CZECH UNIVERSITY
OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

Department of Applied Geoinformatics
and Spatial Planning

Application of landscape metrics for evaluation of landscape structure development in border areas

DOCTORAL THESIS

2020

Author:
Mgr. Martin Dolejš

Supervisor:
doc. Ing. Petra Šímová, Ph.D.

Reviewers:
Dr. rer. nat. Ralf-Uwe Syrbe
Leibniz Institute of Ecological Urban and Regional Development, Dresden

doc. Ing. Jan Skaloš, Ph.D
Czech University of Life Sciences Prague

doc. RNDr. Pavel Chromý, Ph.D.
Charles University in Prague

Declaration

I have written the thesis by myself, and have not used sources or means without their declaration in the text. Any thoughts by others or literal quotations are clearly referenced. The thesis was not published elsewhere except for individual studies that had already been published in scientific journals. Cover photo credits: pxhere.com (CC0 1.0).

Acknowledgements

Despite the fact, that dissertation text is written in singular form, this work is the product of intensive collaboration. Therefore, I would like to thank the following people, without whom I would not have been able to complete this dissertation.

First of all, to my supervisor Petra Šímová, for helpful comments and guidance through the doctoral study. Special thanks to my colleague Pavel Raška for cooperation (especially on microscale study), encouragement and endless patience during discussion of the thesis and through my entire (longer than expected) doctoral study. Jaroslav Janošek, for punctual and accurate transformation of the text to readable and understandable state. Jiří Riezner for inspiring remarks and extensive archival search during Zubrnice research. Karel Hrach for guidance and cooperation on statistical models. The students of GIS seminar at CULS for digitizing part of the dataset for Czech borderland.

Great thanks to my family for all the support you have shown me through these uneasy times. Last but not least, Lada and Charlie, for being supportive and understanding for the time I had to spent with thesis instead of household chores or walks.

Abstract

Land cover and land use changes that we are facing in last decades cause significant problems on global and local scale. The consequences of rapid changes influence global climatic systems, local accessibility of water, food and other important resources. For the sake of timely intervention, the knowledge of the land cover and land use processes is crucial. One of the most important part of the process is initial stage – forces that drives the change of the landscape. The research of the driving forces concludes to broad agreement of irreducibility of the process to single driving force. In other words, the resulting state of the land cover and land use is shaped by complex of interconnected driving forces. Such forces could be divided to biophysical, technological, cultural, socio-economic and political categories.

Socio-economic and political driving forces are considered of major importance dealing with the alternation of cultural landscapes. Deeper insight into political driving forces (e.g. changes in regulations, norms or institutions) revels methodical issues. One example could be the difficulty of manipulative experiment - the regulatory, political or institutional systems are uneasy to manipulate for the sake of experiment. Such limitation might be resolved by appropriate research design of (a) temporal setting, i.e. comparative study of landscape alternation under two different political regimes or (b) territorial setting, i.e. comparative study of the two territories under different political conditions and same time points.

Therefore, thesis aims to research political driving forces of political regime and border permeability in three spatially and temporally interconnected parts. First part focuses on landscape of former Iron Curtain border zone, where changes connected with transformation of economy and politics of former eastern bloc after 1989 are addressed. On one hand, the different evolution based on historical context is expected. On the other, the tendency for harmonization of the Central European countries landscape processes after harmonization of particular regulations via EU enlargement might be observed. Second part of the thesis aims to evolution of landscape of inner border zone of Czechia before and after the revolution in 1989. We seek to evaluate the border permeability effect, where part of the border neighbouring with the democratic countries before 1989 was strictly guarded. The thesis is closing with deeper temporal

probe into landscape evolution of the Czech border zone – case study of one cadastre evolution for past two hundred years.

For the sake of evaluation of the landscape changes, the framework of standard procedure for study of driving forces (Burgi et al., 2005) was used. This procedure consists of spatial data combination (CORINE, digitized aerial imagery, old maps), driving forces determination and spatiotemporal scale. These three features (and its derivate e.g. landscape metrics, and land use land cover classes dynamics) are consecutively analysed and the effects of political driving forces (political regime and border permeability) statistically tested via nonparametric repeated measure designed models.

The results indicates the differences in landscape evolution on both sides of the former Iron Curtain border zone, especially in agricultural structure and dynamics of urbanization of the west side. We interpret the changes in agricultural structure as reactions on Common Agricultural Policy. These changes are marked in case of former West/East German segment of the border. This segment shows the highest dynamics of landscape convergence processes, attributed to reunited administrative after 1989, as well. In contrast, in case of Czechia, Slovakia and Hungary, the strong effect of agricultural land abandonment was observed. This tendency was slowed with the restructuralization of the agriculture accelerated by Common Agricultural Policy after 2004. The second part of the thesis concludes with the effect of border permeability (strict military regime in border zone). Here, the landscape exhibits higher dynamics of non-forest near-nature vegetation. These findings are later extended by cadastral case study with deeper temporal extent. We enhanced observed changes and its possible driving forces with other driver - depopulation of the Czech borderlands after Second World War. We have identified clear contrasts in landscape evolution in Iron Curtain border zone. Despite these findings, the identified driving forces should be verified by other method inclusive to agents of landscape change.

Abstrakt

Změny krajinného pokryvu a využití půdy, kterých jsme svědky v posledních dekádách, způsobují významné problémy na globální i lokální úrovni. Důsledky razantních změn zasahují jak globální klimatické systémy, tak lokální dostupnost vody, potravin a dalších nezbytných zdrojů. Pro včasný zásah a řešení problémů je nezbytná znalost celého procesu změny krajinného pokryvu a využití půdy včetně sil, které stojí na počátku těchto změn a určují míru a povahu těchto procesů – hybných sil krajinných změn. V rámci výzkumu hybných sil panuje shoda na složitosti a provázanosti jednotlivých hybatelů. Jinými slovy, výsledný stav krajiny není výsledkem působení jedné síly, ale spíše komplexu hybných sil od přírodních (topografie), technologických, kulturních, společensko-ekonomických po politické. Poslední dvě jmenované skupiny, tedy společensko-ekonomické a politické jsou považovány za nejdůležitější v případě alternace kulturních krajin. Bližší pohled na politické hybné síly (například dopady institucionálních změn, legislativy nebo změny v politickém režimu států) odhaluje metodické problémy, které výzkum těchto hybatelů přináší. Jedna z metodických překážek tkví v obtížném až nemožném provedení manipulativního experimentu (rozdělení na kontrolní skupinu a skupinu, na které jsou aplikovány legislativní a institucionální změny). Pro určení významnosti jednotlivých politických hybatelů by to znamenalo zavést na vybrané části území jiný legislativní nebo politický režim. Tento metodický problém lze vyřešit komparativní studií dvou oblastí s různými institucemi a legislativou (typicky příhraniční regiony) se srovnatelnými přírodními podmínkami. Druhou možností je srovnání dvou chronologicky navazujících časových období v rámci jednoho území.

Pro účely této práce byly vybrány politické hybatele ve formě politického režimu (a s ním souvisejícího ekonomického režimu) a propustnosti státní hranice. Pro účely studia těchto hybatelů byla dizertační práce rozdělena do tří časově a prostorově se prolínajících částí. První část je zaměřena na prostor hranice bývalé železné opony. Zde je zkoumáno období ekonomické a politické transformace bývalého východního bloku od roku 1989. Na základě srovnání krajiny ve vzorkovacích plochách ležících polovinou na hranici východního a polovinou na hranici východního bloku ve stejných environmentálních podmínkách předpokládám rozdíly ve struktuře a vývoji krajiny. Dále předpokládám konvergenci hlavních

procesů na základě logiky o sjednocování politiky hospodaření v krajině po vstupu zemí východního bloku do Evropské unie. V druhé části se úžeji zaměřujeme na vnitřní hranice Česka se snahou zjistit, zda existuje dopad na krajinu ve formě striktněji střežené hranice se státy západního bloku před rokem 1989. Práci uzavírám časově hlubší případovou studií vývoje krajiny v českém pohraničí, kterou chci demonstrovat možné časově hlubší založení některých procesů ve vývoji příhraniční krajiny.

Pro hodnocení krajinných změn byla využita standardní procedura studia hybných sil dle Burgi et al. (2005). Tato procedura sestává z kombinace prostorových dat (data CORINE, digitalizované vrstvy krajinného pokryvu z leteckých snímků nebo starých map), určení hlavních hybatelů (na základě úvodní rešerše a meta analýz) a časoprostorového rozsahu studie. Tyto tři prvky (a z nich odvozené krajinné metriky a dynamika jednotlivých procesů) jsou následně analyzovány. Efekty politických hybatelů (propustnost hranice a politický režim) jsou následně testovány pomocí statistického modelu pro neparametrická data s opakováním.

Z výsledků první části disertační práce plyne, že efekt železné opony je stále patrný, a to především ve struktuře krajiny spojené se zemědělským využitím a dále ve vyšším tempu urbanizace na západě. Vývoj krajiny, zde interpretovaný jako reakce na společnou zemědělskou politiku, je nejvíce patrný na území Německa. V případě německé části docházím i k nejrychlejšímu tempu konvergence jednotlivých procesů ve vývoji krajiny. Tento fakt přikládám jednotné administrativě po roce 1989. Naproti tomu Česko, Slovensko a Maďarsko vykazují silný efekt opouštění zemědělské půdy, zastavený až restrukturalizací zemědělských subvencí spojených se Společnou zemědělskou politikou. V druhé části práce docházím k závěru jistého efektu přísněji střežené hranice se západními sousedy, a to především v odlišné dynamice nehospodářsky využité vegetace. Tato zjištění jsou dále rozvedena ve třetí části případové studie katastru v pohraničí. Zde byl identifikován hlavní hybatel změn v krajině v depopulaci spojené s odsunem obyvatelstva po druhé světové válce. V práci byly identifikovány jasné kontrasty ve vývoji krajiny v regionech podél hranice železné opony a v českém pohraničí, nicméně pro potvrzení kauzality identifikovaných hybatelů (zejména zemědělských subvencí) je nutné navázat na zjištění ověřením jinými metodami zahrnující jednotlivé aktéry krajinných změn.

List of Abbreviations

CAP	Common Agricultural Policy
CE(Cs)	Central European (Countries)
CLC	CORINE Land Cover
GT	Growing Type
IRC	Iron Curtain
LPI	Largest Patch Index
LU	Land Use
LULC	Land Use Land Cover
LUCC	Land Use Cover Change
LPIS	Land Parcel Identification System
MPS	Mean Patch Size
MMU	Minimal Mapping Unit
NP	Number of Patches
PD	Patch Density
PLA	Protected Landscape Area
PR	Patch Richness
SAPARD	Special Accession Programme for Agricultural and Rural Development
TE	Total Edge
WWII	Second World War
ZABAGED	Základní báze geografických dat

List of Figures

List of Tables

Table of Contents

1 Introduction

Landscape changes associated with anthropogenic activities, in particular changes in the land use and structure, have been for decades considered to be an important topic both locally and globally, in particular in view of their potential to influence the sustainability of food and water production or the climate regulation capabilities (Foley et al., 2005). The changes in the land use and landscape structure are studied in the context of their influence on the environment, from the global perspective (e.g. climate change) up to local changes at the level of individual societies. Such changes and factors influencing them are subject of research in both social and natural sciences (Bürgi et al., 2017; Valipour, 2015). The significance of this topic results in particular from the efforts to accurately reflect the reality and to understand the relationships between the condition of the landscape and key determinants of landscape changes, which is important for agricultural and land use policies of individual countries and, if necessary, for correcting such policies.

This thesis focuses on the border regions that stand aside of the mainstream research in the landscape ecology, although the general idea of studying landscape changes in the areas divided by a strict administrative border (or generally in the border regions) is not new in landscape ecology (Burgi et al., 2005; Sklenička, Šímová, Hrdinová, & Šálek, 2014). In other fields (such as in political geography), borders have been subject to extensive research ever since 19^{th} century (Breitung, 2002; Rumley, 2014). The border landscapes or border areas themselves however represent interesting areas for landscape ecology research, especially as they make it possible to compare the impact of institutional, political, socio-economic and cultural changes on two units with similar environmental conditions. To demonstrate such approach, I focused on the "Iron curtain" (IRC) that until 1989 used to separate two different political-economic blocs. Within the scope of this thesis, analyses are performed both from the perspective of a macro/medium scale of the entire border that used to divide Europe and of the micro scale of a local case study aiming among other things on implications of the landscape development for the needs of nature and landscape conservation.

The issue of defining border areas is relatively open and there are many perspectives on the width of border regions, i.e., on the distance from the border that is still considered border area. At this point, it is therefore necessary to define the term "border area" as it is used throughout this thesis. In this work, the term "border areas" complies with the definition by the European Commission, defining border area as a space within 30 km from the physical borderline. Here, the discussed issues will therefore cover only the actual political borderline and a "strip" of adjacent landscape, not entire neighbouring administrative regions (as is often used for evaluation of cross-border cooperation) (Yoder, 2003).

The presented thesis begins with a broader theoretical framing of the individual components of the research on landscape changes (Chapter 2). There, I aimed to explain some assumptions and approaches, which will be built upon later in this thesis. A part of that chapter is devoted to my own systematic literature review on the frequency, with which the individual driving forces are identified as factors affecting landscape changes. This part illustrates the significance of individual factors considered in this study and demonstrates the possible directions of further research besides the (mainstream) approach used in this thesis. The theoretical background is followed by the chapter Methods (Chapter 3), the structure of which, as well as of the chapters Results (Chapter 4) and Discussion (Chapter 5), the structure, is divided to preserve the structure of the individual studies (subchapters called Part I. – III. in each of the main chapters).

2 The thesis in the context of the present-day research

In individual studies (part I. – III.) of the of related to landscape changes, I chose a simplified approach described below to represent as the "standard procedure for the study of driving forces". This approach consists of (a) analysis of landscape changes and their persistence and (b) determining the driving forces affecting directly or indirectly the landscape evolution. I will begin this part by providing an overview of data sources and their critical analysis, which will be further supplemented with the information about the ways in which of landscape metrics can be used for the description of the development. This will be followed by a description of various approaches to the definition and effects of individual driving forces and their categorization. The categorization of both my own results and those from the literature serves for the reader's better orientation in the system of driving forces. In the final part of the chapter, the current research in the field of landscape changes applied directly to border regions is discussed and further supplemented with is by the historical context of landscape development in Czechia and Central Europe (areas associated with the regions studied within the scope of this thesis).

2.1 Landscape changes – methods and data

When studying landscape changes (in the sense of the changes in the spatial structure and land use over time), the spatial data characterising land cover or land use at various time points or periods are obviously crucial. At present, remote sensing methods are predominantly used for such purposes and the subsequent identification of the land cover allows further analyses of landscape changes. Another approach is based on processing historical data and records on the land use (most commonly cadastral records – written records, maps – and similar data). I mentioned the terms land cover and land use above. Both these terms overlap in their meaning (a combined land use/cover – LUC, land use/land cover – LULC, including the land use/land cover change – LUCC). In this text, in accordance with Bičík et al. (2010), Niemi et al. (2015) and Dale et. al. (2013), I will however distinguish between a more complex term "land use" describing the human use of the area in question (e.g. pasture) and the term "land cover", which is limited to the identification of the particular physical land cover (herbaceous communities or woody stands).

2.1.1 Data sources for the research of landscape changes

Land use data can be obtained from various sources. If the present day data are being sought, the cadastral data, data of land ownership records or specialized databases such as the public Land Parcel Identification System (LPIS), regional forestry development plans, etc., represent important sources of information. Another possible method of the present-day data collection is a field survey. An example of such approach including selection of the sampling sites can be found e.g. in Cherrill, et. al. (1995).To be able to quantify the changes, data characterising the original (baseline) condition of the land use in or around a required time point are needed. The data on the original condition are often derived from the old maps and archival records (forest taxation records, old cadastral records), photographs, iconographic sources, paleographic and geological evidence or retrospective models of the probable species distribution (Yang et al., 2014) – see more in the Table 1. The disadvantages of using historical cadastral data (and other historical written records) include burdening the information with errors resulting from incorrect or too slow recording of changes. Another disadvantage is often represented by an incomparability of the land use classification from various countries (Bičík, Anděl, & Balej, 2010; Forejt, Dolejš, & Raška, 2018).

To name but a few examples of studies using historical map documents, we can refer to studies by Tomson, et. al. (2015), Kanianska, et. al. (2014), Fuchs, et. al. (2015) or Harvey, et. al. (2014). The above mentioned studies all use similar methods – the source map bearing information about the nature of the land use is digitised (or summarised where text records are concerned) and a statistical evaluation of individual changes in the digitised LULC categories follows. The last of the aforementioned studies used old cadastral records for defining the baseline, which is a source lately growing in importance (Dolejš & Forejt, 2019). Multitemporal data from the cadastral records in the region of Czechia served well for preparing a comprehensive database at the level of basic territorial (administrative) units (LUCC Czechia Database; Bičík, et. al. (2001; 2010). This database is available on request for further processing from the website of the Research Centre for Land Use Change in Czechia.

