practices for wood-pastures. The research is executed in three consecutive case studies of sites located in different landscape types throughout Czechia. The first case study is designed to develop and test a suitable methodology for long term spatiotemporal analysis of wood-pastures on the example of lowland areas. The second case study broadens the analysis to cover both lowland and highland areas in two temporal horizons, and also investigates the role of generalised natural characteristics. The last part focuses more closely on the role of various of different natural and human-driven factors and their impact on continuity, occurrence or loss of wood-pastures. Various archival and modern, analogue and digital, sources (e.g. old maps, aerial photographs, etc.) were used. Analytical procedures were performed mainly in GIS (ESRI, 2015) and statistical calculations in R and MS Excel.

Key words: wood-pastures, silvopasture systems, change trajectories, habitat continuity, GIS analysis

Abstrakt

Tato práce se zabývá tématem historických změn pastvin s dřevinami (angl. “ wood-pastures”) jako jednom z nejstarších typů použiti půdy v Evropě. Pastviny s dřevinami jsou krajinné segmenty se stromy rozptýlenými po otevřené ploše, zejména louky, které jsou obhospodařovány jako pastviny. Navzdory vysoké ekologické, kulturní a zemědělské důležitosti, tyto krajiny se v poslední době zaznamenali prudký pokles v celé Evropě kvůli intenzivnímu kácení stromů, změnám ve využívání půdy a nedostatečné regeneraci. Přestože jsou pastviny s dřevinami v české krajině v současné době řídké, jejich stopy lze stále pozorovat. Navzdory některým nedávným studiím chybí informace o jejich historických vzorcích změn. Hlavním cílem této práce je posoudit dlouhodobé vzorce změn pastvin s dřevinami v České republice na úrovni krajiny a identifikovat premarin faktory, které za nimi stojí, což také zvýší znalosti o dlouhodobých změnách land use a land cover v Česku obecně. Identifikace a porozumění příčinných souvislostí mezi vzory změn a současným stavem pastvin s dřevinami může sloužit jako základ pro podporu postupů udržitelného hospodaření na pastvinách s dřevinami. Tento výzkum byl proveden ve třech po sobě jdoucích případových studiích lokalit umístěných v různých krajinných typech po celém Česku. Cílem první případové studie je vyvinout a otestovat vhodnou metodiku pro dlouhodobou časoprostorovou analýzu lesních pastvin na příkladu nížinných oblastí. Druhá případová studie rozšiřuje analýzu tak, aby pokryla jak nížinné, tak horské oblasti ve dvou časových horizontech, a také zkoumá úlohu zobecněných přírodních charakteristik. Poslední část se blíže zaměřuje na roli různých přírodních a člověkem ovlivňovaných faktorů a jejich dopad na kontinuitu, výskyt nebo ztrátu lesních pastvin. Jako zdroje dat byly použity různé archivní a moderní, analogové a digitální zdroje (např. Staré mapy, letecké fotografie atd.). Analytické postupy byly prováděny zejména v GIS (ESRI, 2015) a statistické výpočty v R a MS Excel.

Klíčová slova: pastviny s dřevinami, lesní pastva, persistence stanovišť, GIS

Contents

1. Introduction

Land use/land cover (LULC) analysis has been gaining increasing attention in the last decades and there are at least two reasons for this development (Bičík et al, 2015). First, land use patterns show the results of long-term interaction between humans and nature, and thus, interdisciplinary research approaches are developed to provide evidence for the effects of human interventions in the environment. Besides the general change patterns in selected environments the specific driving forces behind these changes need to be investigated further separately. Secondly, for land use research works, as compared to many other fields, vast databases with precise and well-structured data are available, which can be used to generate accurate research results and provide trustful conclusions.

Landscape combines all natural elements in one complex system, together with their functions (e.g. soil, habitats, biomass production, natural cycles), as well as socioeconomic elements (agriculture, extraction of raw materials, construction works), which function as one whole organism, and the "health" of this "organism" is critically dependant on the balance between all these elements.

Among the theories on LULC change, ranging back up to two centuries, some are touching the question of drivers of landscape change, and among the classic ones, the importance of geographical position of the area is often considered closely. Von Thünen states in his manuscript "The Isolated State" (Von Thünen, 1990) that the geographic location of a piece of land is what predominately defines the structure and intensity of agricultural production (Bičík et al, 2015), and as a consequence the land use structure in the area. However, this author was referring to geographical position more in the sense of distance from the market. This conclusion might seem simplistic now, but in 1826 when this manuscript was composed, it was reflecting the situation quite accurately, before agriculture started to experience rapid changes due to accelerating technological, socioeconomic and political changes, and when animals were still being used for transportation. It also illustrates the application of interdisciplinary approaches to landscape analysis in those early days.

The topic of landscape structure was also approached by economists, firstly in relation to land rent. Marx introduced the term "Differential Rent" (Marx, 1967), where rent depended on natural and geographical conditions of the land's location. He specified two types of rent: Differential Rent I, which differentiates land pieces by geographical position (distance to market) and fertility, and Differential rent II, which considers the invested capital and reflects the factor of agricultural intensification. The latter led to increased role of geographical location of the land parcels for agriculture, building strong mutual connections between food industry and agriculture, which came with the new technologies.

The focus of this study, wood-pastures, constitute an important part of European cultural-natural heritage (Bergmeier et al., 2010), and are one of the oldest land use types in Europe, known since the Neolithic (Luick, 2008). They are generally defined as environments with trees scattered through an open area, mainly grassland, and very dependent on adequate management, such as appropriate livestock grazing regimes (Hartel et al. 2013). The complex ecosystems of wood-pastures are of particular importance for nature conservation (due to their regulative functions, high biodiversity in a relatively small area and a considerable amount of endemic species), local economy (harvesting of wood, tree products, place for feeding (pasturing) of livestock, tourism), for its sociocultural and aesthetic qualities (traditional land management, often dramatic view, high proportion of old veteran trees, as a source of information on history of landscape management, link between nature and local people, etc,).

Of particular interest are ancient wood-pastures, which unite several important components, such as scattered trees which may be centuries old, referred to as ‘veteran’ or ‘ancient’ trees (Read, 2000; Quelch, 2002). They provide a broad range of habitat features with their dead branches or hollows (Gibbons and Lindenmayer, 2003); they considerably impact microclimatic conditions and soil properties and the vegetation structure as a consequence, also supporting a rich flora and fauna, guaranteeing an impressive density of species for the relatively small-scale locations.

Wood-pastures have been undergoing major changes in recent decades. In Czechia, although these ecosystems were formerly common according to Vojta, (Vojta, 2012), they have almost disappeared in the modern history. Despite the growing interest of researchers in wood-pastured elements, the dynamics of their presence within Czech boarders, especially in an extended time-frame, has not been described in details yet and as compared to other, generally well represented works on land use/land cover (LULC) studies in this region. The limited amount of studies conducted specifically for wood-pastures in Czechia still leaves gaps in understanding of historical changes. However, such a long-term large-scale analysis is essential to gain a deeper understanding of the underlying drivers and possible consequences of any changes in LULC and to enable sustainable management of related ecosystems.

This dissertation analyses long-term change trajectories (presence and dynamics) of wood-pastures in Czechia, specifically from the beginning of 19th century until present, as well as the particular trends in these changes in the locations of wood-pastures at the start/end of the study period with relation to different types of landscapes defined for the country (by Romportl et al, 2013) and the impact of different selected natural and human-driven factors. To approach the question of relationship between changing human behaviour and environment and their effects within a particular region a novel method of analysis of change trajectories for LULC change research is used. In practice, the analysis is performed using mainly the GIS environment with additional help of some open-source software (e.g. GoogleEarth). Data sources about landscape structure include historical and contemporary aerial photographs, as well as the Imperial Imprints of the Stable Cadastre, the present othophotomaps and some other sources, more specific for each selected driver (specific data sources are listed in the respective chapters). Statistical evaluation is performed with MS Excel and R.

2. Goals, research questions and hypothesis of the dissertation work

Among the most frequent question that landscape researchers are currently trying to answer are the identification of the driving forces behind landscape changes, whether these are anthropogenic or natural factors that impact the landscape structure the most, and which of these factors specifically play crucial a role for the latter (Bičík et al, 2015). These questions help to define research structure and propose hypotheses, which is necessary for selecting an appropriate methodology of the research. The research presented here is structured following these questions and attempts to answer the research questions posed below step by step in the three subchapters within the Chapter 5 (Studies).

The main goal of the current dissertation work is to define the spatiotemporal dynamics of wood-pastures in Czech Republic and to analyse causalities between historical change trajectories of wood-pastures in the Czech Republic and their present state. Among the already existing works on landscape change analysis (see chapter 4 (Literature review)) many are using complex approaches of interdisciplinary studies, that tend to result in rather broad overviews which are good in showing general trends, but are often too vague to deduce specific conclusions or form accurate theories of LULC changes. Thus, a need of more focused works exists. The factors as drivers of change that are investigated in this work aim to be representative and were chosen based on a general understanding of ecosystem functioning (intuitive choice) as well as recommendations of previous authors of LULC studies in general (details are given throughout the Chapters 5.1, 5.2 and 5.3-5.3 (Discussion subchapters)). A limited number of selected drivers, both of anthropogenic and environmental nature, as in the current work, allows for a more explicit, in-depth analyses than would be possible with an extensive "all-encompassing" set of factors. This should help to understand underlying mechanisms in wood-pastures and provide important lessons to be used in the present and future wood-pastures management.

In essence, this thesis will be answering the following Research Questions (RQ) and testing the Hypothesis (H):

RQ 1. What are the observable change trajectories of wood-pastures in

a) lowlands of Czechia at the landscape level?

b) both the lowland and highland landscapes of Czechia at the landscape level? Are these change trajectories similar to those for only lowlands?

H1. A general decline in the wood-pasture landscapes Czechia can be observed between the historical (first half of 19th century) and the current temporal horizon. Moreover, the decline is even stronger for the second half of the period under study (starting from 1950s).

H2. The general dynamics of wood-pastures observed for only lowlands are similar to those for lowlands and highlands together. For both a general decline of wood-pastures between the beginning of 19th century and current temporal horizon is observed.

RQ 2. How can continuity of wood-pastures in Czechia be characterized?

H3. Most wood-pastures within the current landscapes of Czechia appeared only recently. Very few old wood-pastures remain.

RQ 3. Do change trajectories of wood-pastures differ for different landscape types in Czechia?

H4. The amount of wood-pastures in both historical/present time horizons differs depending on the location within specific natural types of landscape.

H5. The scale of spatiotemporal changes in wood-pastures and their continuity varies depending on the landscape types.

RQ 4. To which extent do other land use/land cover (LULC) types represent sinks of the lost historical wood-pastures, or sources of the recently appeared wood-pastures? Is this affected by different administrative districts and types of landscapes?

H6. The sinks and sources of wood-pastures are comprised of other cultivated/non-cultivated LULC types in a similar proportion within the different administrative districts.

H7. The sinks and sources of wood-pastures are comprised of other cultivated/non-cultivated LULC types in equal proportions within the different types of landscapes.

RQ 5. Which of the natural or human-driven factors have the most significant impact on change trajectories of wood-pastures?

H8. Human-driven factors, such as changes in political and economic structure (incl. industrialisation) are the major drivers for the recent dynamics of wood-pastures area. Natural factors have a secondary role in the stability of these areas.

3. Methodological approach

3.1. Methodological structure

Landscape studies can be subdivided according to whether they approach landscape macrostructure or microstructure. A macrostructure approach distinguishes between shares of land use types, such as arable land, forest, built-up area, etc., whereas microstructure approaches focus on small landscape elements such as lines and small areas. In regard to this categorisation the research presented here belongs to the first group and analyses landscape macrostructure.

Bičík (Bičík et al, 2015) mentioned that a number of typologies can be used (and are used) to summarize the changes of land use structure, for example tracking of areal increases or decreases of selected land use classes over a period of time (marked as +/-). Combinations of the latter define the various types of aggregate change of land structure. Also, comparison of changes of the three aggregate classes (agricultural land, forest areas, and other areas) over time can be done in this manner. A way to merge the basic land use classes into aggregate ones may be through the level of anthropogenic pressures on a land (thus, resulting in (1) agricultural land, (2) forest and water areas combined (e.g. leisure-time activities), and (3) built-up and remaining areas combined). This typology is a simple one and indicates directions only, but not any significance of the changes. Another method, which works with prevailing/dominant land use classes, implies that cadastral districts are sorted by the basic land use class which is the biggest in size, which altogether then reflects the “landscape matrix”. However often this method does not bring much new information, and also dominant importance of certain LULCs is easy to anticipate. To fulfil the tasks of the current research a typology of LULC was created to reflect the main features of the LULC categories, which are most meaningful to distinguish between for this study (**Table 2, Table 6**). For more trustful conclusions, calculations based on relative values instead of absolute areas at each research step were considered.

First studies on land use and land cover analysis in Czechia appeared in early 1960s. Current research projects on this topic may be subdivided into two major streams: either more detail-oriented analyses of small areas, or complex land use studies (Bičík et al, 2015). The latter are referred to as “Prague school” and often deal with projects covering a long period of time (up to two centuries). The research work presented in this thesis considers landscape as a result of long-term interaction between society and environment and falls into the second group.

The work has been executed in three consecutive steps. First the introductory Literature review (chapter 4) provides the theoretical overview of the current state of the art on the subject in existing scientific and public literature. This theoretical overview is followed by three case studies with increasing complexity. Each of them is individually introduced and analysed in a dedicated subchapter. Together these representative case studies provide a sufficient foundation to answer the research questions from the Chapter 2. Finally, the findings are summarized, evaluated and closed with a common conclusion.

The first case study gives a general overview of spatiotemporal changes and continuity of wood-pastures in the sites under study. In this step only lowland landscapes are considered. The chapter shows the trends of losses and gains of wood-pasture areas over three temporal horizons: the first half of 19th century, the current temporal horizon and an intermediate one(1950s). This chapter has a two-fold goal. Firstly, it is aimed to develop and test a reliable methodological approach to analyse the change of landscape between such distant temporal horizons despite the vast differences of the available source material regarding e.g. form, appearance, level of details and quality. Secondly it gives insight into the first, second and the third research questions of general dynamics, continuity, as well as sources and sinks of wood-pastures, though a simplified case of lowland areas only. The analysis was performed within the GIS environment. The results of the study have been published in the Journal of Applied Ecology in the issue of February 2017 (Attachment 1). Thus, the study helped to test the hypothesis H1 and partly H3 and H6, and also to fulfil such practical tasks of the dissertation work as:

- Development and application of an effective approach to define and analyse long-term spatiotemporal dynamics of specific ecosystem areas, using GIS software with limited and differing data sources for the different temporal horizons.
- Attempt to observe existence of a common/differing trends of the LULC changes in different administrative districts across the country with similar natural conditions

The second case study of the research work provides the results of a more detailed analysis of spatiotemporal changes of wood-pastures for the same period but including more areas. Specifically, this time locations are not limited only to lowlands, but include all major natural types of landscapes of the country. This step compares states of wood-pastures between two temporal horizons: the first half of the 19th century and the present. Besides reflecting, for the first time, spatiotemporal dynamics of wood-pastures at the spatial level while at the same time covering such a long temporal scale, it defines the exact trajectories of these changes in Czechia and the relation of these changes to the so-called general types of natural landscapes (GTNL). Thus, it complements the first step in testing the hypothesis H1-3 and plays the key role in testing hypothesis H4-7. The analysis was performed mainly in the ArcGIS environment with additional help of open-access software, such as GoogleEarth. The results of this step were published in the issue of January, 2019 of the journal "Regional Environmental Change" (Attachment 2). This helped to fulfil tasks such as:

- Choice and acquisition of data, which reflects natural/climatic characteristics of separate areas in an integrated form;
- Design and application of a suitable methodology for using this data together with datasets about the state of LULC categories, covering the two different time horizons, acquired in different form to be able to analyse the overlaying changes in the GIS environment.

The third case study uses the same set of study sites and completes the work by analysis of selected anthropogenic and natural factors as possible drivers of changes in wood-pastures presence and continuity. Thus, it mainly checks hypothesis H8, and concludes which of these factors played the key role in long-term spatiotemporal change of wood-pastures. At the same time, it helps with tasks such as:

- Finding and extraction of the essential data about the selected natural and anthropogenic factors ("drivers") from available sources in a suitable form.

- Design and application of the methodology to execute analysis using different forms of data for obtaining comparable results to make a common conclusion about the role of all the different drivers of wood-pastures dynamics.
- Evaluating the importance of the different natural and anthropogenic factors in the various change trajectories between wood-pastures and other LULC categories.

3.2. Choice of drivers as factors of change

The relative importance of the different political, economic, social, technological and natural driving forces for the state of landscape and its sustainability depends a lot on the level of development of the society, inhabiting this landscape. The trends of landscape pattern changes over the last two centuries in Europe are correlated to the "Complex Revolution of the Modern Age" (see details in subchapter 4.5.2), which in Czechia took place in 19th century. In respect to land use patterns it was marked by technological innovations, towards intensification of agriculture, affecting the whole structure of LULC as a consequence. The start of the "Complex Revolution" in Czechia is defined as the Industrial-Scientific revolution, which began in 1848-1849. Of major significance for the land use changes in Czechia is the Agricultural Revolution, which began in the end of 18th century and reached its peak in 1860-70s, when socioeconomical and political forces were gaining more importance. When talking of social drivers, various actors on different levels need to be considered. Their roles and motivation can be hard to identify especially when analysing a bigger territory (such as state-level, in the case of this study), and a quantitative analysis is becoming increasingly challenging. In the case of wood-pastures, social factors are expected to play a significant role, as this LULC is not valued only for its productive use, but also for sociocultural importance. Thus, this work approaches this question indirectly, by investigating the correlation of these social factors to other drivers. Even though true detailed social research requires a separate complex approach, this allows to draw certain conclusions from related factors while still maintaining a not too complex and thus manageable procedure The group of social, political and economic drivers are usually closely interconnected and considered together. Some of these forces are of widespread or "global" impact, such as Differential Rent, Agricultural and Industrial Revolution, development and spread of transportation networks and technological innovations, cultural and economic trends, or international organisations. Those work in combination with more local driving forces which include e.g. agrarian reforms and related state/local laws or measures of environmental protection. Socioeconomic forces, which gained momentum in the 2nd part of 20th century, resulted in an environmental crisis. They initially affected quickly developing regions and then continually spread to remote ones.

4. Literature review: History and State of the Art of Research in Landscape Change Analysis

4.1. Modern developments in studies of changing landscapes

Besides more traditional studies which focus on landscape change (e.g. Hooke and Kain, 1982; Pelorosso et al., 2009; Bender et al., 2005), there are those that address the different landscape change issues in general (Sklenička et al., 2014; Skaloš et al., 2012; Šímová and Gdulová, 2012), or represent multidisciplinary studies introducing adjacent disciplines in the study of landscape change such as historical geography, archaeology, sociology, political economy, etc. (Burghi et al., 2004; Vojta and Drhovská, 2012, Hanspach et al., 2014). A theory commonly accepted by scientists in the field is, that any change in landscape structure will impact the course of energy and material flows in the landscape and, thus, its functional properties (Novotný, 2018, Forman et Godron, 1986). In other words, structural heterogeneity of landscape, which is defined by the number of element types or ecosystems, is based on the laws of landscape thermodynamics, and presents a fundamental feature of each landscape (Sklenička, 2003).

A good example of such a holistic approach was demonstrated by Hanspach et al. (Hanspach et al., 2014) when conducting their study in southern Transylvania, Romania, which is one of Europe’s most significant biocultural refugia. Their aim was to understand the current social-ecological dynamics and assess risks and opportunities for sustainable landscape development. The complex approach used in this study involved estimation of social conditions and natural capital bundles, social-ecological system dynamics, and current development trends, and was shown to be effective for generating an in-depth understanding of the regional social-ecological system.

There have been several studies focusing on the analysis of general spatial changes in the landscape, e.g. a study upon spatial structure and dynamics of landscapes in Tom valley (Tomsk Region, Russia) (Khromykh et Khromykh, 2014). The mentioned research was aimed at the analysis of natural and anthropogenic changes of this area since the end of 19^{th} century, using both field expedition methods and the methods of GIS-mapping coupled with complex spatial analysis based on remote sensing data and digital elevation models with application of ArcGIS 10 (ESRI Inc.), ERDAS Imagine (ERDAS Inc.). This allowed to develop big geodatabase and

GIS “Tom river valley”, its digital elevation model (DEM), morphometric indexes of landscape systems and used to identify main trends of landscape dynamics in the different parts of the valley.

A very interesting example of using GIS environment for spatial analysis with relation to cultural, natural and other factors has been demonstrated by Spanò and Pellegrino (Spanò and Pellegrino, 2013) in their investigation of the dynamics of distribution of craft such as gypsum decorated ceilings in Piemonte, Italy, which was at the same time looking for a relationship between the natural characteristics of the area, it’s political organisation and their artistical and cultural expression of the local rural society. Besides showing this relation, the study also provided a better understanding of the historical landscapes, which is essential for developing future conservation projects.

Again, on an example for the Romanian protected areas, located either in agricultural lands or in their vicinity, a combination of satellite image processing with other cartographic materials was applied and shown to be useful for analysing and modelling the related spatial urban and rural pattern (Huzui et al., 2012). Here, the spatial urban pattern was modelled to reflect the extent of built-up change in recent years and allow to compute a synthetic indicator for the vegetation study, that is especially useful for evaluating human intervention through cultivated fields, farms and deforestation, essential for the further urban planning. The research showed the major (dis)advantages of using such methods as satellite images, remote sensing and GIS for this kind of studies.

A study from Australia (Seabrook et al., 2007) describes spatiotemporal change of vegetation land cover in agricultural landscapes. The work covers the analysis of historical drivers of land cover change and of the trends in deforestation since 1945 in two brigalow (Acacia harpophylla) landscapes of 100,000 ha in Queensland, Australia. Some selected drivers were then applied at a property-level (1000 ha) to test their influence on native vegetation retention in order to quantify the effect of significant human drivers and biophysical properties.

A separate topic of interest is detailed analysis of change patterns on the landscape level. Existing studies in this topic can be grouped according to the type of prevailing land management system, which is typical for studies that are aimed at observation or/and conservation of specific landscape types. This thesis, as a study on wood-pastures, can also be attributed to this group. In this group the study of long-term spatiotemporal dynamics and approaches based on multi-scale analysis, have shown to be the most suitable. As an example, Plieninger et al. (2012) provides an outstanding analysis of the long-term change patterns of woody vegetation in agricultural landscape in eastern Germany. At the same time, Patru-Stupariu et al. (2013) employed the forest history perspective and spatial pattern analysis to identify potential high conservation value forests in Romania, although that study focused only on forest woody vegetation.

When referring specifically to Czech landscapes, as in this work, and to changes in LULC in general, the latter were shown to be accelerating in the end of 18^{th} century, which was accompanied by a complex sequence of historical events, changes in modes of production and peoples' lifestyle and technological advance. Thus, these changes cannot be explained by be traditional methods of only historical science or by sociological generalizations since in this case they would lack the context of geographical organization and natural driving forces (Purš 1973). Thus, principles of environmental history, as a modern interdisciplinary science, which deals with the role and place of nature in human life should be applied (Bičík et al, 2015).

4.2. The concept of wood-pastures

Wood-pastures are landscapes in which livestock grazing co-occurs with scattered trees and shrubs (Plieninger et al., 2015). They are a particular case of so-called "trees outside forests", which are formed by scattered trees, native or naturalized woody species, intermingled into croplands, grasslands, and wastelands. The trees in the landscape are spatially arranged either as point (e.g. isolated trees), line (hedgerows, alleys, riparian buffers), or clustered (e.g. woodlots, tree groups) features (Plieninger, 2012) (**Figure 1**).

Figure 1. Visual examples of European landscapes with wood-pastures

According to Plieninger et. al (Plieninger et al., 2012) European rural landscapes outside closed forests exhibit a diversity of tree-based land use systems, which are defined there indirectly as ”all trees excluded from the definition of forest and other wooded lands” (FAO, 2000) and are common throughout the world, both in traditional cultural landscapes and in recently modified landscapes (Manning et al., 2006). Even 'farm trees' are often considered as belonging to this group (as single trees) (Arnold and Deewes, 1997). Wood-pastures can be the product of spontaneous regrowth or of being planted, domesticated, and cultivated and are usually seminatural habitats within the farmland mosaic and form part of a ”high-quality agricultural matrix”.

In these habitats, mature, open grown trees are scattered among more open areas of grassland, bracken, heath or wetland. Younger trees may also be present, but the total canopy cover through the area as a whole is more open than in woodland. The ground vegetation is very rich in species but is generally managed in an unintensive way (with minimal use of fertilizers or pesticides). They may be grazed by deer or domestic stock and tends to be of a semi-natural nature (Scotland's natural heritage, 2015). As a natural precondition for these habitats, it has been mentioned that solid and drift geology with nutrient poor, free-draining soils with pH 4-5.5, are preferred (Thames Valley Environmental Records Centre, 2015).

From a more technical point of view, wood-pasture can be defined as a historical European land management system in which open woodland provides shelter and forage for grazing animals, particularly sheep and cattle, as well as woodland products such as timber for construction and fuel, coppiced stems for wattle and charcoal making and pollarded poles (Stiven et Holl, 2004). They are a very specific type of European cultural landscape and are probably the oldest land use type here (Plieninger et Hartel, 2014). This kind of (agro)silvopastoral land use systems have been a part of the European culture throughout ages, from prehistoric to present times (Mosquera-Losada et al., 2009).

Bergmeier et al. (Bergmeier et al., 2010) list 13 different ways which are used to refer to wood-pastures across Europe, with some of them differing for example in geobotanical classification and the others only demonstrating locally specific terminology, but altogether this reflects the diversity of wood-pastures in Europe.

Hartel and Plieninger (Hartel et Plieninger, 2014), use the term „wood-pasture“ as an aggregative term, as it is the most widely spread concept in current literature and it incorporates all the regional terms. Namely, this term describes generally lands that include trees and livestock grazing. The scientists stress that the choice of the name is especially important for the proper understanding, management and conservation, including the possibility to provide a protective status.

As stated by Hartel (Hartel, 2012), the nature of knowledge, or specific perspective, is an important determinant of how people perceive wood-pastures. While traditional herders perceive wood-pastures as organic, inseparable units of pasture and trees, professional managers perceive wood-pastures as important factor for biodiversity and landscape complexity.

Considering the diversity of definitions of wood-pastures, the definition accepted for this study was established and is specified in Table 2, along with other LULC categories. This helps to obtain clear and defined results and avoid misinterpretation.

4.2.1. Visual structure of wood-pastures

Wood-pastures can be distinguished by the structure of habitat. Their defining feature are open grown trees of varying ages and sizes including mature, over-mature or veteran specimens, distributed irregularly forming mosaics with open habitats such as unintensively managed grassland which is or has been grazed (Scotland's natural heritage, 2015). Because of this it can overlap with other priority habitats such as lowland mixed deciduous woodland, lowland meadows or lowland dry acid grassland.

Older trees, including over-mature veterans with widely spreading branches, are typical for tree growth in open situations. Denser patches of younger trees may exhibit the more upright growth forms found commonly in woodland. Some older trees may also show signs of traditional silvicultural management such as pollarding.

According to an overview by Scotland's natural heritage (2012), wood-pastures differ from the traditional orchards priority habitat in having larger, more widely spaced trees which are not predominantly fruit- or nut-producing species (**Figure 2**). Therefore, patches of wood-pasture and parkland tend to be larger than traditional orchards, and among the associated ground vegetation types, bracken-dominated vegetation is more common in wood-pasture and parkland, but is scarcer in traditional orchards.

Figure 2. European wood-pastures: example from Great Britain

4.2.2. Wood-pastures vs forests: main difference

As stated by Novotný (2018) there is no globally recognized principle to distinguish between forest and non-forest woody vegetation, since there are at least 624 definitions of forest, which vary from one region to another. English literature uses two close terms: woodland (small area with maximum canopy cover of 40%, allowing sufficient light for other vegetation levels) and forest (relatively large area with canopy cover over 20% and often consisting of several habitats which may differ in age, plant and animal species and the stand structure). A more common definition by FAO, defines forest as an area of over 0.5 ha covered with woody vegetation of at least 5 m height and canopy of more than 10%, which is not used primarily for agricultural or other non-forest purposes. Specifically, for Czechia, according to state legislation (Act No. 289/1995 Coll), forest is defined as 'forests shall mean forest stand with its environment and land designated for the fulfillment of forest functions'.

As seen in the previous sections, definition of wood-pasture as a type of landscape is scarce, and opinions on this question may differ between different authors. Inconsistency in categorization may be related to the location in general, type of woody vegetation, amount and density of trees and canopy cover, intensity of using these lands as pasture, age or continuity etc. Nevertheless, often a wood-pasture, as tree-land, on which farm animals or deer are systematically grazing, involves grass cutting, acorn collecting, litter raking and field crop cultivation (Bergmeier et al., 2010, Rackham, 2004). Being a priority habitat of the UK Biodiversity Action Plan, wood-pastures are officially defined there as areas that have been managed by a long-established tradition of grazing, allowing, where the site is in good condition, the survival of multiple generations of trees, typically with at least some veteran trees or shrubs. In this definition, the woody elements may have been exploited in the past and may occur as scattered individuals, small groups, or as more or less complete canopy cover, with possible presence of other semi-natural habitats (grassland, heath, scrub etc.) in mosaic with woodland communities (Maddock, 2008).

From the nature conservation perspective, the importance of the differences between structural composition of woods and wood-pastures also is seen through other resulting major features. For example, these two categories differ in the tree and plants communities. Generally, wood-pastures are characterized by higher biodiversity, such as in Romanian sites, where wood-pastures are dominated by oak and fruit trees. Woods have a more balanced proportion of beech, oak and hornbeam, which can be mainly explained by the ecology of the trees (Vera, 2000), natural prerequisites and the traditional preferences of local people for oak and fruit trees.

Looking again at the still relatively well-conserved authentic wood-pastures in Southern Transylvania (Romania), the parcels covered by wood-pastures are known for having the largest trees: the majority of the surveyed wood-pastures include ancient oaks while forest sites contained virtually no such trees (Hartel et al, 2013). The relative proportion of young trees appears to be higher in forests than in wood-pastures, while ancient trees are found exclusively in wood-pastures, and most of the surveyed wood-pastures in these places contain ancient trees. This can be mostly attributed to the management of the corresponding areas throughout history, together with traditional preferences of local people, and natural environmental gradients (Hartel et al, 2013).

4.2.3. Types of wood-pastures

Wood-pasture habitats differ between regions in species composition, structure and ecology and depend on various factors such as: climate, soil, topography, geology, regional species-pool, land use history, current management, grazing seasonality, etc.

Depending on the region, wood-pasture occurs as "vanishing relict of historical land use" or are still relatively widespread as multiple-use rangeland according to Bergmeier (Bergmeier et al., 2010). The same scientists state that there in Europe are at least 24 types of wood-pastures, based on the geobotanical criteria of region, such as overall distribution, vegetation structure, elevation and prevailing trees (**Table 1**). Here, according to structure, land use and tree species composition the wood-pasture types may be classified as hemiboreal and boreal (4 types), nemoral old-growth (7), nemoral scrub and coppice (5), meridional old-growth (2), meridional scrub and coppice (4), and grazed orchards (2).

However, there are various other classifications, that use other features as the distinguishing criteria. Plieninger et al. (2015) for example, recognize three categories of wood-pastures according to the density of crown cover and to their land use type:

(1) pastures in open woodlands (density of tree-crown >10%) as the primary land cover (coded in the LUCAS as C10 to C33 (Eurostat, LUCAS, 2015), and with grassland as the secondary land cover (coded as E10 and E30);
(2) pastures with sparse trees (density of tree-crown between 5% and 10%), directly defined in the LUCAS database as a specific land cover class (coded as E10); and

(3) pastures with cultivated trees (coded as B71 to B81) with recorded grazing land use, i.e. excluding points that are ungrazed permanent croplands rather than fully-fledged wood-pastures.

LUCAS stands for Land Use/Cover Area frame Statistical Survey, which has been created following a decision of the European Parliament and the European Statistical Office (EUROSTAT) in cooperation with the Directorate General responsible for Agriculture and the technical support of the JRC (Joint Research Center), with the goal to get a more accurate estimate of the area occupied by different LULC types in Europe (European Soil Portal, 2014).

4.2.4. Presence of wood-pastures in Europe today

Wood-pastures that are still in use can be found especially in Southern and South-Eastern Europe, in parts of boreal and subarctic Europe and in the central European mountains (Bergmeier et Roellig, 2014). They occur on a wide range of soil types and topographical situations in both lowland and highland areas (Scotland's natural heritage, 2015).

Table 1. Survey and characteristics of European wood-pasture habitats by Bergmeier et al. (2010)

Wood-pasture habitat type	Predominant trees	Traditional land-use		Landscape type, potential natural vegetation
		Animals	Trees and ground	
1	*Quercus petraea*, *Q. robur*	Cattle, sheep	Coppicing, lopping, barking	Quercetalia roboris
2	*Corylus avellana*, *Populus tremula*, *Fraxinus excelsior*, *Quercus robur*, *Tilia cordata*	Cattle	Pollarding, coppicing, grass cutting, shredding, cultiv. fields	Fagetalia, Vaccinio-Piceetalia
3	*Betula pubescens* s.l., *Fraxinus excelsior*, *Picea abies*, *Quercus robur*	Cattle, sheep	Coppicing, lopping	Cladonio-Vaccinietalia
4	*Betula pubescens* s.l., *Pinus sylvestris*	Reindeer		Cladonio-Vaccinietalia
5	*Fagus sylvatica*, *Quercus petraea*, *Q. robur*, *Carpinus betulus*	Cattle, pigs, sheep, deer, horses	Pollarding, lopping, shredding	Fagetalia
6	*Fagus sylvatica*, *Picea abies*, *Acer pseudoplatanus*	Cattle, sheep	Lopping, grass cutting	Fagetalia, Vaccinio-Piceetalia
7	*Quercus robur*, *Q. petraea*, *Q. pyrenaica*, *Carpinus betulus*, *Pinus sylvestris*	Sheep, cattle, horses	Pollarding, shredding, bee-keeping	Quercetalia roboris
8	*Quercus pubescens*, *Q. petraea* agg., *Q. frainetto*, *Q. cerris*, *Castanea sativa*	Sheep, cattle, pigs	Pollarding, shredding, acorn collecting	Quercetalia pubescentis
9	*Q. robur* s.l., *Ulmus* spp., *Fraxinus excelsior*, *F. angustifolia* s.l.	Cattle, pigs, horses	Pollarding, shredding, grass cutting	Fagetalia
10	*Larix decidua*, *Pinus cembra*, *P. uncinata*	Cattle, sheep	Grass cutting	Vaccinio-Piceetalia
11	*Pinus heldreichii*, *P. sylvestris*, *Abies alba*, *A. borisii-regis*, *A. cephalonica*, *A. pinsapo*	Sheep, cattle, goats, horses	Bee-keeping	Fagetalia sylvaticae, Quercetea pubescentis, Pino-Juniperetalia, Vaccinio-Piceetalia
12	*Juniperus communis*	Sheep, goats	Bee-keeping	Fagetalia sylvaticae, Quercetalia roboris
13	*Quercus pubescens*, *Q. frainetto*, *Q. cerris*, *Carpinus orientalis*, *C. betulus*, *Juniperus oxycedrus*	Cattle, goats, sheep	Coppicing, pollarding, lopping, barking	Quercetalia pubescentis
14	*Paliurus spina-christi*, *Quercus petraea* agg., *Carpinus orientalis*, *Juniperus excelsa*, *J. foetidissima*	Sheep, goats, cattle	Grass cutting, cultiv. fields, lopping, bee-keeping	Quercetalia pubescentis

Table 1. (contintued) Survey and characteristics of European wood-pasture habitats by Bergmeier et al. (2010)

15	*Paliurus spina-christi, Quercus trojana, Q. pubescens, Q. petraea* agg., *Carpinus orientalis*	Sheep, goats	Grass cutting, cultiv. fields, lopping, coppicing, bee-keeping	Quercetalia pubescentis
16	*Juniperus excelsa, J. foetidissima, J. thurifera*	Goats, sheep	Bee-keeping	Quercetalia pubescentis, Pino-Juniperetalia
17	West: *Quercus rotundifolia, Q. suber;* East: *Quercus coccifera* s.l., *Q. ilex*	Pigs, cattle, sheep, deer	Cultiv. fields, lopping, barking, charcoal, bee-keeping, acorn collecting, resining	Quercetalia ilicis
18	*Quercus ithaburensis* subsp. *macrolepis, Q. pubescens, Q. frainetto, Castanea sativa*	Cattle, pigs, sheep	Cultiv. fields, lopping, pollarding, acorn collecting	Quercetalia ilicis
19	*Arbutus unedo, A. andrachne, Erica arborea, Pinus* spp.	Goats, sheep	Coppicing, burning, resining, bee-keeping	Quercetalia ilicis
20	*Quercus coccifera* s.l., *Juniperus oxycedrus*	Goats, sheep, cattle	Lopping, burning, charcoal, bee-keeping	Quercetalia pubescentis
21	Thermo-mediterranean: *Pistacia lentiscus, Ceratonia siliqua, Olea europaea*; meso-mediterranean: *Quercus coccifera* s.l., *Phillyrea latifolia, Q. pubescens, Pyrus spinosa*	Sheep, goats	Cultiv. fields, tree cropping, burning, bee-keeping	Quercetea ilicis
22	*Quercus coccifera* agg., *Cupressus sempervirens, Acer sempervirens*	Sheep, goats	Lopping, pollarding, charcoal, bee-keeping	Quercetea ilicis
23	*Malus domestica, Pyrus communis*	Sheep	Grass cutting, lopping, bee-keeping	Fagetalia sylvaticae, Quercetalia pubescentis
24	*Olea europaea, Ceratonia siliqua, Phoenix dactylifera*	Sheep	Cultiv. fields, bee-keeping, lopping	Quercetea ilicis

According to Plieninger (Plieninger et al, 2015), wood-pastures cover a total area of approximately 203,000 km^2 in the EU27 (4.7%), with roughly 109,000 km^2 of pastures with sparse trees, 85,000 km^2 of pastures in open woodlands, and 9000 km^2 pastures with cultivated trees (mainly grazed olive groves and fruit trees). Among the member states, pastures with sparse trees have their largest surface in the Mediterranean (Spain, France, Italy) and Eastern European countries (Romania, Bulgaria), pastures in open woodlands are common in Spain and Portugal (referred to as dehesas and montados) with *Quercus ilex*, *Quercus suber*; grazed pastures with cultivated trees can be found in Spain, Greece, Portugal, and Italy (**Figure 5**).

One of the most representative types in Central European are orchard meadows. They spread across 11 European countries concentrated in a belt stretching from Northern France through Southern Germany and Switzerland to Poland and cover approximately 10,000 km² (Plieninger et al, 2015). Depending on the state, wood-pastures may differ in some more specific features, including species composition.

The name, used to indicate wood-pastures in different regions usually comes from some regional term for „pastures" involving presence of woody vegetation. For example, dehesa and montado are Spanish and Portuguese equivalents of open pastoral woodlands, often savannah-like, mainly with old-growth evergreen holm oak (*Quercus rotundifolia*) and cork oak. They are used as grazing grounds for hogs, cattle, sheep and sometimes deer. Forest, hutewald (Hutewald), weidfeld, wytfeld and lovang denote wooded grasslands or grazed open woodlands with old-growth deciduous trees in England, north and south Germany, Switzerland and Sweden, respectively. This type of wood-pasture can be found all across Europe, although some regions might not have a specific term. Open wooded spaces (viehweiden, viehwoadt) in the Northern Alps foreland, which were used for various purposes until the 9th century, such as collecting of leaf-hay and litter, or tree cutting for timber and firewood, are still used in these locations as pasture for cattle and horses. In the Balkan and Black Sea regions Shiblijak represents semi-deciduous shrubland resulting from forest degradation and long-term grazing. Macchia (maquis), garrigue and matorral are Mediterranean evergreen bushland and shrub formations of 1 to 3 meters height and composed of ericacous and cistaceous species, also with some junipers, brooms and many other (Bergmeier et Roellig, 2014). A related term pseudomacchia is an „artificial" pasture, used in South Balkan, and reflects browsed or cut formations with shrubby Kermes oak (*Quercus coccifera*), usually met as patches in grasslands, which are replacing submediterrean woodlands. Kratt (krattwald, krattskog, stuhbusch), characteristic for Northern Central Europe and in Southern Fennoscandia refer to deciduous coppiced oak woodland, which in the past was frequently used as wood-pasture (Hartel and Plieninger, 2014).

In England wood-pastures are highly valued by ecologists, as they are often considered to be the best sites in the country for old-growth features and deadwood, supporting a wide range of specialist fungi and invertebrate species (Natural England and RSPB, 2014). They typically exhibit tree and shrub components (scattered individuals, small groups, or as more or less complete canopy cover), which have been managed over centuries in various ways. Sometimes they also include other semi-natural habitats, such as grassland, heath and scrub in mosaic with woodland communities, depending on the degree of canopy cover. Besides the more common oak, beech, alder, birch, ash, hawthorn, hazel or pine, a wide range of other tree and shrub species may occur as part of wood-pasture systems: lowland wood-pastures are most commonly associated with oak–bracken–bramble woodland, beech-bramble woodland, beech–wavy hair grass woodland, and oak-birch-wavy hair grass woodland; uplands are more commonly covered by sessile oak-downy birch-wood sorrel and sessile oak-downy birch-greater fork moss woodland types. More open wood-pastures may include various scrub, heathland, improved and unimproved grassland communities (by the British National Vegetation Classification) (Rodwell, 2006).

Romania is rich in wood-pastures and serves as a representative example thereof. According to Hartel (Hartel et al., 2012), wood-pastures from Southern Transylvania (Romania) were formed by the Saxon ethnic group through rearing the forests and grazing them with pigs, cattle, sheep and later on buffalo (**Figure 3**). Each Saxon village had historically at least one wood-pasture in its vicinity. Wood-pastures from Southern Transylvania are dominated by oak (*Quercus robur*, *Q. petraea*), and occasionally by beech (*Fagus sylvatica*) and hornbeam (*Carpinus betulus*).

Figure 3. Example of traditional wood-pasture from Southern Transylvania (vicinity of Sighisoara) with an example of a veteran tree (on the right), photo taken in 2015

4.2.5. Specific value of wood-pasture as habitat type

Wood-pastures are of high ecological, cultural and agricultural importance (Hartel et Plieninger, 2014). They are one of the oldest land use types in Europe, known since the Neolithic Period (Luick, 2008) and thus, constitute an important part of European cultural-natural heritage (Bergmeier et al., 2010). They combine several components, which are important from ecological, socio-economical and cultural perspectives (please see details in the following section of the current chapter) (Hartel 2012; Hartel et al. 2012, Szabó, 2013; Szabó et Hédl, 2013, Sutcliffe et al. 2014, Roellig et al. 2015, Surová et al. 2014, Plieninger et al. 2015).

Ecological value

As briefly mentioned before, the presence of scattered woody vegetation is a key factor for the ecological role of wood-pastures. Gibbons et al (Gibbons et al, 2008) define farm trees as ‘keystone structures’, because of their effect on ecosystem functioning, which is disproportionately high in relation to the small area occupied by any individual tree (Gibbons et al., 2008).

Especially old, scattered trees provide a broad range of habitat features, such as dead branches or hollows (Gibbons et Lindenmayer, 2003) and thus, represent local biodiversity hotspots in the ecosystems they are located in (**Figure 4**). The hollowing process and the aging bark of the old trees create crucial conditions for saproxylic organisms and some animal species using cavities for breeding or other purposes. In sum, the trees form 'biological legacies, representing biological and ecological continuity of genetic resources and habitats for a variety of organisms' (Moga et al., 2016). Therefore wood-pastures are able to offer conditions for, e.g., more diverse distinct insect, plant and earthworm assemblages, more distinctive bird communities, with a richer species and functionality composition with more functional groups and higher absolute species richness, in comparison to closed forests and treeless pastures (Plieninger et al., 2015; Moga et al. 2016). Ancient trees, which are still located in wood-pastures, also contain significantly more lichen species than those that were overgrown due to grazing abandonment and are surrounded by secondary woodland (Paltto et al., 2011). Certain saprotrophic fungi and mycorrhizal fungi are more present in wood-pasture type landscapes (Plieninger et al., 2015). Of particular importance in the ecology of ancient wood-pastures is also the slowdown in growth of older trees after a certain age, until the crowns start to die-back. With no competing trees, the period of decline can last for up to centuries, which creates special conditions for various species, such as mosses that grow up on the large branches and in crevices in the bark; wood-rotting fungi on broken branches and stems; beetles in the dry deadwood and sap-sucking flies and hoverflies in the rot-holes; sap runs and other scars that these veteran trees accumulate. The process of ageing provides an uninterrupted supply of deadwood in various stages of decay, ensuring the needs of species continue to be met (Forestry Commission Scotland, 2009). Additionally, against a common opinion about higher importance of young trees in carbon sequestration, recent studies, such as one by an international team of Stephenson et al (Stephenson et al, 2014) provide evidence that big, old trees are better at absorbing carbon from the atmosphere than has been commonly assumed. In more details, according to this study, the growth rate for the most tree species tested is increasing continuously with age, and large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller tree Finally, the old trees store precious information about the past climatic and environmental conditions, ecosystem functions (Moga et al., 2016). For example, the annual rings of old trees can be used as historical records, as they illustrate past climate changes or cutting treatments, and the chemical nature of the wood. Thus, these trees may serve as a resource for research into past climates, pollution levels etc. (Read, 2000).

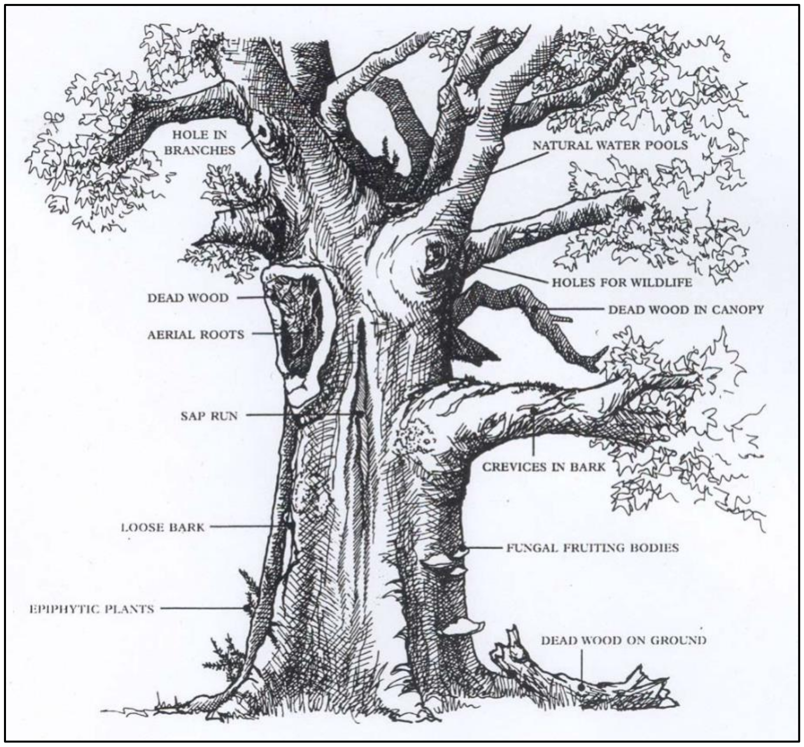

Figure 4. Features of ancient tree providing a variety of habitats for diverse organisms (Chiltern Woodlands Project, 2011)

Farm trees generally create high structural diversity in agricultural landscapes, thereby providing a great number of micro-habitats and permitting multi-directional movements of biota across landscapes and ecological networks (Manning et al., 2009). Moreover, some species may be regionally restricted only to wood-pasture landscapes, such as shade-tolerant unpalatable geophytes, including peonies (Paeonia spp.) and hellebores (Helleborus spp.) in southern Europe (Chaideftou et al., 2009).

A study on estimation of landscape transitions in one of the locations of wood-pasture landscapes within Czechia (Vojta et Drhovska, 2012) was comparing composition of forest species communities in abandoned pastures and those in ancient ungrazed forests, and showed that the number of species in wood-pastures is higher than in forest areas. At the same time, some species, which are indicators of ancient forests in Europe were missing in the case of abandoned pastures. According to Alexander (Alexander, 1998), although wood-pastures are usually not considered “true” forests, they provide micro-environments similar to those of the original natural forests and can support communities and species that are relicts of the natural. The tree and shrub component may appear differently in the landscape structure, forming more or less dense canopy cover. They also may combine with other semi-natural habitats and create a more complex ecosystems with woodland communities. Surprisingly pastures with a long continuity in scattered woody cover (wood-pastures) do not appear to be a better refugia for forest species than more recently overgrown pastures (Vojta et Drhovska, 2012). This indicates that landscapes with this LULC may play a beneficial role for biodiversity regardless of the length of their history. At the same time, according to some authors (Lipský, 1995, Demková et Lipský, 2013), permanent landscape structures are usually characterized by presence of more valuable species in the original local gene pool and are the base of the so-called landscape memory. Despite being only a part of the spatial structure of the landscape, these old, stable structures also identify the landscape structure over time (Supuka et al., 1999).

On a larger scale, a ubiquitous fine-scale heterogeneity appears thanks to canopy-caused gradients of resources such as light conditions, wind, temperature, soil fertility (Hartel et Plieninger, 2014). At the same time, as seen from one example of wood-pastures in Czechia, species richness may be negatively correlated with habitat isolation particularly under the open canopy (Vojta and Drhovska, 2012), but typically, wood-pastures are kept under traditional, low-intensity pasture management, which supports rich flora and fauna (Rosenthal et al., 2012). They are often more heterogeneous, than other managed landscapes, due to the larger cover of native vegetation, and their specific structure and succession stages, density and age structure of the tree communities (Hartel et al., 2013). A large part of the European trees species is represented in wood-pastures, with also potentially high genetic diversity due to human maintenance of certain tree species (Bergmeier et al., 2010), selected over centuries, often for their role as food for pigs and sheep. Those include rare, locally distributed or threatened tree species occurring in wood-pastures and their margins, for example Malus sylvestris (Central and South Europe), Malus dasyphylla (Southeast Central Europe, Balkans), Mespilus germanica (Southeast Balkans and Southwest Asia, naturalized in parts of Central and South Europe), Prunus cocomilia (East Mediterranean), Pyrus pyraster (Central, East and South Europe), and Sorbus domestica (South and Central Europe) (Garbarino et Bergmeier, 2014).

On a higher level, wood-pastures influence microclimatic conditions and soil humidity in general, as they buffer against wind and dryness, control nutrient cycling and soil erosion and, thus, vegetation structure as the consequence (Manning et al., 2006), carbon sequestration and air quality (Burgess et al. 2017), regulation of surface water (Nisbet et al. 2011), which all together helps adaptation to anthropogenic climate change (Manning et al., 2009).

Recognition of the biodiversity and ecological value of the wood-pastures started to be seen very recently, but it is gaining increasing attention since: the number of protected species is potentially high in wood-pastures (Bergmeier et al., 2010)

Socioeconomical and cultural values

Besides essential ecological and biological values, wood-pastures have a special socioeconomic role in culture of local societies.

Firstly, the characteristic mosaic land cover and the presence of both livestock and of scattered, old trees (López-Santiago et al., 2014) gives these landscapes a particular beauty and is therefore attractive for natural tourism and recreation.

The value of aesthetic component of wood-pasture often is seen differently by different stakeholders, and reflects subjective opinion, driven by their motivation or specific interest behind landscape preferences, which could be related to aspects of tradition, knowledge types, cultural identity, or associated recreational activities (Hartel et al., 2014).

From the early stages of agricultural evolution in human history, wood-pastures have been playing an essential role for local communities, being a source of a variety of products of major local importance until nowadays, such as firewood, brushwood, timber and wood for tools and furniture, bark, bast fiber for textiles and rope, cork, litter, fruits, mushrooms and honey (e.g. **Figure 5**). Different tree species serve for different purposes and can fulfill different local demands of sustenance, craft, trade and industry in different regions of Europe (Hartel et Plieninger, 2014). For example, socioeconomic and cultural role of orchard pastures can also be attributed to such provisioning services, as regionally produced drinks (juices, cider, and spirits) or forage for livestock, and serving as reservoirs of old landraces and cultivars (Plieninger et al., 2015 (1)).

Figure 5. An example of a portuguese wood-pasture – „montado“, used as a pasture for animals and collection of cork for traditional products, photos taken in vicinity of Evora, Portugal, September 2016)

Presence of large old trees means even higher historical, cultural, aesthetic, and spiritual values of the respective wood-pastures. People generally have positive feelings toward large trees for their impressive size, shape, and age. In some countries the emotional attitude is specifically notable in the appearance of specific terms (e.g., 'veterans' or 'working trees' in UK) or names or stories associated with them. Old trees can also be a taken as source of historical information on human management of wood-pastures, reflected on the trees, such as pollarding and coppicing (Moga et al., 2016). The role of wood-pastures in local cultures is also attributed to their continuity throughout history and presence since pre-modern times (AD 500-1700), thus, being an inalienable component of cultural landscape. This is demonstrated, for example by presence of typical elements of wood-pastures (large, open grown trees) in the local folk tales and philosophical systems of some communities (Hartel and Plienineger, 2014). This way, they help to keep the „landscape memory", not only as a storage for many traces from historical land uses such as host terraces, stone walls, threshing floors, natural objects, such as ancient borders between wood-pastures and forests and other infrastructural elements, but also for ancient practices and locally specific land management practices (Plieninger et al., 2015). Importance of the inherent link between wood-pastures and people, tracing back to centuries, is also highlighted by Hartel et al. (2012), showing wood-pastures as 'excellent arenas for a holistic, social-ecological approach to understand the dynamics of systems of nature and people' on the example of Romania. Hartel (Hartel, 2012(1)) highlights the role of traditional landscapes as a "living connection between the present and the ancient past, and a potentially huge resource for us to learn" on the example of Romania, where wood-pastures were created for grazing by Saxons, but were used also for acorn production (which was grazed by pigs in autumn) and as shadowing places for people and animals due to the scattered trees". Wood-pastures there were cultural hotspots of places in the past and still are important places for recreation (e.g. walking tours, photography, naturalist trips e.g., in Sighisoara, Romania).

4.3. History of European wood-pastures

4.3.1. Origin and primary development of wood-pastures

Wood-pastures have been common at least from the Neolithic as a part of the subsistence economies of most rural societies across Europe. This is still relevant for some marginal rural areas and their economical integrity (Bergmeier et Roellig, 2014). As reported the ancient, pre-human landscape of Europe was most likely wooded, and contained such key features, as open-grown trees, wood-pasture, scrub, and grazing and browsing animals, which were the major driver of change back then.

Originally, natural phenomena such as fire, tree diseases, soil maturation, soil humidity, and interactions between species (predators and herbivores) were the main driver for the formation of landscapes (Hartel and Plieninger, 2014). After the human colonization, however, the changes in landscape were mainly explained by close interaction of human-driven and natural factors, that supported the existence of treed landscapes, while the recent decline of many valuable treed landscapes of Europe is almost exclusively related to human activity.

A study on wood-pastures by Scottish scientists states that they became widespread in Europe since the middle ages (Forestry Commission Scotland, 2009; Jørgensen and Quelch, 2014). For Scotland, as a location with a long history of these kind of landscapes, wood-pastures have become an integral part of local society's evolution, serving as shelter, pasture and fodder for livestock, as well as source of wood products for local people. Signs of management, such as pollarding, regenerating with multiple stems to provide poles, or browsing for livestock serve as evidence of their importance for local society in harsh times. During medieval times, larger areas of wood-pastures within hunting forest there were often deliberately maintained to hold some wild animals, e.g. deer for sport. Other wood-pastures served as key parts of so-called pre-improvement settlement landscape (Forestry Commission Scotland, 2009), i.e. when Scottish agriculture was based around a system of multiple-tenancy farms, with the houses of the inhabitants clustered together into one or more townships (Boyle et Macinnes, 2000).

Studies on history of Southern Transylvania (Romania) conclude that many wood-pastures originate from forest grazing and selective tree removal from forests (Hartel et al, 2013).

In most modern landscapes, at a global scale, wood-pasture structures have been overtaken by other types of land use. However, in some locations, which contain old trees and pasture signs of an earlier managed landscape and the culture and traditions that created it can still be observed (Forestry Commission Scotland, 2009). According to the same source, still old wood-pastures can often go unrecognised, though where management continued into recent centuries, they can still be identified on estates, farms, townships and common land.

Nowadays, while they are still in actively used in many parts of Southern and Eastern Europe, in Western and Northern Europe current wood-pastures are more seen as either relicts or new instances, primarily maintained for the purpose of nature conservation (Bergmeier et al., 2010). Their total area in these territories has experienced a sharp decline over the past 300 years.

Liberal thinking of the Enlightenment age led to fundamental modernisation of existing peasant agriculture and forestry, which was essential to provide sufficient food surplus as a precondition of industrialization. Enclosure of common land, which was advocated by land reformers to increase animal, plant and timber production, resulted in strict separation of agriculture and forestry and elimination of large number of wood-pastures up until 20th century (Plieninger and Hartel, 2014).

Historical continuity has been recognized as a key factor for evolution and support of herb species diversity (α -diversity) and soil properties in the case of forests (Vojta and Drhovska, 2012). This concept of continuity can be applied to wood-pastures as well, particularly when accepting the hypothesis that the primeval forests had the structure of relatively open habitats, since they were being grazed by large native herbivores.

4.3.2. Recent dynamics of wood-pastures

The most notable changes in wood-pastures took place in the last few decades. Once relatively common across Europe, now they are threatened to become extinct, mainly due to abandonment of traditional management, particularly in developed countries (Rackham 1998).

At the same time, studies of long-term dynamics of non-forest woody-vegetation across Europe in general have shown different trends. Plieninger et al. (2012) for example have found an increase in the number of trees in non-forested areas in the period of 1964–2008 for agricultural lands of Eastern Germany, while Costa et al. (2014) describe a constant decline in density and cover of characteristic tree species for the wood-pastures of South-Western Iberia (dehesas and montados), which is attributed to an interplay of technological advances.

In many locations the latest centuries, which were characterized by intensive grazing in the uplands, resulted in open landscapes with few old trees. During the 20th century, also large areas of commercial forestry were being planted on former wood-pasture territories. Some wood-pastures became parts of more formal parklands or were converted to amenity grounds such as golf courses. (Forestry Commission Scotland, 2009). According to Plieninger and Hartel (2014), in the course of the 20th century wood-pastures in Europe were often simply neglected, which led to their unintentional loss, usually through abandonment of livestock husbandry, and were often converted into commercial forests and properties. As part of the concept of High-Nature-Value Farmland (HNV) landscapes defined by Plieninger et Bieling (2013), wood-pastures were undergoing similar changes as the other marginal farmlands of this group during the last centuries. Driven mainly by socioeconomic changes such as the shift from local to global markets, availability of and higher wages for off-farm jobs and mechanization. The financial revenues of farms, which were managing wood-pastures decreased after these changes compared to other, more intensive livestock operations.

Altogether the currently existing European wood-pastures are subject to the constant pressure of changing environmental, political and socioeconomic circumstances. One of the most significant factors is fires, which though often originate from intentional burnings used as a management method – though often not properly controlled – and are often even illegal. Hartel et al. (2013) mention the example of Transylvania, where in 2012 large wide-spread fires occurred which affected approximately half of the wood-pastures, and most likely caused permanently damage on the large trees located there (Oak and Hornbeam). Although fire has been used in this region for pasture clearing since the 16th century, uncontrolled and illegal pasture burning has increased in recent years, even in protected areas.

From socioeconomic perspective, with the changes in the status of wood-pasture, the attitude towards wood-pastures has changed as well with their status in agriculture, which were taking place in the light of Agricultural and Industrial Revolution and related socioeconomic changes. Notably, rich countries with productive lands have less of wood-pastures as well as of characteristic management practices to support them, weaker traditional ecological knowledge and links between people and nature. At the same time, remaining wood-pastures often have a high aesthetic value among people. Economically weaker countries usually show a more traditional management, and there is still a strong connection between local people and wood-pastures. In these regions people value wood-pastures more for their provisioning services (Hartel, 2012). The concern of local people about the disappearance of old wood-pastures, and, more specifically, of old trees, and the inability of the local authorities to stop this phenomenon, was demonstrated by a survey in a Transylvanian regions held by Hartel (unpublished), as reported in a study of Moga et al (2016).

4.4. Management of wood-pastures: historical overview

4.4.1. Managing wood-pastures as specific habitats

Wood-pastures have been formed and sustained throughout the history with specific management practices, and their existence and continuity are often dependent on those. Land use practices, such as grazing or the use of wood and other forest products, became the very reason for specific vegetation structures and species assemblages (Vojta et Drhovska, 2012).

The landscape mosaic of wood-pastures is defined by the balance between two major processes: 1) grazing and browsing by livestock, which, however, may negatively affects tree regeneration; 2) natural succession, which leads to development of other LULC categories with a more densely covered canopy, and counteracts the first.

This balance is however very sensitive to other „extrinsic“ factors, such as locally specific forest management or the global progress of climate change, which impact the recruitment and growth of tree species and the spatial configuration of grassland and forest patches, and affects both the dynamics of vegetation succession and grazing behavior of free ranging livestock. Such a variety of interactions demonstrates the complexity of wood-pastures creation and dynamics, as well as the ability to predict the effects of management decisions. Additionally, the slow dynamics, related to tree development, at landscape level, leads to a temporal gap between management and the long-term system response. (Gillet et Peringer, 2012). For example, supporting grazing intensity and frequency of wood-cutting allows to hold the balance between herbs, grasses and woody species, and creates highly dynamic and spatially diverse systems. At the same time wood-pastures are very sensitive to changes in this management (Vojta et Drhovska, 2012; Mountford et Peterken, 2003). According to a review by Scotland's natural heritage (Scotland's natural heritage, 2015), the ideal grazing regime may vary between sites depending on the types of vegetation. But, as an indicative rule, stock grazing (especially cattle) can be used for maintaining the ecologically valuable ground vegetation and tree and shrub regeneration where needed. In the cases, when tree cover is too sparse, support of natural regeneration of young trees and shrubs, or planting native tree and shrub species and their protection from grazing may be needed, while the veteran trees should be retained. In case of higher density of young to middle-aged trees between veteran trees, the tree cover surrounding them might need to be opened up to allow the older specimens to continue to grow and to prevent them from dying off due to lack of light. This must be done carefully and not affect any woodland interest which could develop with the increased cover of younger trees. Apart from grazing, ideal management of the ground vegetation and soils is that of minimal intervention: avoidance of the use of fertilizers, slurry, farmyard manure and pesticides, limiting of liming to neutral grassland where this is traditional practice and is not damaging to the botanical interest, and avoidance of direct disturbance to the soil (Stiven et Holl, 2004).

A study by Hartel et al. (2013) provides details about the traditional management of wood-pastures in Romania, such as prevalence of sheep grazing over other livestock (cattle, horse and buffalo) in wood-pastures and wide application of burning as a tool (which can be though threatening for older trees). The authors also mention scrub clearance as a tool applied in most wood-pastures, which is supported by the EU level financial incentives.

A study by Kizos (2014) shows an example from Greece, which stresses significance of anthropogenic factors, such as traditional religion and beliefs, for sustaining and management practices of wood-pastures, and their immediate consequences for persistence of ancient wood-pastures and their biodiversity, via, e.g. choice of „sacred“ wood-pastures, their protection and maintenance of their structure.

When speaking of sustainable management of wood-pastures, the whole range of criteria needs to be taken into account, such as environmental, social and economic, of which socioeconomic development is somewhat tied to environmental boundaries. Namely, as stated by Ross et al (Ross et al, 2016) sustainable management of grazed areas (such as wood-pastures) is important not only for maintenance of vegetation, soil and animal components of these systems, but also due to the balance between delivery of socioeconomic benefits and sustainable environment (e.g. not exceeding the carrying capacity of the land by grazing). This is follows from the commonly accepted definition of sustainable development as guaranteeing the needs of the current generation without undermining the ability of the future ones to meet their own needs (WCED, 1987). This way, sustainable management of pastures in general represents a major challenge, with different opinions around grazing, depending, again, on respective stakeholders (Ross et al, 2016). Gradinaru et al (2017) have provided a comparative analysis of implementation of national spatial planning objectives in landscapes between two countries (Switzerland and Romania), based on use of spatially explicit information and including efficient built-up development, conservation of agricultural land, landscape preservation and human perception. The results have demonstrated the important role of countries' spatial planning approaches for effective sustainable management of these spaces, as well as potentially conflicting land uses.

4.4.2. Managing trees as particular elements of wood-pastures

To conserve ancient wood-pastures, attention needs to be paid to continuing grazing management and protection of trees as well as long as veteran trees are in a good enough state to be maintained. A report by Forestry Commission of Scotland (2015) offers that, if this is not viable, then a conversion to native woodland may make more sense. If the veteran tree resource is already seriously degraded, and there are no mature trees to take their place, then conservation management as open pasture might be preferable (Forestry Commission Scotland, 2009).

Landowners, managers and related stakeholders of the lands with ancient wood-pastures need to understand the conservation value of ancient trees and protect them against potential damage by unintentional or ill-considered actions (Forestry Commission Scotland, 2009). Measures include for example avoidance of herbicides, insecticides and fertilizers, avoidance of activities, which may lead to compaction of the ground around the trees, such as trampling by people or livestock or by parked cars or activities of cultivation of the soil around the tree such as digging ditches, which may interfere with roots or alter the groundwater (Read, 2000). Another threat may arise when livestock is fed or watered close to trees, as this may not only result in undesirable trampling of ground around the trees which damages the roots, but also an excess of nitrogen from urine of animals, which is detrimental to the mycorrhizal fungi. A simple option to prevent this is the installation of physical barriers to protect trees. In order to protect the ancient trees, excessive competition from younger ones needs to be prevented, though a certain amount needs to be left to compensate for the dying-off old trees in the future. Dead and damaged wood can often be left at the place, and trees should be allowed to re-grow.

In recent years, some formal institutions have been established which are focusing on the conservation and management of wood-pastures in Northern European countries and value ancient and veteran trees as an icon of the conservation movement. Especially in Germany and UK a high level of involvement can be seen. The local population is actively participating in development activities such as marketing products of indigenous livestock breeds and voluntary participation in practical landscape management, which have proven to be effective for the maintenance of wood-pastures (Plieninger and Hartel, 2014).

4.4.3. Threats to sustainability of wood-pastures

Wood-pastures are fragile ecosystems because of their intermediate position between open pastures and closed-canopy forests. They require grazing as a condition for their maintenance. If this kind of management activities is abandoned or significantly reduced, they may turn into a scrub- and closed woodland-dominated landscapes. Thus, a balance of divergent ecological processes needs to be maintained for persistence of wood-pasture systems (Gillet, 2008), and it can be disturbed easily, e.g. if the conditions mentioned above cannot be achieved (e.g. grazing is significantly reduced, leading to overgrowth of woody component over the pasture, as presence of scattered trees and shrubs provide high regenerative potential to the woody vegetation (**Figure 6**) (Hartel et Plieninger, 2014).

Figure 6. Veteran oak tree previously growing in a open wood-pasture, which has been overgrown by younger trees, which are shading out the old veteran tree (example from vicinity of Sighișoara, Romanian Transylvania). photo taken in 2015

According to Plieninger (2015) major threats for the scattered trees originate mainly from agricultural intensification, urbanization, and land abandonment. The report by Forestry Commission of Scotland (2015), states that the disturbances caused by the use of herbicides, insecticides and fertilizers and even veterinary products, may be damaging for trees of wood-pastures and the associated wildlife, which need to be kept out of this area for a period after treatment (Forestry Commission Scotland, 2009).

A study of German orchard meadows (Plieninger et al, 2015) demonstrates that these practices lead to a reduction of economic profitability and increase in opportunity costs for orchards, which were a significant reason for the loss of these ecosystems, since they often led to conversion of orchard meadows to other, more profitable land uses. Similar conclusions can be drawn from analyses of other types of wood-pastures formations in Europe, such as the montado and dehesa oak woodlands on the Iberian Peninsula or the wood-pastures of the Swiss mountains and in Southeastern Europe. More specifically, notable loss of wood-pastures has been attributed to three major processes of land use change: (1) replacement by more intensive forms of agriculture, (2) conversion into residential development areas, and (3) abandonment of orchard meadows (due to lack of profitability) and subsequent succession into shrublands or woodlands (Plieninger et al., 2015 (1)).

Another "natural" factor which contributes to the disappearance of wood-pastures is the adaptation of ecosystems to climate change (Plieninger et al., 2015 (1)). Gillet & Peringer (2012) have shown, that, in contrast to historical studies, which demonstrate resilience of the wood-pastures in the Jura to past climate variations, in the nearest future resilience and adaptive capacity of these ecosystems is likely be challenged more by the inevitable changes in tree species composition and landscape structure caused by warming and drought stress.

As for now, though national or local conservation approaches exist, to preserve wood-pastures as important biodiversity hotspots, support on the international level is still insufficient. Within the European Union, wood-pastures are only partially recognized in conservation policies, such as the Habitat Directive (Bergmeier et al., 2010), or under general principles of recently accepted European Landscape Convention, which declares landscape in general as an important part of quality of life and well-being of society and highlights the influence of negative changes (Council of Europe, 2000). At the same time, agricultural policy is actively detrimental to wood-pastures in some areas (Bergmeier et Roellig, M., 2014). According to Donatti et al. (2016) creation of evidence-based policies for wood-pasture management faces the problem of disconnection between scientific information being generated and information needed for policy-making.

4.5. Overview of the Czech Republic as the study area

Since this research work focuses on the territory of Czechia, some essential details about the country that are important for the study topic are summarized in the following section.

4.5.1. Basic sociogeographical description of the country

First, despite being one of the smallest states in Europe, Czechia demonstrates significant climatic and species variation across its landscapes, which is mainly due to the geographical location at the crossroads of Europe. Czechia is divided into four biogeographical subprovinces within two biogeographical provinces. Most of the country lies in the biogeographical province of the Central European Highlands, spanning across two of the subprovinces (Hercynian in Bohemia and western Moravia, Carpathian in Eastern Moravia) (Culek, 2013). The country is landlocked on the main European watershed, but the prevailing winds from North-West bring enough precipitation to compensate evaporation (Bičík et al, 2015). The altitude ranges between 115 m. a.s.l. up to 1603 m. a.s.l., which influences the diversity of temperature and precipitation conditions.