Data sources for studying land cover changes are to a certain degree identical with those that can be used for the study of land use (Table 1). Besides the above mentioned data acquisition methods, remote sensing using aerial or satellite imagery is frequently used to create thematic maps of land cover. Despite undisputed advantages of this approach (the possibility to cover larger areas, relative ease of processing of the acquired data), literature also presents several limitations.

Among them, the lack of consistency in the evaluation the results accuracy (Foody, 2002; Cihlar, 2000; Congalton et al., 2014) and uncertainties related to the classification scheme, in particular at the level of global projects such as DISCover, Globcover or Global Land Cover (Dale & Kline, 2013; Yang et al., 2014; Congalton et al., 2014), as well as temporal limitations (lack of data from the time before the satellite/system began its operation; Jepsen et al., 2015) are the most commonly mentioned.

Above, selected methods of data acquisition for subsequent analysis of land use/land cover changes have been listed and illustrated by case studies. Yang et. al. (2014) discussed the suitability of the use of natural proxy data. Such sources include palynological vegetation reconstruction (Tian et al., 2014), sediment analysis and subsequent radiocarbon dating (e.g. Heckmann et al., 2014). Other possible sources include outputs of LULCC models based on simplifying the relationships between factors and landscape changes and can be used both for predicting the future and for evaluation of historical changes in the land use and land cover. (Table 1) summarizes data sources suitable for investigation of historical and present-day condition of the land use and land cover, including the temporal and spatial scale provided by such sources. Individual sources are inherently limited both from the temporal (invention of a new technology, available age of the records) and spatial (local historical record vs global remote sensing techniques) perspectives. One of the possible solutions of overcoming spatiotemporal limitations of individual data sources is to combine data from several sources (Yang et al., 2014).

Table 1: Comparison of selected methods of data acquisition for the purpose of land use/land cover analyses

Source	Type	Pros	Cons	(A) temporal scale (B) spatial scale
Historical written documents	LU /LC	(1) data availability, (2) heterogeneity and volume of the data, (3) frequent use of such data	(1) time-consuming (2) non-comprehensive data (3) factual inaccuracy (4) qualitative or semi-qualitative data (5) different meanings in terminology (6) changes in record-keeping methods	(A) limited by record availability and dates (B) regional to national
Historical maps and pictures	LU /LC	(1) visual information	(1) inaccuracy (2) geometric irregularities (3) inconsistent classification of land use (4) missing borders for some land use classes (5) usually does not contain quantitative information	(A) centuries (B) local to national
Natural sources/ records	LC /LU	(1) clear spatial localization, (2) broad temporal scale	(1) small availability (2) limitations for some land use classes	(A) millennia, (B) regional scale
Dynamic models of LULC	LU /LC	(1) inclusionding of driving forces and mechanisms of land use (2) spatial quantification of land use	(1) emphasis on the quality of input data (2) reconstruction of only a part of the system (3) historical sources are often spatially inaccurate	(A) decades to millennia, (B) regional to global
Remote sensing	LC /LU	(1) relatively objective processing of extensive areas, (2) not as time-consuming, (3) relatively low costs	(1) uncertainty of data classification, (2) limitation implied by image resolution	(A) decades, (B) regional to global
Specialized databases	LU -LC	(1) comprehensive data with clear data collection methods, (2) undemanding processing	(1) possible limitations resulting from specialization on particular classes of land use only	(A) decades, (B) regional to national
Field surveys	LU -LC	(1) detailed insight (2) variety of methods	(1) errors resulting from observer's subjectivity, (2) time-consuming	(A) decades, (B) local to regional
Multiple sources, multidis-ciplinary analysis	LU -LC	(1) multiple perspectives, (2) completion of missing data, (3) improved complexity of data	(1) data compatibility, (2) need for bigger research teams	No limits

(LU/LC – primarily land use, LC/LU – primarily land cover, LU-LC equally usable for both types of studies; amended and extended; original source: Yang, et. al., 2014)

2.2 Landscape metrics as a source of information in the landscape research

The study of the horizontal structure of the landscape based on landscape metrics is in not novel in the field of landscape ecology research (O'Neill et al., 1988; Forman, 1993). Landscape metrics have been included among the principal research methods of the landscape structure relatively early in the GIS development (McGarigal & Marks, 1995), in particular thanks to the increasing availability of the processable LULC data. The main benefit of the landscape metrics is their capability to quantify the variables, which allows comparative processing of large datasets and presenting qualitative characteristics at the patch/class level (e.g. the proportion of agricultural area) as well as at the landscape level where the structure of the entire area is being evaluated (diversity of LULC types – e.g. Shannon's Diversity Index).

Landscape metrics can be further classified (Leitão, 2006) according to the purpose of information they provide on the landscape structure to metrics characterising (a) composition and (b) configuration of the landscape. By landscape composition, I mean the proportion, presence (or absence) of individual LULC categories without specifying their spatial character or distribution. Examples of such metrics may include e.g. patch richness (number of patch types), class area proportion (proportion of particular LULC class) or indices characterising the overall diversity of classes on the landscape level (typically Shannon's/ Simpson's Diversity Index). On the other hand, metrics describing landscape configuration characterise the relationships among individual patches, such as their connectivity, shape or contrast. Metrics in both categories follow different goals and provide different types of information applicable in ecology. Typically, if investigating the suitability/size of the biotope for the red deer, we will be more interested in the compactness, size and connectivity of individual forests in the area than on the simple proportion of forests in the area. On the other hand, when needing to capture the diversity of the LULC of the same area (various land cover classes) in various time points, we will rather use the landscape composition metrics.

The use of landscape metrics has been nevertheless subject to criticism over the last two decades, in particular due to their perceived redundancy, i.e. of the similarity of outputs of various metrics (sensu Wagner & Fortin, 2005; Cushman et al., 2008; Uuemaa et al., 2009). Another much discussed issue is the behaviour of metrics upon changing the input data in the sense of its grain size (minimal mapping unit), extent of the area of interest and thematic resolution (the number of individual land use/land cover classes. Šímová and Gdulová (2012) concluded that simpler metrics that are easier to interpret show a more consistent behaviour in relation to such changes of input data. The authors make a general recommendation to use preferably the metrics Number of Patches (NP), Total Edge (TE), Edge Density (ED), Patch Richness, Density (PR, PD) and Mean Patch Size (MPS). Where the SHDI, an index evaluating the diversity of individual classes, is concerned, Peng et al., (2010) reported a consistent behaviour of the metrics where the number of patch types changed. Šímová and Gdulová (2012) did not observe this behaviour (this metrics is generally expected to grow with the increasing number of patch types) and they also reported the increase of that metric with increasing the area and its decrease with coarsening the scale, minimum mapping unit or grain of analysis.

The above makes it possible to draw conclusions on the possible use of the individual metrics, with the consistent behaviour being provided e.g. by the Edge Density or Mean Patch Size metrics. If using the SHDI, care must be taken (in particular about scale, MMU, the area extent and thematic resolution). The simplest landscape metrics in the category of composition metrics is the Class Area Proportion (CAP) or its "crude" version, the Class Area (CA), which actually only represents the area of an individual LULC class. This is nevertheless not recommended if comparing areas differing in extent (Leitão, 2006). The use of the CA metrics in areas with unequal total size would result in disproportionate results. When using CAP, this problem does not occur. Where the areas are comparable, this metrics can be nevertheless useful and usable for other calculations as well (e.g. the dynamics of increase or decrease of individual LULC classes).

In addition to the redundancy of some metrics mentioned above, Wu a Hobbs (2002) point out that besides processes that can be captured by such metrics, the LULC changes must be always evaluated in the context of economical, political and natural drivers of land changes (see also Burgi et al., 2005; Bičík et al., 2001). Landscape metrics thus provide a good input for analysis, they however must be properly interpreted and put into context in the sense of identifying the causes of their changes.

2.3 Approaches to the assessment of driving forces of landscape changes

Bürgi et al. (2005) define the driving forces as forces influencing the evolutional trajectory of the landscape. Meyfroidt (2015) in this sense distinguish between driving forces and direct causes of the landscape changes. In his interpretation, driving forces are factors hypothetically leading to landscape changes for which a direct causality explaining the effect or mechanism of the landscape change has not been identified. For example, a globalisation (economic) pressure on the local economy, changes in the population and settlement structure of the region or application of nature conservation strategies may become such driving forces.

The driving forces can therefore be classified according to their origin to: (a) socio-economic, (b) political, (c) technological, (d) natural and (e) cultural (Brandt, Primdahl, & Reenberg, 1999). A more detailed categorization of the driving forces is presented in the separate chapter of this thesis (Chapter 2.4). Another classification of the driving forces may be performed on the basis of the way of action, i.e., to primary (clearly identifiable as a primary cause), secondary and tertiary that contribute to the effects of the primary driving force. The terms principal processes (keystone processes) or drivers are synonymous to the term driving forces (Jeleček, 2007; Kolejka, 2013).

The actors of the landscape changes include institutions (in the broadest sense including cultural traditions, customs or laws) or individual plot owners who can directly or indirectly intervene in the landscape. The difference between a direct and indirect intervention is discussed by Hägerstrand (1995) and elaborated into the concept of territorial and spatial competence. The term territorial competence corresponds with the level of the plot owner capable of performing real, tangible interventions. The term spatial competence is rather associated with the actors at a higher level who are acting indirectly in the form of regulations, planning and directives. In practice, the term spatial competence is mostly associated with local and regional administration and state administration in general.

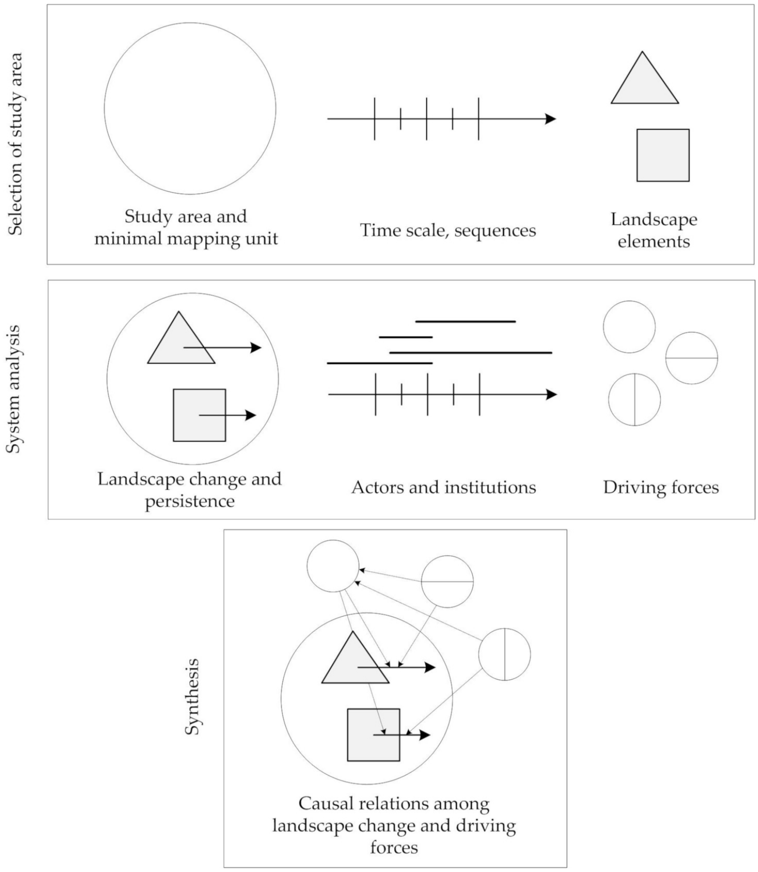


Fig. 1: The standard procedure for study of driving forces (according to: Bürgi et. al., 2004).

2.4 Methodical approaches to the study of driving forces of land use and land cover changes

Bürgi et. al. (2005) are the first to describe a standardized methodological approach to the study focused on the driving forces, suggesting the algorithm of: (i) description of the elements, (ii) analysis of the system (iii) systematic synthesis. The initial stage of the methodical approach (Fig. 1) is dedicated to the definition of the area of interest and of the minimum mapping unit or grain of analysis.

Next, the segmentation of the time periods taking into account the quality and availability of spatial data is evaluated. This initial stage is followed by the analytical one, which describes the change (or lack of it) in the landscape structure, driving forces and actors. The driving forces and actors (institutions) can reach beyond the limits of the area of interest (see the previous chapter on the scale of analysis). In the final stage, the synthesis of elements from the previous stages is performed. The causal relationships between the driving forces and landscape processes are determined as well as their actual impacts on the area under study.

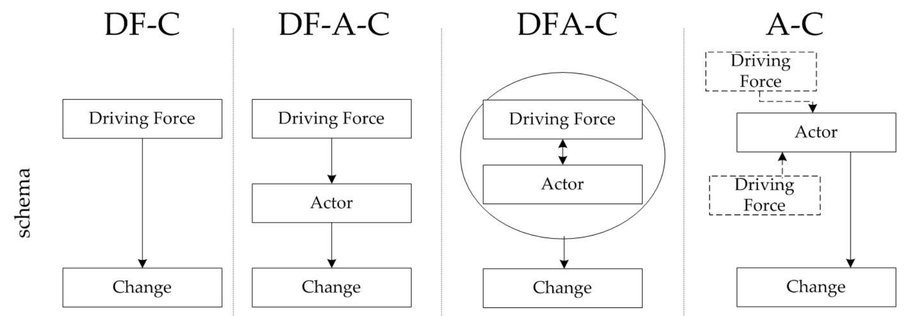
2.4.1 Conceptual models for studying the driving forces

Hersperger, et. al. (2010) build on the standard procedure for studying driving forces, creating four conceptual models (Fig. 2) for the study of (possible) associations among the driving forces, actors and landscape change. In the text and figure below, driving forces are abbreviated as DF, actors as A and change as C.

The classification of conceptual models (Fig. 2; Hersperger et al., 2010) has been further discussed (van Noordwijk et al., 2011; reaction by Hersperger et al., 2011) and supplemented with another dimension, namely that of feedback loops divided into (a) direct physical feedbacks (b) feedbacks among actors (c) feedback across time and (d) spatial scale. Figure 2 shows a schematic depiction of the methodological concepts; for better readability, the feedbacks are not depicted in that picture. Verburg (2014) further uses and describes only the first three models that are further supplemented with the aforementioned feedbacks and re-evaluation of decision processes based on environmental changes (of the environment or of the initial situation).

The model driving force – change (DF – C)

The first model, abbreviated as DF-C, is the one most commonly used at present, dominating among the studies dealing with land change. The model quantifies the dependent variable (change) and independent variables (driving forces) and the correlations of DFs with the land change are subsequently evaluated. The statistical evaluation most commonly utilizes regression analyses. The weakness of this type of the model lies in the possible lack of association between the detected correlation and the causality. The decision-making processes standing between the driver and the change itself are often not explicitly studied, although they are usually discussed in studies of this type (Verburg, 2014).



	DF-C	DF-A-C	DFA-C	A-C
research aim	hypothesis formulation theoretical models parametrization	understanding the causality of driver, actor and change actors and driving forces identification	interaction of driving forces and actors strategy and policy analysis	actors behavior, decision making analysis interactions between actors
spatial scale	+ / +++	+ / ++	+ / ++	+
number of LUCC classes	+ / +++	+ / +++	only those influenced by DFA interaction	only those influenced by actors (e.g. argicultural land)
data types	possible DF, land change data	possible DF, land change data, actors description	possible DF, land change data, behavior and interactions of actors	land change data, behavior and interactions of actors
methodological approach*	empirical instrumentalism /neopositivism	structuration theory/critical realism	structuration theory/ critical realism	structuration theory/ critical realism

Fig. 2: A schematic depiction of relationships between the driving force, actor and landscape change in the used models (spatial scale: + local ++ regional +++ supraregional, number of LUCC classes: +/+++ several selected to a full range of classes; * corresponding methodology in social sciences; amended from Hersperger, 2010)

A study by Opršal et. al. (2013) focusing on the degree of conditionality of land changes by natural drivers in three model cadastral units is an example of the application of such a model. In that study, the natural drivers included the soil type, elevation and the basic geomorphological indicators of slopiness and exposure. The result of a canonical correspondence analysis confirmed a limited effect of the influence of the natural drivers in the overall land use change. The authors emphasise the necessity for including socio-economic driving forces for a deeper understanding to the land use change. On the other hand, Fu et. al. (2006), using identical methods and two explanatory variables (slopiness and soil type) applied on the catchment area of Zhifangg (China) came to a conclusion that the land use change (forest, pastures –arable land) depends on the aforementioned factors. Bürgi et. al. (2002) added socio-economic explanatory variables to similar abiotic ones. Based on a model including data indicating the form of land ownership, economic performance of farms and the population density, they were able to explain the decrease in the total area of arable land along the Wisconsin river.