There are three basic soil classes recognized in Czechia:

1) light soils (about 9% of the agricultural lands), which are quite susceptible to erosion and drying and not well suited for farming, thus, often covered by oaks, pines or black locusts;
2) heavy soils (9% of agriculture lands in Czechia), usually associated with tertiary sediments as mother rock, hard to be used for cultivation purposes, since they do not absorb water easily;
3) moderately heavy soils (83% of Czech agriculture lands), which are the best to be used for cultivation purposes.

All the diversity of geographical and climatic conditions, together with variation of geological composition and geomorphology across the country, is the reason for such a high biological and landscape diversity (Plesník et Roudná, 2000).

Before anthropogenic overexploitation took place, mixed forests were the dominating LULC type in Czechia, more specifically, up to 80% of the land had been covered by forest until the 13th century (Lipský, 1994). However, later on political circumstances across the regions of the country have also been playing a significant role. Since medieval times Czech lands have been a center of intellectual, artistic and culinary influences. It is believed that the lands were first inhabited by the Celtic tribe Boii, which the name of the region ”Bohemia“ likely originated from. Evidence suggests that in the 6th century the area was occupied by Slavs. The long and rich history of Bohemia and Moravia follows through Samo´s Empire, the Great Moravia, the reign of the Premysl´s, the Luxemburg and Habsburg dynasties and the Catholic expansion leading to the Thirty-Year War, and the decline of the Austro-Hungarian Empire. In only the last one hundred years, the history of the country included birth of the Czechoslovak Republic, German occupation during World War II, and forty years under communistic regime. Only in November 1989, remembered as Velvet Revolution, the country became known as Czech Republic (or Czechia). All these changes also affected the current culture of the Czech lands and resulted in its unique diversity. At the same time, there is significant variation in ecological status across the area. After opening of the 'Iron Curtain', Czech Republic has become known as a country of two faces. In respect to landscapes management in the most recent history, it reflects signs of both the period of industrialization and ecological awareness. On the one hand, there are some places with heavily damaged environments (especially Northern Bohemia and Northern Moravia-Black Triangle). On the other hand, the international environmentalist and conservationist community still finds remarkably well-preserved ecosystems, habitats, species, and biodiversity in general in other areas of the country (Sejak, 2000). Since social, political and economic factors have been important in landscape dynamics, a more detailed historical summary on those is given in the following subsection.

4.5.2. Remarks on history of land use/land cover change in Czechia in the light of socio-political and economic development.

A well-structured and rigorous overview of historical trends in land use and cover changes in Czechia through the history has been given by Bičík et al (2015). It serves as the main source for the current subchapter, which offers a synthesis with the focus on details relevant for the current work.

Like most other countries, the current appearance of Czech landscapes results from thousand years-long interactions between humans and nature. According to some scientists in the field (Ložek, 1970) there are three distinguishable major phases of development between the Neolithic Era and the late 19th century:

- transition from hunters/gatherers to early agriculture and animal husbandry,
- Agricultural Revolution and
- transition from extensive agriculture towards more intensive use of arable land.

During the first period, before agriculture activities, human impact on nature was similar to that of big animals, though the following climate warming initiated a change to organized agriculture and land became covered by climax communities (forests, forest steppe in warm, low-lying areas). In the next phase, agricultural land gradually expanded and new fields were overtaking former forest land or permanent grassland. At the same time, the share of forest cover on Czech lands dropped from the original 76% to 25% by the end of 18th century, though starting from the second half of 19th century it has been increasing again. As of today, around 34% of Czechia is covered by forests, which is more than most European countries and more than the Central European countries on average (32.4 %, as per 2014, according to FAOstat, 2014).

Changes in agriculture, population, transport, crafts, etc., were happening fast until the 18th century, when the second phase of development of Czech rural landscape was completed with the start of the Agricultural Revolution. The latter was a part of the so-called "Complex Revolution of the Modern Age", a term coined by Purš (1980) which defines the process of transition from feudalism towards capitalism as a complex result of processes such as industrialization, urbanization, demographic and social restructuring, democratization, etc.. Due to all these processes human society became less dependent on nature. In Czechia, this process started to gain momentum during the 19th century. In this period a big factor for landscape changes was coming from the side of technological innovations (Bičík et al, 2015), which were directed predominantly at agriculture, but affected the whole structure of LULC consequently. The Technical-Scientific Revolution, as also a part of it, was continuing in three waves: first, the period of 1880-1890s, leading to cutting of large areas of forests to be used as new fields; then (until cca. 1940), new technologies started to be used more by smaller farms, and more fertile regions were getting investments, which was also leading to different levels of development between locations in addition to difference of financial capacity between smaller farmers and cooperatives. At the later steps of the Scientific-Technical Revolution these big parcels of land were transferred to large profit-oriented enterprises and the pattern of the LULC, now represented by "big parcels" did not improve. Moreover, due to sensitive competition in Europe, more focus was now on expanding the production. Social and economic changes in that period led to fragmentation of agricultural land. The third phase of development of Czech rural landscape started in the late 19th century and was characterized by advancing capitalism, industrial revolution, industrialization, and population growth.

Since the rate of LULC change within the current borders of Czechia started to increase rapidly in the last approximately two centuries, an overview about how this situation was developing is given below in the light of social, political and economic changes in the country in the same period.

In the first half of the 19th century Czech landscape was characterized by a striking contrast between the Northern half of Bohemia (relatively densely populated) and its Southern half (sparsely populated), despite small regional differences. Typically, Czech landscape consisted of a mixture of fields, meadows, pastures, and forests, demonstrating rather heterogeneous patterns on local level, but quite homogeneous ones on the national level.

Production was limited to local markets due to technological and mainly transport limitations. At the same time any region, including mountainous, had enough arable land, grassland and forest to cover essential needs (Krausmann et al. 2003). This also was supporting environmental balance naturally at all levels. Agricultural land was covering two-thirds of the country in 1845, and arable land specifically was occupying almost one-half, with the ratio of arable land-permanent grassland of about 1:2.75.

During the second half of 19th century a notable decline of proportion of agricultural population in the country was observed in parallel with relative growth of urban population from 20% in 1850 to 50% in 1890. While in absolute numbers the agricultural population within this period remained relatively stable (between 3.6 million in 1850 to 3.7 million in 1890), their relative proportion decreased from 60% to 45%. At the same time, considerable differences between the north and the south regions existed. This was happening in parallel with changes in land ownership system: if before long-term lease was applied, implying that all land was divided by cultures raised at each parcel, and farmers could rent a "share" of those, also helping support crop rotation, after 1848–1849 the fragments of land were divided between smaller farmers, and proportion of land in ownership of big landlords declined from 42% to 38%. Animal husbandry experienced radical modernization throughout the second half of the 19th century, with a sharp rise in the amount of farm animals (up to double in many cases), and even more of them were now kept in sheds and stalls. The only exception was sheep farming, which was gradually shrinking to the mountainous areas and was facing competition from imported wool and cotton. The proportion of land covered by arable land reached its highest in 1896 (52% of the country area), whilst pastured lands declined by over 30 % in the period 1845-1896. Major changes of this kind were happening closer to major cities (Prague, Ostrava) and the important transportation routes, but also in high regions in the frontier induced by the need of feeding the growing workforce.

Over the market-oriented period 1870-1914, which was marked by large-scale farming, animal husbandry almost doubled and it became necessary to secure enough fodder for the animals. However, during the World War I (1914-1918) agricultural production slowed down due to the lack of workforce. This led to significant changes in the structure of Czech (Czechoslovak) agriculture, forced by attempts to transition towards a more cost-effective system. The Land Reform Act, which was accepted in 1919, introduced a new land ownership law (limitation of area one landowner could possess to the maximum of 150 ha of agricultural land or 250 ha of all land, with the excess land to be paid for by the state, and confiscation of lands in the property of the House of Habsburg, aristocratic foundations, owners in Czechoslovakia of a foreign citizenship), which was terminated again shortly after. The land was distributed among farmers by fragments (forested lands were being included only into big farmlands, otherwise given to military). Merging of smaller plots into large units was also in progress. Small farms were being abandoned, especially in less fertile regions. Agricultural intensity declined significantly between 1938 and 1945, during World War II. After the war, crops production recovered the pre-war level only by 1953 (when ration stamps were abolished), and animal husbandry reached its previous level only in 1960. In sum, from the end of the 19th century driving forces of socioeconomic nature have shifted towards industry (and partially services), which also influenced the movement of workforce and abandonment of rural areas.

The Communist era (after 1948) reflects the most considerable land use changes during the period under study, explained by large changes of geopolitical orientation, economic system, large-scale industrialization, introduction of collective farming, emergence of other military training areas, and depopulation of rural areas. Geographically, industrialization and subsequently the workforce were moving eastwards. Western border regions meanwhile were affected by transfer of Czechoslovak Germans, and attempts of their subsequent resettlement were not successful for the economic situation and settlement structure. The Iron Curtain soon after blocked access to some big land plots forcing new-settlers to leave them, and also allowed farming only in a state-owned form, which led to even more abandonment of countryside and traditional agriculture respectively. At the same time the latter allowed re-establishing of wilderness in the abandoned areas, some of which later became parts of National Parks. Farming, now practiced under cooperatives, was focused on the more intense use of the lands, with higher role of mechanization. Animal husbandry was also being modernized with large cowsheds. Additionally, in an attempt to get the most out of the land, a system to support less fertile areas was introduced. Thus, state subsidies for agriculture became more important since early 1970s. Besides industrial plants, residential projects, roads, and dams were built, mines and quarries were opened, while traditional rural society was disappearing. The scale of land use changes drastically and in many cases irreversibly. All in all, the amount of landscapes such as arable lands and grasslands have been declining after 1948 throughout the country, though the exact extend is region-specific.

4.5.3. Overview of Czech landscapes in existing studies

Basic research work of land use was fully established in the Czech Republic (in that time as a part of Czechoslovakia) only after 1989 (Bičík et al, 2015). One of the first statistical landscape classifications of Czech Republic, based on the distribution of different types of natural habitats (in terms of plant communities), which resulted from national habitat mapping, was initiated by Divíšek et al (2014). It should be noted that natural habitats cover a relatively small part of the country (**Figure 7**), while most of it is covered by built-up zones, arable lands, forestry plantations and similar habitats that cannot be considered as natural habitats. Plesník et Roudná (2000), estimated that 55 % of the total Czech territory was covered by agricultural lands, and such a high percentage of arable lands negatively impacts the maintenance of biodiversity in agroecosystems. At the same time, the authors noted that Czech lands had relatively high biological and landscape diversity, with a high number of both endemic species and relics of almost all key taxa from the history of the country's nature, rich wild flora and fauna, including also cultivated plants and domesticated animals, which were selected and bred in the territory of the Czech Republic during the centuries and including original ancient cultivars, varieties, breeds and races.

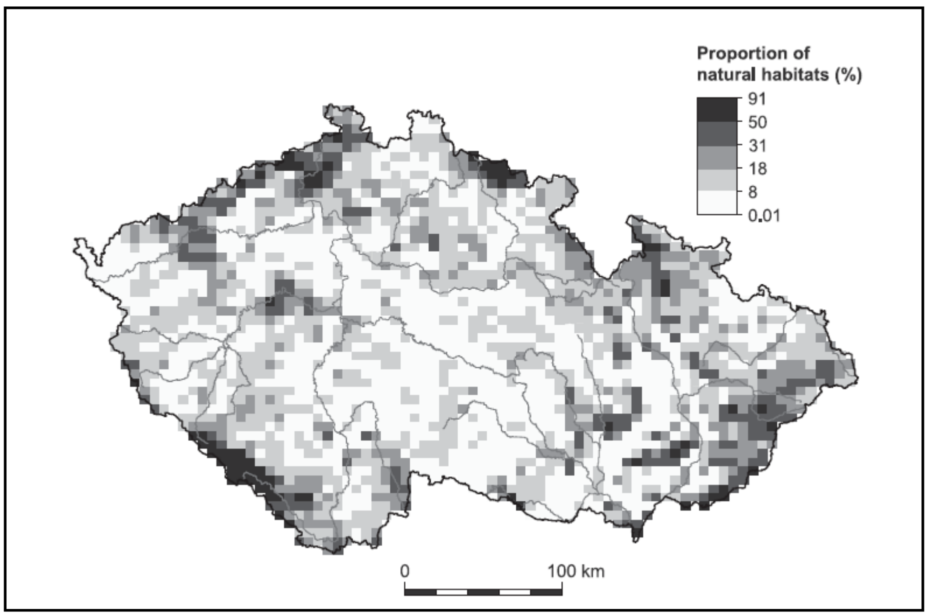

Figure 7. Percentages of the areas occupied by natural habitats in grid cells covering the Czech Republic. Percentage values were classified using natural breaks (Jenks) method. In the Liberecký and Karlovarský regions only habitats of representativeness A and B were considered in order to reduce regional bias (Divíšek et al, 2014)

Divíšek et al (2014) concluded that seven clusters are the optimal number of landscape types in the country in this case. Mountain (1) to submontane (2) landscape types were both defined by mountain meadows, natural spruce forests and mires are separated (the first contain primarily montane Trisetum meadows and natural spruce forests, while the second are defined by acidic moss-rich fens and transitional mires). Hercynian upper-colline rugged landscapes (3) are characterized by Hercynian oak-hornbeam forests, and Hercynian upper-colline gentle landscapes (4) included acidophilous oak forests. Carpathian upper-colline (5) to submontane (6) landscapes contained Carpathian and Polonian oak-hornbeam forests from lowland landscapes. Dry hilly (colline) landscapes (7) were defined primarily by narrow-leaved dry grasslands and low xeric scrub, while lowland landscapes were defined by deciduous forests along lowland rivers (**Figure 8**).

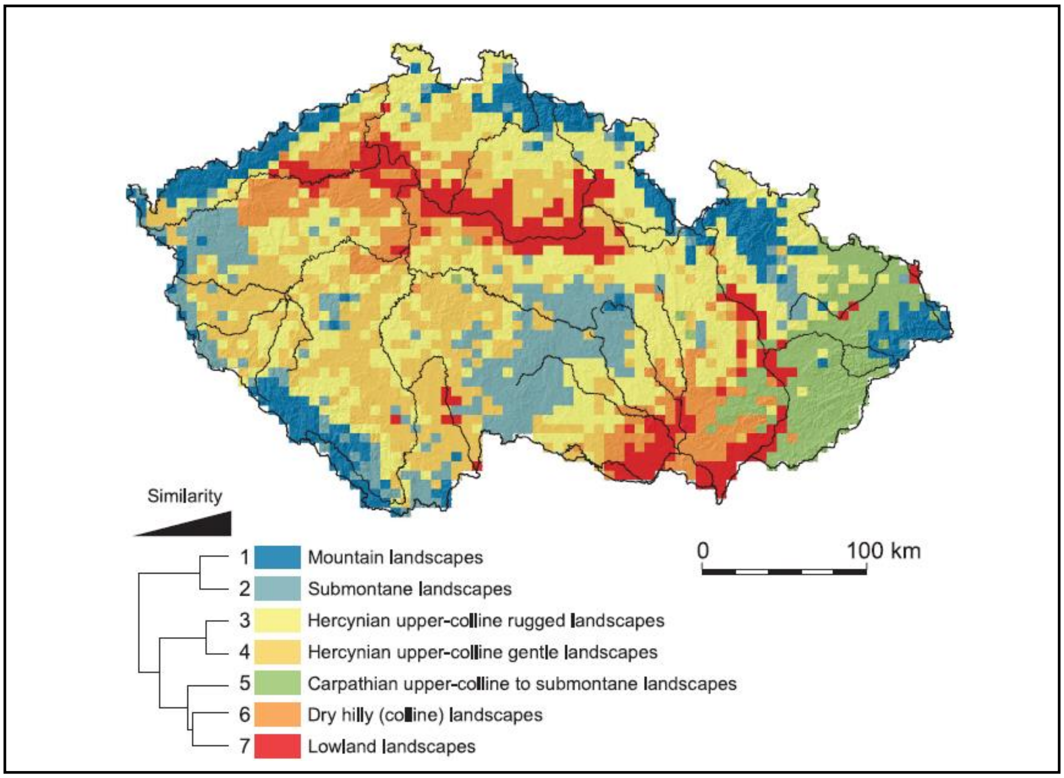

Figure 8. Landscape classification of the Czech Republic based on spatially unconstrained clustering with the optimal number of seven clusters according to the cross-validation procedure (Divíšek et al, 2014).

The mentioned seven landscape types differ in abiotic environment and geology. Some areas in Czechia show a comparatively higher number of natural habitat types. Those include the Křivoklátsko region south-west of Prague, or southern Bohemia, which is explained by high topographical heterogeneity of the landscapes with embedded river valleys. At the same time, very low habitat diversity is observed in lowlands of southern Moravia, in landscapes of the Mostecká Basin and of the Nízký Jeseník Mountains, explained by pressure from human activities in the first two cases or low landscape diversity in the last case.

Chuman et Romportl (2010) offered another landscape typology, which was created using cluster analysis, with a combination of the GIS and statistical tools and based on synthesis of such factors as elevation, aspect, slope, soils, reconstructed natural vegetation, mean annual temperature, mean annual precipitation and land cover. Eleven national landscape types were defined based on this classification (**Figure 9**).

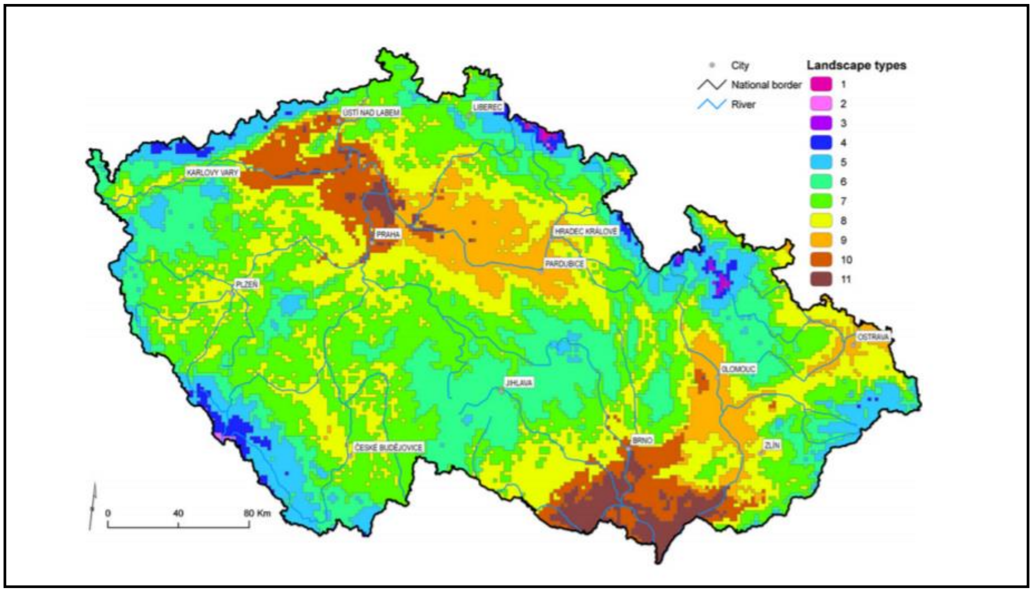

Figure 9. The 11 different landscape types of the Czech Republic by Chuman et Romportl, 2010

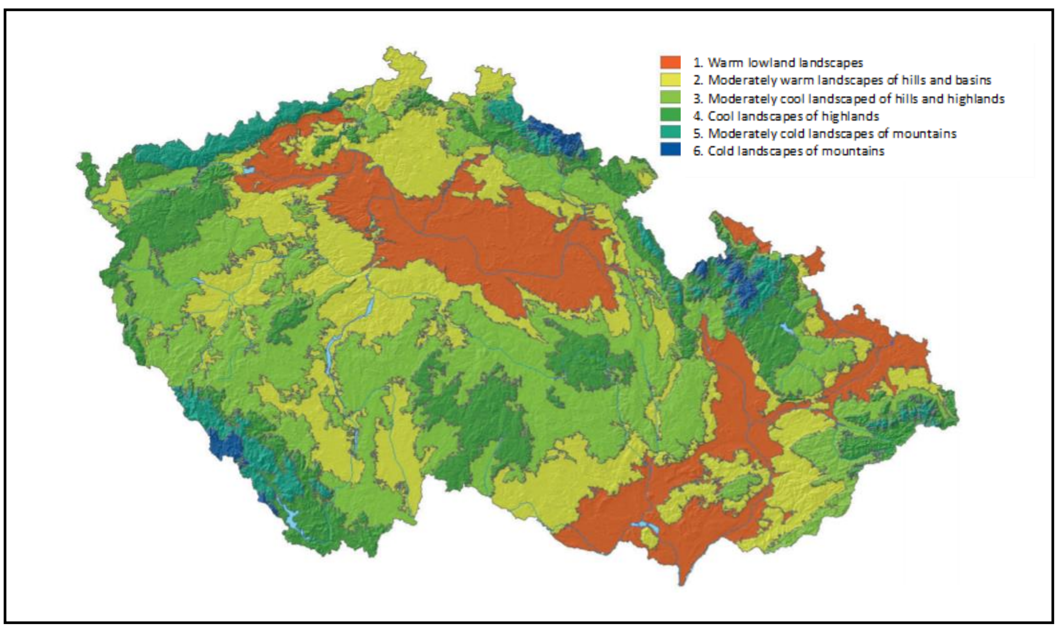

Figure 10. Six main general types of natural landscapes in Czechia (Romportl et Chuman, 2013)

However, in 2013 the same team offered a new classification system (Romportl et al 2013), which resulted in six classes as the framework types of natural landscapes (so called General Types of Natural Landscapes or GTNL) and "reflect the primary differentiation of natural conditions at the highest hierarchical level, which could be meaningfully applied in the spatial scale of Czechia" (**Figure 10**). This classification is also used in this thesis to indicate integrated natural conditions as one of the potential factors defining landscape. As the authors state, selection of relevant data for such classifications is easier to be done when hierarchical dependency and substitutability is considered. Selected variables included, firstly, annual mean air temperature, elevation, vertical heterogeneity, geological conditions and land cover. Additionally, soil conditions, potential natural vegetation and landscape structure have also been used.

This subdivision was considered for execution of the second step of the current research and choice of the cadastral districts, which were taken as the basic units for analysis (as mentioned in Chapter 3) selected in accordance, in order to represent different climate/geomorphology landscape types in the Czech Republic..

4.5.4. Existing studies on wood-pastures in the Czech Republic

Despite a few existing studies conducted specifically for wood-pastures in Czechia, information on changes and stability of these ecosystems at long temporal scale on the landscape level has been missing. LULC change is subject to a number of natural and social factors, so it is necessary to mention the already existing knowledge about these changes, and especially their underlying social driving forces. A review which was also based on administrative division of the country territory into cadastral districts was conducted by by Bičík et al (2015) for the period between 1845 and 2000. The authors found, that the most noticeable changes were the decline of the class of grasslands between 1845 and 1948 (though there has been a notable increase in the period from 1990 to 1999 again) in comparison to other classes, and also a large loss of pasture area and rise in arable lands, which occurred at the end of the 19th century. According to Vachuda (2017), though, the increase in grasslands from 1990 was observed at the national level, the situation differed between intensively and extensively managed areas.

Some researchers that have been working on wood-pastures in Czechia, express doubt about on their existence in the country in present times. According to Vojta (2012) for example, wood-pastures were formerly common in the Czech lands, however, do not appear in the same way as before the modern era. The author mentions that though evidence of their existence in the past times is found in old cadastral maps, old paintings or pre-war aerial photographs, nowadays, wood-pastures, in which traditional management persisted through time are sparse. Presumably, most of those remaining old ones, have at some point been filled by either planted or naturally established trees (Vojta, 2012). Places, in which a traditional form of pastoralism is still practiced by the Czech nationals, are found in multi-ethnical region of Romanian Banat, where a small community of Czechs settled in the middle of 19th century, forming several small villages, and transformed the forests to arable land, pastures and meadows in order to use the land in a similar manner as in Bohemia. These landscapes resemble those, that were formerly common in Czechia, with no sharp boundary between forests and pastures and with appearance of wood-pastures. However, these landscapes do not have large trees, but only shrubby beeches and hornbeams and relatively short-living shrubs (e.g. hawthorns), though they still show an outstanding species richness and feature-high spatial variability.

Habitats similar to the ancient wood-pastures can be found in Central Bohemia (Bohemian Karst), Western and Northern Bohemia, and Southern Moravia. However, they have diverse origins and management, and most are likely coming from pastures that had been abandoned for some decades (Vojta, 2012). This can be explained by abandonment of less accessible lands during communism and extensification of agriculture in the 1990s (Bičík et al, 2001; Feranec et al, 2010).

A good example of wood-pastures in present Czechia is the game park in Lany, north-west of Prague. Though it belongs to one of the largest and heavily naturally exploited areas in Europe, the park is a part of UNESCO Biosphere Reserve and Landscape Protected Area, with ancient woodlands spreading across an area of 30 km^2. It is inhabited by many threatened species, some of which are strongly connected to woodlands, including saproxylics, such as stable beetle populations of the violet click beetle (*Limoniscus violaceus*), the great Capricorn beetle (*Cerambyx cerdo*), the hermit beetle (*Osmoderma banabita*) and the stag beetle (*Lucanus cervus*) (Horak et Rebl, 2012).

A special case of wood-pastures of a recent origin can be found in park-like habitats in the abandoned landscape of Doupovské hory in Karlovy Vary region, which appeared after establishment of a large military area and the subsequent discontinuation of cultural landscape management in 1952 for several decades. This led to a natural succession and turned the area into wood-pasture-like landscape.

Issues in conservation practices for wood-pastures within Czechia, and their ecological values are related to the characteristic elements of their structure, and mainly associated with lack of information on the species richness and variability of new wood-pastures, such as interactions between shrubs and grazing on the small scale vegetation variability. This leads to misunderstanding of the role of scattered woody elements and their interactions with grazing for the small-scale vegetation variability (Vojta, 2012).

A clear understanding of the importance of wood-pastures, including their role for „productive“ and "non-productive" activities, specifically for the country, needs additional and deeper investigation and formulation (Vancura, 2006).

5. Studies

This chapter consists of three different case studies, each of which fulfilling specific tasks which together will answer the initially posted research question. First, each case study will be separately introduced, evaluated and closed with an individual conclusion, before the combined result will be summarized for a common conclusion in the next chapter.

5.1. Change trajectories of wood-pastures at the landscape level in the Czech Republic: the case of lowland areas

The main focus of this first study step lies on the analysis of general spatiotemporal dynamics and continuity of wood-pastures in the lowlands of Czechia during a long-time span and with respect to other LULC categories. Following the brief description of this step given in Chapter 3.1. Methodological structure, the goal of this first research step is to develop and test a methodological approach for defining the pattern of land LULC change at the landscape scale for a territory that spans the whole country, using GIS software. This is relevant for the following research questions:

RQ 1a. What are the observable change trajectories of wood-pastures in lowlands of Czechia at the landscape level?

H1. A general decline in the wood-pasture landscapes Czechia can be observed between the historical (first half of 19th century) and the current temporal horizon. Moreover, the decline is even stronger for the second half of the period under study (starting from 1950s).

RQ 2. How can continuity of wood-pastures in Czechia be characterized? (on the example of lowlands)

H3. Most wood-pastures within the current landscapes of Czechia appeared only recently. Very few old wood-pastures remain.

RQ 4. To which extent do other land use/land cover (LULC) types represent sinks of the lost historical wood-pastures, or sources of the recently appeared wood-pastures? Is this affected by different administrative districts and types of landscapes?

H6. The sinks and sources of wood-pastures are comprised of other cultivated/non-cultivated LULC types in a similar proportion within the different administrative districts.

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5.1.1. Study sites

Two major criteria were considered when choosing the study sites. First, as already touched in the previous chapters, the locations were selected in a way that they represent different administrative districts (cadastral districts). Nine cadastral districts were taken for this step (**Figure 11**). For better consistency and due to accessibility of data on historical land use, delimitation is based on their historical borders (their position and size in the first half of 19th century). Current boundaries of the districts might thus differ for some of the areas. As reported, in Czechia approximately 25% of the cadastral units have changed their areas during this period, and the total number of basic territorial units of analysis went from 13,000 to 10,000 (Harvey et al, 2014).

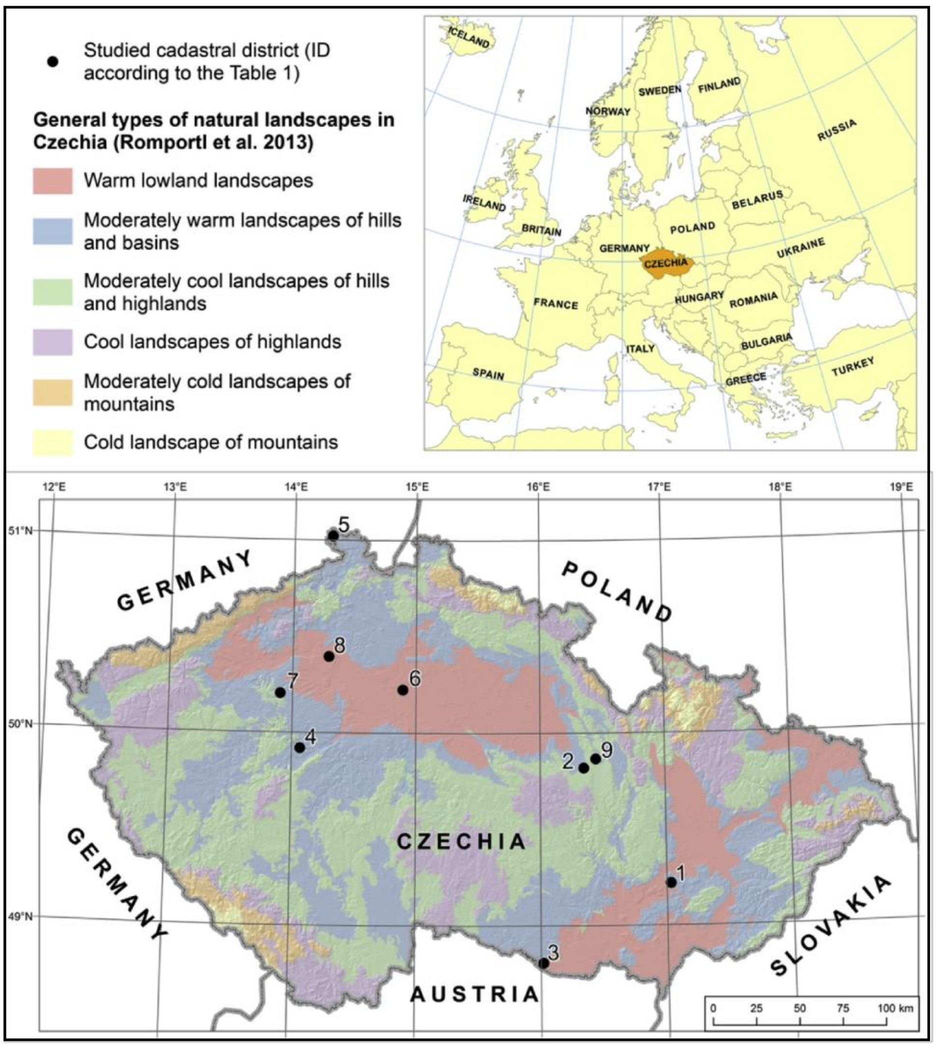

Figure 11. Localisation of the 9 studied cadastral districts with the context of the general types of natural landscapes in Czechia (Romportl et al., 2013). The number of a district refers to Table 3

The second criteria is related to climatic and geomorphologic characteristics. Namely, the two mildest climatic types of the country, located in the lowlands, were included here, referred to as "warm lowland landscapes" and "moderately warm landscapes of hills and basins", following the regional categorisation of the country territory into the six "general types of natural landscapes" by Romportl et al (2013) (GTNL), based mainly on such criteria as average annual temperature, slope and elevation. These two types cover as much as 46.6% of Czechia, with generally a high population density (71% of inhabitants of Czechia) (CSÚ, 2011), a relatively low cover of forests (20.4%, as compared to 33.3% by the whole country) and a high cover of agricultural land (67.7%, as compared to 57% in all Czechia) (CENIA, 2014). Only the cadastral districts with at least 0.5% of its area covered by wood-pastures as the LULC category were selected for further analysis (which could be pre-defined by orthophotos), which was necessary, first, to reduce the immense amount of manual work to a manageable level and, at the same time, to allow to see the changes of traits of wood-pastures (thus, to focus on areas where at least some reasonable amount of wood-pastures are present at the current moment). The areas of districts range from 3.8 to 28.6 km^2, and the total area of all analysed districts together equals 98.6 km^2, which is 0.3% of the total area of the selected types of natural landscapes (warm lowland landscapes and moderately warm landscapes of hills and basins) in Czechia (Table 3). According to information from CORINE (in 2012), the studied districts are composed of arable land (45.8 ± 20%), forests (23.3 ± 16.7%), heterogeneous agricultural areas (12 ± 7.8%) and grasslands (6.7 ± 11%) (CENIA, 2014).

5.1.2. Data sources

Since three temporally distant time horizons are considered in the analysis, various data sources are used in combination in order to reflect the state for all the three periods in a comparable manner. These data sources are specified below separately for each time horizon.

1st half of the 19th century

The period of the 1st half of the 19th century was chosen as the first temporal horizon to be include into analysis, because it is the earliest known period, which the LULC has been described for relatively precisely in the maps, which are still available, and which covers the whole extent of current Czechia.