The model driving force – actor – change (DF – A – C)

The second model (DF-A-C) contains in addition to the previous one the component of an actor and in general, it is a one-way model: the driving force influences the actors, the actors in turn cause the change. The driving forces therefore in this case influence the autonomous decision-making of the actors. Methodologically, the concept can be divided into two stages; the first one aims to capture the actors' level using predominantly qualitative methods. The second part, i.e., deriving data necessary for quantification of driving forces, is based (just like in the previous approach) on the use of maps and databases. Verburg (2014) states that this conceptual model typically considers an actor whose behaviour is uniform (unlike in other models), for example in accordance with the theory of the rational choice. In the case of land change studies, this may be based for example on the price of the land, which depends on its quality and other factors.

Following structured interviews with inhabitants of selected villages, which was supplemented with basic socio-economic data, Rasul et. al. (2004) determined the main factors of the land use (land management) change. The factors influencing/motivating the land use change were identified as the institutional support, closeness of sales outlet (such as regional centres) and the quality of the productive resource base. A similar approach was adopted by Qasim, et. al. (2013) in their extensive study of the local population and its motivation for intervention in the vicinity. In the next study (Thapa & Rasul, 2006), the closeness of a regional centre and maintaining the ownership rights to the lands by the local population were identified as factors supporting more sustainable condition of the landscape. Bieling, et al. (2013) analysed, on the basis of historical map sources and written records, the evolution of the land use for three selected cadastral units in the region of the Swabian Alb between 1828 – 2009. They discussed the socio-economic driving forces acting at the regional as well as superregional scale, the pressure those forces subsequently put on the population (industrialization, collective agricultural policies), and the changes in land use. Last but not least, we can mention the work by Campbell, et. al. (2005), representing a typical example of combining multitemporal analysis of remote sensing images and questionnaire polls on a large number of households aimed to find the principal drivers of the evolution of agricultural lands in the north-eastern Kenya.

The model driving force – actor (DFA – C)

The third conceptual model (DFA – C) focuses on the interaction of the driving forces and actors, the combination of which leads to changes in the landscape. Compared to the previous conceptual models, the strongpoint of this model lies in a deeper understanding of the two-way relationships driving force – actor and actor – driving force, i.e., it includes the feedback influence of the actors on the driving forces. Methodologically, such studies usually offer purely socio-economic (qualitative) research focused on the actors and decision-making process. The approach builds upon an assumption that identical circumstances at the level of actors may result in different land changes (unlike in the previous type of models where the actors are expected to act in the same way under the same circumstances). The weak spot of this approach lies in particular in being locally specific and the conclusions of such a study cannot therefore be applied to a wider area.

An example of the use of the DFA-C approach could be represented by research focused on preferences and motivation factors in the decision making process in the land planning. By focusing on the actor – i.e., on the representative of the decision-making component – it facilitates detection of the most important factors leading to the land use change itself. In this case, a feedback loop would be represented by an individual response of an actor resulting in the actual change of the land planning. In their work studying the motivation to changing the agricultural land use on the Luzon Island (Philippines), Overmars, et. al. (2007) use a framework (Action in Context) for explanation of the actors' behaviour, which was combined with independent variables of slopiness, ethnicity and distance to the centre.

The actor – change model (A – C)

The last concept, actor – change (A – C) builds exclusively on the attitudes, values and decision making process of individual actors. Unlike in the DFA-C model, the driving forces are here included at the level of the actor. The focus of the research lies at the level of the individual rationale of the actor's intervention in the landscape. So far published studies based on this concept build on the qualitative forms of research (structured interviews) supplemented with quantitative data of land change. A very popular approach towards modelling relationships of the actor and land change is the use of multi-agent models/systems (Agent Based Models, more generally Multi-Agent Systems). Such systems simulate the activity and feedback of individual actors. The typology of the systems and their use are in detail classified and discussed by Parker et. al. (2003).

The A – C model was used e.g. in the study by Röder et. al. (2015). In their study, the quantification of land changes along the Okavango river using remote sensing methods combined with structured interviews revealed a trend of transition from the non-cultivated to agricultural land caused in particular by small subjects at the level of individual households motivated predominantly by the endeavour of such households to improve their economic situation.

The end of the Fig. 2, comparing the individual models, represents an attempt for classification of models to the respective epistemological approaches in the social sciences, summarized for our area by Ženka et. al. (2012). Thanks to the simplification it provides, such categorization can indicate some methodological flaws of the individual models and help formulate an optimum method for one's own research goals.

The first model type (DF – C) can be, owing to its emphasis on the statistical evaluation of the quantified land use/land cover change, counted among neopositivist research approaches that are subject to criticism in particular due to the (i) impossibility to capture the intangible, often unrepeatable (and thus unquantifiable) factors affecting the studied changes and (ii) limited capability to determine the causality between the change and its drivers (see also Dale & Kline, 2013).

Remaining models can be, due to the emphasis on the analysis of the structure (institutions, actors) and focus on understanding the causality, counted among the critical realist directions of the current social science. To determine the causality, methods of process tracing are employed in case studies (Collier, 2011; Mahoney, 2012). Process tracing verifies causal relations derived from theoretical background at the individual stages of the modelling. The critical realist approach does not reject statistical or comparative methods, it uses them for determining suitable sites, factors (etc.) for case studies.

2.5 Categorization of driving forces

Different authors categorize driving forces differently. The agreement is probably only on the basic classification into drivers resulting from human activities and biophysical drivers (Niemi et al., 2015). For testing causal relationships as mentioned in the previous chapter, it is necessary to derive the principal drivers from the landscape-ecological, geographical, economic, demographic and other theories, i.e., from a sum of all possible drivers (see also Geist & Lambin, 2002) that can be further tested, e.g. using the process tracing method (will be detailed below) or discussed (in case of the DF-C approach).

A rough categorization of driving forces into basic categories that will be also used throughout this thesis, was performed by Brandt, et. al. (1999). There, the authors categorize the driving forces into (i) socio-economic, (ii) political, (iii) technological, (iv) natural and (v) cultural. The driving forces can also be divided into (i) direct (proximate, this term is practically identical with the term "direct causes") and indirect (underlying) (Geist & Lambin, 2002), (ii) intrinsic and extrinsic (Burgi et al., 2005).

Another method of classification distinguishes the drivers into intrinsic (those that can be delimited by borders of a certain area) and extrinsic (sensu Hägerstrand, 1995). If the identified driver acts only within the area of interest (e.g. a local regulation affecting a studied municipality), it can be considered intrinsic. If, on the other hand, the driving force originates beyond the borders of the studied area (e.g. national legislature regulating local conditions in the respective municipality), we speak of extrinsic factors.

2.5.1 A review of the frequency of use of (input) predictors in studies from 2010-2015

For the purposes of further selection of driving forces that will be investigated in this thesis, a brief review of works dealing with similar topics will be provided here. From these studies, I extracted the results in the form of identified driving forces and classified them according to the methodological approach (acc. to Fig. 2). The results of my own investigation (summarized in (Fig. 3) of the observed factors (drivers) are based on the selection of 95 studies found in the SCOPUS database based on keywords related to the drivers of land change (driving force, landscape change, drivers). Only papers from 2010 – 2015 complemented with selected studies used in the presented thesis were analysed. Another selection criterion was the possibility to classify the study method into one of the aforementioned model approaches (conceptual models acc. to Hersperger et al., 2010; chapter 2.4.1). Only applied studies focused on a real study area were therefore selected. Subsequently, all driving forces (factors) considered in the study (i.e., including those the effect of which was not shown to be significant or important) were extracted. The aim of the selection and identification of the predictors (factors) was two-fold. Firstly, the gathered data were used as a list of candidate drivers later in the dissertation. Secondly, the gathered data confirm or disprove the hypothesis about the dominance of DF-C conceptual model among publications and the use of factors in the aforementioned publications.

Of the 95 papers meeting the criteria, 64 % corresponded with the DF-C approach, 33 % with the DF-A-C approach and the remaining two models were represented by one study each. This distribution therefore confirms the conclusions by Hersperger, et. al. (2010) that the first model is by far the most commonly used.

The evaluation of the main groups of drivers revealed that the greatest representation of the used factors (predictors, single factors in (Fig. 3) falls into the category of socio-economic drivers (55 %), which are, together with political drivers (Fig. 4; 11 %), often referred as having significant influence on the overall land use change and land cover (which corresponds to the conclusions by Munteanu et al., 2014; Hersperger et al., 2010; Bičík et al., 2001; Reid et al., 2000; van Dijk, 2003; Antrop, 1997, 2005; Kuemmerle et al., 2006; Plieninger et al., 2016).

Major group of driving forces	Subdivision of driving forces	Factor		Frequency (cout)	A*	B*
Biophysical	geology / geomorphology	A1	altitude	13	3	9
		A2	slope	20	1	3
		A3	geology	5	8	24
	soil	B1	soil type	18	2	5
		B2	soil amount	3	10	30
	climate, meteorology	C1	precipitation	13	3	9
		C2	meteo phenomena	10	6	16
		C3	wetness, moisture	10	6	16
		C4	solar radiation	4	9	27
	others	D1	fires	13	3	9
Socioeconomic	demography	E1	age of population	1	19	37
		E2	change of the population structure	40	1	1
	societal	F1	urbanization	11	8	15
		F2	expansion of settlements and agriculture	13	6	9
		F3	industrialization	5	14	24
		F4	density of infrastructure	18	3	5
		F5	population density	15	4	7
		F6	migration	8	11	20
		F7	education	3	16	30
		F8	ethnicity	1	19	37
	economy	G1	distance to regional centre	15	4	7
		G2	employment / unemployment structure	10	9	16
		G3	industrial output	3	16	30
		G4	agricultural output	20	2	3
		G5	tourism income	7	12	22
		G6	price of agricultural commodities	6	13	23
		G7	land rent	3	16	30
		G8	GDP/GNP	13	6	9
		G9	agricultural commodities demand	4	15	27
	others	H1	type of land ownership	9	10	19
Technology		I1	mechanization	8	1	20
Political	directive	J1	change in regional policy	24	1	2
		J2	environmental protection	4	3	27
	support	K1	financial support	12	2	14
		K2	knowledge transfer / support	2	4	34
	others	L1	war	2	4	34
Cultural		M1	tradition	2	1	34
		M2	attitude towards environment	5	2	24

Fig. 3: Driving forces and the frequency of their use in the selected studies (A* - rank in the main group of driving forces, B* - overall rank).

This group also includes the most commonly utilised (and identified) LUCC driver, namely the change in the population and population structure, which builds on the expectation of the increasing population being associated with the increasing pressure on the land utilization (a directly proportionate relationship). The second most common factor – the change of (regional) politics and/or economical system was used in most studies with the DF-A-C approach, i.e. the approach taking into account the institutional environment in the form of the actor.

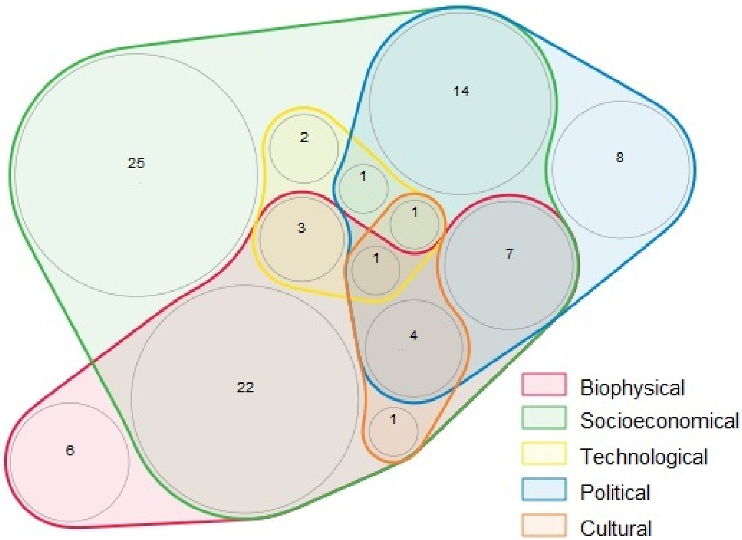


Fig. 4: The frequency of combination of major driving forces in particular records (n = record)

The natural drivers are represented in almost 30 % of studies. Natural factors are included into the studies quite often, in particular due to their relatively simple acquisition from spatial data through GIS processing (geomorphometric factors calculated from digital terrain models). As just six studies dedicated solely to testing of biophysical factors were found, those factors seem to play rather a role of supplementary datasets (Fig. 4). The emphasis on socio-economic predictors (factors) in analysis of drivers in the selected studies is also illustrated in Fig. 4. 26 % of selected studies were „monothematic" studies utilizing solely socio-economic factors as explanatory variables. 8 % and 6 % of studies focused purely on political and biophysical factors, respectively, without involvement of other factors. The combination of socio-economic and biophysical factors was found in 23 % of studies. A combination socio-economic and political factors was represented by 17 % of records. Remaining approx. 20 % was a combination of other categories of factors.

Drivers counting among the technological and cultural categories occurred in the studies rather sporadically, which is caused by the temporal and financial demands of data acquisition (often extensive polls using questionnaires or structured interviews). Where introduction of new technologies is concerned, attempts to create a comprehensive algorithm for quantification of technological driving forces have been reported (Hasselmann et al., 2010) as the technologies have had a fundamental influence on the land change dynamics (e.g. Killeen et al., 2008 – historical studies focused on the mechanisation in agriculture). The difference between the composition of the factor categories in the two dominant conceptual models lies in a greater involvement of cultural and technological driving forces at the expense of biophysical driving forces in the DF-A-C model when compared with the DF-C model. This difference results from the above described orientation of the latter model (almost) exclusively on quantitative data.

2.5.2 Other studies on driving forces

For identification and analysis of technological,institutional and economical driving forces, an approach using narratives can be utilized (Jepsen et al., 2015). Such narratives describe the evolution of the landscape and the text is subsequently analysed to derive principal drivers. Results of evaluation of narratives covering the last 200 years and the identified driving forces of land change for 28 European countries are summarised in the Table 2. The conclusions of that study can serve as a basis for determining predictors and their subsequent verification in case studies (if data are available)

The so far most detailed metaanalysis classifying the driving forces (proximate vs. underlying) was performed by Plieninger et al. (2016). Their study is focused, similar to the previous study, on Europe. The main driving forces are categorised and a causal relationship between the proximate and underlying driving forces is suggested (Fig. 5). The agricultural land abandonment was found to be the most common proximate driving force for land use change. Based on the cluster analysis of the indirect drivers, the authors conclude that the agricultural land abandonment results from a combination of several categories of underlying driving forces.