Generally, tracing landscape changes, which were taking place for up to three last centuries, has become possible with the possibilities of modern technologies, and few data sources such as the old maps, including the lands of current Czechia, created cca. between the early 18th and mid-19th century have become available. However, many of these old maps do not give enough details or are not accurate, which is the case of the maps of the 1st Military Survey (scale 1:28,800), carried out under Emperor Joseph II between 1785 and 1789, which are popular among scientists. The 2nd Military Survey, which was started under Emperor Francis II produced much more accurate results and is also compatible with modern maps. The Survey began in Lower Austria in 1817 and was finalized in Tyrol in 1861. Maps of the Second Military Survey, derived from the so-called "stable cadastre" (a very precise map of scale 1:2,880), were put together in Bohemia (1826–1843), and Moravia and Silesia (1824–1836). They are also directly linked to the more recent cadastral maps (incl. present situation) and thus represent a valuable source of information for studying long-term land use changes (Bičík et al., 2015). Altogether, the series of Stable Cadastre maps covers the whole former Habsburg monarchy and has been widely used in recent years for studies of LULC of the territories, which are currently Czech territory (e.g., Bičík et al., 2001; Lipský, 1995; Raška et al, 2016) and was chosen for the analysis of historical temporal horizon in the frame of the current work. The whole document is created as a collection of map sheets, each representing different parts of Czechia, and completed continuously in the period between 1824 and 1843. Thus, it is only possible to use the dating "1st half of the 19th century" to indicate the time horizon, since the precise dates for each of these sheets are unknown. These maps not only reflect usual land use classes, but are also providing evidence on whether or not each of these landscapes can be classified as agroforestry (Krčmářová and Jeleček, 2017), e.g. by presence of pastures, meadows or arable land with scattered woody vegetation. The map sheets of the scale 1:2880, commonly called *"Imperial imprints of the Stable Cadastre"*, or "*Franciscan cadastral maps*", were obtained from the Czech Office of Surveying Mapping and Cadastre (ČÚZK, 2015) in the form of scanned imprints. According to INSPIRE Thematic Working Group Cadastral Parcels (2009) in general, the assignment of cadastral districts in the modern time is focused on the geometrical aspects of the parcels as presented in the national systems of the Member States, but not exclusively their ownership and related rights. More specifically, the districts should be as much as possible, single areas of Earth surface (land and/or water) under homogenous real property rights and unique ownership (as defined by national laws). The current Cadastre of Real Estate of the Czech Republic originated from the former Land Registry and the Land Cadastre, joined in one state administrative body, and is maintained by Cadastral Offices within their competences (UNECE Working Party on Land

Administration, 2000). Comparison of the changes based on the "technical" division into cadastral units, allows also to see the influence of local government and traditions on those changes, regardless of other factors. Each sheet of "*Imperial imprints of the Stable Cadastre"* was georeferenced to S-JTSK coordinate system on the basis of the current Land Registry map, as well as of those from 1930s-1950s (both available as Web Map Service via ČÚZK, 2015), using ArcGIS software (ESRI., 2015). To do this, control points were identified on the more recent map and distinct corners and edges of parcel boundaries or parcel intersections at the old imprints, which could be confirmed to have saved their shape throughout the whole study period. In total, 71 map sheets were processed, and polynomial transformation of the 1^{st} order needed to be applied for 62 of them, with the root mean square error (RMSE) equalling to 1.4 per map sheet on average. For the remaining imprints 2^{nd} order polynomial transformation was used, with the average RMSE equalling to 1.6 per map sheet. Generally, the transformation was done to best suit the current cadastral map.

Temporal horizon: 1953/54

The period of 1950s was chosen as the second temporal horizon not just because it is a middle point of the whole studied period, but is also notably distinct and characteristic for the history of Czech landscapes, due to significant changes taking place during this period. In more details, this period was followed by huge and systematic changes in the landscape structure and use. This was caused mainly by general political changes within the country, resulting in total intensification of agriculture and consolidation of land parcels. At the same time, this led to abandonment of many lands, which are located in more remote areas, or are simply less productive (Lipský, 1995). As the main source of data about the landscape structure for this period, historic black-and-white orthophotos, from 1953/1954 (CENIA, 2012) were used. However, an important disadvantage of this source, which makes it inferior in its accuracy compared to the other two temporal horizons, is that it is only able to give information about land cover for, but not the land use. No other reliable sources were available which could fill this gap. Thus, the period of 1953/1954 provides a good evidence on dynamics and the age of woody vegetation, but the land use cannot be identified accurately from the photos, which is one of the complications for examination of this time horizon. This period still yields valuable information and is thus included into this whole analysis of the first research step, described in this subchapter. However, as a way to counter this lack of data, the chapter does not consider a separate class of „wood-pastures“, but instead looks at a more general category of „semi-open habitats“. It should be noted that there have been studies where aerial images were used to identify wood-pastures. However, this approach is not suitable in the current case study, since it only allows to identify wood-pastures, where common and traditional land management is present, which is not characteristic for the majority of Czech lands (Costa et al., 2014; Plieninger, 2006; Schaich et al., 2015).

Temporal horizon: 2015/2016

The third temporal horizon offers a larger selection of accurate data sources. Thus, several complementary sources for defining the LULC for this period were used. The current orthophoto as provided by ČÚZK (ČÚZK, 2016) was taken as a basis, as it reflects well the land-cover and helps to identify current locations of wood-pastures. Further, a map of Land Parcel Identification System (LPIS) was applied in addition to help distinguish agricultural land uses (Ministry of Agriculture of the Czech Republic, 2016). LPIS contains updated information on the subsidies, offered by the state in support of farming lands of the country, available as Web Map Service (WMS). It provides information on which crops are represented at the plots, in case the farmers applied for subsidies for these plots. However, LPIS can only include parcels of small non-market subsistence, and if each specific parcel is larger than 0.1 ha. As another additional source the *Regional forest development plan* (Czech: *"Oblastní plán rozvoje lesů"*) was used (ÚHUL, 2000), which gives the area, which is treated as forest. Overall, this plan represents a methodological tool of the state forestry policy, which provides recommendations on forest management principles and contributes to the implementation of key actions of the National Forestry Program. Locations within the country, where presence of wood-pastures at current moment are very likely were identified from the above-mentioned sources. Their presence was later on directly confirmed in the field. For this purpose, field trips were done to each of the cadastral areas in the period between July and August 2015 to confirm if the land cover and land use of the locations had been defined correctly. The second series of trips was done during October and November 2016 for a review of the conclusions on presence of wood-pastures at the current moment, which were done according to the information collected previously, and also to be able to make more secure judgements about the current LULC (to account for possible changes on a shorter time-scale). Since different data sources originally represented data in differing forms a unified classification system was created to be applied to this research. Five categories of LULC were defined, according to tree density and tree canopy cover and interpreted visually (Table 2).

Table 2. Categorisation of the studied areas of recent(lost) wood-pastures by past/present LULCtype as accepted for the current study

LULC category	Description
Open landscapes	All open habitats with less than 7 trees/ha. For the 1st half of the 19th century, only those parcels depicted as agricultural with no woody vegetation
Semi-open landscapes	At least 7 trees/ha and maximally 80% tree canopy cover. The threshold was inspired by other studies on sparse woody vegetation development (Garbarino et al., 2011; Grossmann & Mladenoff, 2007). For the 1st half of the 19th century, all parcels with agricultural land use with woody vegetation as subordinate land use.
Closed landscapes	Habitats with at least 80% tree canopy cover. This class also includes land declared as forest by ÚHUL (2000), although these may be temporarily open but no pastoral management can be expected because grazing by domestic animals has been prohibited since 1960 (NS CSSR, 1960) and is not practiced now. This class also contains all forest parcels of the Stable Cadastre, despite uncertainty of what the actual tree canopy cover on the parcels was.
Wood-pastures	As a subtype of semi-open habitats where grazing is the dominant management of semi-open grassland (applied only to the 1st half of the 19th century as pastures with trees and for 2015/2016)
Other areas	All areas not mentioned in the other categories, such as urban and industrial areas, water streams, water bodies, etc.

As additional sources, and for fast navigation at the most general level, web applications such as Google StreetView (https://maps.google.com/) and Panorama on Mapy.cz (https://mapy.cz) were also used. The base map of the Czech Republic (scale 1:10 000) (ČÚZK, 2016) served as an additional source of other information, such as occurrence of water courses and routes etc.

5.1.3. Primary analysis of changes and continuity of wood-pastures

After all the data was collected, the analysis was performed in the GIS environment, using ArGIS 10.4 software (ESRI, 2015). All parcels were classified into segments manually by LULC categories (as defined in Table 2) based on the visual interpretation of historic and current aerial photos and map legends of different source-maps. First, wood-pastures and other LULC categories of the 1st half of the 19th century and of 2015/2016 were vectorized in the ArcGIS 10.4 environment, with the minimal mapping unit set to 0.3 ha. Next, interpretation of LULC of current wood-pastures in 1953/1954 and in the 1st half of the 19th century was completed. In a similar manner, LULC of wood-pastures from the 1st half of the 19th century in 1953/54 and in 2015/2016 were interpreted.

The vector layers, created for wood-pastures and other LULC categories were topologically checked by the rules “Must not overlap” and “Must be covered by feature class of” (every possible combination of layers was examined). Here, only those areas were vectorized, where wood-pastures exist or existed in any of the studied periods, as it was done in some studies on non-forest woody vegetation (Demko et Lipský, 2015; Plieninger et al., 2012). Attribute tables were also checked for missing data. Former LULC categories of the locations, where current wood-pastures are defined, were interpreted according to the situation in both time horizons of 1953/1954 and the 1st half of the 19th century.

Overlay analysis using the *Intersect* and *Union* tools was performed to reflect the difference between the polygons of the different time layers. The final layer was transformed into raster using the *Feature to raster tool* to eliminate sliver polygons (Grossmann et Mladenoff, 2007). The raster cell size was set to 5x5 meter and was controlled by the value of the largest area in the cell. As a result, all the parcels, which at some point were covered by wood-pastures could be classified, according to their continuity, into the 5 groups:

- **persistent:** if the area kept the same LULC (wood-pastures), through all the Old Land Registry Maps, historical aerial photographs from 1950s, and the present orthophotomap;
- **lost by 1950s / lost by 2015/2016:** if the area appeared as wood-pastures according to the Old Land Registry Maps, but was transformed into another LULC type by 1950s (or by 2015 respectively);
- **gained by 1950s / gained by 2015/2016**: if the area represents a newly established wood-pastures on current orthophotomap, but was of a different LULC category in the Old Land Registry Maps (or only in 1950s respectively), and therefore was transformed into wood-pastures at any of the more recent temporal horizons.

A few general possible patterns of change trajectories were considered, demonstrating the changes between the wood-pasture and other different LULC categories, reflecting the changes between all the three time horizons, and, thus, allowed to highlight the dominating sources of the more recent wood-pastures and sinks of the lost ones.

5.1.4. Results

5.1.4.1. Overall changes

The total areas of wood-pastures in the different temporal horizons were found for the selected study sites, with the total area of cadastral districts of 98.6 km^2. After applying the minimal mapping unit (0.3 ha) to the parcels, for the horizon of 2015/2016 the total area of wood-pastures reaches 163.7 hectares, which is 1.7% of the total area of the cadastral districts, in which they are located. This number appeared to be considerably lower for the situation in the first half of 19th century, equaling 78.1 hectares, which covers only 0.8% of the studied area of the same cadastral districts. This means, the area of wood-pastures between the very first and the last time horizons has more than doubled. At the same time there is a notable difference of this change pattern, when comparing the individual cadastral districts. As a notable example, Milovice (ID6 in **Figure 11**) district has large wood-pasture now, as well as large proportion (3.2% of the cadastral district or 37.5 ha) of its area, covered by wood-pasture now, though it had no large ones in the 1st half of the 19th century, and generally there has been a notable increase of the wood-pastured area in this region. In contrast, in Bohdalice district (ID1 in **Figure 11**) a sharp decline of 77% of this LULC category was observed between the first and the most recent temporal horizons under study. A more detailed overview of the changes between all three temporal horizons and the change trajectories between the different LULC categories is given in the next subsections.

Table 3. Overall changes of wood-pastures cover in the studied areas between the 1st half of the 19th century and 2015/2016

			Wood-pastures 1824-1843		Wood-pastures 2015/2016		
ID	District	Area (km^2)	Area, ha	Relative area, % of district area	Area, ha	Relative area, % of district area	Net change (% of initial area)
1	Bohdalice	5.0	12.8	2.6	2.9	0.6	-77.0
2	Čistá	28.6	14.4	0.5	30.5	1.1	111.9
3	Havraníky	11.3	23.2	2.0	28.7	2.5	23.9
4	Koněprusy	4.4	1.8	0.4	19.4	4.4	980.9
5	Lobendava	11.4	4.9	0.4	18.3	1.6	271.7
6	Milovice	11.8	1.8	0.2	37.5	3.2	1932.2
7	Mšec	13.8	15.8	1.1	7.4	0.5	-53.2
8	Rovné	3.8	1.8	0.5	4.3	1.1	136.3
9	Semanín	8.6	1.7	0.2	14.8	1.7	792.7
	Total	98.6	78.1	0.8	163.7	1.7	109.6

5.1.4.2. Habitat continuity

Here further details, beyond the general changes of the total area of wood-pastures for the whole period under study, are given, now considering also their relative stability through this

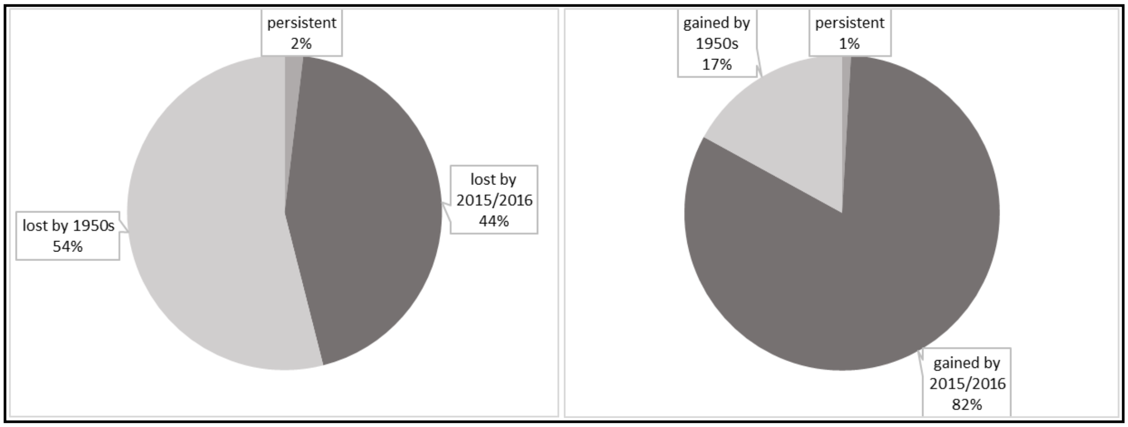

Figure 12. Continuity of wood-pastures present between the periods of 1824-1843 and of 2015/2016

time. This should also allow to see how many of the wood-pastures of the later temporal horizons can be characterized as “ancient”, and, thus, the most valuable from both ecological and social points of view. The results of comparison between the three temporal horizons, taken by pairs, are offered here. First, the horizons of the 1st half of the 19th century and the 1950s were compared, which has revealed that a loss of over a half of wood-pastures appeared in the beginning of the socialist era. Another 44.1% of wood-pastures area was lost later, in the period between the 1950s and 2015/2016 (**Figure 12**). Only 1.9% of the wood-pastures, which existed yet in the 19th century were present at all three temporal horizon, thus could be characterized as continuous, which means that the oldest parcels should be expected there. Two cadastral districts, namely in Rovné and Mšec (ID 8 and 7 in **Figure 11**, respectively), are outstanding by the area of persistent wood-pastures. From wood-pastures, present at the moment, the majority (over 80%) are of recent origin, and appeared after the 1950s-temporal horizon, thus, throughout the last 60 years.

5.1.4.3. Losses of wood-pastures and their sinks

Out of the wood-pastures, which were lost between the temporal horizons of the 1st half of 19th century and 1953/1954, the majority was converted into some of the open LULC

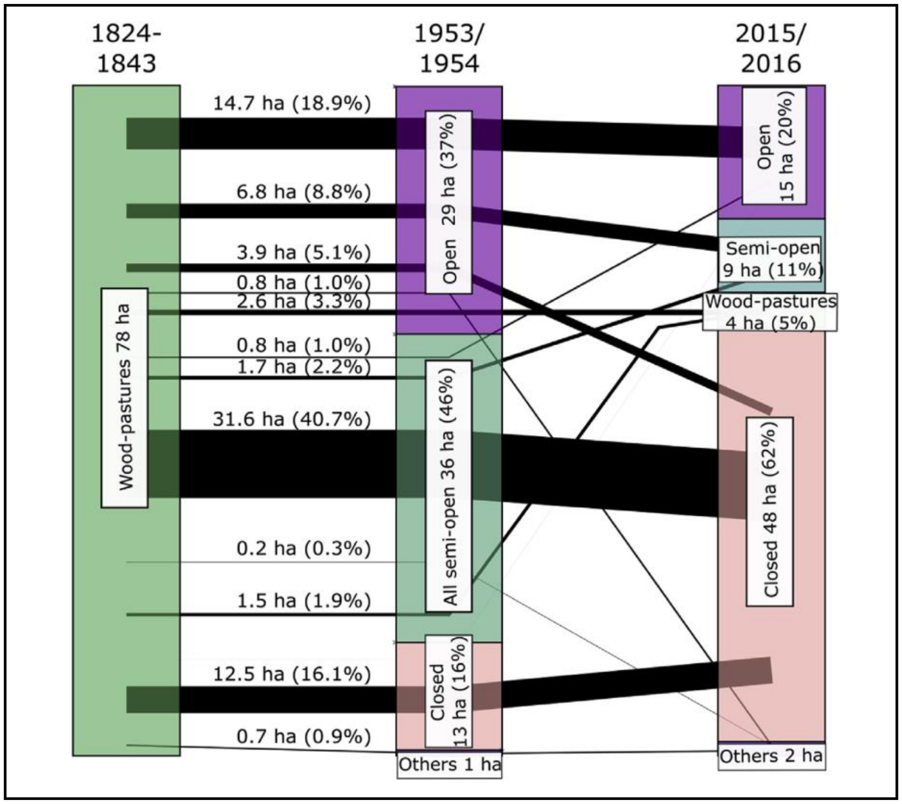

Figure 13. Change trajectories of wood-pastures present in 1824-1843

category, such as arable land or grassland (**Figure 15**B, **Figure 13**), thus the main trend of landscape changes was towards general loss of the tree cover. At the same time, some of these areas, which were losing wood-pastures in the first period, started to get overgrown by trees later on and, thus, recovering to either semi-open or closed LULC types by 2015/2016. As a result, a few of them have gone through a transformation from wood-pastures to open landscapes and back to wood-pastures. Interestingly, almost all locations, which were covered by semi-open landscapes in 1953/1954, thus, potentially being wood-pastures at that time, later turned into forests by 2015/2016, and only a small part of former wood-pastures (less then 3%) were turning into any other categories, such as urban areas.

5.1.4.4. Gained wood-pastures and their sources

When looking at wood-pastures, which were newly appearing by either 1953/1954 or 2015/2016 temporal horizons, the patterns of their sources differs noticeably between these time frames (**Figure 14**). Most of the wood-pastures found in the 2015/2016, appeared during the last 60 years due to overgrowth of formerly more open landscapes. This also means that the woody

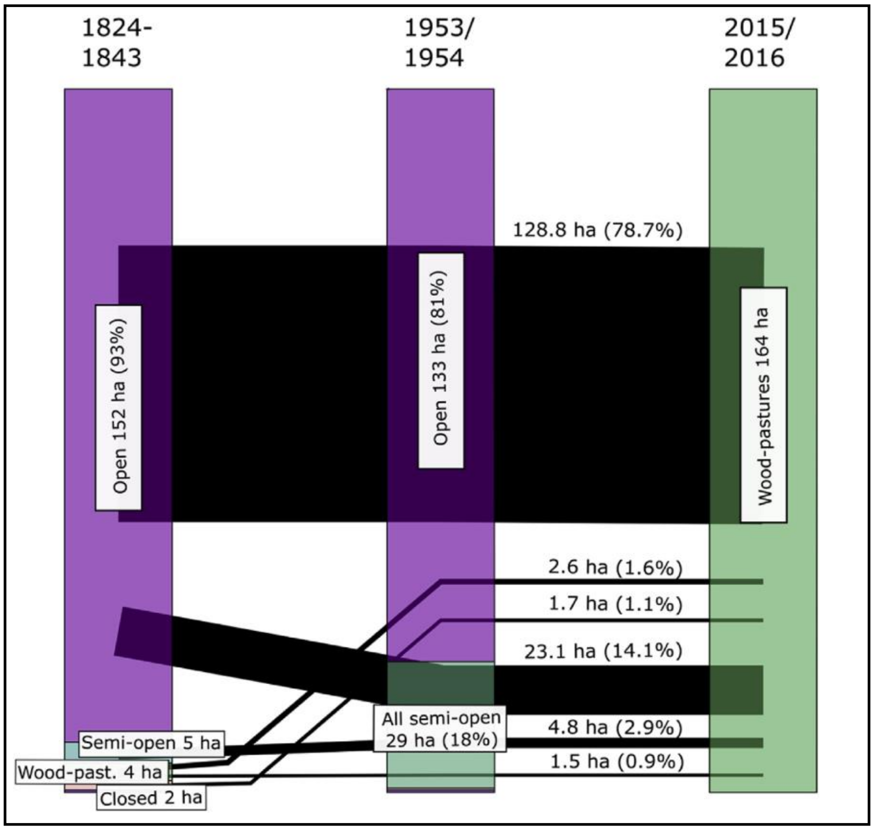

Figure 14. Change trajectories of wood-pastures present in 2015

vegetation found there can be expected be relatively young and with none of the most valuable, ancient trees. Typically, such transitions could be happening as a result of abandonment of former military training areas and their transformation into wood-pastures due to overgrowing. Two examples of the latter among the study sites of the current research step are the cadastral districts of Milovice and Semanín. This way, these districts got covered by the more valuable grasslands, which are being conserved by grazing, as the major tool for wood-pastures management. About 58% of these areas are represented by grasslands with high biodiversity and maintained as territories under either natural reserves or private natural reserves. The locations, which used to be covered by forests in 19th century could not be characterized with certainty as one of the characteristic sources of the current wood-pastures, meaning change trajectory „forests-to-wood pastures" between the very first and the very last temporal horizons seems to be very rare and close to zero. Those wood-pastures, which are located in areas, previously covered by forests, were converted before 1953/1954. Even if this selection is broadened (in the case of the second temporal horizon) from only wood-pastures to all semi-open habitats, still only 3.8% of the current wood-pasture area can be proved to have been continuously present during the last 170

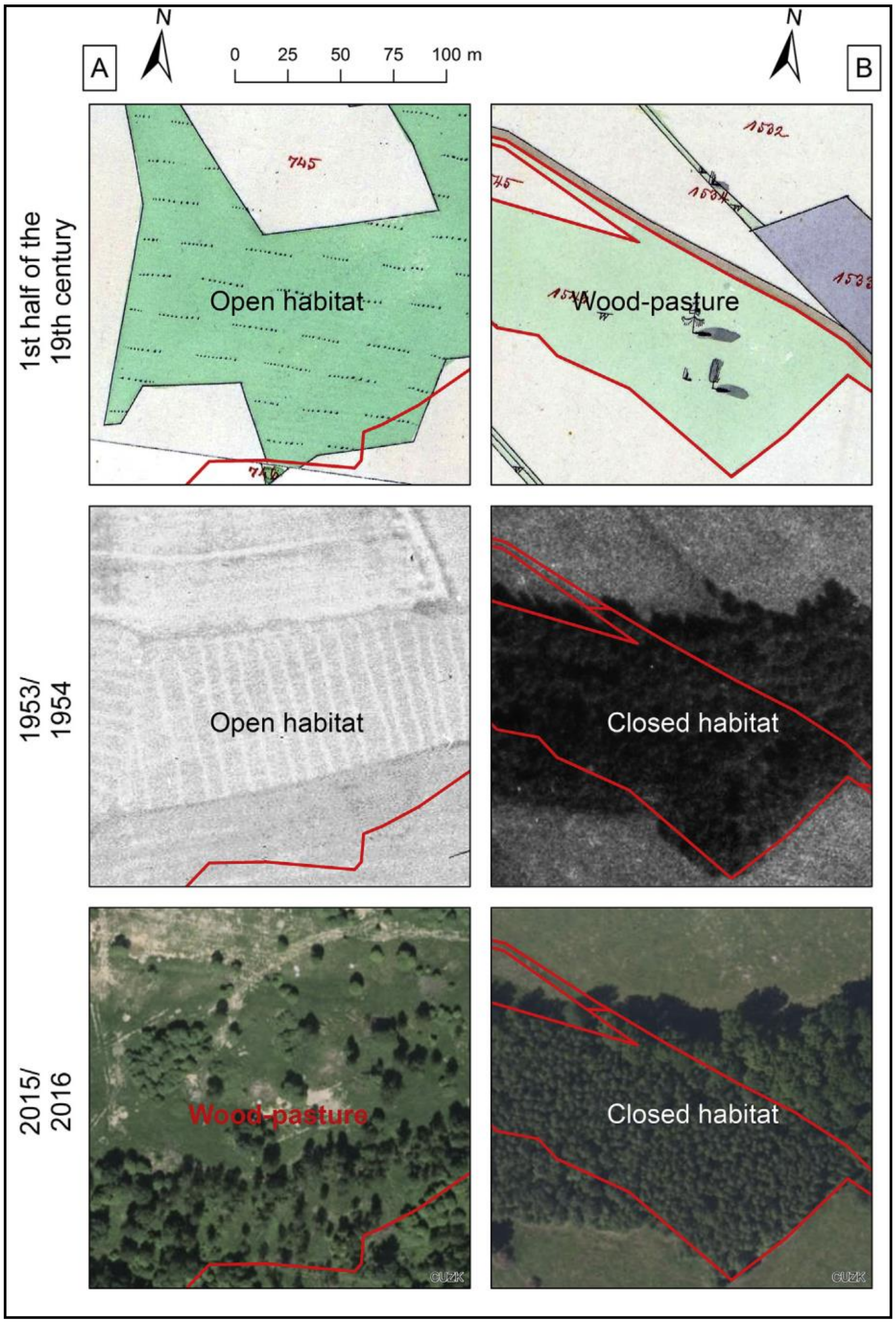

Figure 15. Examples of typical change trajectories of wood-pastures present in 2015/2016 (A) and wood-pasture present in the 1st half of the 19^{th} century (B)

years. As an example of such development, a wood-pasture in Rovné district was formed on historical parcel of previously arable land with fruit trees.

5.1.5. Discussion

5.1.5.1. Discussion on results

According to most previous case studies, focused on analysis of long-term spatiotemporal changes of wood-pastures and their causes, a general decrease in the extent of these landscapes is observed, and is usually related to different natural and cultural conditions (Costa et al., 2011; Garbarino et al., 2011; Plieninger, 2006; Schaich et al., 2015; Varga et al., 2015). Though a general increase of total area of wood-pastures was observed within the study sites of the current step, this does not allow to state that these results are contradicting the previous conclusions of the mentioned researches, and that the trajectory change patterns of wood-pastures for the whole country is also a positive. In fact this discrepancy can be explained by how the study sites had been selected: instead of their random allocation in lowland and warm landscapes of hills and basins of the Czech lands, the sites were purposely picked in places with at least some of currently existing wood-pastures. The reasons for such selection were, firstly, as this would allow to observe the change of wood-pastures' traits over time, and also as this would help to include more of potentially ancient or persistent parcels. Another point to remember is that during the second half of 19th century arable lands became quite concentrated closer to industrial centres, mainly in lowlands, with all the other related farming activities (mainly due to demographic factors) (Bičík et al, 2015). Altogether, this means that despite the emergence of wood-pastures (with an increase by over 100%) on the examples of the current research step, this finding might not be true for the overall area of wood-pastures in Czechia.

Another important fact is that, even though a positive total net change of wood-pastures by area was noticed, hardly any of the current wood-pastures can be characterized as continuous throughout the whole period under study. In other words, only a tiny portion of the habitats have stayed the same for the last 60 years. This sets Czechia apart from the rest of European countries, when looking at other studies, which were held, e.g. in Spain (Plieninger, 2006), Portugal (Costa et al., 2011), Germany (for the case of orchard meadows) (Plieninger et al., 2015) and Greece (Schaich et al., 2015). The only other location, for which a similarly low persistence of wood-pastures was described are the Italian Alps (Garbarino et al., 2011). However, it should be noted, that the time periods which all of these other papers describe are much shorter. The mentioned study in Italy by Garbarino et al. (2011) analysed the changes of wood-pastures for that region and demonstrated losses of those, though still covers a considerably shorter and recent temporal interval (between 1961 and 2003). A related research for Lesvos island (Greece) considered a similar period between 1961-2010 (Schaich et al., 2015) and multitemporal analysis was made for some location within the Iberian Peninsula (Plieninger, 2006), which covered a similarly short period of time, but included three temporal horizons (1956 - 984 - 1998). A study, which did include a much longer period (1818-2005), was completed by Varga et al. (2015) in Hungarian hilly area. It also included subdivision of the whole study period into four temporal horizons, and used old maps besides the aerial photographs data source.

The conclusion above leads to the idea of consequences of the observed changes in wood-pastures in relation to biodiversity. In more details, ancient wood-pastures are generally considered as those most important from this point of view, as they form biodiversity hot-spots (Falk, 2014; Paltto et al., 2011). Since here high losses were identified specifically among the older wood-pastures, which also means losses of potentially old trees, a significant decline of biodiversity could be expected at both local and regional levels in the present time. At the same time, it is hardly possible to calculate these losses precisely, especially considering that some of the species could have found alternative habitats in the grasslands and forests as a replacement of the original wood-pastures, and the parallel compensatory process of diversity gains thanks to establishment of new species at the lands, formerly covered by wood-pastures. Some authors have reported that open grazed shrublands may express higher species diversity, in comparison to other habitats, and thus, independently of presence of older trees in the landscape, but with the important role of shrubs, e.g. for specific bird species (Vojta et al., 2014), while , other studies (Jakobsson et Lindborg, 2015) confirm increase of γ- and β- diversity with the increasing tree density at the pastured landscapes (e.g. East Vättern, Sweden).

From the 1st half of the 19th century to 1953/1954, slightly less than half of the area that was covered by wood-pastures seem to have persisted. Most former wood-pastures turned into landscapes of more open land cover categories of both cultivated and non-cultivated land uses (either arable lands or pastures without trees or meadows). A much smaller part of the original wood-pastures has overgrown into more closed land cover categories. Altogether, these observations reflect intensification of land use in agriculture during this period. Agriculture in the period between 1840s – 1950s was represented by private peasant form of production, with a dominant role of human and animal force. Meanwhile, new technical equipment and newly introduced plants resulted in more intensive use of lands which were originally less productive (Grešlová-Kušková, 2013; Jepsen et al., 2015; Šantrůčková et al., 2015). The main change presumably occurred in the end of the 19th century when a significant loss of pastured lands in general and an increase of land use for agricultural purposes took place in Czechia (Bičík et al., 2001).

The observed changes of wood-pastures in Czech lowland areas differ e.g. from those in a similar site in Bakony hills (Hungary). There, a wood-pasture appeared on the territory of a former forest in the period between 1818-1880 (Varga et al., 2015) or another comparable site in Romanian Carpathians, where significant losses of pastures experienced a conversion into forests in period of 1790-1867, which also differs from observations for the study sites in Czechia, reported in this chapter (Pătru-Stupariu et al., 2013).

Out of the wood-pastures of the 1st half of the 19th century in the area of the current study, which could still be characterised as semi-open until the 1953/1954 (since only the land cover could be identified for the temporal horizon of 1953/1954), almost all have changed into forest by the current temporal horizon. Thus, hardly any wood-pastures, which existed in the 1st half of the 19th century stayed throughout the whole period covered by the research, and most of them have overgrown into forests. This reflects mainly the extensification of agricultural land use, which was taking place after 1950s. Specifically, the characteristic trends of this period included collectivization and turning towards use of large open fields and heavy mechanization, which also led to abandonment of the less accessible lands, including arable, some of which were reforested (Grešlová-Kušková, 2013; Jepsen et al., 2015). On a broad scale, these results agree with researchers dealing with the wood-pastures' dynamics in the period of 2nd half of the 20th century in their conclusions about the nature of major driving forces of wood-pasture decline, as well as (to a lesser extent) upon the emergence of recent wood-pastures. he role in losses of wood-pastures is attributed to the processes of intensification and particularly more intensive grazing (Plieninger, 2006; Schaich et al., 2015; Varga et al., 2015). It is noteworthy, that among the factors of wood-pasture losses quite opposed processes are mentioned, such as the farming extensification on one hand and the land abandonment on the other. Both of these processes were leading to tree and shrub encroachment (Plieninger, 2006), coupled with the depopulation and disappearance of traditional management techniques, which had a considerable impact on the wood-pastures decline.

Comparing the outcomes in this section to those described for Spain, Portugal or Greece (Lesvos), wood-pastures of Czechia seem to be more dynamic and less persistent landscapes. Also, though generally wood-pastures have a long tradition in European history as a land use (Jørgensen et Quelch, 2014), specifically in the lowlands and hills of Czechia, which are described here, they cannot be considered as a traditional land use (Krčmářová et Jeleček, 2017), and might be considered as allochthonous. Generally speaking, the majority of the wood-pastures, that are currently found in the lowlands and hilly landscapes of Czechia, were shown to have originated from former open habitats recently, which is again likely linked to the fact that the less accessible lands were being abandoned during the communist times and the trend of agricultural extensification in the 1990s (Bičík et al., 2001, Feranec et al., 2010). Thus, ancient trees may hardly be expected in these places, though according to Krčmářová (2016), some ancient trees can still be found in the landscapes, formerly occupied by agroforestry lands. At the same time, some authors (e.g. Roellig et al., 2015) state that there is enough chance to restore some of these lost wood-pastures, specifically, those, which became overgrown and converted into landscapes with closed canopy, and at the same time, are not registered as forest land in Czech Cadastre. Thus, even though these landscapes were not here in the past (Antrop, 2005), we might see them as sustainable landscapes of the future and as an example of integrated landscape management (Manning et al., 2006). Yet, their sustainability should be further studied especially by means of land users' motivation analysis.

5.1.5.2. Discussion on the methodology

This 1st case study was based on 9 selected cadastral districts (sample plots), located exclusively in warm lowlands and moderately warm landscapes of hills and basins in Czechia (as defined by Romportl et al., 2013). The total area analysed covers 98.6 km^2 which includes about 0.3% of all the lowland territories of the country. Furthermore, only districts where wood-pastures take at least 0.5% of the district area, where selected for the final analysis. Simple extrapolation of the changes of wood-pastures of this research to the whole country should not be done. Yet, the outcomes help judging about continuity of current wood-pastures.

One of the advantages of the current study, is that it covers a relatively long period of time in comparison to other existing studies on the topic. The majority of previous works on wood-pastures were focused on dynamics within a shorter period and relied on historical aerial photographs as the main source of historical data (typically a few decades, as the studies mentioned in the previous section).

It is important to note that usage of the different types of data sources to cover the three temporal horizons in this work implies specific limitations to the methodology (Table 4). Generally, the method described in this research step can be applied the entire territory, which was included into Stable Cadastre mapping, thus, covering most of the former Habsburg Empire with the whole area of current Czechia. Certain obstacles come from georeferencing and digitising of old maps, such as sliver polygons, here they were avoided by transforming vector layer into raster with 5x5 meter cell size. Another limitation of the old maps of the Stable Cadastre is that they do not allow to precisely define land cover for all locations (e.g. density or specific location of woody vegetation), even though generally they can serve as a solid data source. Considering also that the definition of wood-pastures is partly relying on the tree density, the ability to prove that the patches marked as pastures with trees or shrubs on the Stable Cadastre are actually wood-pastures is sometimes limited.

According to Bičík et al (2015), information on land use, contained in current cadastral maps may be often incorrect. This is partially related to the fact, that the documented land use is updated only after the change is formally made by authorities. At the same time, starting from 1990, the landowners are given up to two years to report the respective changes. Still, the use of historical and the current Land Registry data has a number of advantages, since it not only covers long time periods, but also allows to get relatively precise and comparable data representation as it is defined by stable areas. These maps were created originally for taxation purposes and can now be used to see more detailed information of different nature (e.g. spatial, economic), which is related to each cadastral district. This allows to potentially use studies such as the current one in combination with further findings to relate them to other factors. As the cadastral maps are usually of detailed scale, they are relatively easy to be digitized with a good level of accuracy.

Compared to old cadastral maps, aerial photographs, which were used as another data source in this step, usually provide precise and detailed visual information, which is sufficient to judge about the land cover for the period of interest (Herold et al., 2003). However, they do not reflect land use, and with lower quality photographs – such as in case of the photographs for 1953/1954 – the land cover sometimes cannot be clearly identified. Thus, information about the landscape obtained for this temporal horizon is not always precise or reliable, and unlike for the temporal horizon for the 2015, additional sources are not available for additional proof. This way, aerial photos from the 1950s can only distinguish semi-open habitats as a generalized category, but not wood-pastures specifically. Moreover, grasslands with shrubs could sometimes be classified as open habitats because the shrubs are not clearly visible in the orthophotos. Another serious disadvantage of this method via visual interpretation of aerial images is that it requires a immense amounts of manual work, potentially involving several people. As a result, the outcomes can also be sensitive to individual perception manner of working when defining LULC categories of each parcel, and, altogether, the whole process is time-consuming.

Table 4. Limits and assets of the different graphical data sources used for description and analysis of LULC at different temporal horizons

	1824-1842: Imperial imprints of the Stable Cadastre	1950s: archival orthophoto	2015/2016: orthophoto, field mapping, LPIS, thematic layers
Advantage	Large scale mapping; existing classification of landscape segments	Detectible land cover	Diversity and availability of sources guaranteeing access to any information
Disadvantage	Lack of information about land cover (abundance and location of trees and shrubs at the plot)	Need of classifying the landscape segments; lack of information about land use (grazed/not grazed); low resolution of orthophoto, leading to uncertainty in locating shrubs	Time demanding, need of classifying the landscape segments

Old maps and aerial photographs, with statistical data about land use in addition, are the only solid data sources for checking LULC changes, but they need to be interpreted carefully. Firstly, the data, which was extracted from each of these sources, reflects the state at the time of mapping (temporal horizons). However, there is still a possibility that multiple and repetitive changes in presence of wood-pastures took place between these time horizons, which are not registered using the current methodology. All in all, it is practically impossible to distinguish all the continuous changes of wood-pastures within the timeframe of the research However, the results allow to define the major trends of these changes. A second issue is that the earliest existing accurate data suitable for this analysis is for the beginning of the 19th century. Information about previous LULC changes is scarce and often disregarded, though changes of the landscape before should not be ignored. Finally, the fact that some semi-open habitats were found on data sources from all three temporal horizons does not necessarily mean that these landscapes in the current state are covered by wood-pastures with ancient trees. In other words, the maps serve only to identify potential habitat continuity and thus high conservation value (Pătru-Stupariu et al., 2013).

5.1.6. Conclusion

The results help to answer the research questions posed in this study step.

Firstly, they contribute to answer for the Research Question 2 touching the character of wood-pasture continuity (see 5.1) for the case of lowland landscapes. Specifically, they confirm that most of wood-pastures have not been continuously present in all three studied temporal horizons (1st half of the 19th century, 1953/1954, 2015/2016). Moreover, most of the current wood-pastures are of recent origin and have been formed during the last 60 years (which supports Hypothesis 3). In addition, since the most common source of the present wood-pastures present are open-habitats, few old trees should be expected in these areas. In connection to Research Question 4, concerning LULC categories which act as sources and sinks, for the case of lowland landscapes, slightly less than a half of wood-pastures from the 1st half of the 19th century remained as semi-open habitats until the 1950s (thus conserved at least the same land cover category), which indicates that the landscape in the first period was relatively stable. At the same time, the process of agricultural intensification seems to have been affecting these areas more during this period, as the transformation the wood-pastures was going into open habitats rather than into forests, whereas the second time interval from 1953/1954 to 2016 is characterized by rapid transition of semi-open habitats into forest. Indeed, the socialist and post-socialist era was characterized by an increased rate of abandonment of the remnant wood-pastures. In the present time, wood-pastures are emerging again, although now they are valued predominantly as species rich grasslands, which are getting overgrown by woody vegetation and where grazing serves as a conservation management tool. In connection to the Research Question 1 about change trajectories in the case of lowland landscape, a general increase of wood-pastures was observed (which contradicts the Hypothesis 1in this case). However, the overall changes found in this section, especially the significant increase of wood-pastures area, cannot be generalized for all warm lowlands and moderately warm landscapes of hills and basins. This analysis fulfils the goal of studying the habitat continuity and change trajectories especially with consequences for the current wood-pastures so only specific, exemplary cadastral districts where wood-pastures cover at least 0.5% of the district area were selected.

5.2. Country-wide change trajectories of wood-pastures in Czech Republic: comparison of lowland and highland areas and relation to General Types of Natural Landscapes.

The second research step also investigates spatiotemporal dynamics of wood-pastures in Czechia between the beginning of the 19th century and the present temporal horizon. Different from the previous section, the analysis here is not limited only to lowlands areas, but all other landscape types across the country are also included. In addition, the role of aggregate influence of major natural conditions ("General Types of natural Landscapes", GTNL) as a driver of these changes was evaluated. The following research questions were considered in this step:

RQ 1b. What are the observable change trajectories of wood-pastures in the lowland and highland landscapes of Czechia in both the lowland and highland landscapes of Czechia at the landscape level? Are these change trajectories similar to those for only lowlands?

H1. A general decline in the wood-pasture landscapes Czechia can be observed between the historical (first half of 19th century) and the current temporal horizon. Moreover, the decline is even stronger for the second half of the period under study (starting from 1950s) *(on the example of lowland and highland landscapes).*

H2. The general dynamics of wood-pastures observed for the lowland and highland areas of Czechia taken together is similar to those of lowlands separately. Thus, a general decline of wood-pastures between the beginning of 19th century and current temporal horizon is observed.

RQ 2. How can continuity of wood-pastures in Czechia be characterized *(on the example of lowland and highland landscapes)*?

H3. Most wood-pastures within the current landscapes of Czechia appeared only recently. Very few old wood-pastures remain.

RQ 3. Do change trajectories of wood-pastures differ for different landscape types in Czechia?

H4. The amount of wood-pastures in both historical/present time horizons differs depending on the location within specific natural types of landscape.

H5. The scale of spatiotemporal changes in wood-pastures and their continuity varies depending on the landscape types.

RQ 4. To which extent do other land use/land cover (LULC) types represent sinks of the lost historical wood-pastures, or sources of the recently appeared wood-pastures? Is this affected by different administrative districts and types of landscapes?

H6. The sinks and sources of wood-pastures are comprised of other cultivated/non-cultivated LULC types in a similar proportion within the different administrative districts.

H7. The sinks and sources of wood-pastures are comprised of other cultivated/non-cultivated LULC types in equal proportions within the different types of landscapes.

5.2.1. Study sites

This second research step covers a total area of 757.57 km^2, thus is considerably larger than in the previous chapter. This includes study sites, from each of the six General Types of Natural Landscapes (GTNL), as defined for Czechia by Romportl et al. (by Romportl et al., 2013) (**Table 5, Figure 16**). This categorisation subdivides all Czech landscapes based on climatic and geomorphologic characteristics or natural conditions (such as geomorphology, climate, altitude) and groups them according to the specific combination thereof. Originally six groups are distinguished, however, for in this work the groups of moderately cold and cold mountain landscapes were united into one category, as they often appear within similar areas and have close natural characteristics. At the same time, the selection of study sites for this step was also based on administrative division of the country into cadastral districts. Initially 57 districts were selected in such a way that all GTNLs would be equally represented and each of them would presumably contain enough wood-pastures. Then, neighbouring wood-pastures (e.g. under

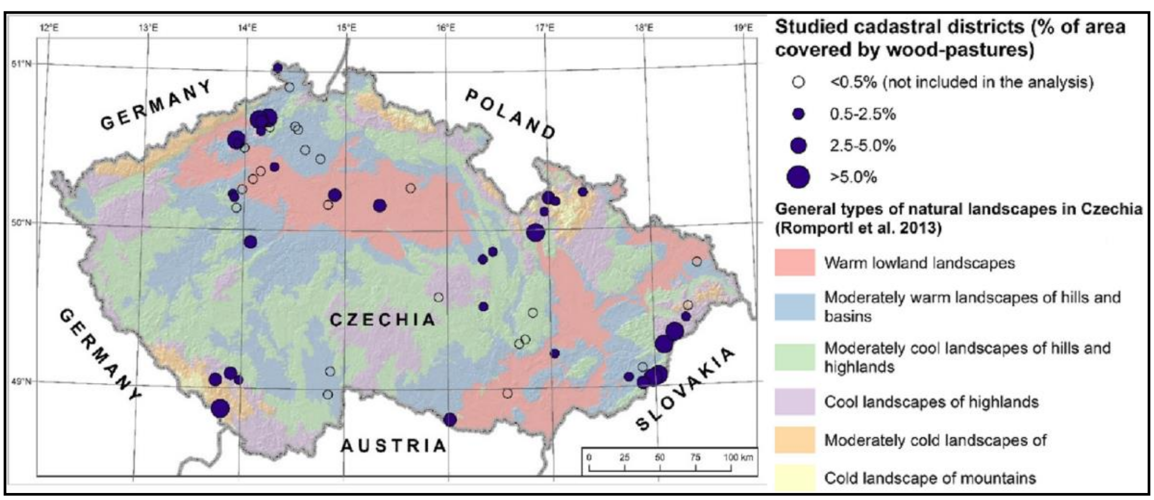

Figure 16. Location of the studied cadastral districts according to the general types of natural landscapes (Romportl et al. 2013)

different ownership) were merged, and parcels with areas below 0.3 ha were excluded from the analysis, as well as the cadastral districts with less than 0.5% of wood-pastures by area in their current state. In the end 30 districts with areas from 1.94 to 80.58 km^2 were included in the final analysis. Since the borders of some cadastral districts were changing throughout the studied period, the historical borders of the beginning of 19th century were chosen as reference to delimitate the cadastral districts for analysis of both temporal horizons. Also considering accessibility of data on land use at historical time horizon, the consistency of measurements can be ensured this way.

Table 5. Characteristics of the study areas - general types of natural landscapes (GTNL)

GNTL, code	GTNL, name	Characteristics	Area, km^2
1	Warm lowland landscapes	A landscape unit with a character of intensively agriculturally used landscape	36
2	Moderately warm landscapes of hills and basins	A landscape unit that represents a mosaic of forestry, agricultural and pond landscape	37
3	Moderately cold landscapes of hills and highlands	A landscape unit with a character of extensively agriculturally used landscape	28
4	Cool landscapes of highlands	A landscape unit with a forestry and extensive agriculture using	39
5	Moderately cold landscapes of mountains	A landscape unit with forests and extensively agriculturally used grasslands	37
6	Cold landscape of mountains	A landscape unit with predominating forests and ecosystems above the forests	33
Total			210

5.2.2. Data sources

Two temporal horizons were considered in this second research step, which correspond to the first and the last horizons of the previous step. The middle temporal horizon

(1953/1954) is excluded due to lack of reliability and details on LU, characteristic for this data source and lack of alternative additional data sources. However, some conclusions from the previous research step, which included analysis of land cover change of the middle temporal horizon, were used to support interpretation of the outcomes of this second step. The analysis of the first and the last temporal horizons was done based on similar data sources as in the first research step. Specifically, old maps, orthoimages, aerial images, publicly available online interactive sources (Google Earth 2015) were used, and results were further validated with field trips. Below the data sources for each temporal horizon are described in more details.

1st half of the 19th century

As in the first step, scanned images of old Franciscan cadastral maps (ČÚZK, 2015), were used as the main data source for the first temporal horizon, reflecting parts of Czechia as map sheets, completed between 1824–1843, which were georeferenced manually in ArcGIS software environment (ESRI, 2015), as described in the subchapter 5.1.2. These maps appear to be the best available source for this period, and besides ordinary land use classes, they allow to distinguish between pastures, arable land with various woody vegetation and meadows with or without woody vegetation (Krčmářová et Jeleček 2017). The S-JTSK coordinate system was used here as well. First-order polynomial transformation (RMSE=1.4, average per map sheet) or second-order transformation (RMSE = 1.6, average per map sheet) was applied for different map sheets depending on the quality of the scanned images.

2015–2017

For the latest (current) temporal horizon, several complementary sources were used. Firstly, similar to the first step, the current orthophoto images (ČÚZK, 2016) and the base map of the Czech Republic (scale 1:10,000) (ČÚZK, 2016) were used as the basis, and the Land Parcel Identification System (LPIS) was applied to distinguish better agricultural land use (Ministry of Agriculture of the Czech Republic, 2016). Additionally, publicly available sources, such as Google Earth for desktop (Google Earth, 2015) were 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). Several field trips to the study sites were done between August 2015 and September 2017 to confirm observations.

A slightly different categorisation of LULC was used this time, as in comparison to the first step of the research (**Table 6**). The category of open and semi-open landscape was divided into two groups to observe the influence of cultivation status.

Table 6. Categorisation of former(new) LULC 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, 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; Grossmann & 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 urbanized areas).
7	Wood-pastures	Semi-open habitats where grazing is the dominant management of semi-open grassland.

5.2.3. Analysis of changes and continuity of wood-pastures

All parcels with wood-pastures, which were defined according to the above-mentioned sources, were vectorized for both temporal horizons in the ArcGIS 10.4 environment (ESRI, 2015). Similar to the first research step, all data was first filtered in a way that all cadastral districts with the cover of wood-pastures was below 0.5% of the total district area, were excluded. Next, individual wood-pastures, which were smaller than 0.3 ha were also excluded from the analysis. The former LULC categories of current wood-pastures (as per their state in the first half of the 19th century) and current LULC categories of the parcels, which were covered by wood-pastures in 1st half of the 19th century in 2015/2017 (per the state in the 2015/2017) were defined.

Similar to the previous state, *Overlay analysis* was performed in ArcGIS environment for this new set of study sites, using the *Intersect* and *Union* tools and the results were checked by the *Repair Geometry* tool to eliminate sliver polygons. Depending on presence of each parcel in either the historical or the current temporal horizons only or in both, all wood-pastures were then classified again into lost, gained or persistent respectively. Same as in the first step, groups of lost and gained wood-pastures were analysed for sinks and sources, respectively. Additionally, all the three groups were categorised by their location within different GTNLs using *Overlay analysis*.

Statistical calculation

To analyse the results with statistical tools, two separate ANOVAs tests were performed. Namely GTNL types and former(new) LULC-category were used as predictors. As the response variables, areas of former(new) LULC-categories and shares of areas of gained(lost) wood-pastures were used respectively. Since both response variables were expressed in percent, 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 2013 and R programs. The four null hypotheses defined for this test are as follows:

1A: The areas of gained wood-pastures do not differ significantly depending on the former LULC category of the area they are located in.

1B: The areas of lost wood-pastures do not differ significantly depending on the current different LULC categories of the areas they used to be located in.

2A: There is no significant difference in the areas of the gained wood-pastures, depending on the different GTNLs of the areas they have appeared in.

2B: There is no significant difference in the areas of the lost wood-pastures, depending on the different GTNLs of the areas they used to be located in.

5.2.4. Results

5.2.4.1. Overall changes

Out of the total area of 45,903.79 ha for the 30 cadastral districts in the final analysis, 2128.12 ha were covered by wood-pastures in the time horizon of 2015/2017 (4.7% of the total area of the cadastral districts). In the 1st half of the 19th century this LULC category within the same districts occupied 4910.66 ha (10.89% of the total area of the same cadastral districts). In other words, more than half of the wood-pasture area disappeared between these two temporal horizons. It is however noteworthy that considerably different trends can be seen for the different GTNLs (**Figure 17**, Appendix 3). Difference between the E.g. in the Babětín district, which is located in the GTNL of moderately cool landscapes of hills and highlands, an increase of 23.84%, of a large wood-pasture, has been observed, whereas Horní Bečva, which belongs to cool landscapes of highland landscape type, shows a loss of 19.14% of this LULC category. As a historical source (Historie obce Těchlovice nad Labem, 2020) of the Techlovice region states (which Babětín district is a part of), after the war, the Babětín collective farm was established (JZD Babětín), which was merged in 1960 with the collective farm in Těchlovice and 4 years later with the collective farm in Boletice. The collective farm in Babětín had 9 members with eighty hectares of land when merging. After the merger, it was used for pasturing of cattle. Historical sources on Horní Bečva state that here after 1945, during the settlement of the border, the population in this district decreased considerably, and it only started to increase again after 1950. However, after 1961 there was a further decrease in population (Místopisný Průvodce, 2020)

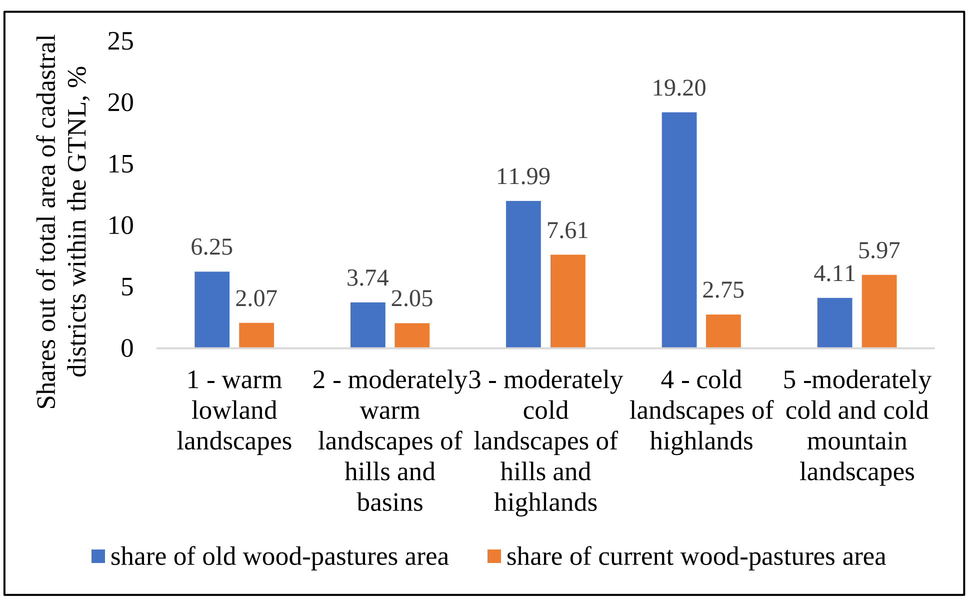

Figure 17. Presence of wood-pastures in historical and current temporal horizons in each GTNL

5.2.4.2. Habitat continuity

Only 263.08 ha of wood-pastures were present in both temporal horizons and thus could be categorized as persistent (**Table 7**). This amounts for 5.36% of the total area of wood-pastures of the 1st half of the 19th century and up to 12.36% of the area of all the wood-pastures, found in the current temporal horizon within the same cadastral districts. **Table 7** and **Figure 18** demonstrate how the spatiotemporal changes of wood-pastures differ between the five GTNL, which reflect natural characteristics of areas and therefore relatively stable. The table lists relative values (shares of areas of persistent wood-pastures from total areas of the districts within each of the GTNL) since the total areas of the different cadastral districts within each GTNL differ.

From a comparison between the GTNLs, relative areas of persistent wood-pastures were the highest for the cadastral districts within GTNL 1 (warm lowland landscapes) and GTNL 3 (moderately cold landscapes of hills and highlands) reaching 0.997% and 0.801%, respectively, and smallest in GTNL 2 (moderately warm landscapes of hills and basins) going down to 0.20%. However, in general, this value was very low for all GTNLs. **Figure 18** and the last two columns of **Table 7** demonstrate the relative abundance of persistent wood-pastures, compared to the total areas of all historical or current wood-pastures of the same GTNL

Table 7. Presence of persistent wood-pastures within each general type of natural landscapes

GTNL *	Areas of studied cadastral districts within the GTNL, ha	Areas of persistent wood-pastures, ha (share out of total area of cadastral districts within the GTNL, %)	Share out of total area of persistent wood-pastures, %	Shares out of area of historical wood-pastures within the GTNL, %	Share out of area of current wood-pastures within the GTNL, %
1	4140.66	41.29 (1.00)	15.70	15.96	48.16
2	7536.76	15.17 (0.20)	5.77	5.39	9.82
3	13946.69	111.67 (0.8)	42.45	6.68	10.52
4	12361.41	49.69 (0.4)	18.89	2.09	14.62
5	7918.27	45.27 (0.57)	17.21	13.92	9.58
Total	45903.79	263.08 (0.57)	N/A	5.36	12.44

* see Table 6

.

For both periods, they have maximum presence within GTNL1 (warm lowland landscapes) with 48.16% and 15.96% of total area of wood-pastures in these temporal horizons respectively, while the minimum differs between the time horizons. By comparison with the area of wood-pastures in the historical temporal horizon, the minimum of 2.09% corresponded to GTNL 4 (cold landscapes of highlands) while comparison to the aeras of wood-pastures in the current moment, the minimum of persistent areas is seen for GTNL 2 (moderately warm landscapes of hills and basins) and GTNL 5 (cold highland landscapes) with 9.82% and 9.58% of total current area of wood-pastures in these GTNLs respectively.

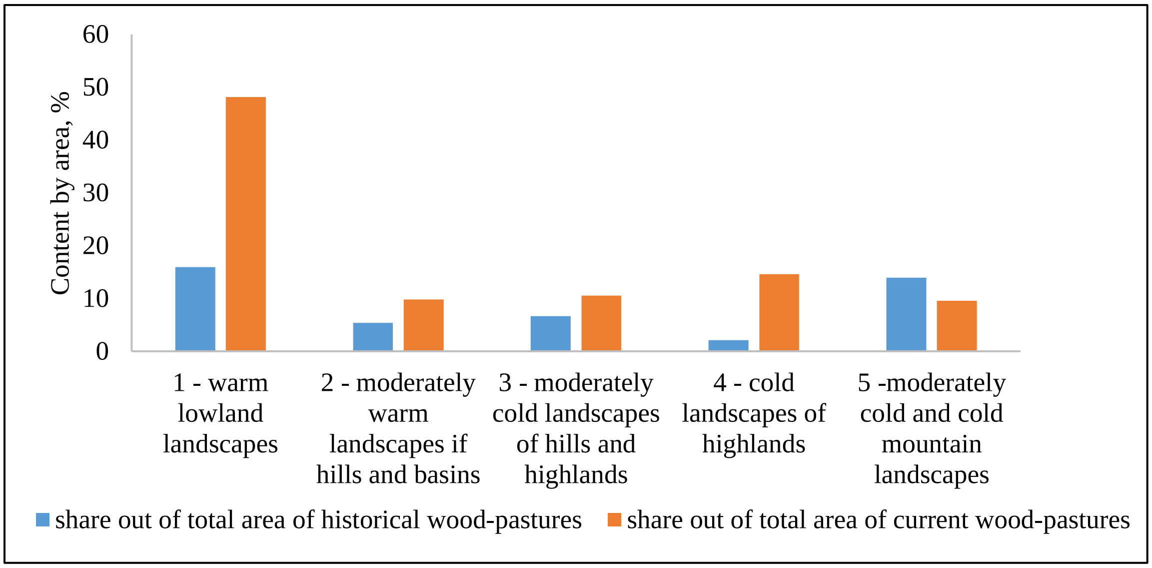

Figure 18. Relative content of the persistent wood-pastures by total area of all historical and current wood-pastures within each general type of natural landscapes

5.2.4.3. Sinks of wood-pastures from the past

Figure 19A shows the major direction of change trajectories of historical wood-pastures. More information can be found in and Appendix 1. The most significant change trajectory with 69% percent is towards closed areas (mainly forests). Only 5.36% of the original area of wood-pastures of the first temporal horizon under study has the same LULC in the current time horizon. It can however not be ruled out that some of those wood-pastures only appear to be persistent, but in fact had intermediate changes of LULC in between both temporal horizons, e.g. to more open land cover types which then overgrew again to wood-pastures. Notably, such a pattern has been observed in the previous section for lowland areas, where out of approximately

5.2 % of original wood-pastures, which were present in the first and last temporal horizon, 3.3% were not present in the middle temporal horizon and thus, only appear to be persistent. Only 14% of the area of historical wood-pastures has transformed to semi-open areas (wooded grasslands (13%) or gardens (1%)). This means that only land use has changed, but land cover stayed the same. The fact that semi-open land cover of these areas was conserved (and no overgrowth has occurred) implies that these areas were not abandoned for too long, and only the type of management has changed. Only 2% of historical wood-pasture areas changed into open-cultivated lands (arable lands), reflecting both land use and land cover changes, and 8% turned into other open landscapes (grasslands, pastures, cut-outs, etc.).

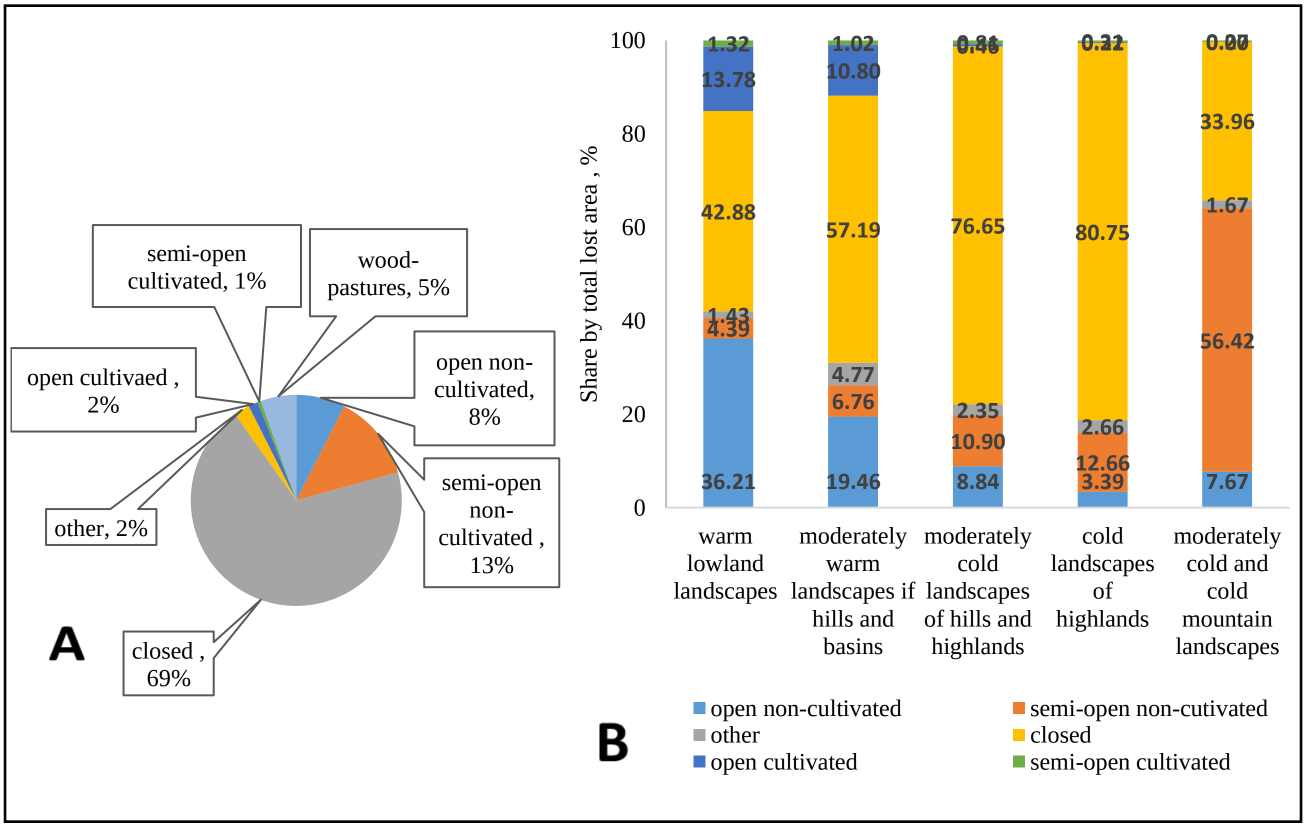

Figure 19. Shares of the current land use and land cover categories in (A) total area of original wood-pastures of the first half of 19th century, (B) areas of the lost wood-pastures by general types of natural landscapes (sinks)

5.2.4.4. Sources of gained wood-pastures

As shown in **Figure 20**A, most of the wood-pastures (50.96% by total area of current wood-pastures, or 60.65% by total area of gained wood-pastures), found in the temporal horizon of 2015/2017 within the studied cadastral districts, formed from previously open cultivated areas (arable and rotational lands). A smaller but still considerable amount of gained wood-pastures formed from former non-cultivated open and semi-open landscapes (grasslands with woody vegetation) (13.66 % and 12.16% of the total area of current wood-pastures, respectively). These parcels have changed either land cover or land use type. Only 5.54% of the total present area of wood-pastures within the studied districts came from the previously forested areas. Looking at the difference of the LULC dynamics between the different GTNL (**Figure 20**(B) and Appendix 1), it is notable that open cultivated landscapes appear to be the major source of gained wood-pastures for all the GTNLs. While this LULC is a source for 50.96% of gained wood-pastures, which ranges from 35.85% (in moderately cold and cold mountain landscapes) to 91.75% (in warm lowland landscapes) out of total area of gained wood-pastures. Thus, open cultivated areas are consistently the main source of the gained wood-pastures, with an exception of warm lowlands, where former open non-cultivated areas prevailed. Open non-cultivated landscapes (e.g. pastures and grasslands) are also considerable sources of recent wood-pastures in most GTNL and amount to 13.66% of total area of current wood-pastures and 16.25% of total area of gained wood-pastures in average, though in the latter case ranging from 1.92% to 42.4% depending on GTNL. Such a big variation is largely explained by low representation of this source-LULC in warm lowlands, where the dominating role of open cultivated landscapes as a source-LULC is seen instead. Contribution from former forested areas was very low and they provided a considerable proportion as sources of recent wood-pastures only in the case of moderately cold and cold mountain landscapes. Simplified, this means that the majority of wood-pastures appears due to overgrowing of open areas rather than opening of closed areas.

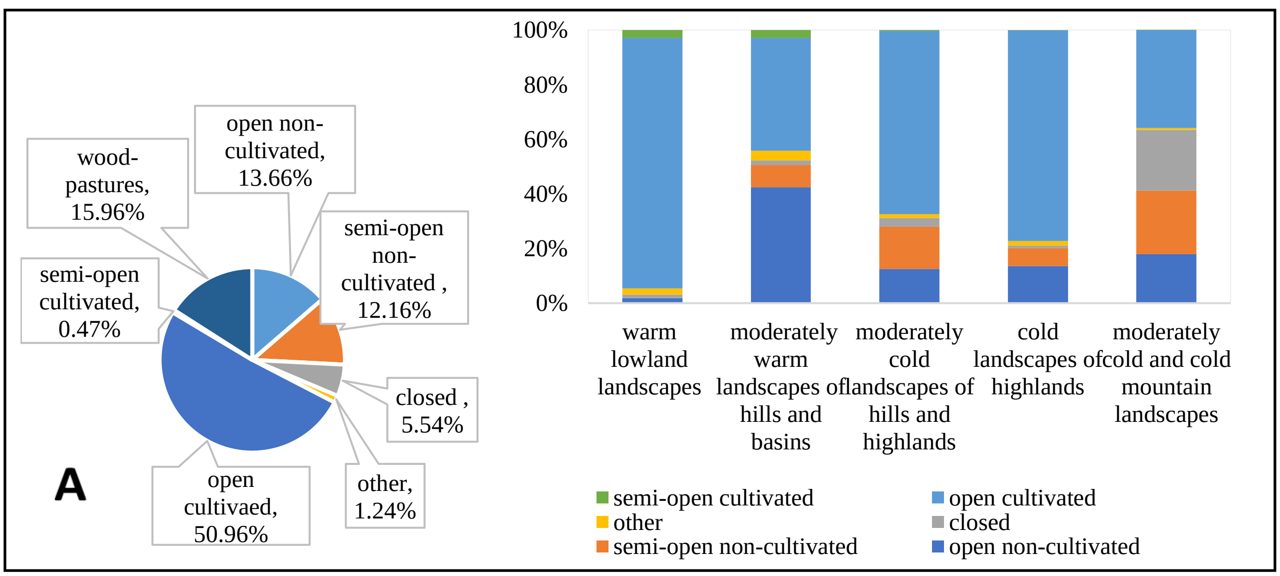

Figure 20. Proportional representation of the former land use and land cover categories in (A) total area of current wood-pastures, (B) areas of gained wood-pastures by general types of natural landscapes (sources)

5.2.4.5. Statistical analysis of the impact of environmental factors on spatiotemporal changes of wood-pastures

The earlier mentioned two-factor ANOVA test for the dataset of gained wood-pastures (**Table 8**) gave the values of $F = 13.39$ and $P < 0.01$ for the explanatory variable "former LULC category" of the areas, where these wood-pastures appeared (**Table 9**: rows). This means that the null hypothesis 1A ("The areas of gained wood-pastures do not differ significantly depending on the former LULC category of the area they are located in.", see section 5.2.3) can be rejected. Thus, with statistical confidence, it can be concluded 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 9**: columns) show the values $F=0.09$, $P = 1$ so null hypothesis 2A (There is no significant difference in the areas of the gained wood-pastures, depending on the different GTNLs of the areas they have appeared in) for the case of gained wood-pastures cannot be rejected. Thus, it cannot be stated, that there is a statistically significant difference in the areas of the gained wood-pastures for the different GTNLs they were appearing in (though there may still be a less significant dependence on this factor.

Table 8. Shares of areas of gained wood-pastures by the former land use of the parcels

Former LULC category*	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

* see Table 6
**see Table 5

Table 9. 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

Analogous the test for areas of lost wood-pastures (**Table 10**) with the new LULC categories as the explanatory variable has resulted in $F = 1.61$ and $P < 0.01$.Thus, the null hypothesis 1B ("The areas of lost wood-pastures do not differ significantly depending on the current different LULC categories of the areas they used to be located in.", see section 5.2.3, can be rejected. Hence, at a 95% level of confidence, it can be concluded that there is a significant difference between the areas of lost wood-pastures, depending on which other LULC they transformed into (**Table 11**: rows). At the same time testing of the factor of GNTL in this case gave F = 0.19 with P = 0.94 (**Table 10**: columns), which means that the hypothesis 2B cannot be rejected. Thus, same as for the case of the gained wood-pastures, it cannot be stated that the areas of lost wood-pastures differ significantly depending on the GTNLs they are located in.

The post hoc Tukey test, for the case of gained wood-pastures (**Error! Reference source not found.**) confirms the outstanding role of the former open cultivated area category (e) 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. From the comparison of the relative input of former LULC categories as the sources, the most significant difference was observed between the categories of open cultivated areas from one side and closed (c), semi-open cultivated (f) landscapes or „other" areas from the other side, supporting the idea that the type of former LULC of an area is important for the appearance of new wood-pastures. The same test for the case of lost wood-pastures also allowed to confirm the previous conclusion, that the category of closed (c) areas was the most common sink. Here all the pairwise comparisons of this LULC with all other have resulted in with the P < 0.05 (**Table 13**), underlining that transformation of wood-pastures was more likely going into specific LULC categories. The most significant difference of impacts was observed between this group and those of open-cultivated (e), semi-open cultivated (f) and "other" (d) landscapes.