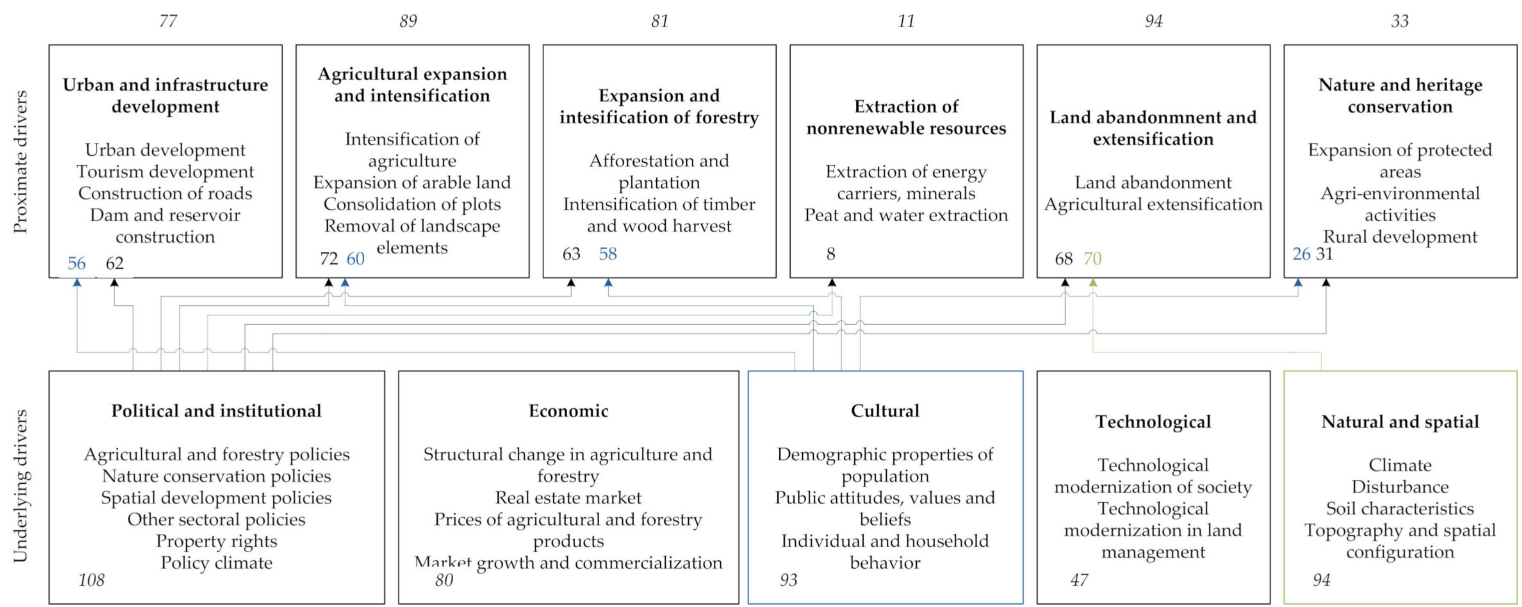


Fig. 5: The frequency of the references to the relationships between direct and indirect driving forces at the European scale, detected causal relationships (review, 144 studies); (Reprinted from: Plieninger et al., 2016)

Table 2: The number and type of drivers mentioned in the narratives (as the study was divided into five periods, those drivers can be counted repeatedly)

Institutional	n	Technological	n	Economic	n
Land reforms	58	Mineral Fertilizer	48	Demand for wood	24
Forest protection	39	Tractors	47	Production for the market	22
Voluntary cooperatives	24	Drainage	37	Specialization of agriculture	13
Land reclamation	21	New crops (clover, potatoes, beets, feed crops in rotation)	33	Shift from grain to dairy	10
Subsidies, guaranteed prices	21	Roads	26	Cash cropping of certain cropse	9
Protectionist policies	17	Railroads	24		
Forced collectivization	17	Irrigation	20		
Nature conservation	17	New plough types	9		
Abolition of serfdom	15				
Freeholders right to buy land	11				
Military operations	8				
Set-aside programs, agro-environmental schemes	8				
Shift from production to area based subsidies	8				
Land consolidation schemes	6				
Subsidies for organic farming	4				
Marshall plan, European recovery plan	4				
Tax on agricultural inputs	1				
Fascist land use paradigm	1				

(Source: Jepsen et. al., 2015)

The results of the published reviews (Jepsen et al., 2015; Plieninger et al., 2016) are to a certain degree different from the results of the review by the author of this thesis (chapter 2.4.1), in particular in the higher frequency of records related to the population change in the both authors review, which results from (1) different methods (focus on the proven driving forces in the published studies vs. endeavour to capture all studied variables including those that might not necessarily affect the landscape evolution), (2) a different classification of the main categories of the principal types of driving forces (cultural vs. socio-economic) and (3) limited period utilised in the author's own review.

2.6 The effect of political borders in the study of landscape change

Possible directions for the research on driving forces have been proposed and discussed in a relatively older study by Bürgi et al. (2005). There, the authors suggest that administrative borders might represent an interesting area for investigation of driving forces as they allow comparison of two areas with expected difference in political and socio-economic driving forces. For such area, they propose the use of a method applied in botany and other sciences – the transect method. The transect space can be also used for studying the dependency of the land change on the distance from the regional (evolutional, industrial) centre. This approach was applied in the study by Yu et al., (2007) on the development of urban areas in China.

The reason for testing by comparing landscape on two sides of the border or of the inside of the border is that it is impossible to perform a manipulative experiment for studying land change (Kuemmerle et al., 2006). A manipulative experiment is a standard research method capable of confirming or disproving the influence of a studied factor (typical e.g. in medicine with establishing control and treatment groups). While in medicine, such approach is relatively easy to perform, it is basically impossible in case of a real landscape and bigger areas. Still, there are two research designs allowing researchers to perform experiments similar to the manipulative one even for landscape. Based on the available data, it is possible to compare either the same space in two periods, or two areas divided by a border at the same time point. We can call these two approaches temporal design (sensu Palang, 2010) and spatial design (sensu Burgi et al., 2005; Senetra et al., 2013; Sklenička, Šímová, et al., 2014).

Cross-site and cross-border (spatial) research design is used for comparative purposes in many places worldwide, often testing the impact of legislative interventions or sectoral policies on landscape. However, the final condition of the landscape under study is a result of many complex forces (Plieninger et al., 2016) affected by historical circumstances (Ernoult et al., 2006; Zarina, 2010) recorded in the site/region specific memory of the landscape (Balej et al., 2010). The differences in historical settings of a particular landscape therefore imply the different reaction to intervening policies. Cross-border studies (spatial design) are therefore quite often used to assess the change of particular LULC classes or of the whole landscape in the borderlands of Vietnam-Cambodia (Grogan et al., 2015), China-Hong Kong (Xie & Ng, 2013), Angola-Namibia (Röder et al., 2015), Mexico-USA (Zhao et al., 2017) Austria-Czechia (Rašín & Chromý, 2010; Sklenička, Šímová, et al., 2014), Poland-Ukraine-Slovakia (Kuemmerle et al., 2008), Baltic states-Russia-Belorussia (Prishchepov et al., 2012) or along the former firm borderlines such as the "Iron Curtain" (hereinafter IRC) line (Kupková et al., 2013) separating different political blocs of states.

Areas suitable for studies using temporal design for investigation of the influence of political regime changes on the landscape can be found in countries that underwent political regime changes from communism to democracy (e.g. central Europe in late 1980s). Despite the regional differences in environmental conditions, Czechia shares some common underlying and proximate driving forces of LULC change with some other transitional countries and the trends for LULC change could therefore be similar across such countries. Besides the change in the political regime, we can find the direct effect of the past communist regime in parts of the borderlands of Czechia in the form of an almost complete exclusion of the active land use for almost 40 years (Bičík et al., 2015). As such, this particular area represents an unique example of abandonment in the context of Europe.

2.7 Landscape evolution in the Central Europe

Particularly in the Northern, Western and Eastern Europe, political and socio-economic underlying driving forces have had a significant influence on the evolution of LULC (Plieninger et al., 2016). Especially in the Central and Eastern Europe, the driving forces related to the transition from socialist to post-socialist regimes were found to be frequently mentioned as having major importance for LULC changes (Skokanová et al., 2016).

Based on the differences in historical political settings of the Eastern and Western blocs in Europe (following the division by a formal boundary), significant differences in the LULC change and trajectories were observed and described. Since the early 1950s, major differences stemmed from the productivist (west) market oriented and socialist (east) centrally planned agricultural management (Skokanová et al., 2016). In the West, the period lasting from 1950s till the 1990s (economic and societal transition of the Eastern bloc) followed a productivist agricultural scheme with intensification of the agricultural output, which was further accelerated by the Common Agricultural Policy (CAP, 1960s; see Strijker, 2005). Similar process was described in the East as well, catalysed there by the idea of self-sufficiency (Prokopová et al., 2018). Contrary to general intensification of the land use, extensification (mainly afforestation of agricultural land use or land abandonment) took place in remote areas and in the areas with worse conditions for agriculture both in the Eastern (e.g. border areas of Czechia; see Bičík et al., 2001) and Western blocs (Strijker, 2005).

The transition towards market oriented economies in 1990s in the Eastern bloc impacted the general extensification of land use (i.e. land abandonment). The extensification trend was observed across the entire continent as a predominant proximate driver (Plieninger et al., 2016) with higher accentuation in the Eastern Europe (van Vliet, de Groot, Rietveld, & Verburg, 2015) due to factors such as technological lags, price liberalization, concurrence, abolishment of subsidies or restitution of state property (Skokanová et al., 2016; Levers et al., 2018). Contrary to the rather stable and intensive land use in the West, the period before accession to EU (all countries except German Democratic Republic in 2004) led in the Eastern bloc to a significant shift towards de-intensification and afforestation (Feranec et al., 2017; Levers et al., 2018; Prokopová et al., 2018). The trend of land abandonment later diminished due to the CAP implemented in the Eastern bloc after accession to EU. The implementation of CAP led to improved sustainability of agriculture and application of agri-environmental schemes resulting in the increase of grassland areas (Prokopová et al., 2018). A similar trend, i.e., stabilisation of the land use intensity by CAP, was observed in the Western block in the decade of 2001 – 2011 (van der Sluis et al., 2016).

The former line dividing the Eastern and Western bloc, so called "Iron Curtain", that persisted until the late 1980s, is a good example of an area suitable for performing research in a spatial design. A border of more than 2700 km spanned from the Baltic to the Adriatic sea, separating the „Eastern" states (the former German Democratic Republic, Czechia, Slovakia, Hungary and Slovenia) with central planning from the „Western" states with market economies. As can be seen from the Table 3, the borderline was not just an administrative demarcation, the borderline was in most places represented by a physical barrier. If comparing the level of permeability (or impenetrability) of the border, it differed across the

Table 3: Comparison of the border control regime in the Iron Curtain sections

Iron Curtain Section	Physical restriction measures (since)	Spatial extent of measures	Clearance zone (inter-fence area)	Additional restrictive measures
East Germany	1952	5 km - special permit; 500 m control strip	10 m	mine fields (until 1983)
Czecho-slovakia	1951	12 - 15 km (1950); 1 - 3 km (1964) special permit	20 m + 15 m	mine fields (until approx. 1955); electrified fence (1965)
Hungary	1951	15 km (1950)	50 - 1000 m	minefields (1949 - 1956)
Slovenia	no physical restrictive measures (but guarded)			

Sources for East Germany (Sheffer, 2011), Czechoslovakia (Pulec, 2006), Hungary (Schubert, 2011), Slovenia (McWilliams, 2012)

sections from the strict physical barrier in Germany, Czechoslovakia and Hungary to a relatively open (although guarded) border in Slovenia. The restrictive measures were applied in the beginning of 1950s following the tightening of the regime (after the 1948 coups). In the three states of the Eastern Bloc with the more strictly guarded border, 1950s witnessed installation of the physical barriers including extreme measures such as minefields (usually removed in late ninety fifties due to the political pressure by the West, although certain pressure was exerted by the own armies as well due to the life losses of own soldiers) or electrified fences. The implementation of these measures had a profound impact on the LULC in the vicinity of the border in the sense of (a) clearance zone between the fences (regularly maintained, ploughed and harrowed to allow easy tracking) and (b) the outer zone. Formation of the 1 – 15 km wide outer zone was associated with moving thousands of inhabitants considered unreliable by the regime out of the area and, in particular, with limiting economic activities and demolition of buildings. The significance of those measures in early 1950s is apparent from the fact that after the re-evaluation of the zone requiring special permit in Czechoslovakia in 1964 (after the grip of the regime was partially released), the zone was narrowed from 12-15km to 1-3 km due to economic reasons.

Not many studies focused directly on the LULC change along the former Iron Curtain. Bičík et al. (2010) studied the land change along the Iron Curtain in the period of 1990 – 2000 (extended by an additional period of 2000 – 2006 in their subsequent work, Kupková et al., 2013). Based on the evaluation of the land change in a 15 km wide strip along the border, they conclude that the land use in 1990, i.e., at the beginning of the studied period, differed between the sides of the border. In that year, the proportion of the arable land was higher in the "Eastern" part of the borders, while heterogeneous agriculture (combination of smaller patches of pastures, arable land, combination of permanent crops/forests with annual crops on the same parcel, etc.) was more represented on the "western" side. The higher volume of the arable land in the East results from the historical emphasis on bigger plots and areas of the arable land facilitating a higher financial profit and easier land management in the centrally planned agriculture (e.g. Batáry et al., 2017 – Germany; (Sklenička, Šímová, et al., 2014) – Czechia).

From the perspective of trends over the entire period of 1990-2006 studied by Bičík and Kupková (Bičík, Kabrda, & Najman, 2010; Kupková et al., 2013), the most significant difference was in the pace of afforestation that was much higher in the "East" than in the "West" where a slight tendency to deforestation was observed. In the second analysed period (2000 – 2006), they also identified a trend of increased representation of permanent crops in the "East" (in particular along the borders with Austria where the area covered by vineyards increased). Where the dynamics of changes is concerned, a significantly higher volume of changes was observed in the Czech parts of the "Eastern" side of the border than in the remaining parts. On the other hand, the Austrian ("Western") part of the study area was stable, therefore only with a low volume of LULC changes. In general, major LULC changes on the "Western" side of the borders were only detected in parts of the former West Germany, which the authors explained by inferior natural conditions for agriculture. A dominant type of the LULC transition on the "Eastern side" in 1990-2006 is the transition to the extensive forms of land management (arable land to pastures, afforestation) with the exception of South Moravia. On the "Western" side, the transition from the forest stands to shrubs was the most common land change, albeit highly variable among the individual sections of the border. The authors also predicted further decrease of the area of the arable land accompanied with formation of new forest stands and pastures on the "Eastern" side of the border.

2.8 Specifics of the landscape evolution in Czechia

LULC changes in Czechia are relatively well described and documented since approx. the 1850s (Bičík et al., 2015). Between the Revolution year (1848) and the end of the 19th century, dramatic changes including industrialization, boom of transportation and railways, and, in particular, land tenure reform have occurred. These factors significantly influenced the LULC structure in the sense of increasing the area of arable land and decline of the permanent grassland. Curiously, the increase of the arable land area is observed even in regions with poorer conditions for agriculture (border regions, higher elevations), which was caused by the efforts to secure enough food for the increasing population. This trend of increasing the tillable area culminates by the end of 19th century as later, the intensification of agricultural production associated with the development of new technologies allowed further increase of the crop without the necessity to further increase the areas of the arable land.

The land tenure reforms (1848 and 1869) also had a great influence as it removed much of the restriction that used to be associated with the ownership of land (it used to be limited to the nobility or state only). Since the end of the 19th century, a gradual slight decline of the arable land can be observed (agriculture lost its position and significance where HDP is concerned, the importance of industry and services grew), together with a so-called forest transition, i.e., the increase of the forest area at the expense of untilled plots (Bičík et al., 2015).

In general, two opposing trends of land use change were observed in Czechia during the Communist period (1948 - 1989). The first of those was the agricultural intensification) in the suitable (fertile) areas driven by motive of self-sufficiency (Grešlová Kušková, 2013 and the other was extensification associated with land abandonment (Kabrda, 2008). The latter, i.e., abandonment and extensification, are ascribed predominantly to the loss of workforce by depopulation and expulsion of Czech Germans after WWII and by strategic decisions of depopulation and exclusion of agricultural activities in the borderlands (Glassheim, 2015; Bičík et al., 2001). The regime change to democracy in 1989 led to a restitution of the property "nationalised" in 1950s and privatisation of most of the state-owned property. Those events, together with the transformation to the post-productivism concept in agriculture, catalysed a further extensification trend, manifested e.g. as an increase in the representation of grassland in the peripheral regions. Besides the underlying politically driven decisions leading e.g. to the agricultural intensification or loss of the workforce and employers, political decisions can impact LULC development in many other ways, such as establishing areas with prohibited access and/or exclusion of a particular use of land (e.g. agricultural, housing, industrial). Such restrictions can be driven by environmental protection policies (formation of strictly protected areas) or by security needs (military zones, forbidden access areas). The security reasons often lead to the installation of restrictive measures (e.g. guarding, fences, walls) with significant negative impacts on environment e.g. restrained movement of animals leading to isolation of populations (Flesch et al., 2010; Linnell et al., 2016). Although areas that are subject to measures aiming to the restriction of use are often monitored for landscape changes (e.g. core zones of protected areas, military training areas), studies dealing with assessment of LULC changes on a broad scale (large areas) are scarce due to the lack of suitable study opportunities, which results from the impossibility to manipulate the conditions in a broad scale (e.g. country-wide).

The observation of landscape changes in the whole Czech borderlands (Bičík & Kabrda, 2007; Bičík, Kabrda, & Najman, 2010) or its parts (Vaishar et al., 2013; Kupková et al., 2013; Breuer et al., 2010) has been so far mostly based on the information about the land use for the entire cadastral units or on land cover datasets with low spatial resolution (typically CORINE land cover). Neither of those sources allow fine scale assessment of long term changes due to their spatial (a cadastral unit in case of cadastral data or minimal mapping unit of 25 ha in case of CORINE) and temporal (CORINE data available only from 1990 onwards) resolutions. Besides, the cadastral data cannot provide answers about the individual LULC categories as the spatial distribution of those throughout the area can change significantly even if the total area of individual LULC classes remains more or less constant. As pointed out by Yang et. al. (2014), cadastral data may also be burdened by mistakes caused by incorrect entries or delays in recording the category changes. A suitable solution for identification of the historical LULC may be offered by manual vectorisation of aerial photos or historical maps that has been used in numerous studies (Skaloš et al., 2011; Plieninger, 2012; Godet & Thomas, 2013; Sklenička, Šímová, et al., 2014).

3 Objectives

The previous chapter emphasised the suitability of areas divided by an administrative border for the purposes of studying impact of (in particular) political driving forces on the landscape. Such areas often offer, despite identical environmental conditions, different LULC trajectories in the observed periods. Although such research offers great potential and a possibility to simulate a manipulative experiment in the temporal and, in particular, spatial design (see Chapter 2.5), studies dealing with this issue are rare. Border regions separating the former Eastern and Western bloc states (the Iron Curtain), i.e., two different political-economical systems that underwent a subsequent harmonisation after 1989, appear to be a suitable area for such research. Studies focusing on this area are however very rare indeed and, in some cases, they do not take the variability of natural conditions along the borders into account. Another suitable area for such study is represented by the borders of Czechia as during the Communist era. Czechia was neighbouring on both Western (democratic) and Eastern (socialist) countries and the management of the two types of borders differed significantly, which was also associated with differences in the intensity of the land use. Studies on that space are more common but they either focus on a micro scale of a single or several cadastral units, or they utilise cadastral reports that may be burdened by inaccuracies (for details, see Chapter 2.1.1).

The presented thesis aims to study and discuss the role and significance of the political border in the LULC evolution on the examples of the former Iron Curtain (Part I.), the Czech side of the borders of Czechia (Part II.) and a microprobe – a case study (Part III.) of a selected cadastral unit from the Czech borderlands. From the perspective of the study of this topic, it has been studied hierarchically here – from the macro scale of the entire Iron Curtain up to the detailed insight into the changes of the borderlands analysed in the aforementioned case study. The reasons for such arrangement are in particular (i) the possibility of comparing the evolution of borderlands in a broader spatial context and variable political and socio-economic environment of the Central Europe (in particular in view of the 1989 turning point and the subsequent diversity of transformation trajectories of individual countries) and (ii) the necessity of a broader temporal framing for explaining the drivers of land change; this is especially important because the political and societal changes or decisions are reflected in the landscape in a much longer time frame (years, decades) than e.g. in economy (Hampl & Müller, 2011). Based on the above, I assumed the following:

1. various political conditions (drivers) and transformation dynamics necessarily must be reflected in the different structure of changes between the states of the former Eastern and Western bloc in the period after the fall of the Communist regime as well as in the individual segments of the borders, defined by the individual state neighbourhoods. In addition, I expected the convergence of the volume and structure of individual processes (e.g. afforestation, urbanisation) between the former Eastern and Western countries over time from 1989 onwards (based on an assumption that the same political and economical system will elicit similar types of pressure on the changes in landscape).

2. the former border permeability has an observable effect on the landscape structure in the present. I assumed that the strictly guarded borders neighbouring on democratic states will rather show trends of agricultural land abandonment and increase in the extensive land use due to the limitations or even exclusion of economic activities in such borderlands between 1948 and 1989. A sharp change in the trends of landscape evolution was expected to be revealed after 1989.

3. On an example of a case study of a smaller area with a greater temporal scale, I attempted to describe the landscape development in the borderlands, including identification of the principal drivers (processes) and of the landscape elements and configuration that (i) best represent the process of the landscape evolution, (ii) represent a static or reconstructed part of the landscape (i.e., do not reflect the landscape changes but rather conserve a condition achieved at a certain period without diachronic depth) or (iii) are a combination (a hybrid condition) of the two above. The expected outputs of the Part III were recommendations towards the practice of nature and landscape conservation and education.

4 Areas of interest, data and methods

The Methods chapter is divided into subchapters focusing on areas of interests, datasets, data processing and evaluation. Some algorithms or methods are identical for all parts of the thesis, some differences between individual studies in the spatio-temporal context (Fig. 6) are however explained separately in the subchapters dedicated to the Parts I. – III. The case studies are presented in the order of the scale – from the meso/macro scale (the spatial scale is hereinafter explicitly perceived as spatial extent/area) of the entire Central European space (Part I) to the microprobe of a selected cadastral unit in the third study (Part III).The increasing spatial extent of the individual studies (Fig. 6) is associated with the reduction in the temporal extent. This is caused by the obvious fact that the microscale (Part III) allows a detailed description of the landscape evolution using other methods and sources (e.g. the study of archival, iconographic a written records).

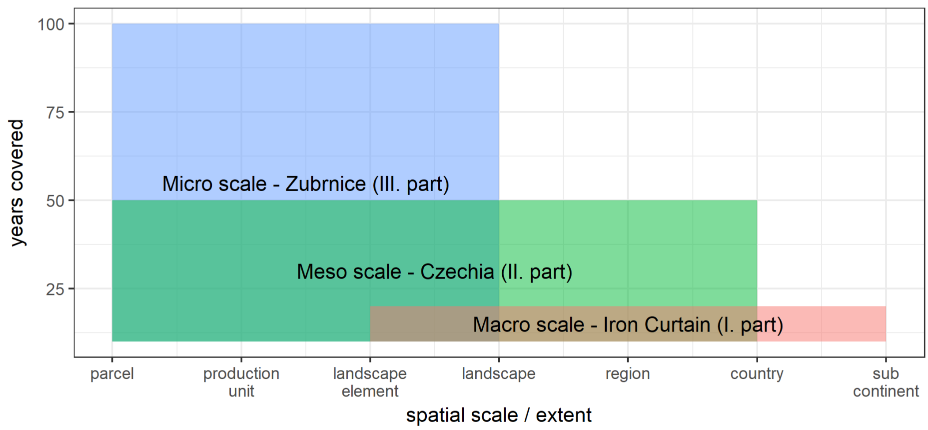


Fig. 6: Temporal and spatial extent of the studies. The x axis shows the spatial scale (spatial extent) of the studies – from the smallest spatial unit to the maximum spatial extent analysed in the respective study. The y axis shows the temporal extent of the studies in the temporal distance from the present day (0 - 100+ years). Part I is a study on the Iron Curtain, Part II on the inner borders of Czechia, and Part III is a case study of a small area in the Czech borderlands (Zubrnicko).

A detailed description in the sense of the "landscape narrative", landscape history or landscape biography grows however more complicated with the increasing spatial extent and is practically impossible once a certain spatial extent is exceeded (due to the immense amount of archival sources that would have to be processed and the complexity of factors affecting the landscape development). For these reasons, coarsening the scale of analysis (Part I. and II.) was in this thesis associated with the assessment of the landscape evolution using quantitative data, i.e., landscape metrics.

From the perspective of the methods, the first two parts (Part I and II) are therefore similar in the sense of using landscape metrics on the landscape or patch level. Both studies subsequently utilise a non-parametric alternative to the ANOVA test for evaluating the development of indicators (response variable) and their relation to the predictors. The last study explains the landscape evolution (land change) based on the archival sources (old maps and documents). In all three parts, land use is classified – be it from the ready-to-use datasets (Part I) or from own datasets acquired from aerial photographs and maps (Parts II, III). All statistical evaluation was performed in R (R Core Team, 2019). Figures other than map layouts were constructed in the R package ggplot (Wickham, 2009).

4.1 Rationale, sampling design and description of case study areas

4.1.1 Area of interest and sampling design of the borders of the "Iron Curtain" (Part I)

For investigation of the transition of the border landscapes on the level of macro scale, the former line dividing the Eastern and Western blocs during the Cold War (so called "Iron Curtain" that persisted until the late 1980s) was chosen. This former border (Fig. 7a) of more than 2700 km spanned from Baltic to Adriatic Sea, separating the „Eastern" states – the former German Democratic Republic; Czechia and Slovakia (former Czechoslovakia); Hungary and Slovenia (former part of Yugoslavia) with centrally planned totalitarian economies – from democratic „Western" states with market economies (Italy, Austria and former Federal Republic of Germany. Despite such clear division, there were vast differences in the border permeability (see Introduction and Table 4).

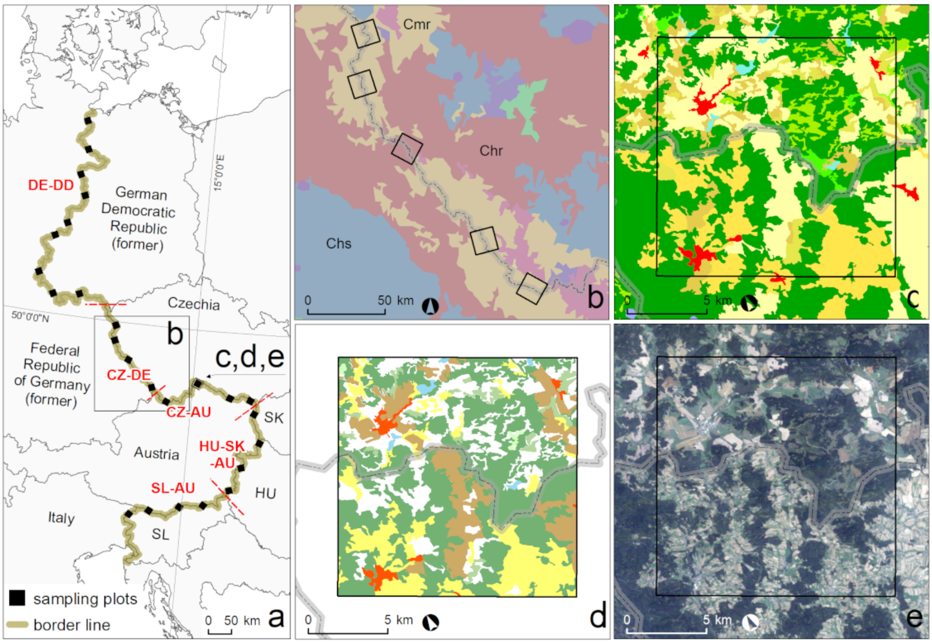


Fig. 7: a) Localisation of the sampling plots on the Iron Curtain border (border line divided Germany to Western and Eastern part; Czechia and Slovakia (SK) were by the time of iron curtain one state – Czechoslovakia, HU – Hungary; SL – Slovenia, by the time of Iron Curtain part of the Yugoslavia), b) position of the sampling plots within landscape types (Chs = Continental (climate) - hilly (relief) – sediments (parent material); Chr = Continental – hilly – rocky; Cmr = Continental – mountains – rocky), c) 2010 state of the land cover d) persistent features based on the intersection of the 1990 and 2010 (white patches indicate land use change between the time points)and e) Landsat-5-TM image, 1991 (U.S. Geological Survey).

Concerning the biophysical characteristics, the landscape settings of the border line were highly variable. Based on the LANMAP (landscape) typology (Mücher et al., 2010; Table 4), the altitude was ranging from 50 – 1500 m a.s.l. The majority of the sampling sites used in the Part I of the thesis (Fig. 7a) are located in the Continental (54 %), followed by Pannonian (23 %) climate, with the rest belonging to the Alpine south, Atlantic North and Mediterranean Mountains climate. Correspondingly to the variation in climate and altitude, the majority of the parent material forms are Crystalline rocks and migmatites (35 %) and Soft loam (31 %), the rest includes Calcareous rocks, Sandstones and Soft and hard clayey materials.

I have decided on using a sampling plots design instead of the evaluation of data of the entire border line (e.g. entire border zone of 15 km width), in particular because of the unbalanced representation of landscape types (environmental conditions - climate, relief and parent material, Fig. 7b) on both sides of the former Iron Curtain. In order to explore the possible differences of landscape types on both sides of the border, I have gathered the data of the land typology (LANMAP, Table 4, Fig. 7b; cf. c,d) for both East and West side of the boundary, covering the distance of 15 km from the border. The comparison of the proportion of the landscape types on both sides (both strips) was conducted via the pairwise proportion test with Bonferroni correction.

Such a rather simplistic comparison of the area (disregarding spatial distribution) led to unequal proportion in 10 landscape types ($p<0.001$) out of 20. Despite the fact that incongruent landscape types covered only 12 (east) and 16 % (west) of the area under investigation, I have decided to proceed with the design of sampling plots localised in areas where the landscape type was identical on both sides of the border (Fig. 7b). Due to the above-mentioned unbalanced representation of the landscape types, sampling plots were placed on the borderline. The placement of 10x10 km squares was performed in a way ensuring that the entire square lies within an identical landscape type according to LANMAP Level 3 typology layer and that half the square area lies on each side of the border (Fig. 7b). The conditions of the size end equal distribution inside the same landscape type resulted in identification of 25 sampling sites in total that (due to character of the landscape and border line) unevenly followed the border line from north to south. The sampling plot (Italy - Slovenia) was later excluded from all processing and calculation because of the fact that only a single plot met the criteria on that border (Fig. 7a), which would subsequently render any statistical analysis impossible.

4.1.2 Area of interest and sampling design of the inner borders of Czechia (Part II)

The study area for the country-wide level (meso scale / spatial extent) was represented by border regions of Czechia neighbouring on Germany, Austria and Poland (Fig. 8). From the historical perspective, therefore, the study area represented borders of a socialist Czechoslovakia with two other socialist countries (Poland and German Democratic Republic) and

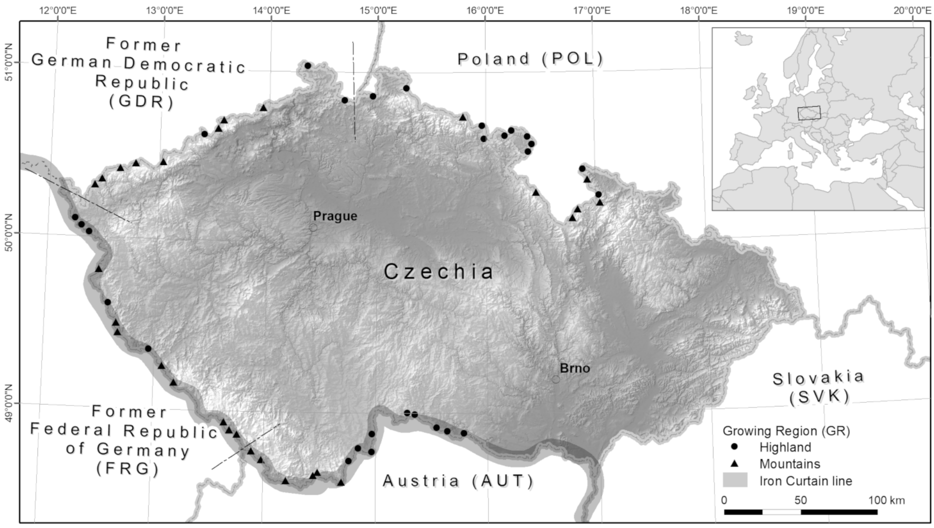


Fig. 8: Location of sampling plots along the state border of the Czechia.

two traditionally democratic countries with market economy (Federal Republic of Germany and Austria). The current border with Slovakia was not included into the study as Czechia and Slovakia used to be one country until the end of 1992 (Czechoslovakia).

For the analysis of the landscape changes along the borderline of the study area (2075 km), 56 square samples 1 x 1 km were randomly generated. The number of square samples was determined to achieve a balanced number (28/28) of highland (450 – 600 m a.s.l.; average temperature 7°; annual precipitation 700 – 800 mm) and mountain (600 m a.s.l. +; average temperature 6°; annual precipitation 800+ mm) sample positions. Besides the balanced environmental settings, balanced number (28/28) of positions inside and outside the Iron Curtain was achieved. Lastly, sampling areas must have met the criteria of the availability of airborne imagery for all time points employed in the study (it was not available for all desired time points for every randomly generated site). The categorisation into the mountain and highland samples was conducted via the spatial layer of the Growing Regions database (Table 4) categorizing the whole country according to environmental factors (for details, see Chapter 4.2.2).

All of those squares had to touch the border (see Fig. 8). The sampling plots were classified according to the Iron Curtain presence (sampling plots neighbouring with democratic vs. socialist regime) due to different restrictive measures applied during the Communist era. Positions on the borders with traditionally democratic neighbours (Fig. 8) represent a restrictive border mode before 1989 (i.e., landscape separated from the inland by continuous high (electrified) fences, mine fields and other barriers), while the sampling positions neighbouring till 1989 with socialist countries represented a less restrictive border regime, i.e., a guarded border almost without technical measures, such as high fences (Pulec, 2006; Rak et al., 2016).

4.1.3 Area of interest and rationale for the case study of Czech borderlands - Zubrnice (Part III)

The selection procedure of the area for the micro scale study differed from both above mentioned scales (Parts I and II). Addressing challenges for developing a cross-cutting approach to present landscapes of the past as narratives of social and environmental change required a multicriterial procedure when selecting the case study. The case study area had to be representative of the major drivers of landscape change, but still allow the operation of the conceptual approach and provide clear implications for landscape conservation (Antrop, 2005). Moreover, the case study had to comply with a mixed-methodology approach combining quantitative analyses of landscape changes with qualitatively driven contextualisation of these changes (for the case study methodology see George, 2005). Therefore, I first looked for an area that encountered significant social and environmental changes due to both external and internal drivers, while presenting relevant challenges for conservation planning at a landscape scale.