Table 10. Shares of areas of lost wood-pastures by the former land use of the parcels

New LULC category*	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

Table 11. Results of two-factor ANOVA test for relation of the area of lost 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	12.61	< 0.01	2.71	5
Columns	0.19	0.94	2.87	4

Table 12. 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	Diff	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

Table 13. 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	Diff	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	2.57
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

5.2.5. Discussion

5.2.5.1. Discussion on results

The results for the general direction of change of wood-pastures presence within the period of study for lowland and highland areas together in this subchapter, matches the expectations. A notable decrease in the area of these landscapes could be confirmed, which corresponds to the trends of agroforestry dynamics as described in the majority of previous related research studies for 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 et Jeleček 2017). This also supports the assumption in the conclusion of the previous case study (Chapter 5.1), that the observed increase in the area of wood-pastures in lowlands only, can be explained by the particular selection of the areas for this analysis, which was relatively small and covered only districts with currently significant cover of wood-pastures and only within warm landscapes of hills and basins. As it is generally accepted among scientists, climatic conditions have a grand influence on local farming patterns, and thus, they predefine presence and type of human activities in any area to a significant degree, as well as the related land use patterns, which require management as a consequence. Therefore, the GTNL classification, which summarizes local climatic conditions, was selected as the first natural factor to analyse. A decrease of wood-pastures with time was observed for all GTNLs, except for moderately cold and cold mountain landscapes. The latter were less affected by socio-political factors, thus this exception indirectly highlights the strong impact of human-driven factors on landscape change during this period. However, the increase in the case of the latter was relatively small and so was the total areas of wood-pastures found within this GTNL for both time horizons and might thereby be influenced by other, local factors that are of small significance for the general trend. For example, as may be concluded from the observations made during the fieldtrips, many wood-pastures in these areas have seasonal rotation of land use. Specifically, some slopes are used for recreation (ski resorts) in winter and as pastures in summer.

It can be assumed, that most changes took place in the second part of the 20th century due to the faster changing political situation, leading to collectivisation, large open fields and heavy mechanisation (as it has been demonstrated for lowlands in section 5.1). Additionally, as mentioned by Bičík et al (2015) trends in political and economic situation and agriculture, related to husbandry, which were aiming for higher production levels, starting form the end of the 19th century, led to more animals being kept in stables and reduced the importance of any kind of pastures, including wood-pastures. The advent of the "Complex Revolution of the Modern era" in the beginning of the 19th century led to considerable changes in agriculture, which as a consequence affected the whole structure of LULC. Compared to e.g. England, in Czechia the Agricultural Revolution was the most important factor for land use change, which started there in the end of 18th century and intensified in 1850-60, with the transition from ley farming to crop rotation, leading to disappearance of fallow land. Arable lands started replacing the former pastures and their territorial expansion reached their maximum in 1860-70s. The importance of geographical location of land as a defining factor of LULC was growing in parallel due to development of transportation networks and access.

This trend is especially valid for warm lowland landscapes. According to many authors, rapid loss of wood-pastures was prompted by intensification of land use and more intensive grazing (Plieninger 2006; Schaich et al. 2015; Varga et al. 2015). Invasion of woody vegetation occurred as a consequence of extensification of agriculture and abandonment of farming (Plieninger 2006), depopulation of former farming areas and abandonment of traditional management. Increased migration of former farmers to urban areas was already happening in 19th century, partly as a result of Industrial revolution and also due to serfdom abolishment (1848-1849) (Fialová et al, 1996). Another wave of depopulation of rural areas, was caused by the transfer of Czechoslovak Germans to Germany and Austria after World War II. Even though new-comers were also arriving to the country, they were mainly settling down in urban centres, thus, some rural areas were still being abandoned together with management of the adjacent wood-pastures. During the communistic era (after 1948) private farming was being supressed and the agriculture was mainly under cooperative or state ownership. Right after the collapse of the communistic regime (after 1989) rural areas became significantly influenced by social and economic transformation, predominantly, through changes such as privatization, denationalization, and restitution of property.

With the total area of all current wood-pastures being relatively small itself, only 12.44% them (5.36% of the total area of historical wood-pastures) are persistent. Taking the role of GTNLs into consideration, a large proportion of persistent wood-pastures (out of the total current area of wood-pastures) is seen for warm lowland landscapes. However, the calculation is based on small absolute values, thus, the actual area is still small compared to the other GTNLs. In several cases, the same districts include more than a single GNTL group in its territory, e.g. moderately cold landscapes of hills and highlands and cold landscapes of highlands are often present within the same cadastral districts. However, both types show comparable and high content of persistent wood-pastures. Altogether, presence of persistent wood-pastures in these remote lands, less reactive to state sociopolitical changes and with similar local governance, confirms significance of socio-cultural characteristics and local policies for the sustainability of wood-pastures, which is also underlined by non-formal conversations with local people, who describe wood-pastures as a local tradition. These districts are often more remote, have a stronger connection to pastoralism and were less affected by political changes in the second half of the 20th century. Peripheral areas are known for more traditional economic structure, lack of (non-agricultural) jobs, as well as higher proportion of elderly, which results in higher presence of traditional farming and, thus, of arable lands. At the same time, the latter fact puts sustainability of wood-pastures in the coming years at risk with this lack of continuity of generations in the transfer of knowledge and skills. From the structural point of view, in these GTNLs wood-pastures are also more “integrated” into the internal territory of the villages and “scattered across” them, thus, forming a part of the local lifestyle.

Out of the lost wood-pastures, the dominant proportion turned into landscapes with closed land-cover, which is likely related to afforestation either due to abandonment and natural overgrowth of former semi-open areas or planting for commercial reasons in the last decades (Postulka, 2008). This dominance is less notable in moderately cold and cold landscapes, where closed landscapes share the leading position with semi-open non-cultivated landscapes, which could be partly attributed to development of tourism.

Most of the current wood-pastures are of a recent origin and mainly appeared from former cultivated open landscapes, such as 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-pastures came from semi-open (woody grasslands) or open non-cultivated landscapes (pastures, grasslands). Some of these changes of LULC can be explained by just periodical rotation of land use and/or slow successional overgrowth (in the case of open non-cultivated landscapes) of grazed areas and could be observed in most GTNLs.

In regard to the patterns described above, introduction of the Differential rents (Differential land rent I and II), **see p. 9**) needs to be mentioned, which supported a shift to more fertile areas for farming from 1880 (Bičík et al, 2015). In combination with natural conditions, this led to abandonment of the less fertile regions, meaning not only interruption of arable activities, but also of management of adjacent areas, such as wood-pastures. The more fertile areas, which were beginning to be re-populated and to enjoy new support, were mostly exploited as arable lands to get the most of each meter of the land, and therefore wood-pastures were not the first-priority LULC category to be established there. Thus, when earlier a higher concentration of arable lands was characteristic for closer vicinity to industrial centres with higher population, later and during the 20th century this trends changed to the contrary: the amount of arable land around urban areas decreased, as the fertility of soil became the defining factor for their allocation in response to the introduction of Differential rent, which in the end led to redistribution and spatial differentiation of land use. In parallel with the described depopulation of some rural areas, centres of decisions-making also moved to the more urbanized areas, together with production centres, and any innovations and decisions (including political) now were following the concept of consequent and often slow diffusion from centres towards remote areas.

From the point of view of general structure, similar to what was seen for the case of lowlands, two main types of wood-pastures can be defined in Czechia for the current temporal horizon. The first type is represented by large areas with either oak, pine or birch, with dry grasslands on slopes, or with maples, spruce or rowan in highlands, often in former military areas. Wood-pastures of the second type are formed as small patches with fruit trees with sheep, goats and horses grazing them. Presence of either bigger plots with more deciduous trees around some villages, or smaller plots, mostly with fruit trees, scattered across the villages (mostly in highlands) is mainly explained by their location within different GTNLs and local management traditions. Old oaks and silver spruce are still present but need more recognition and protection to remain in the future. Veteran trees are gradually disappearing. Looking at the aspect of conservational value of the current wood-pastures and considering that that the persistent wood-pastures are scarce, very few old, and more relatively young trees can be expected in the current wood-pastures, which was also confirmed with fieldtrips. However, as it was also mentioned in the previous subchapter, in some cases the possibility of restoring former wood-pastures from the currently overgrown closed areas may exist, (Roellig et al., 2015). The old trees that are still remaining today (Krčmářová, 2016) are becoming endangered if they get overgrown by younger stronger trees, which also affects the particular ecosystems around these trees (Hartel, 2015, personal communication).

In comparison to other European countries, the spatio-temporal change pattern of wood-pastures in Czechia, as described for the studied sites in the current research, appear more dynamic and is also lacking traditional land use (Krčmářová and Jeleček 2017).

Significant correlation between overall presence of wood-pastures and the GTNL type they are located in could not be confirmed, according to statistical analysis for areas of wood-pastures at historical and current moments. However, there likely is an impact of this factor which though could not be identified from the acquired data (e.g. due to a lower impact than other factors, such as anthropogenic ones). This can be affected by the fact that most of current wood-pastures are gained and most of the historical wood-pastures have been lost (remembering that the statistical test was done for the areas of lost and gained wood-pastures). Another interesting conclusion, indicated by the results of statistical analysis is that occurrence of gained wood-pastures is much more significantly dependent on GTNL, than of the lost wood-pastures. This observation may be attributed to the fact that the loss was related to economic and political changes across the country more than on the GTNL. According to Quitt (1971), who has proposed a system of climatic subzones of the country, similar to the one used in the current research (by Romportl et al., 2013), warm and very warm landscapes (lowlands) are naturally good for farming and crop production. They also include the highly populated economic centres, which affect the LULC patterns. At the same time, colder areas, especially with high elevations, tend to be depopulated for long time as they are not suitable for farming. Gained wood-pastures were reappearing predominantly in specific GTNLs (e.g. moderately cold and cold landscapes of mountains, moderately cool landscapes of hills and highlands, cool landscapes of highlands). This was mostly happening in the second half of the twentieth century, also when there was less pressure from political and economic circumstances, towards other land uses, such as arable activities. In sum, the conclusion that the presence of wood-pastures does depend on GTNL is likely, but this dependency is not very strong.

Relation of appearance of new wood-pastures (gained wood-pastures) to the previous LULC category of the area could also be confirmed statistically by ANOVA test to be significant. As described above impact of GTNL was shown to be much lower, which agrees with the information found in most literature sources. Similarly, ANOVA shows stronger relation of presence of lost wood-pastures to their new LULC categories, than to GTNL, which is interpreted as evidence of the bigger influence of industrialisation and political regime, leading to either forest plantations or overgrowth of wood-pastures.

5.2.5.2. Discussion on methodology

The methodology used in this step is similar to the first step of the research (Chapter 5.1.3). Though some improvements were made following the conclusion about some of its limitations. Most notably, more cadastral districts were considered in this second step, which leads to a bigger sample size and thus gives more informative and statistically more reliable results. Moreover, cadastral districts from all 6 different natural GTNLs of Czechia were included. Two thresholds were applied to confine the selection of parcels: firstly the minimum size of individual wood-pasture patches to be included into the analysis was set to 0.3 ha; secondly, cadastral district with less than 0.5% of their area covered by wood-pastures were excluded from the analysis (see section 5.2.1. Study sites). Both measures reduced the amount of manual work to a practicable level and ensured that each area is large enough to be included into detailed analysis of the GTNL impact.

Another difference in methodology compared to the first step is, that only two temporal horizons were taken into consideration, since the data, which could be acquired from the sources of the intermittent temporal horizon (1953/1954) has proven to be unreliable in regards to LULC details. The intention to investigate changes between two relatively distant temporal horizons, as compared to most other studies (Plieninger, 2006; Garbarino et al., 2011; Schaich et al., 2015) is still given. Since the focus of this case study was to observe the relation of different characteristic trends in change trajectories to natural/anthropogenic factors, rather than to see continuity as such on a detailed time scale, the exclusion of the intermittent temporal horizon is justified. The conclusions from the previous case study, based on a more narrow selection of cadastral districts, but more detailed in its historical scale, in combination with the conclusion of this second step with a spatially broader scale, allow to make detailed conclusions on the change trajectories within the whole country throughout the history.

One of the alterations, which could potentially affect the results is the exclusion of wood-pastures below 0.3 ha. This particularly concerns locations with wood-pastures in „mosaic"-structure, which is characteristic for some cadastral districts, which contain high quantities of small patches scattered across the district's area, instead of being covered by fewer, but bigger „merged" patches. The particular structure may depend on relief, type of woody vegetation or local tradition of land use and management. In an attempt to minimise this effect, bordering small wood-pastures were merged at initial steps of the analysis.

A higher risk of getting less accurate results could be expected at this second step, compared to the first one, as considerably larger amounts of data needed to be processed. But at the same time, additional data sources were applied to improve the accuracy.

The same data sources and analytical method as in the first step were applied for describing the period of the beginning of the 19th century, based on Franciscan cadastral mapping, as the most informative data source for this period known which also covers the whole current area of the Czechia., Obstacles, such as sliver polygons, were faced while georeferencing and digitising old maps, similar to the first case study. Here they were eliminated by Repair Geometry tool of data management toolbox in ArcGIS. As mentioned before, old maps as a data source have a limited reliability, as they have limited accuracy in reflecting density and spatial distribution of land cover. Thus, the definition of wood-pastures, as accepted for this research (**Table 6**) is not always easy or clear to evaluate. These challenges are limited to the older maps and not relevant for the current time horizon. Firstly, the main data sources, used for the current temporal horizon, are more detailed and accurate. Also, additional sources, such as Google Earth for desktop, could be used, which helped to confirm stability of the patches on a shorter-time scale (within the period of up to 10–15 years, depending on the district). The latter source also allows to create polygons for newly found patches directly within this software and conveniently convert them into a format suitable for the further analysis within ArcGIS environment.

Still the need of large amount of manual work remains as an issue for both time horizons, especially for vectorising all data, which can be particularly challenging for old maps. In contrast to our first step, the ArcGIS analysis was done by the same researcher, which eliminates the possible effect of personal workstyle on the results for different cadastral areas.

5.2.6. Conclusion

The results of this case study found clear support for the research questions and hypotheses proposed in the beginning of this subchapter. Firstly, it can be concluded that the net area of wood-pastures in Czech lands, with all the GTNLs taken into account, has decreased in the period between the 1st half of the 19^{th} century and the current temporal horizon (2015-2017) (a decline of over 50% of the original area of wood-pastures by the current temporal horizon was observed in the selected study sites). Only a small part of the present wood-pastures can be characterised as persistent. Generally speaking, the presence of wood-pastures in Czechia in total has been less stable than in the majority of other European countries, where similar studies had been held. This may serve as a confirmation of the 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 is very likely that most of the gained wood-pastures (and thus, most of the current wood-pastures) were formed during the second half of the 20^{th} century.

Sources of gained wood-pastures and sinks of the lost ones have been analysed, and the relation of the character of those to GTNLs could be seen, though statistical analysis have not confirmed a strong significance of these factor. The link between change trajectories and GNTL could be partly attributed to the difference of natural conditions but can also serve as an indirect confirmation of the role of socio-cultural factors, which often correlate with certain GTNL. According to statistical analysis, the role of GTNL does not show significant impact for presence of wood-pastures in general. Still, it is likely that this factor does play a role, and it could not be confirmed by the statistical test because it is masked by other factors with stronger impact (e.g. socio-political, economic). This is also confirmed by the stronger relation to the former(new) LULC categories of the gained(lost) wood-pastures. Though relative significance of each of those factors is not described in more detail here, as it is out of scope of this case study, the importance of appropriate management, including support from the state/local government, to counteract the decline of wood-pastures in Czechia, is reflected.

5.3. Selected natural and human factors as possible drivers of spatiotemporal change of wood-pastures and the character of this change

The third research step analyses the spatiotemporal dynamics of wood-pastures in Czechia for the same 200-years period with a close focus on the relation of these changes to the most likely natural and anthropogenic drivers. The analysis is based on the same 30 cadastral districts as in the second case study, but pays special attention to factors such as elevation, slope, proximity of water sources, transportation access, dominating soil and rock type, protection status and coverage by certain forms of state financial support programs.

This third step answers the last research question:

RQ 5. Which of the natural or human-driven factors have the most significant impact on change trajectories of wood-pastures?

H8. Human-driven factors, such as changes in political and economic structure (incl. industrialisation) are the major drivers for the recent dynamics of wood-pastures area. Natural factors have a secondary role in the stability of these areas.

5.3.1. Study sites

This case study includes the same cadastral districts as the previous case study (please refer to chapter 5.2.1 for more details), which were selected out of original 57 cadastral districts by applying the criteria of minimum 0.5% of the cadastral districts to be covered by wood-pasture and the criteria of 0.3 ha as the minimal area of a wood-pasture parcel, leading to 30 cadastral districts ranging between 1.94-80.58 km^2, allocated within the different GTNL. As in the previous 2 case studies, since borders of districts changed throughout the researched period, the original historic borders of the districts were taken as reference for both time horizons.

5.3.2. Data sources

The same two temporal horizons as in the previous step are analysed: the first half of 19th century and the current temporal horizon (2015-2017), based on old maps, orthoimages, other currently available digital sources and field trips.

1st half of the 19th century

The data source and procedure of its interpretation was the same as described for the previous research step (section 5.2.2): Scanned images of old Franciscan cadastral maps were used, acquired from the Czech Office for Surveying, Mapping and Cadastre (2015), to identify historical LULC of the studied lands in the first half of 19th century (Lipský 1995; Bičík et al. 2001; Raška et al. 2016). The images were georeferenced manually in ArcGIS (ESRI 2015)

2015–2017

The detection and calculations of wood-pastures of the latest temporal horizon in the third research step relied mainly on the same data sources as in the second study (5.2.2. Data sources). The following sources were used for mapping of wood-pastures:

- orthophotomap of the Czech Office for Surveying, Mapping and Cadastre served as the basis,
- the Land Parcel Identification System (LPIS) was used to distinguish agricultural land use (**Table 14)** (Ministry of Agriculture of the Czech Republic, 2016),
- base map of Czech Republic (scale 1:10,000) was used to check occurrence of watercourses, roads, protected areas) (ČÚZK, 2016),
- Google Earth for desktop (Google Earth, 2015) was used to confirm land cover in cases of concern at a closer scale and in sequences of several years (stability/rotation of landcover

New sources were added get information about the factors, which were selected as possible drivers of change. Those included

- Digital relief model (ArcČR 500 by Arcdata Praha, 2016), used as a source of topographical data such a elevation and slope
- European Soil Database v2 Raster Library (1kmx1km) (European Soil Data Centre, 2018), used as a source of data about soil types.

The geological characteristics were identified using data included in the layer of GTNL by Romportl et al (2013), where they were included as one of the criteria for categorization of GTNL (Figure 21). Similar to previous research steps, several trips to the study sites between August 2015 and September 2017 were made to confirm preliminary conclusions. The categorization of LULC by density of woody vegetation and its canopy cover, described for the second research step, was applied for this step as well (Table 6).

5.3.3. Analysis of changes and continuity of wood-pastures with relation to selected natural and anthropogenic drivers

The process of defining the presence and primary analysis of changes in the area of wood-pastures, as well as change trajectories in general and in relation to the different GTNL, has been described in the previous step (see 5.2.3) All wood-pastures were then classified into *persistent*, *lost* and *gained*, where the latter two groups were analysed for sinks and sources, respectively.

Table 14. Types of agricultural crops by Land Parcel Identification System (Ministry of Agriculture of the Czech Republic, 2016)

LPIS categories grouped	LULC category by LPIS	Definition by LPIS
Grassland	Permanent grassland	agricultural land used in accordance with the definition of permanent grassland under a directly applicable European Union regulation laying down common rules for direct support schemes under the common agricultural policy (land used for growing grasses or other herbaceous forage on natural (natural sowing) or artificially created (artificial sowing) areas which has not been included in crop rotation on the holding for five years or more and, if Member States so decide, soil that has not been plowed for five years or more).
Arable land	Standard arable land	farmed arable land under European Union legislation, applied directly, regulating common rules for direct support schemes under the common agricultural policy, on which crops are grown in regular succession to produce crops, farmed land under greenhouses, under fixed or portable shelters, and which is not a grassland as defined by LPIS.
	Outfield	fallow farmed arable land, including set-aside areas, in accordance with the requirements of European Union regulation, which is kept in register of arable land, hop gardens, vineyards, orchard, fast-growing trees grown in young plantations and other perennial crops or nurseries; created by natural tannery, establishment of crop or maintenance without vegetation
	Permanent grassland on arable land	farmed arable land used for growing grass or other fodder crops, under directly applied European Union legislation applied directly, stating common rules for direct support schemes by common agricultural policy on natural or man-made areas, included in crop rotation of a land user for a period < 5 years.
Permanent culture	Other permanent culture	farmed land with other permanent crops, not listed in the description of any of the categories
	Orchard	cultivated land with permanent culture, planted uniformly and continuously with fruit trees at minimum density of 100 individuals per hectare or fruit bushes with a minimum density of 800 individuals per hectare of soil block part (rootstock or propagation stands are not recognized); includes the associated handling area not exceeding 12 meters between all rows and

		maximum of 8 meters of one row width, with maximum spacing 12 meters for fruit trees and 5 meters for fruit bushes.
Other	Forested land	land with trees grown for forestry purposes and recorded in the land register as afforestation of agricultural land with agricultural, also including unplanted areas up to 4 meters-width, serving mainly as segmenting clearings or unpaved forest culture.
	Non-production land	area of an ecologically significant element that forms entire area of a separate soil block and is not part of another soil block.

Further, all three groups were analysed for correlations with the natural and anthropogenic drivers, including elevation and slope (by intervals), vicinity to water sources or roads of different categories, dominating soils and underlying rock types, presence and level of protection status or state financial support (subsidies). To get information about elevation ranges for the areas, Digital Relief Models were used. These Raster layers were transformed using *Raster-to-Polygon* tool. The same procedure was used to extract information about soils, which were categorized following Soil classification, offered as raster map layers, by World Reference Base (WRB) (European Soil Data Centre). The resulting layer of elevation model was separated into 50-m elevation intervals. The elevation layer was also used further for creating the slope layer (by 10-degree intervals), which was done by applying the *Slope* tool of the Spatial Analyst toolbox. To classify all the areas by protection status, three levels of protection were considered: National Parks, Protected Landscapes and not protected. Following the Czech system related to defining conservation status (Act No. 114/1992 Coll., on the Protection of nature and landscape protection), the categories of protection were defined as follows: *National parks* represent large areas with considerable part of natural ecosystems, or ecosystems mostly unaffected by human activities, with unique scientific and educational importance of the abiotic features, flora and fauna on an international or national level (this category started to be applied from 1963 and on); *Protected Landscape* is a large area of harmonic landscape with a typical relief, with a considerable share of natural forest and permanent grassy ecosystems, sometimes with preserved human settlement monuments (the areas under this category were being established starting from 1955 and on). In order to analyse the role of vicinity to water sources, first, all waterbodies and streams, from the base map of Czech Republic (scale 1:10,000), were merged in one layer and buffer-zones of 200 and 500 meters were created out of this merged layer. One of the important facts to consider when choosing the buffer size, was that the cattle tend to congregate near water sources, and the distance of 200 meters is generally advised to modulate grass utilization and impact on streambanks and water thereof. To define the role of accessibility by transport, 500-

meter buffers were created for the roads, which had been divided into the following different categories: international and long-distance roads (category 1); roads connecting different districts (category 2); roads connecting municipalities and other roads (category 3); highways; speedways; “unknown” (such as dirt road). For defining underlying rock types GTNL-layers developed by Romportl et al (2013) were used, which contain information about rock-categories, based on Geological map of the Czech Republic (1: 500 000) following Zoubek et al. (2003). The original 19 categories of rocks are grouped here into 6 classes, which sufficiently represents spatial distribution of specific sets of rocks (**Figure 21**, see also Romportl, Landscape classification - data, methods and approaches (On-line). The categories of LPIS, which contains a reference database of the agriculture parcels serving as a basis for the direct payments to the farmers in relation to the Common Agricultural Policy (CAP), were organized into 5 groups. The wood-pasture parcels were analysed for relation to these groups. LPIS reflects Agricultural Parcels, as a land over which payment entitlements may be activated and for which payment may be claimed (Copernicus, 2015).

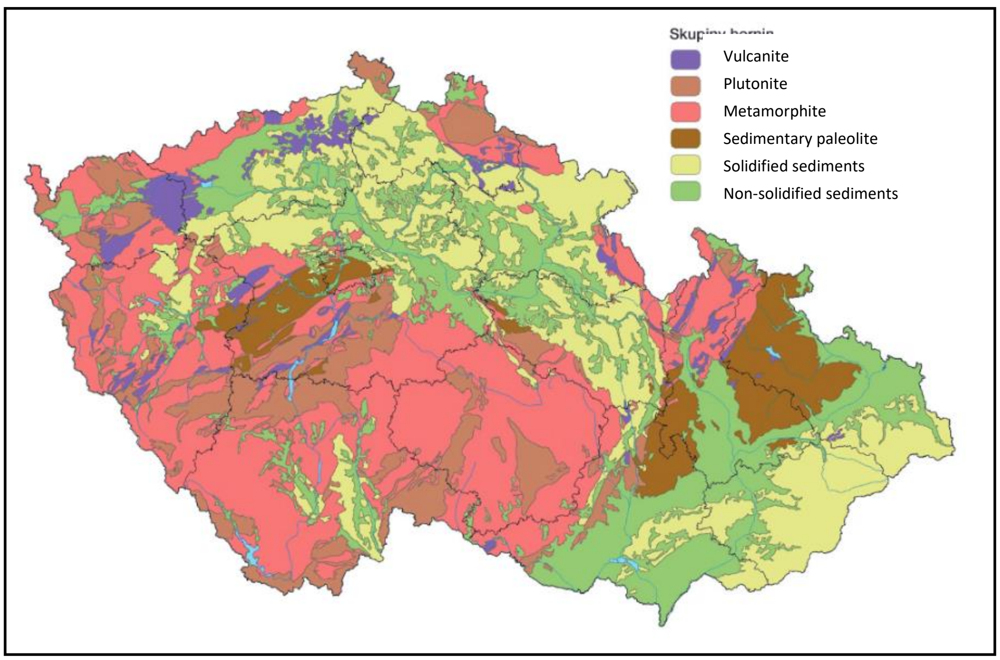

Figure 21. Generalized geological map of Czechia. (Romportl et al 2013, Zoubek, ed. 2003)

Statistical calculation

To check the for statistical dependencies, 2-way ANOVAs analysis was performed for each of the drivers with former (new) LULC category as predictors (independent variable). Areas of different former (new) LULC categories in the first case, and of *gained (lost)* wood-pastures in the second case, were used as response variables. Raw data for the statistical analysis was exported from ArcMap 10.6 into a Microsoft Excel 2016, and analysed using Microsoft Excel/R.

Below are the null hypotheses for the 2-way ANOVA tests, defined for the combinations of LULC categories (similar to the second research step), as the first factor, and separately each of the mentioned natural/anthropogenic drivers, as the second factors:

1A: The areas of *gained* wood-pastures do not differ significantly depending on the former LULC category of the area, in which they are currently located.

1B: The areas of *lost* wood-pastures do not differ significantly depending on the current different LULC categories of the areas, in which they used to be located.

2A: There is no significant difference between the areas of the *gained* wood-pastures, depending on how the *selected natural/anthropogenic driver* characterizes the areas they have appeared in.

2B: There is no significant difference in the areas of the *lost* wood-pastures, depending on how the *selected natural/anthropogenic driver* of the areas they used to be located in.

5.3.4. Results

5.3.4.1. Overall changes

The pattern of the overall area change of wood-pastures in general has already been described in chapter 5.2. Most notably, a decline by over 50% of wood-pastures was observed, as compared to their area at the first (historical) temporal horizon, when it equalled 4910.66 ha.

5.3.4.2. Overview of change trajectories of wood-pastures in relation to the roles of the selected natural and anthropogenic drivers

Distribution by slopes

The pattern of wood-pastures distribution by *slopes* matches between the two temporal horizons, with the highest total areas of those found within the slopes ranging between 10-15^{o}. Interestingly, *historical* wood-pastures show a relatively high proportion of the wood-pastures (compared to current wood-pastures) at steeper slopes as well (at the slopes of over 15 degrees) (**Figure 22**).

The graph for the gained wood-pastures in general shows a similar form of distribution as the one for the current wood-pastures, and general trend for the lost wood-pastures resembles the one for the historical layer, which is explained by generally low persistence of wood-pastures (**Figure 23**). The pattern of proportional distribution of *sources* of the gained wood-pastures appears comparable for the different slope ranges. As already seen in the previous step, open cultivated landscapes appear to be the most common source LULC-category, followed by open non-cultivated and semi-open landscapes. Interestingly, for steeper slopes, there is a slight increase of open landscapes as sources in relation to semi-open. Built-up areas, as a source-LULC were a less typical source of the new wood-pastures at steeper slope. For "sinks" of wood-pastures, as mentioned previously, a clear majority of former (lost) wood-pastures changed into

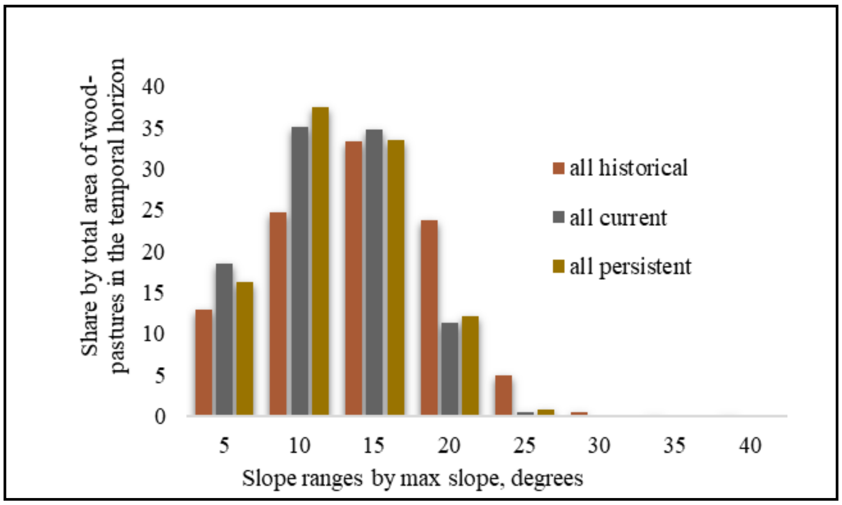

Figure 22. Shares of wood-pasture areas by slope ranges in different time horizons

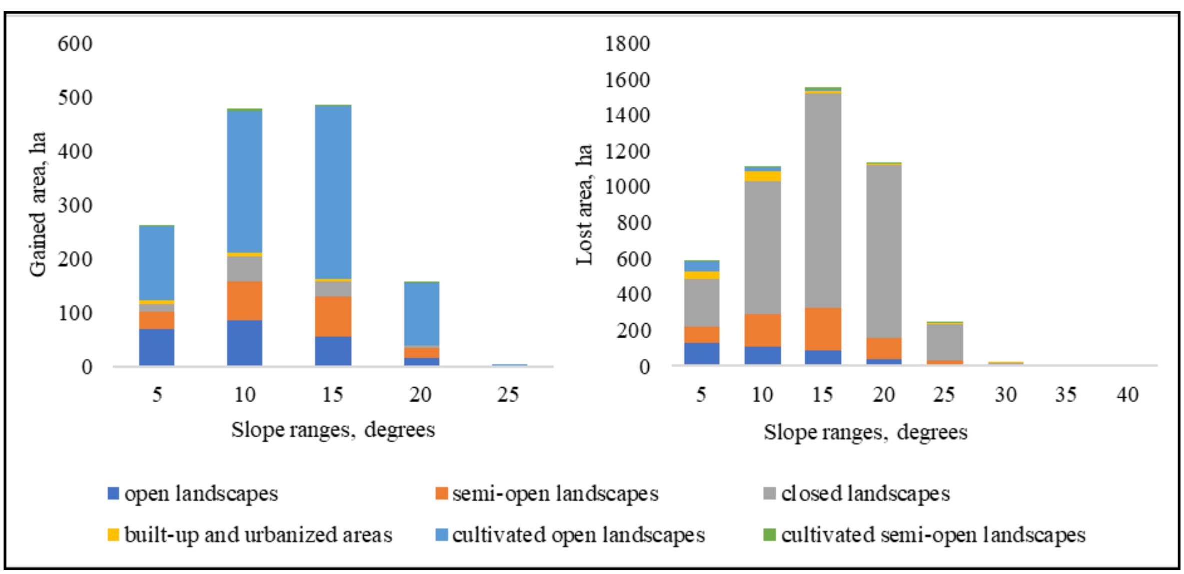

Figure 23. Former(New) LULC categories of gained(lost) wood-pastures at different slope ranges

closed landscapes, which is especially characteristic for the hillier areas (slopes with over 5 degrees incline). Flatter areas transformed more often into open non-cultivated areas compared to steeper ones. Open cultivated lands are very rarely the new LULCs of lost wood-pastures. Semi-open landscapes, both cultivated and non-cultivated, appear more in the less steep areas.

Distribution by elevation

Looking at elevation as the driver, the distinct main peak for both the historical and current temporal horizons is observed at the elevations within the range of 540-640 m a.s.l., which is slightly less expressed for the current wood-pastures. Current as well as persistent wood-pastures both show a second peak between 890-990 m (**Figure 24**).