The implicit selection procedure resulted in focusing on a relatively small study area (4.99 km2) of the Zubrnice village and its surroundings in northern Czechia (Fig. 9a) near the border with Germany. The study area is located in the České středohoří Mts., a volcanic range with mild climate (annual precipitation 700 mm/p.a. and average temperatures between 5-10 °C). The region contains Eutric Cambisols and Stagnic Luvisols, which, together with the climate and steep slopes, limit the scope of agricultural use. The settlement structure has dynamically changed over the last two centuries. Established in 1352, the Zubrnice village and its surroundings later represented an area of extensive agriculture and forestry and was mainly inhabited by Czech Germans until the mid-20th century. The study area is under a legal protection for its natural and cultural value. The part of the housing that forms the current protected heritage was transferred to Zubrnice to protect the architecture from demolition, partly due to open-pit brown coal mining (Glassheim, 2006). The village architecture therefore combines non-native and native elements that legitimise the selection of this case study area as a place that reflects the crucial changes in a border region.

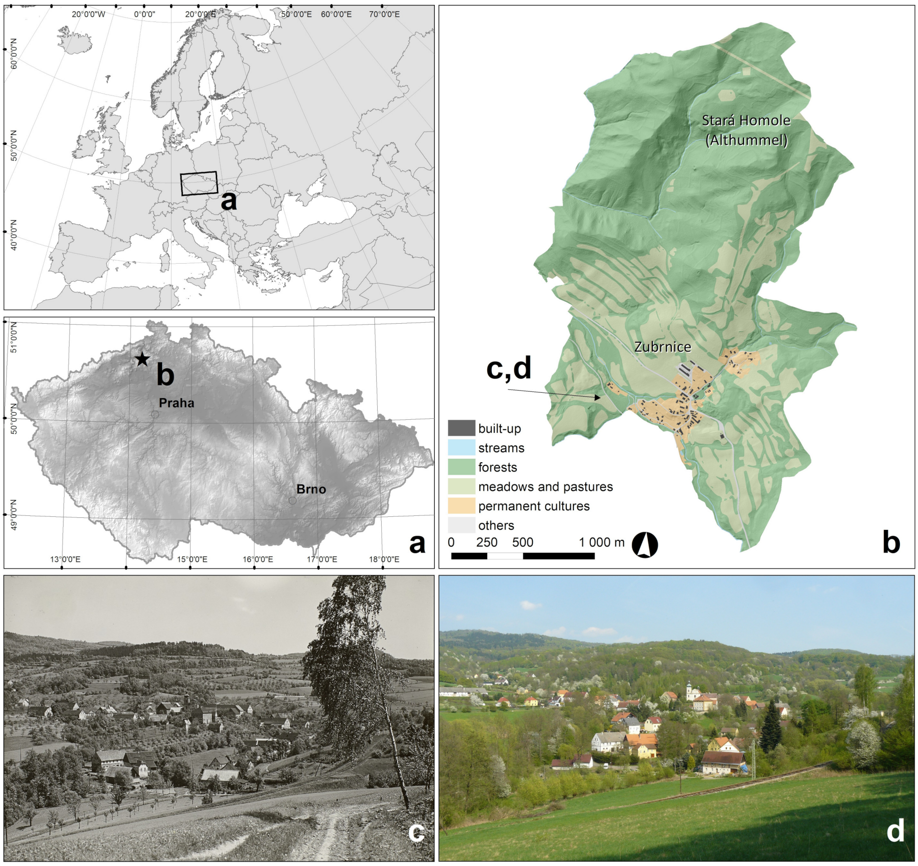


Fig. 9: a,b: Study area and current (2013) LULC of Zubrnice case study area (data source: State Administration of Land Surveying and Cadastre); c: Zubrnice village and surrounding landscape, 1935, source: SLUB / Deutsche Fotothek, Walter Möbius; d) repeat photography (2017), source: Jiří Riezner.

4.2 Overview of datasets used in the thesis

4.2.1 Data used in the Part I – Iron Curtain

In order to gather the information about the LULC change, CORINE Land Cover (CLC) datasets for three particular years (Table 4) were employed. I used the level 2 of CLC classification categorising the landscape into: Urban fabric; Industrial, Commercial and transport units; Mine, dump and construction sites; Artificial, non-agricultural vegetated areas; Arable land; Permanent crops (vineyards, fruit trees plantations); Pastures; Heterogeneous agricultural areas (orchards, mixture of intensive agricultural use, gardens and agroforestry use); Forests; Shrub and/or herbaceous vegetation associations; Open spaces with little or no vegetation; Inland and Maritime wetlands; Inland and Marine Waters. The minimum mapping unit of 25 ha was assessed as sufficient (Fig. 7c) for further investigation.

For the sake of the homogeneity of the landscape under study, we have incorporated the pan-European landscape typology of the LANMAP project (Mücher et al., 2010, for comparison of other options see Hazeu et al., 2011). This dataset divides the European landscape according to the climate, altitude and parent material (geological composition) into 76 classes (Fig. 7b) on the third level of classification. The more detailed (fourth level) division with 350 classes (the addition of land cover information – fourth variable) was deemed unnecessary for the research objectives due to the change (unstability) of the land cover through time. The information about the former Eastern bloc boundaries delimitation were obtained as a shapefile from the Mosaic project administered by Max Planck Institute (Table 4). The information about the former delimitation of the boundary was necessary due to the nonexistence of such bordering in the current spatial datasets dealing with administrative division of Germany.

4.2.2 Data used in the Part II - Czechia

In this part of the dissertation, the analysis of the landscape changes in the period before and after the change of the political regime in 1989 was based mainly on airborne imagery. More precisely, historical airborne images acquired by the Military Geographic and Hydrometeorology Office in Dobruška (1950s and 1980s periods) and orthophotos available via Web

Table 4: Comparison of the border control regime in the Iron Curtain sections

Name / Type	Used in part	Year	Min. mapping unit/ Spatial Resolution/ Original Scale	Digitisation scale (on the side of author)	Original repository	Source	Spatial extent
CORINE Land Cover (CLC)	I	1990; 2000; 2012	25ha / 100 m	not digitised	Copernicus System, ESA	a)	EU
LANMAP database (ver. 3)	I	2010	11 km^2	not digitised	Wageningen University	b)	EU
Historical country boundaries	I	1989	N/A, line feature class (vector)	not digitised	Max Planck Institute for Demographic Research	c)	Germany
Historical Aerial Imagery	II	1953*; 1988*	<1m (digitised analog imagery)	1 : 500; 1 : 1500	MGHOD	b)	Czechia
	III	1954	<1m (digitised analog imagery)	1 : 500; 1 : 1500	MGHOD	b)	Czechia
Current Orthophoto	II	2012	0.25 m/px	1 : 500; 1 : 1500	SALSC	d)	Czechia
	III	2003; 2013	2003 - 0.5 m/px; 2012, 2013 - 0.25 m/px	1 : 500; 1 : 1500	SALSC	d)	Czechia
Growing Region Database	II	2009	N/A (polygon feature)	not digitised	MACR	f)	Czechia
Land parcel identification system (LPIS)	II	2015	N/A (polygon feature)	not digitised	MACR	f)	Czechia
Forestry maps	II	2015	N/A (polygon feature)	not digitised	The Forest Management Institute (FMI)	e)	Czechia
Current Cadastre	II	2015	N/A (polygon feature)	not digitised	SALSC	d)	Czechia
Historical (stable) Cadastre	III	1843	digitised analog cadastral maps (1 : 2880)	1 : 1000	Archive of SALSC	d)	Czechia
ZABAGED	III	2014	min. 1 : 1000	not digitised	SALSC	d)	Czechia
Digital terrain model (DMR 5G)	III	2010	0,18-0,3 m (std. Error of altitude)	not digitised	SALSC	d)	Czechia

a) Copernicus Programme, 2019; b) Obtained via personal communication; c) Max Planck Institute for Demographic Research, 2019; d) SALSC, 2019; e) Forest Management Institute (FMI), 2019; f) eagri.cz; MGHOD - Military Geographic and Hydrometeorology Office in Dobruška; MACR - The Ministry of Agriculture of the Czech Republic; ZABAGED - Fundamental Base of Geographic Data; *median values, please see the section 4.2.2 for further details.)

Map Service (WMS) of the State Administration of Land Surveying and Cadastre (2012 version). As the date of acquisition of airborne imagery varied for 1950s and 1980s images, the median year value was calculated and used for further analysis, resulting in reference years 1953 and 1988.

For the subsequent comparability of sampling plots, the sampling design had to consider (as in Part I) the data on the environment. For the spatial extent of Czechia, this was solved using a spatial data layer of growing regions categorising individual cadastral units according to the soil, metrological and topographic conditions for agriculture in the respective units (NSRC, 1954), providing a clear typology of individual units. In this work, the types "highland" (potato-growing region) and "mountains" (mountain region) were present. The use of the typology of growing regions for ensuring consistent environmental condition is relatively common in studies on Czechia (e.g. Sklenička, Šímová, et al., 2014; Bičík & Kabrda, 2007), the typology is comparable with the LANMAP typology used in Part I.

The primary data used in this part of the study was nevertheless supplemented with additional data. The additional data served as auxiliary where it was not possible to determine the LULC class from orthophotos with certainty. The auxiliary data were represented by forestry maps containing the delimitation of forest areas including their typology and age (i.e., where there were clearings in the forests, they could have been classified as temporary clearings with planned afforestation or a forest-free patches not intended for new afforestation). In case of agricultural patches, the procedure was similar. (In particular) pastures and meadows that are subject to subventions have to be detailed in the land parcel identification system (LPIS) and agricultural plots with uncertain classification were therefore specified using this source. The LULC classes can, in addition, be verified by consulting the cadastral maps. All those auxiliary data sources must however be critically evaluated as the information (in particular in the cadastral map) may not necessarily be valid.

4.2.3 Description of data used in Part III

Primary and secondary data sources were used also for the study on the microscale level (a single cadastral unit). To acquire data from a wide time range, it was necessary to use, besides the oldest available aerial photograph (1954) for the site in question, also historical cadastral maps, inaccurately called the stable cadastre (Franziscean Cadastre).

The Franziscean Cadastre is extensive from the perspectives of the spatial extent (the entire area of the former Austrian-Hungarian Empire), detail (a detailed level of individual plots) and thematic detail (more than 30 LULC categories). These maps were available as a colorised imprint (digital scan), from which the information about the particular LULC type was relatively easily available. Despite all the above advantages, however, the Franziscean Cadastre is (as any such extensive work) burdened with certain errors (for details see Forejt et al., 2018). On the other hand, it still represents a crucial source for studies of the preindustrial landscape from the mid-1800s, which is also documented by the frequent use of this source (Dolejš & Forejt, 2019).

The source for the second time probe for the land use in the study area was the aforementioned aerial orthophotograph from 1954. A black and white photograph with this date fully covers the entire area of interest and was used as no sources of a similar or older date (speaking of the period after the Franziscean Cadastre) were available. For other time probes, orthophotos from 2003 and 2013 were used. The reason for using the 2003 orthophoto lies in particular in the intended densification of data about the latest period of time. Similar to Part II, auxiliary data were used in addition to these primary sources, serving in particular for verification of the presence of land use relicts. Such relicts (e.g. hollow ways or agrarian terraces) are well observable in the ZABAGED topography and even better in the very accurate digital terrain model of the fifth generation.

4.3 Spatial data processing

4.3.1 Data processing for Part I – Iron Curtain

After defining the sampling plots along the Iron Curtain border, it was necessary to acquire data on the degree of transition of individual LULC types on the CLC 2 level. In other words, it was necessary to detect the trajectory of land change on the level of individual patches. Data from individual investigated years (1990, 2000, 2012) were in the ArcGIS environment (ESRI, 2019) mutually compared by intersecting the individual layers in the chronological order. The change (or lack of it) of the intersections of the individual areas (Fig. 7c) between the years 1990 – 2000 and 2000 – 2012 was therefore observed. For the purposes of the subsequent evaluation, tabular records were created from the spatial data containing the actual intersection polygons with records of the original (e.g. 1990) and resulting (e.g. 2012) LULC type including the area.

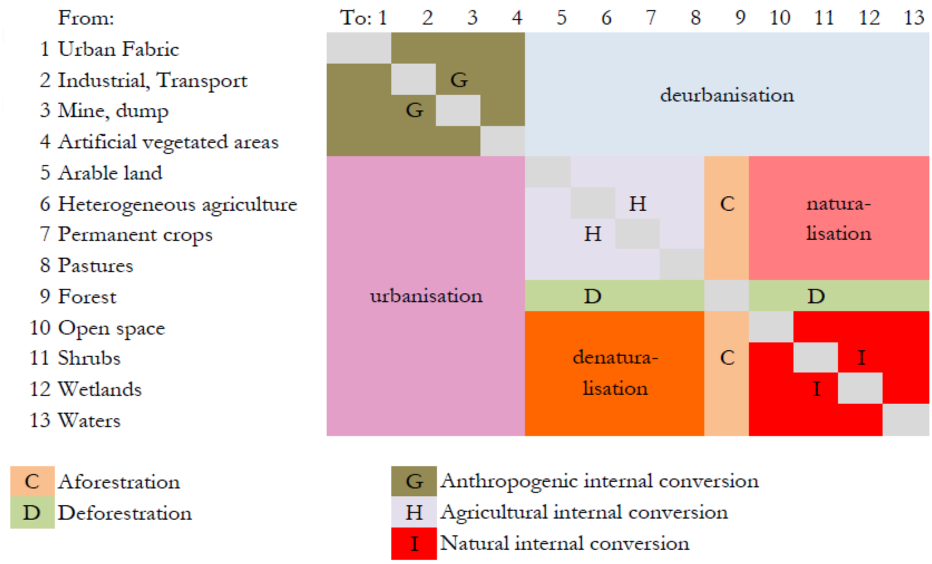


Fig. 10: Generalisation scheme - clustering transition of the individual LULC classes into specific processes.

In order to further analyse the transition of land use classes between individual years (periods), the first step was to visualise the transition via circular plots (Gu et al., 2014). A circular plot demonstrates the exchange between particular LULC classes. Next, the transition scheme was created. The transition scheme (or matrix, Fig. 10) was used to generalise the processes of land cover classes transition into nine groups. In this way, the whole area for multiple LULC classes that belongs to single process was summed. Thus, three (Fig. 10 G,H,I) internal conversion groups of anthropogenic classes, agriculture and natural classes were distinguished. Changes between such classes, to some extent, do not represent change of their ecological value. The antagonistic processes of urbanisation and deurbanisation follow the transition to urban or urban-like forms (Industrial, Mine, Dump and transport areas, artificial vegetated areas) from the rest of the categories and vice versa. The naturalisation and denaturalisation process express conversion from potentially valued natural classes (Open space, Shrubs, Wetlands and Waters) to agricultural use or vice versa. Finally, afforestation and deforestation processes are distignuished (Fig. 10 C,D).

For the purpose of comparison between the individual processes on both sides of the former Iron Curtain (IRC) line and time, the rates of change between processes were calculated as sum of the particular land cover classes in transition between 1990 – 2000 and 2000 – 2012. Therefore, I derived the information about the area of all e.g. Agricultural intensification classes as a single rate of change for each of the two periods. Such rates were divided by the factor of 10 (years) for the first and 12 (years) for the second period in order to normalise the results (dynamics in hectares per year). I have obtained relatively low values for individual processes; therefore, we excluded the Anthropogenic internal conversion, Denaturalisation, Natural internal conversion and Naturalisation (where the mean values plus standard deviation did not exceed five ha per year, see Table 4) from subsequent statistical analyses. Data on the rates for both 1990 – 2000 and 2000 – 2012 periods and for all five remaining processes (Fig. 10) were later employed for statistical modelling as a response variable together with predictors of time (two levels reflecting the periods) and side of the border (two levels - East and West).

4.3.2 Data processing for Part II – Czechia

Imagery processing and landscape data acquisition

The airborne imagery (Table 4) was scanned, georeferenced and manually vectorised at a reference scale of 1 : 1500 (where smaller landmarks such as individual trees or alleys were concerned, georeferencing was performed at a 1 : 500 scale) according to a detailed methodology of vectorisation and interpretation of data prepared for the purpose of the study prior to its commencement. In particular, the methodology included an index and description of distinguished LULC classes, rules for determining borders between classes, and examples of the appearance of the individual classes on the airborne images. LULC types were classified into 6 main classes (LC1 level) that were further divided into 15 detailed land cover classes (LC2 level; see Table 5). The quality of the vectorisation and interpretation of the images was twice independently scrutinised. The imagery was processed in a timewise reverse order (on the basis of the most recent map) by editing, with information being adapted to older time levels (see Walz, 2008 for details). Besides, in order to acquire as precise information about LULC classes as possible, the more recent map was compared with other sources such as the cadastral data, Land Parcel Identification System (LPIS) and forestry maps. All GIS data processing was performed in ArcGIS (ESRI, 2019).

Landscape data processing

In order to follow the objectives of this part, I have gathered the data describing the LULC with a focus on individual landscape classes (e.g. the proportion of forest or farmland) and calculated indices characterising individual sampling plots for all three time points. To express the dynamics of change, the rates of individual response variables were derived.