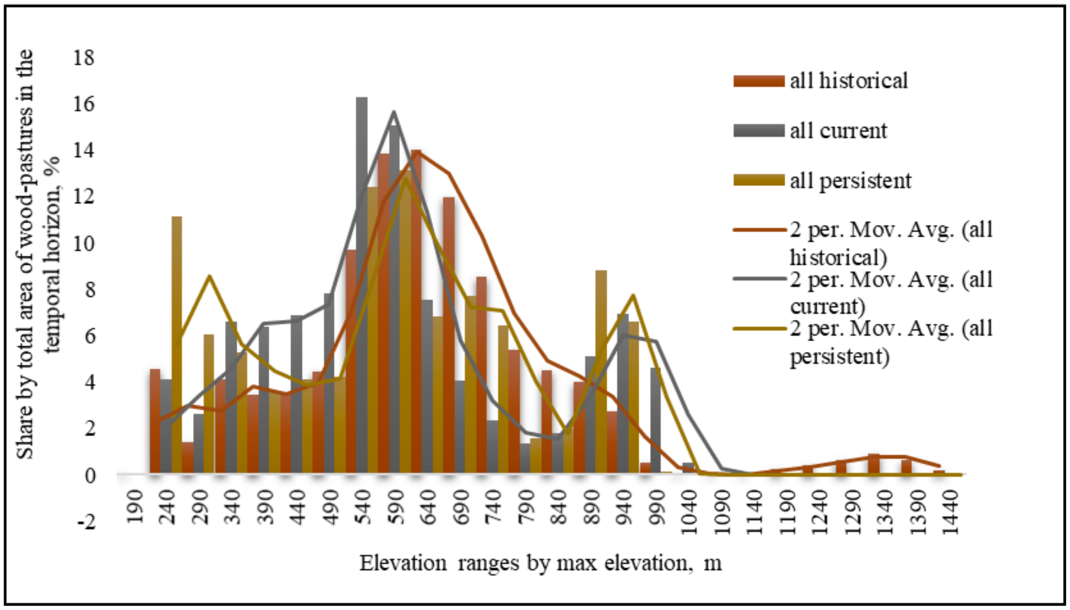

Figure 24. Shares of wood-pasture areas in different time horizons by elevation ranges

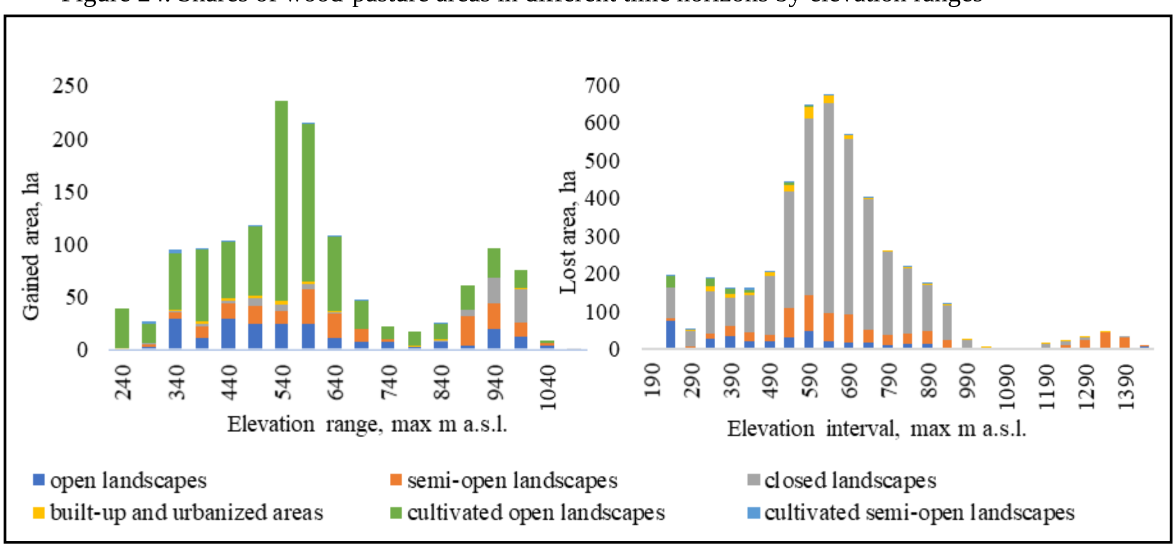

Figure 25. Former(New) LULC categories of gained(lost) wood-pastures at different elevation ranges

New wood-pastures were appearing at lower elevations (which explains the increase of total wood-pasture area in lowlands observed in the first case study, as opposed to the results of the second case study). Former cultivated open landscapes appear to have been the most common source of the gained wood-pastures at most elevations with the exception of the highest altitudes (**Figure 25**). Though it should be considered in combination with the fact that generally the total area of gained wood-pastures there is comparatively low, so the difference in absolute values is still relatively low as well. As for the sinks of the lost wood-pastures, closed landscapes seem to play the major role as the new LULC category at most elevations, with a minor exception above 1000m of elevation, where semi-open landscapes dominate.

Distribution by vicinity to water sources

For all the three cases of wood-pastures presence (existing in historical, current, and persistent), the highest proportion of area can be found in locations that have a bigger distance to water (which will be explained in more details in the following Discussion on results section). This prevalence is expressed slightly more for the current landscapes (**Figure 26**).

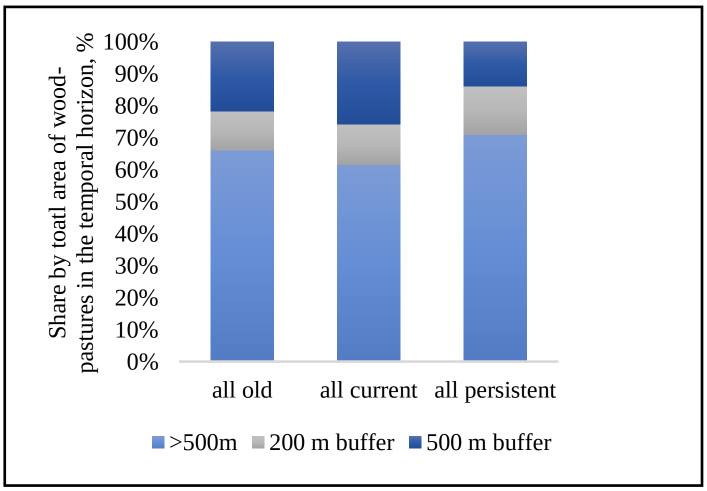

Figure 26. Shares of wood-pasture areas in different temporal horizons by vicinity to water source

Looking at the distribution patterns of the various LULC-categories among sinks and sources, transformation of former semi-open/open non-cultivated landscapes into wood-pastures (thus, gained wood-pastures) is also more notable further away from water sources. In parcels located within the area between the 200 and 500m buffers, cultivated open landscapes dominate among the sources of gained wood-pastures even more than further away (>500m) or closer (within 200 m buffer) to water sources (**Figure 27**).

Sinks of the lost wood-pastures resemble the general change pattern almost independently of the distance to water sources, with exception only of the higher rates of built-up areas near water.

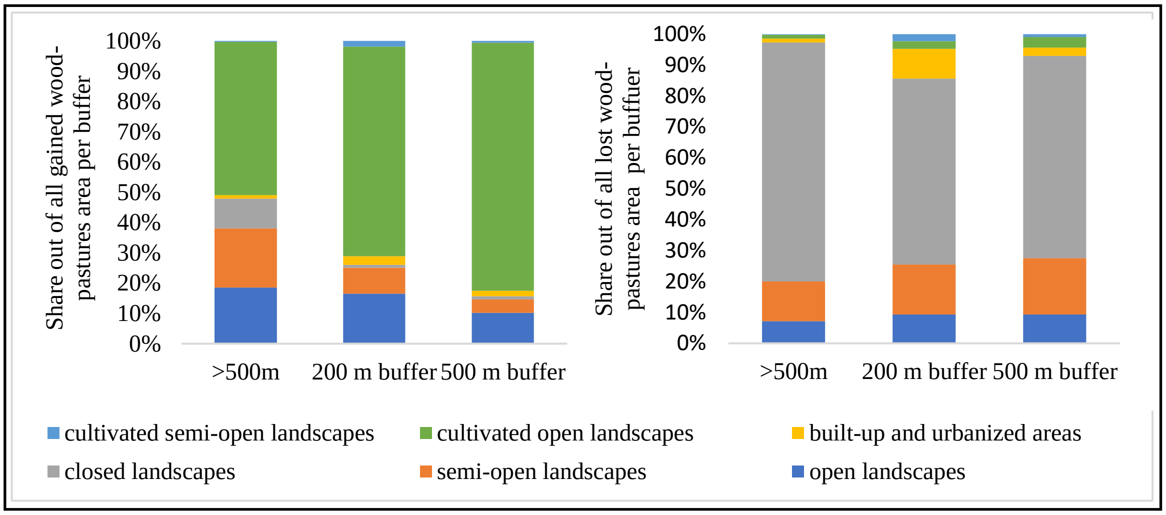

Figure 27. Former(New) LULC categories of gained(lost) wood-pastures in vicinity to water

Distribution by dominating soils

Figure 28 shows, that among the soils, which could be identified in the territories of wood-pastures, Dystric Cambisols are the most typical for both temporal horizons, as well as for the persistent wood-pastures. A relatively high amount of persistent wood-pastures was observed in the lands with Gleyic Phaeozem. A notable portion of gained wood-pastures, which appeared on the places of former cultivated semi-open landscapes, was underlaid by Haplic Chernozem (**Figure 28**, **Figure 29**), and former open landscape on the places with Calcic Chernozem. Some notable losses in wood-pasture with Gleyic Phaeozem were specifically observed in the case of

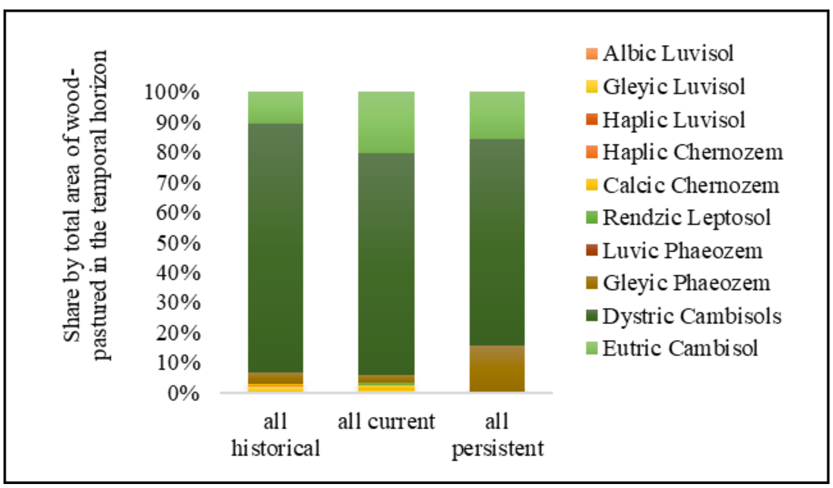

Figure 28. Shares of wood-pasture areas in different temporal horizons by dominating soils

transformations into open/cultivated open/semi-open landscapes. Lands with Calcic Chernozems and Eutric Cambisols were involved in all different types of loss-transformations of former wood-pastures described in this work.

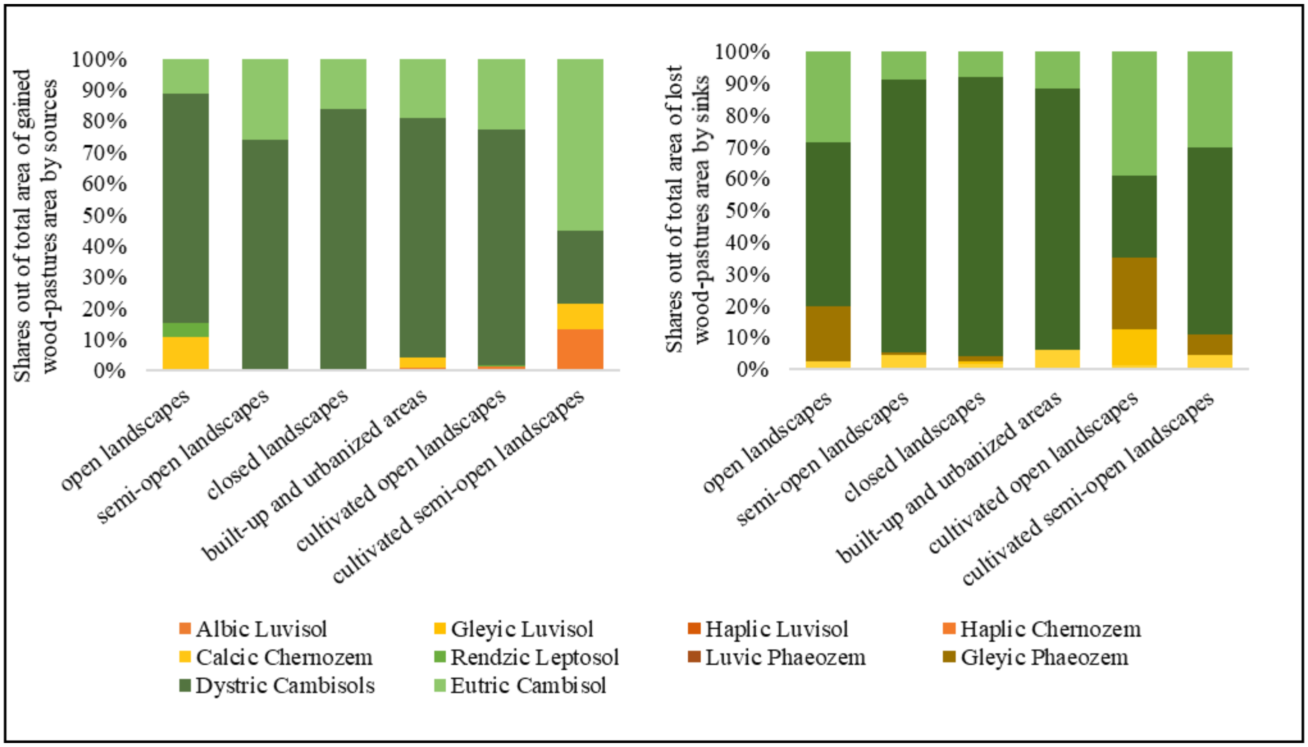

Figure 29 Former(New) LULC categories of gained(lost) wood-pastures by dominating soils

Distribution by dominating rock type

The next potential natural driver analysed was the underlying rock type. The results show that the group of solidified sediments is the dominant rock type for both temporal horizons and the persistent wood-pastures. At the same time, a higher proportion of vulcanites and plutonites was observed for the current and persistent wood-pastures compared to historical ones, whereas the graph shows slightly higher proportion of metamorphites for historical and current wood-pastures, which is though almost negligible among the persistent ones (**Figure 30Error! Reference source not found.**).

The comparison of the proportional distribution of rock types for the lost and the historical wood-pastures indicates that losses were happening mostly uniformly in lands with different rock types (**Figure 30** and **Figure 31**). As the graph for the lost wood-pastures and their sinks (**Figure 31**) also shows, a slightly higher proportion of areas with underlying metamorphic rock is observed for the transformation of former wood-pastures into semi-open (non-cultivated) landscapes, and a higher proportion of areas on non-solidified sediments was involved into the transformation into cultivated open landscapes.

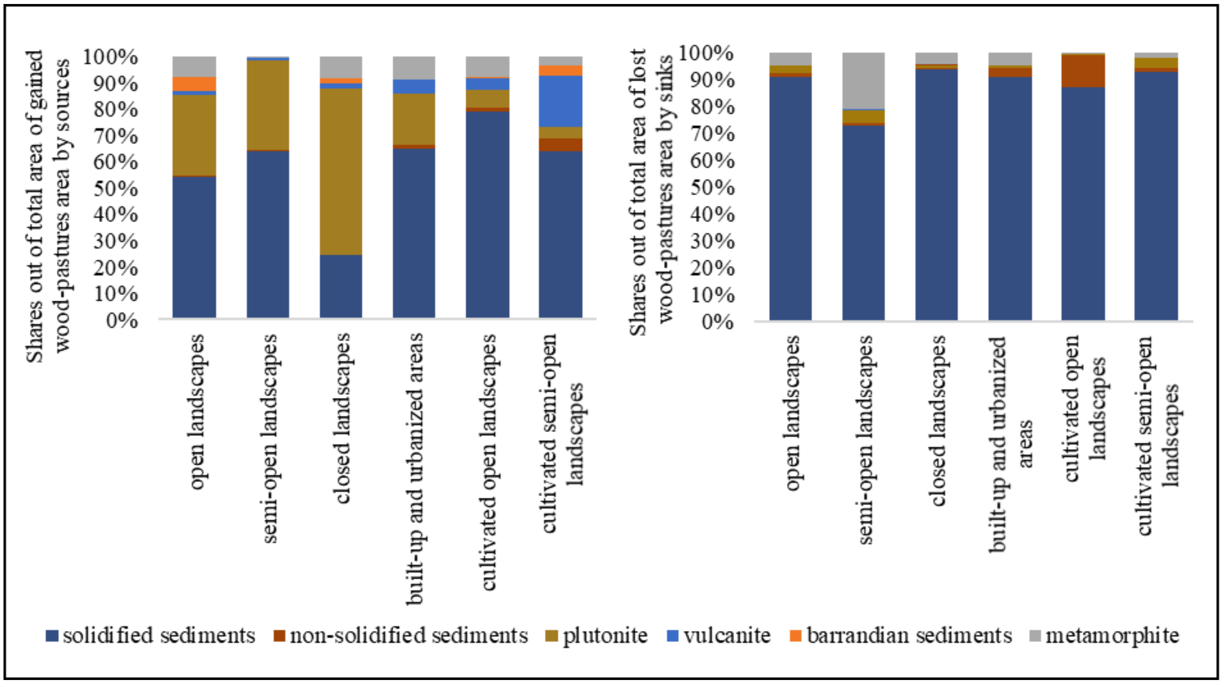

Figure 31 Former(New) LULC categories of gained(lost) wood-pastures by dominating rock types

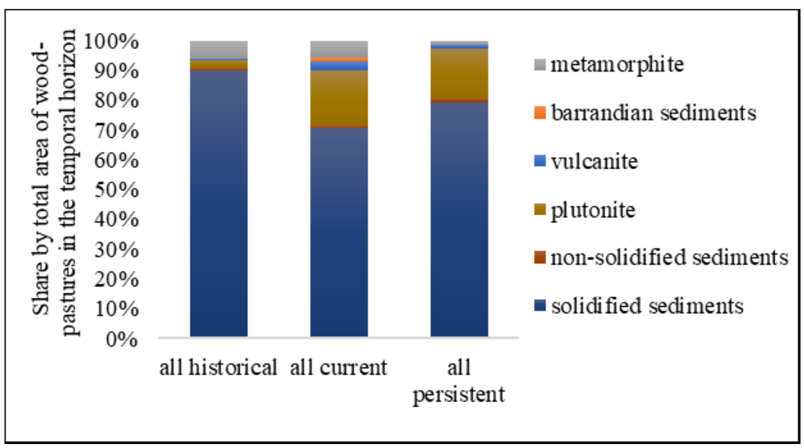

Figure 30 Shares of wood-pasture areas in different temporal horizons by dominating rock types

The graph for the gained wood-pastures generally shows a good alignment in its pattern of relative distribution by the different rock types compared to the relative distribution of current wood-pastures, indicating that the gains were also happening proportionally in the location characterized with different geology. Thus, in cases of both current and gained wood-pastures, a relatively high proportion of areas with plutonites for is observed. Moreover, plutonites even dominate among the other rock types in the areas where transformation from former closed areas into wood-pastures at the current temporal horizon was taking place, and have a relatively high share in the cases of the transformations from all non-cultivated LULC types, while they are almost absent in the lands, where transformation to any of the cultivated LULCs took place. In addition, there is a notable gain of wood-pastures in areas, underlaid by vulcanites, which is especially expressed for the case of transformation from former cultivated (both open or semi-open) landscapes to wood-pastures.

Distribution by vicinity to roads.

The analysis of the role of vicinity to roads of different categories shows that the presence of wood-pastures in vicinity to today's roads is higher than for historical (**Figure 33**). (especially those of the higher categories). It should be mentioned that the road network in Czechia became relatively developed only in the second half of 20th century, so for the historical

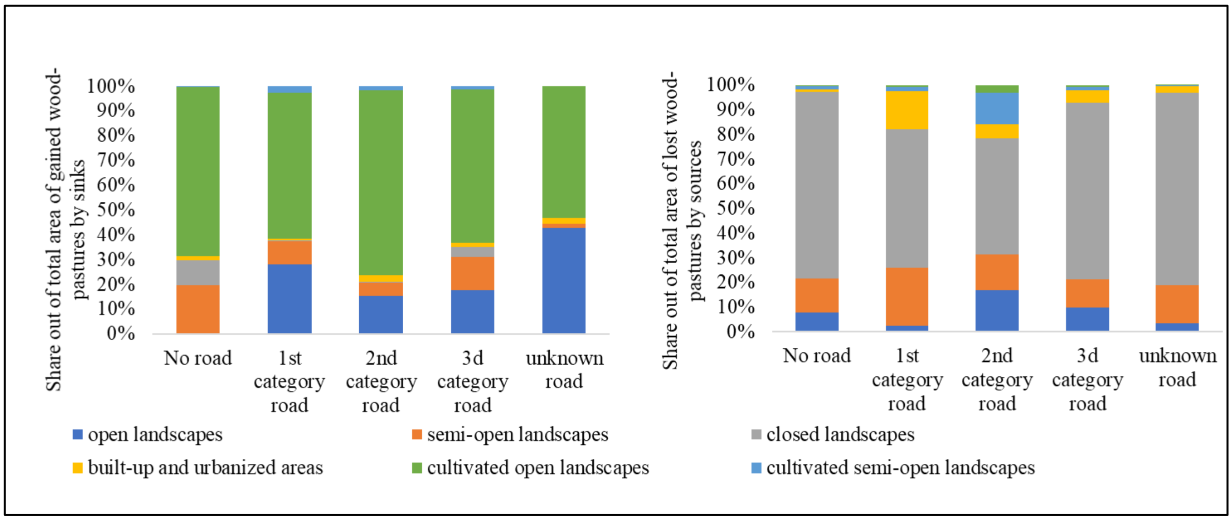

Figure 33 Former(New) LULC categories of gained(lost) wood-pastures by vicinity to roads of the different categories

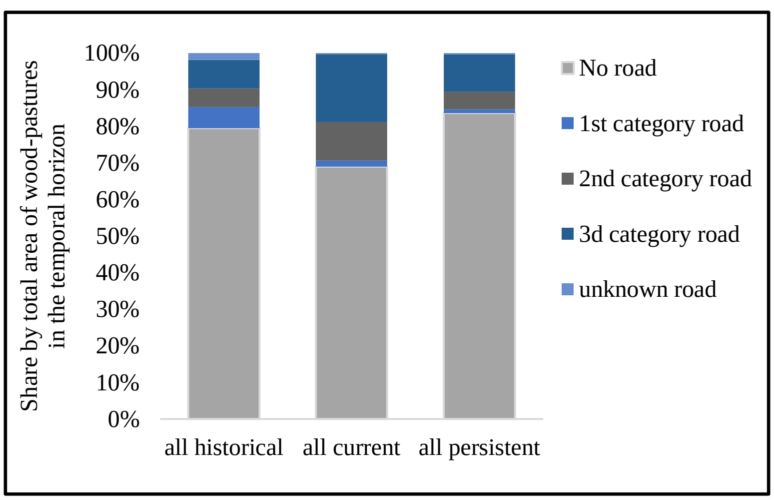

Figure 32 Shares of wood-pastures areas by vicinity to roads of different categories

layer they were not actually present and only have a nominative character. This comparison allows to see if there was a change in the amount of wood-pastures due to better access. Still only qualitative conclusions can be made, since a precise estimation of the road network for the first temporal horizon is hardly possible (comparable, modern means of transportation were not yet available).

Among the lost areas, a relatively large proportion of former wood-pastures turned into closed landscapes regardless the distance/category of roads, and recently gained wood-pastures were originating mainly from former open cultivated landscapes in the same manner (**Figure 32**).

For the areas, which do not have roads in their vicinity, transformation between the wood-pastures and other semi-open landscapes in both directions is also well represented. In vicinity to the roads of 1-3 category, transformation between the former cultivated semi-open/open or built-up landscapes and wood-pastures is quite notable

Distribution in relation to Protection status of the area

Analysis of the role of protection status of the location shows that larger proportion of wood-pastures is observed within the landscapes with the currently higher protection status in both the historical and the current temporal horizons. However, a lower share is seen among current or persistent wood-pastures (**Figure 34**). It needs to be considered that the mentioned protection statuses started to be assigned to these areas only during the 20th century, thus, for the temporal horizon of the first half of 19th century they can only be applied formally.

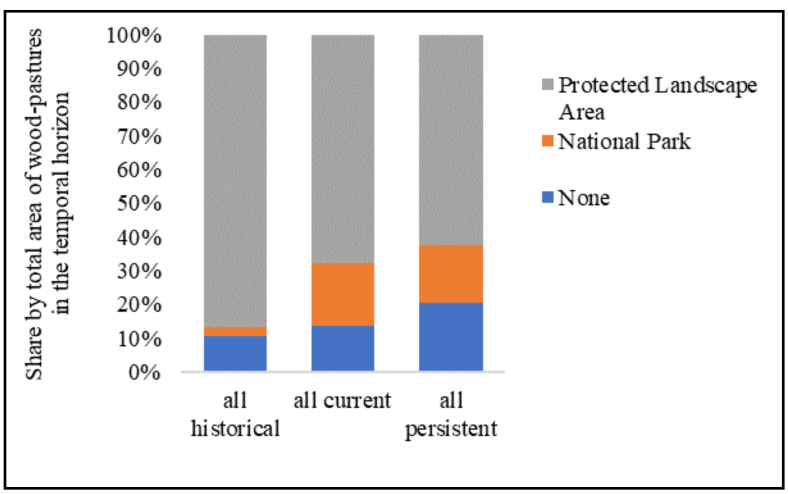

Figure 34. Shares of wood-pastures areas by protection status per time horizon

When comparing the distribution of areas of persistent, historical and current wood-pastures, it can be seen, that most changes took place in Protected landscape areas. As seen in **Figure 35**, gained wood-pastures, located within the current National Parks have their origins almost equally in former closed, cultivated/non-cultivated, non-cultivated semi-open landscapes.

In other areas (Protected landscape areas and without protection status), cultivated open landscapes are still the dominant source of the recent wood-pastures. The role of closed landscapes as the most common sink of wood-pastures is specifically characteristic in the current Protected landscape areas, while in National Parks semi-open landscape are almost equally common as new LULC of former wood-pastures.

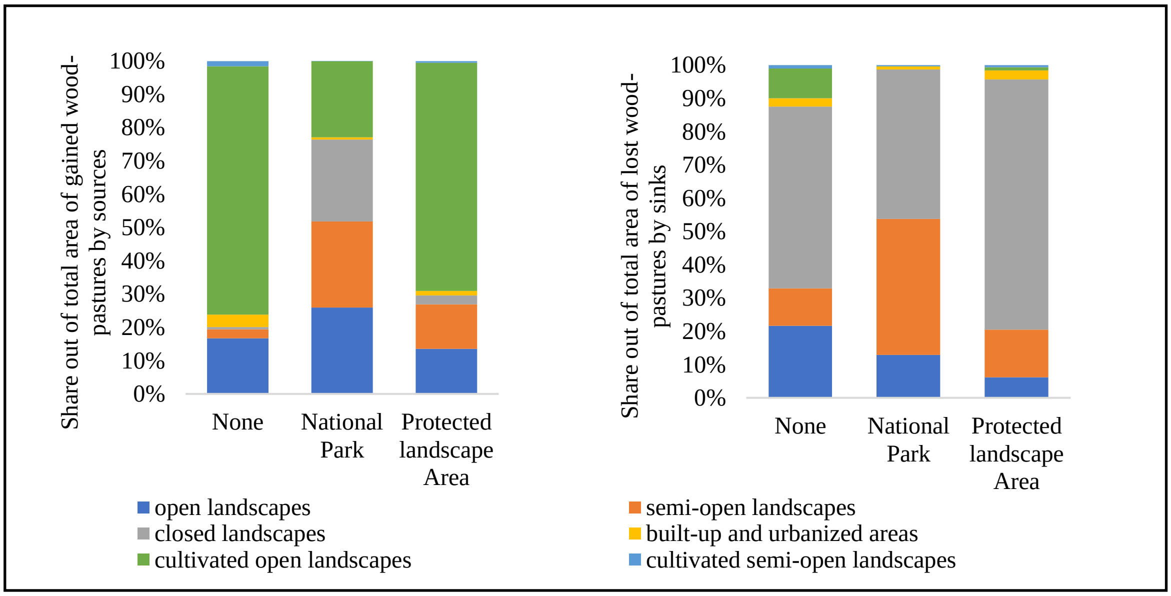

Figure 35. Former(New) LULC categories of gained(lost) wood-pastures by protection status

Distribution in relation to LPIS status

Results of analysis of different LPIS categories for the locations of the current wood-pastures show a higher proportion of the latter in the areas that are currently as eligible for subsidies, in comparison to the same for the persistent wood-pastures (all categories except "no subsidies" in **Figure 37**, which are lands not registered in the LPIS database, see also Table 14. Types of agricultural crops by Land Parcel Identification System (Ministry of Agriculture of the Czech Republic, 2016). Wood-pastures of historical period were not analysed specifically for this factor, as the criteria of LPIS was only introduced during 2003-2004, based on the law on Agriculture (Zákon č. 252/1997 Sb., o zemědělství § 3a), and different from the factor of protection status it has a much shorter history and is geographically less stable through time.

The higher proportion of recently gained wood-pastures in the areas formerly covered by cultivated open landscapes is especially notable for lands, which according to LPIS database layer fall currently under the category "other cultures" (**Figure 36**), which though can be disregarded since the absolute area of wood-pastures marked with this category in the studied sites is very small and therefore is not representative. Among the wood-pastures, which do not fall under any LPIS-subsidy category ("no subsidy"), apart from the considerable portion of cultivated open landscapes as source-LULC category, a significant proportion of current wood-pastures formed from former cultivated open and more semi-open cultivated/non-cultivated areas.

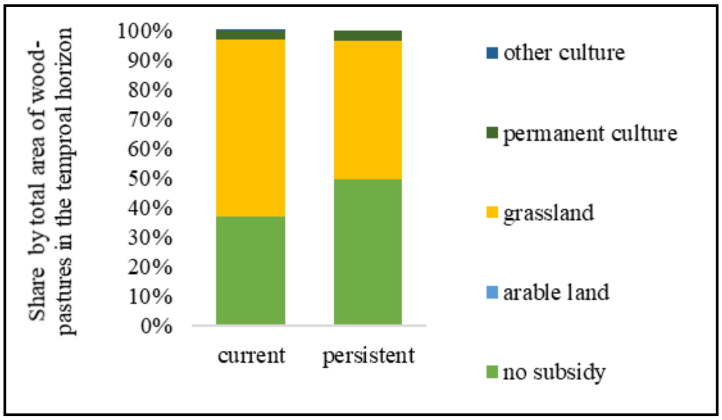

Figure 37. Shares of wood-pastures areas by current LULC of the parcel in LPIS registry

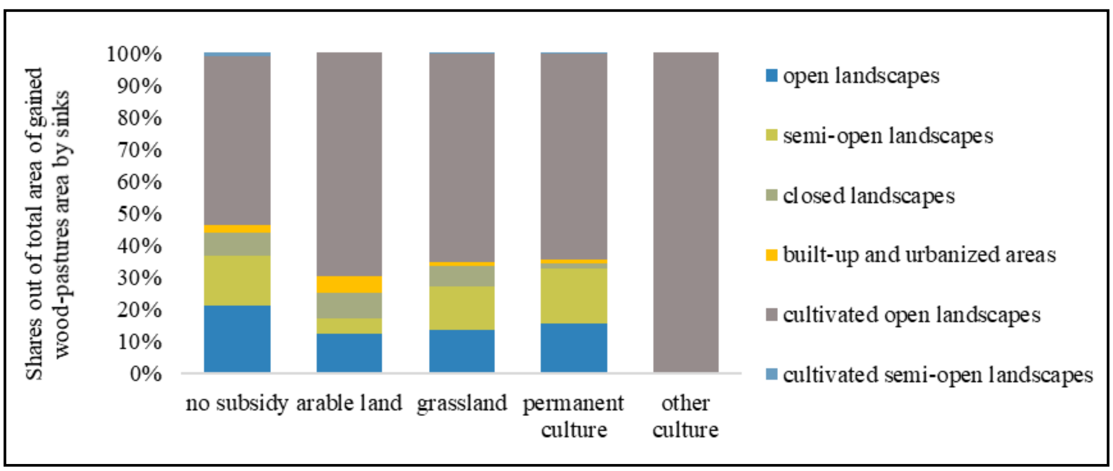

Figure 36. Former LULC categories of gained wood-pastures by LULC category of the parcel in LPIS registry

5.3.4.3. Analysis of the impact of environmental factors on spatiotemporal changes of wood-pastures using statistical tools

The results of statistical analysis using 2-way ANOVA (**Table 15**) return P-values of testing each driver and each new(former) LULC-category by area of lost(gained) wood-pastures respectively to check judgement about relative significance of each driver for change patterns.

The result of the test for the slopes ($p>0.05$) in combination with the one for the current LULC-categories of the lost wood-pastures ($p<0.05$) indicates that likely the relation of the latter factor to the dynamics of wood-pastures was more significant, and that steepness of the areas was not necessarily defining for the decline of these ecosystems at the first place (though transformation to specific LULC categories is somewhat dependent on the slope, as seen from the graphs for this factor in the previous subchapter (**Figure 23**A). At the same time, when looking at the results for the case of the gained wood-pastures area, slopes seem to have a more significant role as the driver ($p<0.05$).

Table 15. Cumulative results of two-factor ANOVA test for relation of the area of lost(gained) wood-pastures to the natural/anthropogenic drivers and new(former) LULC category respectively

Factor	Lost wood-pastures		Gained wood-pasture	
	p-value for correlation between factor and area of lost wood-pastures	p-value for new correlation between factor and new LULC of lost wood-pastures	p-value for correlation between factor and area of gained wood-pastures	p-value for correlation between factor and former LULC of gained wood-pastures
Slope	0.123	0.000	0.035	0.000
Elevation	0.043	0.000	0.057	0.000
Vicinity to water source	0.250	0.070	0.023	0.003
Dominating soils	0.086	0.291	0.005	0.150
Rock type	0.124	0.361	0.082	0.195
Vicinity to roads	0.114	0.210	0.008	0.039
Protection status	0.204	0.345	0.208	0.170
LPIS	N/A	N/A	0.045	0.080

Elevation appears to be more meaningful for the case of lost wood-pastures ($p<0.05$), than for the gained, again in combination with a strong association with new (former) LULC-categories of lost (gained) wood-pasture locations.

Relation of changes to vicinity to water does not appear to be significant in the case of lost wood-pastures and the same is seen for the role of former LULC-categories here. However, both these factors are characterized by p-value <0.05 for the case of gained areas, which may indicate stronger connection of these factors to the wood-pasture dynamics.

Similar pattern results for vicinity to roads.

Dominating soils of the parcels also show significant relation to the area of wood-pasture and to the former LULCs categories of the lost wood-pastures.

No significant relation was found for the factor of underlying rock types.

Significance of protection status is not obvious from the test, however allocation of state subsidies (LPIS) appears to be strongly correlated to the presence of wood-pastures ($p<0.05$), regardless of the former LULC-categories of the locations ($p>0.05$).

5.3.5. Discussion

5.3.5.1. Discussion on results

This last study aims to provide a detailed and evidence-based comparison of the roles of selected natural and anthropogenic factors as drivers of LULC change, specifically for the dynamics and stability of wood-pastures. In regard to the role of these two kinds of factors for the LULC-dynamics of landscapes in a broad sense, environmental factors are usually believed to play a more important role in less fertile areas.

As it could be concluded from the results of the previous chapters, most losses of wood-pastures occurred during the 2nd half of the 20th century, and the major change trajectory was towards more closed landscapes, which was attributed to the faster changing political situation leading to collectivisation, spread of large open fields and heavy mechanisation, in addition to intensification of land use and intensive grazing (Plieninger 2006; Schaich et al. 2015; Varga et al. 2015), overgrowth of formerly cultivated open or semi-open areas following extensification and abandonment of farming, depopulation and decrease of traditional management (Plieninger 2006). The spread of close-canopy LULC on the area of former wood-pastures through the time under study is confirmed not only for the lowlands, but also the other landscapes. According to literature, a general increase of forested lands could be observed in this period and reflects the process of “forest transition”, which is in other words the process of reversal of the forest decline, which was characteristic for the previous period due to the agricultural expansion.

Following the last two research steps, persistent wood-pastures make up only 12.44% of the area of the current wood-pastures, which is 5.36% of the those found for the 1st half of 19th century in the study sites. The fact that most current wood-pastures appeared recently from open, mainly arable landscapes, can be attributed to abandonment of less accessible lands during communism and extensification of agriculture in the 1990s (Bičík et al. 2001; Feranec et al. 2010).