The landscape composition and configuration in the individual time points and at the individual levels of thematic resolution (LC1, LC2) were described using simple landscape metrics at the class and landscape levels. In order to capture the dynamics of landscape change, the rate of change between 1953 – 1988 and 1988 – 2012 time points (similarly to Part I) was used as a response variable for all the landscape metrics (see Chapter 4.4.2). As the duration of the periods was not equal, all rates were normalised by dividing them by 35 (years) for the first and 24 (years) for the second period. The normalisation step moved the decimal separator. For the sake of better comprehensibility and maintaining widely accepted units (ha, km) we have multiplied the class level variables by a factor of 10 and landscape level variables by factor of 100. The overview of the response variables and their resulting values is provided in the Chapter 4.4.2. For the coarser LC1 resolution at the class level (McGarigal & Marks, 1995), I used a proportion (hectare) of the forest (FOREST), farmland (FARM) and non-forest near-nature vegetation (NNVEG) for further analysis. At the detailed resolution (i.e. LC2), we used the proportion (hectare) of cropland (CROP), agricultural meadows and pastures (GRASS), near-natural non-forest woody vegetation (WOOD) and non-agricultural herbaceous vegetation (HERBS). Classes representing only minor fractions of the area of interest, such as urban areas or transportation infrastructure, were not evaluated at the level of classes but were used for metrics calculation (across all sampling sites, hereinafter "landscape level").

At the landscape level (McGarigal & Marks, 1995), the landscape heterogeneity was quantified using the Shannon Diversity Index (SHDI) and landscape texture through the Edge Density index (ED). Other indices of heterogeneity (e.g. Simpson index) and landscape texture (e.g. Patch density) were not used as they are strongly correlated with SHDI and/or ED, respectively (Šímová & Gdulová, 2012; Šímová, 2017). The used landscape level metrics were calculated for both levels of thematic resolution (LC1, LC2). ED was in addition calculated using two different input

Table 5: An overview of the main (LC1) and detailed (LC2) LULC classes used for vectorisation and interpretation of the airborne imagery from three time points and their average areas in the individual sample sites (mean±standard deviation, n=234). Names of variables representing individual classes for further landscape analysis are in capital letters. The year in the header indicates the median of the imagery acquisition for the time point in question.

Time point	1953	1988	2012		1953	1988	2012
LULC classes (ha, mean±std) main thematic resolution LC1				LULC classes (ha, mean±std) detailed thematic resolution LC2			
Forest FOREST	39.48 ±34.54	42.06 ±32.75	47.78 ±34.67	Forest FOREST	39.48 ±34.54	42.06 ±32.75	47.78 ±34.67
Farmland FARM	50.24 ±33.74	42.44 ±33.25	39.51 ±32.98	Cropland CROP	27.66 ±30.52	27.54 ±32.83	20.68 ±31.46
				Agricultural grassland[1] GRASS	22.11 ±23.33	14.59 ±19.61	18.47 ±23.22
				Vineyards	0.08 ±1.21	0.2 ±2.56	0.25 ±2.77
				Orchards	0.39 ±3.33	0.11 ±1.33	0.11 ±1.33
Near-nature vegetation NNVEG[2]	6.64 ±8.45	10.86 ±14.78	7.25 ±11.24	Woody[3] WOOD	2.43 ±3.41	3.56 ±4.79	3.75 ±9.75
				Herbaceous[4] HERB	4.2 ±7.3	7.3 ±13.57	3.5 ±6.07
Water	0.77 ±3.29	1.38 ±5.75	1.41 ±5.77	Water bodies	0.49 ±3.22	1.09 ±5.74	1.1 ±5.75
				Streams	0.28 ±0.44	0.3 ±0.44	0.3 ±0.48
Urban areas	1.66 ±3.95	2.14 ±5.38	2.94 ±7.27	Built-up areas	1.57 ±3.92	2.05 ±5.27	2.63 ±7.04
				Others	0.09 ±0.53	0.09 ±0.53	0.31 ±1.92
Roads	1.22 ±0.73	1.12 ±0.73	1.12 ±0.76	Paved	1.07 ±0.73	1.06 ±0.73	1.11 ±0.75
				Unpaved	0.14 ±0.38	0.05 ±0.23	0.01 ±0.07
				Railways	0.01 ±0.09	0 ±0.01	0 ±0.01

[1]meadows and pastures;[2] Non-forest near-naure vegetation [3]tree alleys, solitaire trees, riparian vegetation with trees and shrubs, hedgerows and small patches of trees and shrubs etc.; [4]wet meadows, abandoned meadows, herbaceous edges of forests and fields, herbaceous riparian vegetation, herbaceous ruderal vegetation etc.)

data (Fig. 11): (i) a layer capturing the borders between polygons of the cropland in the form of narrow grassy or shrubby baulks and (ii) a layer without those baulks. The reason for this is a well-known fact that the forced collectivisation of the agriculture under the communist regime in 1950s resulted in a substantial change in the structure of the landscape through destruction of baulks between smaller plots of fields (Sklenička et al., 2009), thus increasing the grain. The ED variables (EDv, ED_LC1, ED_LC2) thus should capture both these abrupt changes between the first and second time point and any potential finer changes in the structure of the ecotones (Fig. 11).

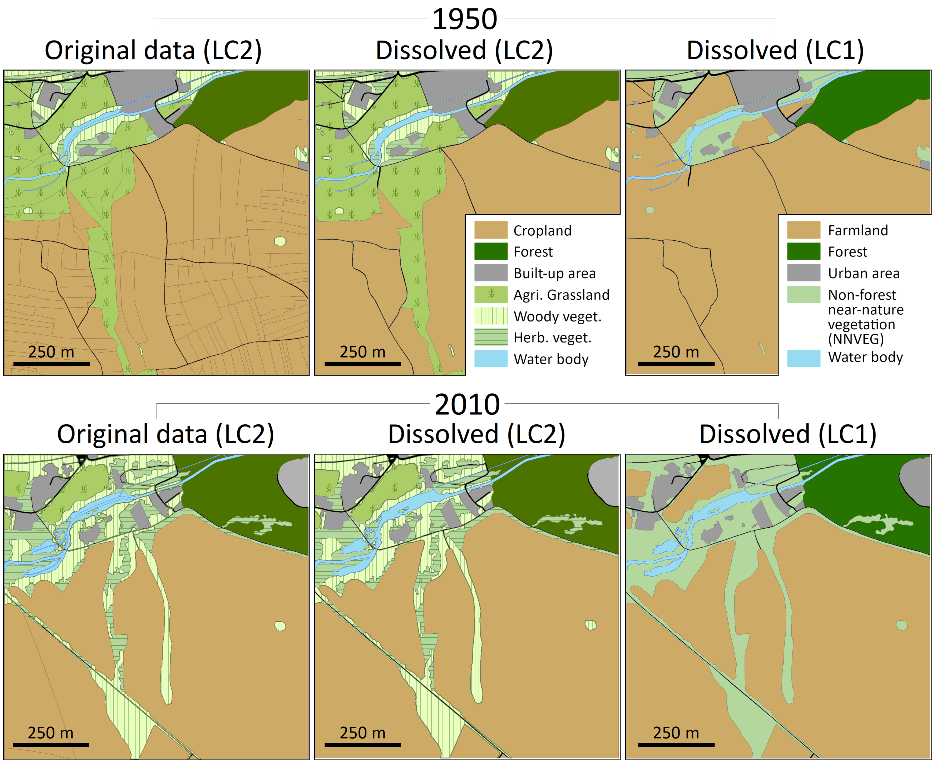


Fig. 11: Versions of sampling site data in a detailed (LC2) and main (LC1) thematic resolution in the 1950s and 2012 time points used for Edge Density calculation with and without dissolving the baulks.

4.3.3 Data processing for Part III – Zubrnice

The dynamics of the LULC structure was analysed using the historical map sources available for the case study area (e.g., Beranová, Balej, & Raška, 2017). The historical raster dataset of the Franziscean (so called stable) cadastre was georeferenced together with rest of the sources (that were already orthorectified) of aerial imagery and ortophotomaps (Table 4). It will be noted later that the selection of these time horizons (years) was based on the availability of sources, and although they coincide with certain social processes, they rather represent a probe into the more continual periods of landscape transitions. The digital sources were manually vectorised in a detailed scale (1: 1000) to create a seamless polygon LULC layer in the ArcGIS software package (ESRI, 2019). The LULC was divided into eight categories: (i) arable land, (ii) permanent cultures (hop fields, gardens, vineyards), (iii) meadows and pastures, (iv) forested areas, (v) water bodies and streams, (vi) built-up areas, and (vii) others (areas that do not belong to any of the above mentioned categories).

To evaluate the alterations in LULC, four different landscape metrics were calculated. The Shannon's diversity index (SHDI) was selected to gather information about the heterogeneity of LULC classes on the landscape level (whole study area level). The total edge metric, mean patch size and largest patch index were calculated for the purposes of characterizing the grain structure of the landscape under study. The dynamics of the structural changes (e.g., the transition from the forest to arable land, change of the LULC over time) were examined by the raster algebra processing of digitised land-use (LU) layers for a particular time point in the ArcGIS package (ESRI, 2019). The identified land use on every source for a particular time point was recorded and presented in a synthetic map. Map outputs were generalised into a raster with the cell size of 50 x 50 m to clarify the major trajectory and to avoid spatially insignificant results. The researched trajectories of particular patches, calculated metrics and data from field surveys were analysed together to determine the delimitation and description of dynamics for the study area.

Landscape features and documentary evidence

The analyses of LU structure and dynamics was complemented with the field survey and data from archival documents to obtain information about the qualitative attributes of land use structures (e.g., agricultural management practices) and the contextual data for the interpretation of land-use dynamics (e.g., documents about political decisions, economic data). First, the field survey aimed to localise the relicts of former settlements and landscape alterations with a focus on clearance cairns, agrarian terraces, and remnants of walls and fruit trees (as relicts of former solitary trees and orchards). All objects in the study area were systematically localised by GPS and subsequently analysed in GIS. The data from the field survey were compared with the current cartographic source of the vector data (ZABAGED and Digital terrain model - Table 4) and with a detailed digital terrain model in order to verify the field survey of relicts of agrarian terraces and remnants of walls and clearance cairns. Second, the contextualisation of identified LU structures and features has been supported with documentary evidence from local archives (mainly local chronicles, archival records of local administration and collective agricultural unions, personal archival records, and historical photographs; for typology, see Raška et al., 2014).

Deriving the typology of the land-use dynamics

The last step in the methodological framework of the Part III was based on the selection of representative examples from the study area that respected one of the two major conditions, i.e., either (i) the particular trajectory should be of significant extent, or (ii) should represent the persistent patches in the study area. The first condition was employed in order to localise the patches in transition that would be interconnected with the driving forces to a major extent. The second condition aims to derive the geographical dimension of unchanged or persistent patches. Therefore, six major transition schemes (e.g., change from arable land at the first time point to current forest via permanent cultures in mid-20th century) were selected to fulfil the first condition. This main trajectory covered 47 % of the area. Afterwards, the persistent permanent cultures and meadows, forest and pastures were added to cover altogether 66 % of the total area.

4.4 Data evaluation

4.4.1 Construction and evaluation of statistical models for Part I – Iron Curtain

In order to find out the influence of the border (BORDER) and of the time period (TIME) on the individual processes (Table 6) in the vicinity of the Iron Curtain, the repeated measures design was selected for statistical testing. The repeated measures design was chosen due to the spatial and temporal dependency in the data. The spatial dependency was in our model represented by the BORDER predictor, where sample squares were divided into half but still shared a common border. Secondly, the temporal dependency was represented by the TIME predictor, where the same sampling plots were tested in two different time periods. The Table 6 shows the response variables together with the values of the individual processes (variables marked by asterisks met the criteria stated in Chapter 4.3.1 and were used for further statistical testing).

Table 6: Response variables and predictors used in the study

	Response variables	Values min–max; mean±StD (ha per year)
Afforestation*	The dynamics of afforestation, i.e. conversion of non-urbanised patches into forest (ha/year).	0–101.18; 17.01 ± 24.02
Agricultural internal conversion*	The dynamics of conversion among Arable land, Heterogeneous agriculture, Permanent crops and Pastures classes (ha/year).	0 – 287.28; 60.33 ± 71.98
Anthropogenic internal conversion	The dynamics of conversion among Urban Fabric, Industrial & Transport, Mine & dump and Artificial vegetated areas (ha/year).	0–7.73; 0.59±1.65
Deforestation*	The dynamics of forest loss, i.e. conversion of forest patches to other than forest (with the exception of anthropogenic land use types; ha/year).	0–94.62; 10.18±15.66
Denaturalisation	The dynamics of water, wetland, open space and shrubs loss, i.e. conversion of natural patches to agricultural use (ha/year).	0–13.08; 0.7±2.24
Deurbanisation*	The dynamics of conversion from Urban Fabric, Industrial & Transport, Mine & dump and Artificial vegetated areas to other types (ha/year).	0–14.77; 2.02±3.45
Natural internal conversion	The dynamics of conversion among water, wetland, open space and shrubs (ha/year).	0–18.13; 0.41±2.13
Naturalisation	The dynamics of conversion in favour of water, wetland, open space and shrubs (ha/year).	0–13.48; 1.12±2.35
Urbanisation*	The dynamics of conversion in favour of Urban Fabric, Industrial & Transport, Mine & dump and Artificial vegetated areas from other types (ha/year).	0–39.79; 6.15±7.79
	Predictors	
TIME **	Time period divided into the span of (1) 10 and (2) 12 years; two levels	(1) 1990 - 2000; (2) 2000 - 2012
BORDER **	Traditional democracy (1) vs. Post-socialist countries (2)	(1) East; (2) West
REGION	Part of the frontier divided according to the specifics of bordering countries; five levels (see Fig. 7) (1) DE - DD: West and East Germany; (2) CZ - DE: Czechia and West Germany; (3) CZ - AU: Czechia - Austria; (4) HU - SK - AU: Hungary and Slovakia - Austria; (5) SL - AU: Slovenia - Austria	

*processes with sufficient areal extent, ** repeated measure

Unfortunately, the violation of assumptions for parametric testing made it necessary to use a nonparametric test. Nonparametric analysis of longitudinal data in factorial experiments (nparLD R package) in ld.f2 and f1.ld.f1 settings was therefore conducted as a nonparametric alternative to ANOVA (for details see Noguchi et al., 2012). The predictors of TIME and BORDER acted as repeated measures predictors, therefore the twofold temporal (TIME) and spatial (BORDER) dependency was articulated. Testing via nparLD provided two types of results – the Wald statistics and ANOVA type statistics. For the sake of reliability, a conservative approach was adopted. The results where considered significant only where both analyses (both ANOVA type and Wald type) yielded a significant result.

4.4.2 Construction and evaluation of statistical models for Part II - Czechia

In order to explore the effect of the regime (REGIME) and of the regime of the neighbouring country (NEIGHBOR) on the response variables, statistical testing of such effects was conducted (similarly to the previous chapter). Of the predictors (Table 7), the influence of the political regime in Czechia before and after 1989 (REGIME) on the response variables was examined. A potential influence of the regime of the neighbouring state (and therefore the presence of the Iron Curtain, Fig. 8) on the rate and direction of the landscape changes was captured by the NEIGHBOR variable. Finally, the predictor of the GROWING REGION (GR) was introduced in order to examine the behaviour of response variables in similar biophysical conditions (this characteristic, originally designed for agricultural use, represents the typology of the landscape consisting of the soil type, climate conditions and altitude; for details see Hruška et al., 2018). Here, similar to the previously mentioned approach the Part I, we have faced the violations of assumptions for parametric ANOVA model design (homogeneity of residual variance, sphericity) and nonparametric methods were therefore employed for the repeated measures designs (nparLD, Noguchi et al., 2012) as well. The model was constructed as a response (e.g. FOREST) variable with dependent (repeated measure, sub-plot effect) REGIME predictor and independent (whole-plot effect) factors of NEIGHBOR and GROWING REGION.