Similarity of distribution patterns of wood-pastures by slopes, which is noticed for the different temporal horizons, shows that this factor does affect stability or presence of specific LULC of the landscape to a significant degree (keeping in mind that most of historical wood-pastures were lost and most of the current were gained recently, they tend to reappear prevalently at locations characterized by this factor in a similar way). The alignment between the patterns for the different temporal horizons is even closer at steeper slopes, and with only slightly more of persistent wood-pastures (intervals of 15-20 and 20-25 degrees). This also may reflect the fact that generally LULC changes have been happening there slower. The difference in absolute numbers seems very small, but it should be considered together with the fact that the areas of wood-pastures at both temporal horizons in these lands were relatively small. Losses, however, were generally higher here, especially compared to lowlands, which resembles the conclusions of the first case study (where increase of wood-pastures was observed in lowland areas). As mentioned in literature slopes are one of the defining factors for the possibility of using specific agriculture methods (especially machinery) (Bičík et al, 2015), which may be a limiting factor for presence of LULC categories including arable activities of certain scale there. A common opinion is that arable activities are possible at a gradient of maximally 12-20 degrees. This may be especially notable when looking at the change trajectory patterns of the lost wood-pastures (showing explicit transition to open (cultivated) landscapes the lands at slopes >10%), while considering that the turn to arable activities on a larger scale and with higher involvement of machinery was taking place in the last century. Besides, the areas with such gradients are mainly located higher in mountainous regions, and thus the observations of higher relative persistence of wood-pastures at higher gradients support the idea about the importance of traditional management, which is better conserved in these remote regions, which were less touched by socio-political changes during the period under study. It also supports the hypothesis about the gradual diffusion of effects of socioeconomical changes (Bičík et al, 2015), which first are taking effect in the “core areas” and then slowly spread to more remote zones. Observation of still quite high losses and lack of regeneration may also indicate the process of depopulation and abandonment of these remote areas during the last two centuries with massive movement of population closer to industrial centres.

All in all, the results for distribution of former non-cultivated open and semi-open landscapes (as sources) by slopes, and the way their presence has changed over time in relation to this factor (from comparison of sinks and sources), reflects the fact that the transformation of LULC at steeper slopes occurs less quickly, and that relative presence of certain LULC categories is related to the slope, including the observation that the very presence of wood-pastures in steeper lands appears less expressed.

A similar conclusion about stability of wood-pastures can be made from analysis of elevation as the driver, which shows an even closer alignment of the distribution patterns for the current and persistent wood-pasture areas at higher elevations. Though the peak of wood-pastures presence found between the elevations of 540 and 640 m a.s.l. is slightly less distinct for the current temporal horizon than for the historical, this observation may be also related to generally much lower absolute area of the current wood-pastures compared to historical ones and is probably statistically not very relevant and likely coincidental. Lowest dynamics of change trajectories at the highest elevation may simply reflect that the natural conditions there only allow for few land cover types and that they are typically less populated (thus, the processes are mainly ruled by natural factors). The distribution patterns of areas of gained and lost wood-pastures among the different elevation ranges (by absolute values), resemble by form those for the total areas of historical and current wood-pastures respectively, which may indicate direct relation of presence of wood-pastures to this driver. At the same time, it should be remembered that the proportion of persistent wood-pastures is very low, thus, most of the current wood-pastures are gained and most of the historical wood-pastures were lost, thus, such a conclusion is questionable. At lower elevations a significant amount of recently-formed wood-pastures replaced cultivated open landscapes as the former LULC, which underlines the role of changing agricultural policy in the 20th century, characterized by general extensification of arable lands and followed by their continuous decline after 1994 (Vachuda, 2017), thus representing the concept of "landscape turnaround" (Walker, 2012) as a process of recovery of natural areas. This also matches the observation that these lower landscapes showed less conversion of former wood-pastures into closed landscapes and a higher proportion of them converted into open non-cultivated landscapes. Meanwhile, dominance of closed landscape as sinks of the lost pastures at most elevations still reflects the general processes of abandonment of traditional means of management and commercial afforestation.

The prevalence of wood-pastures in areas further from **water sources**, specifically when comparing the 200 m and 500 m buffers, may partly be explained by the choice of the locations for these managed areas, with consideration of how cattle tends to distribute within wood-pasture areas, mentioned above in the Study sites section (5.3.3), thus, to minimize negative effects on grass utilization as well as streambanks and water quality. At the same time, the highest proportion of wood-pastures outside of any of those buffers may also be explained by generally higher total proportion of such areas, though the exact proportions cannot be extracted and quantified in a meaningful way due to disproportional distribution of the waterbodies. Yet, the presence of persistent wood-pastures is observed to be notably lower closer to water bodies (compared to historical or current wood-pastures), which indicates that closer vicinity to water resources appears to have a negative effect on stability of wood-pastures (which might be indirect).

The distribution of source-LULC-categories in different vicinities to waterbodies for the lands, that were recently overtaken by wood-pastures shows that cultivated open landscapes have the highest representation within intermediate distances from the water sources (200 - 500 m), which may be partly related to the structural changes of arable lands following extensification. To be more precise, smaller-size parcels were traditionally more common in the historical temporal horizon, and more of those smaller patches were located closer to water sources. Additionally, changes in irrigation systems may have an impact, such as new drip irrigation systems, which are currently supported by subsidy programs (Ministry of Agriculture of the Czech Republic, 2018). Notably, no apparent differences for distribution of “sinks” of the lost wood-pastures in relation to vicinity to water are observed, except for the role of built-up areas, reflecting a common urbanization trend.

Soil types were included into analysis as one of the potential drivers, since they are believed to be a crucial factor for spatial distribution of forests, arable lands, permanent grasslands and other related or adjacent LULC types. Note that the classification of soils in this analysis is somewhat simplified, in order to reflect the impact of soils on wood-pasture dynamics in general, without overloading the analysis. Czech terrains are formed by rocks of various compositions and ages (more details follow in the analysis of rock types as a factor of LULC change), and the underlying parent rock is at the same time known to be a defining factor for composition of soils. Geographically, the different types of soils are scattered across the country, as a result of the combined effect of climatic specificities and landscape features. At the same time, this scattered distribution means that the results for analysis of soils type as the driver are more representative and reliable, regardless of the possible location-specific aggregation or similarity of other factors (for example, different soil types may be encountered even in the same cadastral districts, characterized by similar local political and socioeconomic development). According to the reviewed literature, existing opinions about the relation of the presence of specific LULC categories and their dynamics within a landscape in connection to the underlying soil differ, but some authors mention, that weak soils often serve as a basic reason behind LULC changes (Krajewski et al 2018). Importance of soil types for presence of one or another LULC-category in general is seen through distribution of e.g. forests, arable lands or permanent grasslands. For example, the best soils for farming are mostly found in South East Moravia and to a certain extent also in the Elbe Plain, and at the same time forests are poorly represented in these areas. Thus, a relatively high importance of soils for the distribution of wood-pastures may also be expected, but how significant their role is in relation to other factors, and how the different sinks and sources are represented should reflect how much this natural factor is affected by the other, especially human-related ones. However, the relative representation of the soil types across the country needs to be taken into account. E.g. the results obtained in this study, which show significant domination of Cambisols, simply reflect the fact that these soils are generally the most widespread soil type in Europe and are most often found in forested lands on steep slopes (particularly in highlands). In Czechia they occupy 55% of agricultural land. The dynamics of wood-pastures (**Figure 29**) shows a considerable contribution of Gleyic Phaeozems among the sinks of lost wood-pastures, specifically in the cases of their conversion into open/cultivated open or semi-open cultivated landscapes. Gleyic Phaeozems are high fertility soils and are excellent for agricultural production, thus, this fact is most probably also a consequence of the process extensification of agriculture, when the most fertile soils were being used for agricultural purposes. Calcic Chernozems, involved in all types of loss-transformations of wood-pastures, are again one of the most spread types of Chernozem (the most productive soils) in Czechia. Of concern is also the stability of this factor from a long-term perspective. Fertile zones are being used intensively, which may be affecting the soil structure with time, even if protective measures are applied.

According to existing works on land use, geological conditions (underlying **rock type**) of the areas play a key role for landscape formation (Bičík et al, 2015). Firstly, it impacts landscapes directly on a grand scale, e.g. by impacting the relief, which affects farming methods. Secondly, it influences the diversity of soil properties, and thus has an indirect effect at local ecosystems, species composition and their stability. Specifically, the geological composition of the area defines the mineral content, and thus soil nutritive properties. In Czechia much of the bedrock consists of Paleozoic rocks, overlaid by sediments of Mesozoic in various sequences (see **Figure 21**), and the largest local geological diversity in the country in present times is noticed for Carpathians, with some isolated fragments of Mesozoic sediments (sandstone). The distribution of wood-pastures in relation to dominating geology of the areas shows that solidified sediments are prevalent as the dominating rock type for this LULC in all temporal horizons, which occupies around 22.5% of the country and is found in all GTNL. A notably higher share of current and persistent wood-pastures, as compared to historical, is found on areas with plutonic rocks. The same is seen again in the case of gained wood-pastures, which reflects both higher stability and preferable emergence of wood-pastures. The higher amount of current wood-pastures in lands underlain by vulcanite is mostly of recent appearance and consists mainly of wood-pastures that are displacing former cultivated (open/semi-open) landscapes. Volcanic rocks are known for their richness in elements such as potassium and phosphorous. Fine grained volcanic rocks are even used as fertilizers. In nature, they are also show fast rate of weathering, leading to a relatively fast release of their contained macro and micronutrients and results commonly very fertile agricultural areas (Straaten, 2006). Similarly, plutonic rocks are also known for high mineral content, which is released to soils during weathering processes and thus, becomes available for plants. However, the same process of weathering leads to high content of sandy or clay rich texture with very little silt, which means that the water retaining capacity of these lands may be reduces. Still, regardless of the described prevalence of volcanic and plutonic rock types, the direct impact of this factor cannot clearly be assessed within the frame of this study. At the same time, since locations dominated by metamorphic rocks are less characteristic for persistent than historical or current wood-pastures, most probably many former wood-pastures were naturally existing in locations with this geology before the forced changes leading to their loss, but the newly gained wood-pastures, in different locations, were still expanding often in similar geology later. This is supported by the fact that the dominant sink-LULC-category of the lost wood-pastures are semi-open (non-cultivated landscapes) which means that the landcover was in many cases conserved, even though the land use has changed, implying that anthropogenic factors were driving the decline of wood-pastures.

Significant impact of anthropogenic factors in driving LULC change has been already noticed from the results of the previous chapters. These factors were gaining increasing importance during the last two centuries. One of the factors, which touched many areas of human life was the ability to access more remote areas and, thus, growing coverage of transportation systems. The importance of road connections was increasing together with the industrial revolution in 1860-70, with the highest impact of agricultural expansion and the rise of steam engines, development of mining activities and industrial centres. However, modern roads were appearing quite late in Czechia. The intense construction of tarred roads started around 1930s and was carried out with delays due to the war and related economic limitations. Since 1990 until present time the number of motorways has increased more than twice and generally roads were often built on lands occupied by valuable LULC-categories. The major way of how **vicinity to roads impacts** LULC pattern nowadays is still related to the distance of production areas to the potential market (ability to transport the agricultural goods quickly), thus, it is arable lands which would usually be occupying the parcels closer to roads. All in all, higher density of transportation network is characteristic for urbanized areas, which generally show a higher rate of LULC change. The current study technically shows that there are more wood-pastures further from the roads (especially from those with higher categories). This may simply result from a bigger absolute area which is not lying in close vicinity to roads and therefore these absolute numbers only have limited relevance. However, the higher share of areas with transport access in vicinity in the case of current compared to persistent and historical wood-pastures (the latter effectively resembles a sort of average since the roads were not existing back then) may indicate that such locations are actually positively related to the presence of wood-pastures. Though this could not be univocally concluded from the available data.

The largest amount of historical, current and persistent wood-pastures can be found in **protected areas**. However, due to the target-focused data selection of the areas under study (focusing on locations with currently present wood-pastures), they may contain a disproportionately high share of protected areas, which makes a quantitative analysis of the absolute areas unfeasible. A comparative analysis is still possible and yields, that the area of persistent and current wood-pastures located in national parks (the highest level of protection) is significantly higher than for historic wood-pastures. This clearly reinforces the effectiveness of designation of the protection status to these lands to help preserving the traditional LULC areas. Gains in these areas originate in almost equal extents from the former cultivated open-, closed-, non-cultivated semi-open-/open- landscapes, whereas in case of lost wood-pastures the transformation was happening mainly towards closed or semi-open landscapes, which altogether is considered to be positive pattern of transformation from environmental perspective. These findings match the conclusions of other authors working on the topic of the effectiveness of designation of protected areas against undesirable LULC changes in Europe, and in support of those more environmentally sustainable LULCs, which is also an achievable global policy measure to slow-down the loss of biodiversity in the long-term (Rodríguez-Rodríguez et al, 2019), and also more socioeconomically sustainable for the agricultural guild than outer unregulated areas (Rodríguez-Rodríguez et Martínez-Vega, 2018).

LPIS (Land parcel identification system) status describes a factor, which provides a more active impact on landscape dynamics, since it uses subsidies, intended for farmed lands of Czech Republic, which farmers have applied and will potentially get financial support for. The study results serve as a confirmation of existing concerns about the accuracy of LPIS data (see details in 5.3.5.2). One of the limitations worth noting is the difference in definitions of agricultural land between LPIS and State maps: "farmed land" in the first case, and total agricultural land according to cadastre in the second case (Vachuda, 2017). LPIS states that grassland should have minimum livestock intensity (any animals of the species from the central livestock register of farms with "ecological status", at least 0.3 large livestock units/ha of grassland), minimum stocking, grassland maintenance by mowing, grazing and disposal of the shorts. Grasslands with/without woody vegetation are not distinguished by LPIS. "Permanent cultures" may include fruit trees, fast-growing woody vegetation, hops, nurseries, and similar semi-open areas, which may often be used for cattle as well; "other cultures" are defined scarcely. Inconsistence exists between LPIS and real allocation and size of arable lands. At the same time, sometimes farmers, applying for the subsidies, declare the areas that are potentially eligible for support bigger than they actually are. In details, results acquired during this study reflect, firstly, that, areas which are registered in the LPIS do contain more wood-pastures, and, especially the "gained" ones, which is seen from the comparison with the graph for the persistent wood-pastures. At the same time, looking at the categories which these areas are marked with in LPIS, the latter seems to be misleading often, as it does not reflect correctly the possible LULC of the areas or at least does not specify it enough.

The distribution pattern of sources among the territories currently covered by wood-pastures, meaning that open cultivated lands appeared to be the dominating source of gained wood-pastures, may related to the total loss of arable lands described for the last decades and estimated as 21.71 ha/day for period 2008-2013 (or 396.50 km^2 for the 5 years in this period, thus from 30254.42 km^2 to 29857.92 km^2 or from 38.36% to 37.86% of the total country area) (Vachuda, 2017). In this case the change is an ecologically "positive" resolution of the situation brought by desertification of former arable lands and the inherent consequences such as soil degradation/erosion in intensively used arable areas. Unconformity of semi-open areas as the source for the wood-pastures, marked as “permanent cultures” by LPIS, may reflect both imprecise data on LULC and spreading human activity towards the former uncultivated areas (e. g. currently fruit trees used for cattle at the same time). Semi-open cultivated/non-cultivated landscapes are manifesting as the former LULC categories among the lands, currently lying in non-subsidized areas, reflecting a more “natural” process of change of land use only.

Altogether the conclusions of this chapter confirm the importance of anthropogenic drivers in spatiotemporal changes of wood-pastures in Czechia. They also show that most ecosystem changes are coming from the growing demand for the provisioning ecosystem services (food, water, timber, fibre, fuel), which substantially improves human well-being and economic development, but goes along with ecosystem degradation expressed in loses of natural capital, that often happens at scale larger than could be justified by producing greater gains in other services (Dumanski, 2015).

Though some authors state that major decisions regarding land use are often made by urban people with limited knowledge of agriculture (Dumanski 2015), the results in this study show that administrative measures on state level, such as introduction of subsidies and protected areas, can bring significant support for positive trends in LULC changes. However, some improvement need to be made here to the mechanisms of implementation of the governmental programs and policies in order to get more reliable data as the basis for implementation thereof, such as increasing the accuracy of data by means of stricter and more regular updates of the LPIS databases and regular audits of the farmlands involved in the programs. Following the conclusions made in the previous chapter about the structure of current wood-pastures (specifically, that they often consist of either (1.) large areas with oak, pine or birch in lowlands on slopes with southern exposition; with maples, spruce or rowan in highlands – often in former military areas, or (2.) small patches with fruit trees anywhere with sheep/goats), these landscapes bring different ecological, economical or socio-cultural values, and at the same time they may and need to be supported by a different combination of administrative approaches. The low proportion of persistent wood-pastures, as well as the field trips observations clearly show that very few old trees are present in the current wood-pastures and that they require protection and active support via appropriate management of these ecosystems.

To follow on the above-mentioned considerations, besides the confirmation of the role of purely anthropogenic factors, significance of elevations, for example, reflects the same indirectly. Importance of state financial support for landscape stability is highlighted by the results of statistical analysis as well. Altogether, conclusions of statistical (ANOVA) test and pairwise comparison of factors as drivers reflects that losses of wood-pastures are more likely explained by human-driven factors whilst natural factors play a more defining role for the appearance of the new wood-pastures.

In sum, this discussion leads back to the thought mentioned in the beginning of this section that "environmental factors are usually believed to play a more important role in less fertile areas", or to extend this idea, areas that are less convenient for agricultural activities, and thus, confirming the role of human intervention in natural landscape dynamics. A balanced coexistence of healthy sustainable landscapes with presence of human activity appears possible but requires application of measures, that modulate human behaviour e.g. by assigning protection status or making sustainable landscape management financially attractive.

5.3.5.2. Discussion on methodology

Though the methodology of the research step described in this chapter is in principle similar to the previous chapters, it is significantly more complex in execution due to the bigger number of drivers that were analysed. More different types of data sources were used, some of which requiring considerable amounts of manual work. At the same time, with even more data sources included into the analysis, data accuracy improved, and the results of the research are more reliable. The possibility to use publicly accessible real-time sources, such as Google Earth, helped to control the LULC of areas of concern, and continuity of LULC within the recent years. As mentioned in the discussion on results of the previous study (see section 5.2.5.1), there are specific constraints for using LPIS databases as a source. In addition to the issues described there, the program is aimed at small non-market subsistence farmers, and also only works with parcels bigger than 0.1 ha and does not include lands of farmers who do not apply for subsidies. Agricultural land not used for agricultural purposes (gardens, which are not primarily aimed for production purposes, golf courses, solar power stations, etc) are also discarded (Vachuda, 2017). According to information published by the Ministry of Agriculture of the Czech Republic (Ministry of Agriculture of the Czech Republic, 2018), out of the total area of the agricultural land resources in the Czech Republic (4,208,000 ha), 76.5% is *owned* by natural persons, 13.8% by legal entities, 5.5% by municipalities and regions and 4.2% by the state. The structure of economic operators on agricultural land differs from the ownership structure. However, natural persons *manage* approximately 30.6% (28.2% of this are farmers) of the agricultural land area. The remaining 69.4% of agricultural land are managed by the enterprises of legal entities. Thus, from the above-mentioned criteria for lands included in LPIS database, the differences in areas categorized as "arable land" between the LPIS and cadastral maps (ČÚZK) are considerable (Vachuda, 2017). Furthermore the data in LPIS is not always accurate, since data is often updated slowly and as a result may not reflect the land use correctly, which results in farmers renting parcels which are marked with a different land use than claimed (e.g. arable lands vs. forests). In addition, LPIS accuracy has not been systematically examined, but discrepancies between the shown LULC and reality have been observed.

It should also be noted that some inaccuracies in acquired data about presence of some LULC-categories in the 1st half of 19th century may have occurred (such as cultivated semi-open landscapes, where only the land use has changed), partly due to imprecisely marked lands in the historical maps, leading to possible confusion between this LULC and wood-pastures in some areas.

Here again, the possible impact of individual work style has been minimized, since manual digitalization of the data has been done exclusively by the author.

5.3.6. Conclusion

The results of this section help answer more of the research questions and hypothesis that are investigated in this thesis. Firstly, it can be concluded the spatiotemporal dynamics of wood-pastures are related to both natural and anthropogenic drivers. However, looking deeper at the character of their interplay, the human-driven factors appear to be more significant. Specifically, the changes of political situation and measures for landscape protection from the side of the state has proven to play a determining role in modern age, directly or indirectly. Designation of the protection status and allocation of governmental support (including but not limited to financial) to the areas of valuable landscapes has been proven to positively affect sustainability of wood-pastures. Regarding indirect impact, the visible relation of landscape dynamics to the natural factors elevation and slope can also be partly attributed to how these areas were being differently affected by political changes in the period under study. Factors such as soils or vicinity to water sources at least partially also reflect changes of agriculture policies and related structure of agricultural lands. This allows to conclude that, as highlighted by FAO (FAO, 2018), for mediating landscape changes happening at the current times, institutional developments are playing an increasingly important role.

6. Summary and Conclusion

The question of recent changes in presence and state of wood-pastures has been gaining increasing attention throughout the last years, also due to a rising interest in the more general topic of the processes of landscape transformations. This work is focused on the analysis of long-term spatial changes of wood-pastures in Czech lands and potential driving forces behind them. Understanding these forces allows to make predictions about future changes and thus make informed decisions for the management of such valuable landscapes.

The case studies, which form the core part of this dissertation, are logically linked to each other and were created in the same order as they are presented in the thesis, leading to a gradual solution of the research questions and hypothesis.

The first case study is mainly aimed at creating and testing a methodological approach for defining the pattern of LULC change at the landscape scale for the territory of Czechia using GIS software, and to understand long-term spatiotemporal change trajectories of wood-pastures in lowland areas.

The second case study extends the results of the first beyond lowland-areas and allows a more comprehensive understanding of spatiotemporal dynamics of wood-pastures in Czechia between the beginning of the 19th century and the present temporal horizon across all the rest landscape types present in the country. In this part also the influence of major natural conditions (general types of natural landscapes, GTNL) as a driver of change is evaluated.

The third case-study investigates the importance of different potential factors for sustainability of wood-pastures with a focus on assessment of anthropogenic and natural factors through a synthesis of analytical processing of selected data and existing literature resources. This is an essential step to also understand how to preserve the very few ancient wood-pastures, or to successfully reintroduce them in some of the landscapes where they have disappeared completely, especially in regard to the confirmed multi-side value of these ecosystems. Through an analysis of factors such as elevations, slopes, proximity of water sources, transportation access, dominating soil and rock type, protection status and coverage by certain forms of state financial support programs these effects could be estimated.

The thesis answered the following research questions and hypothesis as follows:

RQ 1. What are the observable change trajectories of wood-pastures in a) lowlands of Czechia at the landscape level? b) both the lowland and highland landscapes of Czechia at the landscape level? Are these change trajectories similar to those for only lowlands?	
H1. A general decline in the wood-pasture landscapes Czechia can be observed between the historical (first half of 19th century) and the current temporal horizon. Moreover, the decline is even stronger for the second half of the period under study (starting from 1950s).	a) The hypothesis could not be confirmed for the first study when only lowlands were considered. In fact, the area of wood-pastures in this case has more than doubled between the first and the last temporal horizons. At the same time the changes were happening at a higher rate in the last period under study (starting from 1950s): most of the recent wood-pastures appeared in this period, and at the same time, the loss of former wood-pastures, with their transition into closed LULCs was happening also mainly during this period. b) A general decline of wood-pastures across the country was observed, when both lowland and highland were taken into account. Wood-pastures covered 4910.66 ha in the beginning of the 19th century and only 2128.12 ha in the current temporal horizon (or 10.89%, resp. 4.7% of the total area of research). The conclusion about higher rate of changes in the period after 1950s could be formed indirectly, by combining the results of the first study with observations of the general change trends in the second study step.
H2. The general dynamics of wood-pastures observed for the lowland and highland areas of Czechia taken together is similar to those of lowlands separately. Thus, a general decline of wood-pastures between the beginning of 19th century and current temporal horizon is observed.	A general (strong) decline of wood-pastures has been observed. However, the fact, that this can only be seen in lowland and highland areas of Czechia taken together, while lowland areas show a strong increase, indicates that the dynamics are not similar (though general mechanisms of change drivers apply similarly to both).

RQ 2. How can continuity of wood-pastures in Czechia be characterized?	
H3. Most wood-pastures within the current landscapes of Czechia appeared only recently. Very few old wood-pastures remain.	In both first and second study step (thus, both in the case of lowlands only and lowlands and highlands taken together) the dominance of recently formed wood-pastures among all currently present was confirmed. In the case of lowlands, only 1% of wood-pastures could be characterized as persistent throughout the whole study period, while

	17% were gained by 1950 and 82% appeared after. In the case of both lowlands and highlands considered together, only about 5.36% of the wood-pastures present in the beginning of the 19th century were also present in the current temporal horizon. At least 87.64% of current wood-pastures were not present in the beginning of the 19th century and thus formed recently. This number might even be higher as some wood-pastures might have disappeared and newly formed between the observed temporal horizons.

RQ 3. Do change trajectories of wood-pastures differ for different landscape types in Czechia?	
H4. The amount of wood-pastures in both historical/present time horizons differs depending on the location within specific natural types of landscape.	The role of the GTNL for presence of wood-pastures could be confirmed by the results of the study step 2. However, the role of GTNL appear to be less significant than the role of purely anthropogenic nature (political, economic, etc).
H5. The scale of spatiotemporal changes in wood-pastures and their continuity varies depending on the landscape types.	The 2nd research step has shown that there is a relation of the character and scale of change trajectories to GTNLs, though statistical analysis did not confirm a strong significance of these factor. A higher significance of this relation could be seen in the case of appearance of the recently gained wood-pastures and could be partly attributed to the difference of natural conditions but can also serve as an indirect confirmation of the role of socio-cultural factors, which often correlate with certain GTNL.

RQ 4. To which extent do other land use/land cover (LULC) types represent sinks of the lost historical wood-pastures, or sources of the recently appeared wood-pastures? Is this affected by different administrative districts and types of landscapes?	
H6. The sinks and sources of wood-pastures are comprised of other cultivated/non-cultivated LULC types in a similar proportion within the different administrative districts.	The first and the second research step have shown that the presence and the persistence of wood-pasture areas varies significantly between the different cadastral districts. Additionally, the very structure of wood-pastures and the change trajectories may differ between cadastral districts.
H7. The sinks of the lost wood-pastures and sources of recent wood-pastures are represented by other different	The second research step has shown that allocation of the landscape within different GTNLs does have relation to both sources/sinks of the

cultivated/non-cultivated LULC types in a similar proportion within the different types of landscapes.	recent/former wood-pastures. The statistical evaluation has also confirmed this connection.

RQ 5. Which of the natural or human-driven factors have the most significant impact on change trajectories of wood-pastures?	
H8. Human-driven factors, such as changes in political and economic structure (incl. industrialisation) are the major drivers for the recent dynamics of wood-pastures area. Natural factors have a secondary role in the stability of these areas.	The impact of human-driven factors for the dynamics of wood-pastures (especially recent ones) could be seen partially through all three research steps, and was explicitly confirmed by comparison of the different natural and anthropogenic factors in the third research step. First industrialisation and technological development, and later the related socioeconomical, as well as political factors on the local and state level (state support, political changes, landscape protection) were shown to have a significant impact on change trajectories.

Systems like wood-pastures are a good example of socioecological systems, and despite originating as a result of human management, they carry high ecological value. To guarantee sustainable existence of such systems, the roles and positions of the different stakeholders need to be considered, and e.g. local (traditional) knowledge should be supported and used wisely in combination with scientific knowledge. The current formal definition of sustainable development ("development that meets the needs of the present without compromising the ability of future generations to meet their own needs", according to the 1987 Bruntland Commission Report) is all-inclusive and, besides of environmental issues, also considers socioeconomical well-being. Thus, when judging about change trajectories of landscape as "positive" or "negative", its definitions as "societal", "governmental" and "environmental" landscapes should be included to help avoid conflict of interests and, thus, resistance from the side of the different stakeholders, which may be achieved through complex participatory researches, by creating connections between the land users and political and executive institutions by researchers. Traditional knowledge is often disregarded if it does not have a scientific base. Building connections and mutual knowledge-sharing between the different stakeholders and developing plans in mutually beneficial way may be an effective solution to help guarantee informed management in combination with genuine interest

While the presented work is focused on specific study cases, the results can be used to make general conclusions and provide a basis for subsequent research. The developed methods used for the analysis of change trajectories of wood-pastures can be applied to identify long-term spatiotemporal changes of other LULC-categories or landscape elements as well. Thereby, the results and conclusions of this work lead to a better understanding of dynamics of wood-pastures and its most valuable elements, factors of vulnerability and explains the necessity of their protection, not only for their aesthetic value but also due to practical importance for future challenges.

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Act No. 114/1992 Coll., on the Protection of nature and landscape protection (Czech: zákon č. 114/1992 Sb. Zákon o ochraně přírody a krajiny)

8. Attachments

List of attachments:

Attachment 1: Impact Publication: Spatio-temporal dynamics of wood-pastures in lowland and highland landscapes across Czechia

Attachment 2: Impact Publication: Novel methodological approach to analysis of spatio-temporal change trajectories of wood-pastures on an example of a case study in the Czech Republic

9. Appendices

Appendix 1. Sinks of lost wood-pastures in relation to GTNL

Total area of wood-pastures lost in the study period	GTNL				New LULC category**		
	Type*	Area of the lost wood-pastures within the GTNL, ha	Share of lost wood-pastures within the GTNL (out of total lost wood-pastures area), %	Share in total original area of wood-pastures, %	Category	Area within the GTNL, ha	Share by area in total area of lost wood-pastures per GTNL, %
4577,76 ha (93,22 % of the original historical area)	1	221,94	4,85	4,52	1	80,37	36,21
					2	9,73	4,39
					3	95,16	42,88
					4	3,16	1,43
					5	30,57	13,78
					6	2,94	1,32
	2	257,7176	5,63	5,25	1	50,15	19,46
					2	17,42	7,85
					3	147,40	66,41
					4	12,28	5,53
					5	27,85	12,55
					6	2,63	1,02
	3	1513,034	33,05	30,81	1	133,72	8,84

					2	164,89	10,90
					3	1159,80	76,65
					4	35,49	2,35
					5	6,90	0,46
					6	12,23	0,81
	4	279,9531	50,44	47,02	1	78,35	3,39
					2	292,42	12,66
					3	1864,40	80,75
					4	61,49	2,66
					5	5,16	0,22
					6	7,07	0,31
	5	78,86	6,12	5,70	1	21,48	7,67
					2	157,95	56,42
					3	95,08	33,96
					4	4,68	1,67
					5	0,00	0,00
					6	0,76	0,27

* see Table 5

**see Table 6

Appendix 2. Sources of gained wood-pastures in relation to the GTNL

Total area of recent wood-pastures, ha	GTNL				Former LULC type of the area**		
	Type*	Area of recent wood-pastures within the GTNL, ha	Share of recent wood-pastures within the GTNL, in total recent wood-pastures area, %	Share in total current area of wood–pastures, %	Category	Area within the GTNL, ha	Share by area in total recent wood-pastures area within the GTNL, %
1384,94	1	42,55	3,07	2,00	1	0,82	1,92
					2	0,00	0,00
					3	0,51	1,19
					4	0,97	2,27
					5	39,04	91,75
					6	1,22	2,87
	2	126,12	9,11	5,93	1	53,48	42,40
					2	10,30	8,16
					3	2,12	1,68
					4	4,49	3,56
					5	51,99	41,23
					6	3,74	2,96
	3	686,91	49,60	32,28	1	85,94	12,51
					2	106,75	15,54

					3	21,74	3,16
					4	9,21	1,34
					5	460,70	67,07
					6	2,57	0,37
	4	238,12	17,19	11,19	1	32,46	13,63
					2	15,54	6,53
					3	2,32	0,97
					4	3,76	1,58
					5	183,78	77,18
					6	0,27	0,11
	5	291,25	21,03	13,69	1	52,38	17,99
					2	67,73	23,26
					3	64,69	22,21
					4	2,02	0,69
					5	104,40	35,85
					6	0,02	0,01

* see Table 5

**see Table 6

Appendix 3 Overall changes of wood-pastures cover in the studied areas between the 1st half of the19th century and 2015/2017

Cadastral district	Area, km^2	Presence of wood-pastures 1824-1843		Present of wood-pastures 2015 - 2017		Net change of wood-pastures area		GTNL
		ha	Share out of district area, %	ha	Share out of district area, %	ha	Share out of original area, %	
Babetin	1,94	5,97	3,07	52,29	26,91	46,32	776,46	3
Bludovice	10,88	24,36	2,24	0,57	0,05	-23,79	-97,66	1+2
Bohdalice	4,95	12,78	2,58	2,90	0,59	-9,88	-77,31	2
Brumov-Bylnice	16,09	359,89	22,37	163,64	10,17	-196,25	-54,53	3
Ceske Zleby	42,53	96,21	2,26	382,28	8,99	286,07	297,32	5
Cistá u Litomyšle	28,61	14,38	0,50	30,47	1,07	16,09	111,89	2+3
Dolni Udoli	6,20	13,02	2,10	14,62	2,36	1,60	12,29	5
Habartice u Jindřichova	9,73	71,68	7,37	5,67	0,58	-66,02	-92,10	4
Havraniky	11,31	23,09	2,04	28,70	2,54	5,61	24,31	1+2
Horni Becva	42,55	868,70	20,41	54,08	1,27	-814,61	-93,77	4
Husinec	6,26	3,62	0,58	10,09	1,61	6,47	178,68	3
Knezicky	11,88	244,87	20,62	42,02	3,54	-202,86	-82,84	1
Koneprusy	4,37	1,74	0,40	19,40	4,44	17,66	1015,80	2
Lobendava	11,41	4,76	0,42	18,28	1,60	13,52	283,93	2
Milovice	11,77	1,84	0,16	37,48	3,19	35,63	1932,25	1
Msec	13,83	15,74	1,14	7,38	0,53	-8,36	-53,09	2+3
Novy Hrozenkov	80,58	1701,84	21,12	698,65	8,67	-1003,19	-58,95	4 + 3
Ostruzna	18,20	166,25	9,13	19,69	1,08	-146,56	-88,16	5
Pitin	23,25	304,48	13,10	76,23	3,28	-228,25	-74,96	3
Rovne pod Ripem	3,75	1,73	0,46	4,27	1,14	2,53	146,29	1
Ruda	3,79	2,67	0,70	0,71	0,19	-1,96	-73,42	3
Rudice	7,67	119,10	15,52	14,58	1,90	-104,53	-87,76	2
Semanin	8,57	1,65	0,19	14,81	1,73	13,15	794,91	3+2
Setechovice	3,20	0,00	0,00	12,08	3,78	12,08	12027182,18	4
Štítná nad Vláří	29,64	252,88	8,53	169,08	5,70	-83,80	-33,14	3
Svarec	2,73	0,00	0,00	3,37	1,24	3,36	75653,99	3
Velke Vrbno	10,30	45,29	4,40	28,16	2,73	-17,13	-37,82	5
Vimjperk	11,87	11,76	0,99	39,69	3,34	27,93	237,51	5+4
Zdechov	12,89	540,34	41,90	177,06	13,73	-363,28	-67,23	4 + 3
Total	450,75	4910,66	10,89	2128,12	4,72	-278,44	--56,66	