Table 7: Description of response variables and predictors

	Response variables		Thematic resolution	Values min–max; mean±StD
Class level	FOREST	The rate of change in the proportion of forests (ha/year*10).	main LC1	-40.65–38.95; 1.56±6.31
Class level	FARM	The rate of change in the proportion of farmland (ha/year*10).	main LC1	-39.68–17.24; -1.72±3.67
Class level	CROP	The rate of change in the proportion of cropland (ha/year*10).	fine LC2	-39.58–21.96; -1.45±6.25
Class level	GRASS	The rate of change in the proportion of agricultural grassland (ha/year*10).	fine LC2	-23.37–29.02; -0.27±6.34
Class level	NNVEG	The rate of change in the proportion of non-forest near-nature vegetation (ha/year*10).	main LC1	-33.46–40.68; -0.15±5.42
Class level	WOOD	The rate of change in the proportion of non-forest woody vegetation (ha/year*10).	fine LC2	-15.62–40.68; 0.2±3
Class level	HERBS	The rate of change in the proportion of near-nature herbaceous vegetation (ha/year*10).	fine LC2	-29.5–20.9; -0.35±4.54
Landscape level	ED_C1	The rate of change in the density of the borders between the main LULC classes (km/year*100), i.e., of the main types of ecotones. Borders between the same LULC classes are not included.	main LC1	-117.76–139.41; -6.58±32.17
Landscape level	ED_C2	The rate of change in the density of the borders between detailed LULC classes (km/year*100). Borders between identical detailed LULC classes are not included.	fine LC2	-150.31–139.41; -9.28±36.12
Landscape level	EDv	The rate of change in the density of the borders between detailed LULC classes (km/year*100). This variable is based on the original vectorised layer capturing narrow line boundaries (such as narrow grass stripes/baulks between fields). Unlike the previous two ED variables, EDv reflects rather the development of the cropland texture than the overall length of the ecotones between various LULC classes	fine LC2	-232.45–91.92; -18.24±43.68
Landscape level	SHDI_C1	The rate of change in heterogeneity (Shannon diversity index) of the main LULC classes (SHDI/year*100).	main LC1	-2.87–2.90; 0.01±0.72
Landscape level	SHDI_C2	The rate of change in heterogeneity (Shannon diversity index) of the detailed LULC classes (SHDI/year*100).	fine LC2	-3.85–2.67; -0.16±0.95
		Predictors		Values
Predictors	NEIGHBOR	Political regime in the neighbouring state		Communist; Democratic
Predictors	REGIME	Political regime in the territory of the present day Czechia		Communist (1953–1988); Democratic (1989–2012)
Predictors	GROWING REGION (GR)	Typology of biophysical environment based on precipitation, altitude and soil type		Highlands; Mountains

4.5 Summary of the methodical approaches in the individual parts of the thesis

Table 8 sums up the principal methodical elements of the individual parts of the thesis. The relationship between the growing spatial extent and decreasing temporal extent is obvious. This fact is implied by the individual research designs of Parts I-III where the macro scale level requires harmonised data on an international level. Where a single state is concerned (Parts II and III), aerial imagery in combination with old maps represented relatively easily available sources within a single state or administration that were also well harmonised where the data standard is concerned. From the perspective of research units, the sampling plots reflect the spatial scale, i.e., the sampling plots in Part I (with the biggest spatial extent) also contains the biggest sampling plots. Methodologically, the difference can only be found between the first two parts of the thesis (Part I and II) and the third one (Part III). In the first two parts, a robust statistical analysis was employed, in case of a detailed focus of an individual cadastral unit (Part III), this was supplemented by a description based on a detailed case study of a relevant cadastre.

Table 8: Summary of methods in the individual parts of the thesis

	part	spatial scale	temporal scale	researched unit	primary method	LULC data source	LULC data manipulation
Iron Curtain	I	macro	1990 - 2012	10 x 10 km plot	statistical	CLC / imagery	raw data
Czechia	II	meso	1953 - 2012	1 x 1 km plot	statistical	aerial imagery	interpretation
Zubrnice	III	micro	1843 - 2013	cadastral unit	descriptive	combination	interpretation

5 Results

5.1 Results of the macro/meso scale study (case study of the former Iron Curtain)

The differences in the dynamics of individual processes (e.g. Afforestation) on both sides of the border for individual periods will be presented in the first part of the Results. The findings will be illustrated and documented by graphs and transition charts presenting in detail the individual LULC classes participating in the differences to the highest degree. This part will be followed by detailing regional differences, i.e., differences between the individual segments of the border.

5.1.1 The evaluation of the effect of the BORDER and TIME variables on the entire area

If looking at the entire study area, differences between the individual studied periods were detected almost in all processes (Table 9). The individual processes characterise the grouped LULC classes (see Fig. 10) that underwent changes or remained unchanged over the individual periods. For clarifying the situation before the analysis of the dynamics (i.e., of increasing or decline in the areas of individual classes), the comparability of the initial situation in 1990 was assessed (to allow subsequent evaluation of the trajectory of the processes). In other words, I analysed whether or not there were significant differences in the areas (e.g. of the arable land)

Table 9: Evaluation of the principal differences between the investigated periods and the Western and Eastern parts of the border

	TIME (1990 - 2000 and 2000 - 2012)	BORDER (East and West)	TIME*BORDER (interaction)
Afforestation	**	****	n.s.
Agricultural internal conversion	n.s.	n.s.	*
Deforestation	***	n.s.	n.s.
Deurbanisation	*****	n.s.	n.s.
Urbanization	*	**	n.s.

Asterisks express the significance levels as follows: *p < 0.05; **p < 0.01; ***p < 0.001; ***p < 0.0001; *****p < 0.00001; note: all results have to be significant in both Wald test and ANOVA-type statistics (ats) to be considered significantly different.

between the two sides of the border. From the perspective of sampling areas along the entire border, the proportions of LULC classes did not differ significantly between the two sides of the border (compared using the pairwise proportion test, R Core Team, 2019); the only exception was the category of shrubs (which includes transitional forest development stages and shrubby formations with sparse trees), the representation of which was greater in the East (W – 1.51 %; E – 3.9 % of the total area on the Eastern or Western sides of the border, respectively).

Differences in the processes between the East and the West (Table 9 column BORDER) were only observed in Afforestation and Urbanization. In case of the Agricultural internal conversion, a significant effect was found only for the interaction between the period (TIME) and sides of the border (BORDER).

The afforestation dynamics, i.e., the increase of the areas of the LULC class identified as forest, was significantly different if comparing the East and the West. Here, the dynamics was much more apparent on the Eastern part of the border and in the second studied period (Fig. 12 a,b). A higher afforestation rate in the East is in particular due to a conversion from shrubs (Fig. 13), to a smaller degree from heterogeneous agriculture and arable land. A similar transition was not apparent in the West in the first period when the forest areas were solely increasing at the expense of shrubs. In the second period, the afforestation dynamics had similar patterns as in the East. As far as the total converted area is concerned, the dominant transition process was Agricultural internal conversion. Fig. 12 c showed that the dynamics of the Eastern part of the borders was relatively stable in both periods while in the West, a significant increase in the dynamics can be observed in the second period. In a more detailed assessment, the process of internal agricultural conversion was consistent on the Eastern side of the border throughout the periods, namely due to the change of arable land into pastures. In the West, the situation was more diverse. In both periods, the pattern was similar, namely a conversion from heterogeneous agriculture into pastures and arable land; in the second period, a transfer of arable land into pastures was an additional trend. The total values for the process of the agricultural internal conversion were caused by a higher rate of change (15%) in the West (see Fig. 13). As far as the deforestation is concerned (Fig. 12 d) a significant change was only found between periods – a higher rate of deforestation was seen in the second period. This process was to the greatest degree

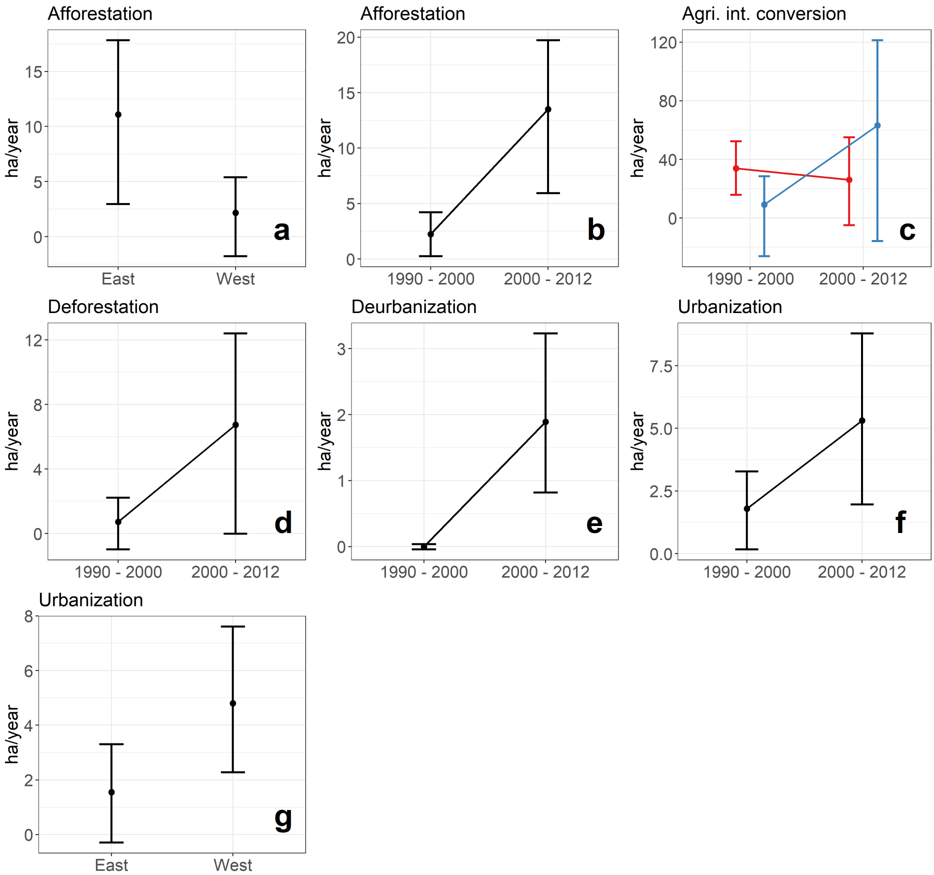


Fig. 12: Significant differences of the process dynamics for the entire Iron Curtain border. c) red – EAST, blue – WEST. Note: Median values with 95 % confidence interval for median based on bootstrap method (normal method, R=10 000).

caused by the losses in favour of shrubs (Fig. 13), which is not surprising from the viewpoint of the forest life cycle in forestry management. In the second period, however, we can observe conversion of forests into arable land and pastures on both sides of the border.Deurbanisation and urbanisation processes, i.e., the conversion to or from urban areas (including industrial use, etc.), were marginal in the area of interest. A gradual increase in dynamics of both losses and increases of the urban areas can be, however, observed in the second period (Fig. 12 e, Fig. 12 f) and a significantly higher urbanisation rate was detected in the West (Fig. 12 g). An increase in deurbanisation processes in the second period can be attributed to the transition to arable land and pastures on both sides of the border. The opposite process, urbanisation, was more pronounced in the West and it was in particular at the expense of arable land.

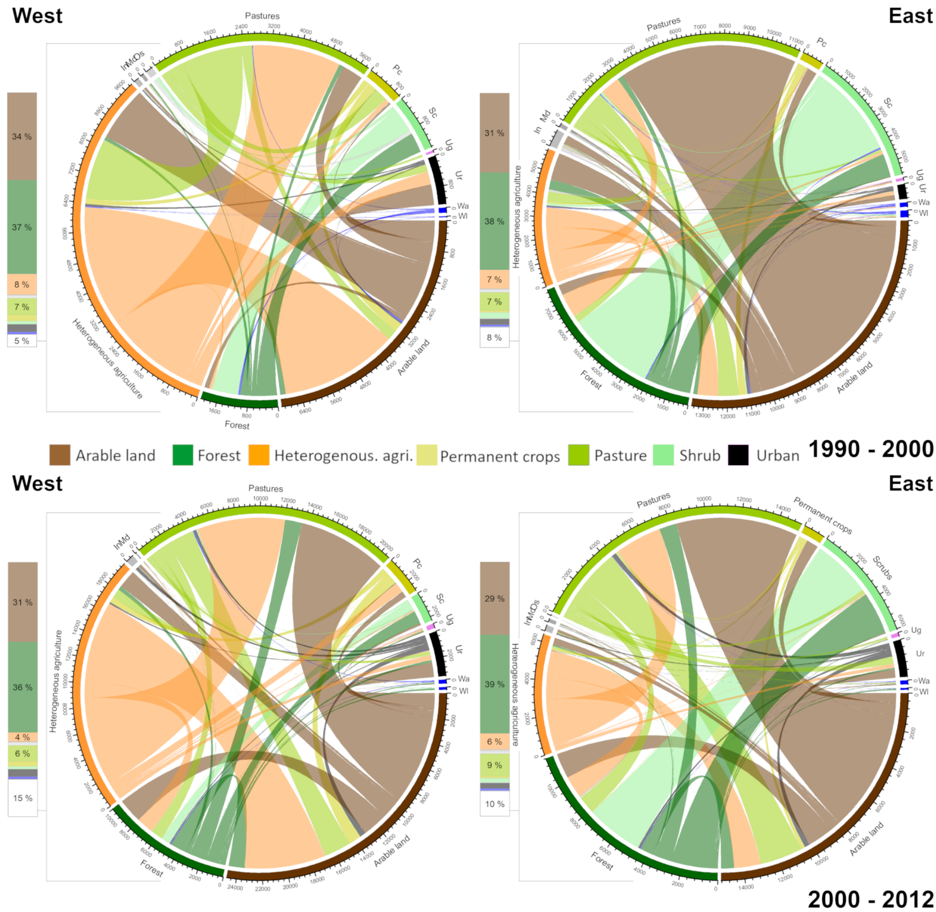


Fig. 13: Transition scheme for LULC classes at the general level for both sides of the border (East, West) and both time periods (1990-2000, 2000-2012). Circles represent the area under transition (indicated in the bar to the left of the circular graph; for example, the circular graph for West 1990-2000 presents only 5 % of the entire area as only 5 % underwent transition). Each colour of the perimeter represents a particular LULC class. Inner bands represent the part of the LULC class transitioning to another LULC class (to a different perimeter colour

5.1.2 Evaluation of the influence of the BORDER and TIME variables on the individual REGIONs of the border

Besides the evaluation of the overall dynamics along the entire Iron Curtain, the identification of differences between individual segments of the border is another important output. A different representation of individual processes is expected, depending on the different administrative (political) specifics. For clarity, the testing was performed independently for individual periods and the REGION and BORDER variables.

In the first period (Table 10), differences between individual regions were identified for all processes but afforestation where only the Wald test was significant but the other test (ATS) was not. It can be therefore concluded that for individual border segments (without distinguishing between the West and East), differences exist for almost all of the processes. From the perspective of this study, an even more important question is whether there is an interaction between factors, i.e., whether or not the interaction of the border segment and its attribution to the East/West (REGION*BORDER) affected the results. For the first studied period, such interaction was detected for all processes except for Urbanisation and Deurbanisation.

In the second period (Table 11), significant differences between individual border segments for all studied processes were observed. Unlike in the first studied period, a difference was also observed for the afforestation dynamics. A more detailed analysis for individual regions (segments of the Iron Curtain) and the side of the border revealed significant differences for all processes except for afforestation, which was

Table 10: Differences in the dynamics of processes in the individual regions (segments of the Iron Curtain, e.g. Czechia - Austria) and the East-West classification in the first period (1990 – 2000)

1990 - 2000	REGION (e.g. Czechia-Autria)	BORDER (East and West)	REGION*BORDER (interaction)
Afforestation	ats n.s.	*****	*****
Agricultural internal conversion	****	n.s.	****
Deforestation	****	n.s.	*****
Deurbanisation	*****	n.s.	n.s.
Urbanisation	***	n.s.	n.s.

Asterisks express the significance levels as follows: *p < 0.05; **p < 0.01; ***p < 0.001; ***p < 0.0001; *****p < 0.00001; note: all results have to be significant in both Wald test and ANOVA-type statistics (ats) to be considered significantly different.

Table 11: Differences in the process dynamics in the individual regions (segments of the Iron Curtain, e.g. Czechia - Austria) and the East-West classification in the second period (2000 - 2012)

2010 - 2012	REGION (e.g. Czechia-Austria)	BORDER (East and West)	REGION*BORDER (interaction)
Afforestation	*****	n.s.	ats n.s.
Agricultural internal conversion	*****	***	*****
Deforestation	*****	n.s.	**
Deurbanisation	*****	*****	*****
Urbanisation	*****	*****	*****

Asterisks express the significance levels as follows: *p < 0.05; **p < 0.01; ***p < 0.001; ***p < 0.0001; *****p < 0.00001; note: all results have to be significant in both Wald test and ANOVA-type statistics (ats) to be considered significantly different.

only significant in the Wald statistics. In the second period, unlike in the first one, differences in the urbanisation/deurbanisation were also revealed. These results of the interaction of the border segment and Eastern/Western part of the border will be subsequently utilised as an initial rough metrics for a more detailed evaluation of the results in the individual segments of the border.

5.1.3 A detailed comparison of the results in the individual border segments

The Iron Curtain passed through several countries with various environmental conditions and various developments after 1989. For this reason, it is necessary to analyse the results separately for individual regions (segments of the Iron Curtain). Fig. 14 shows the rate of dynamics for individual segments. It demonstrates the low volume of changes in the Slovenian part of the border compared to the other segments. It also shows a relative similarity in the volume of changes in the Hungarian-Slovakian and German segments. The development of the East-West comparison however differs a lot between those two segments.

Table 12 and Fig. 15 present results of the dynamics of individual processes for the first period. I found significant differences for the individual border segments when comparing their Eastern and Western part for all processes apart from deurbanisation. The most significant differences

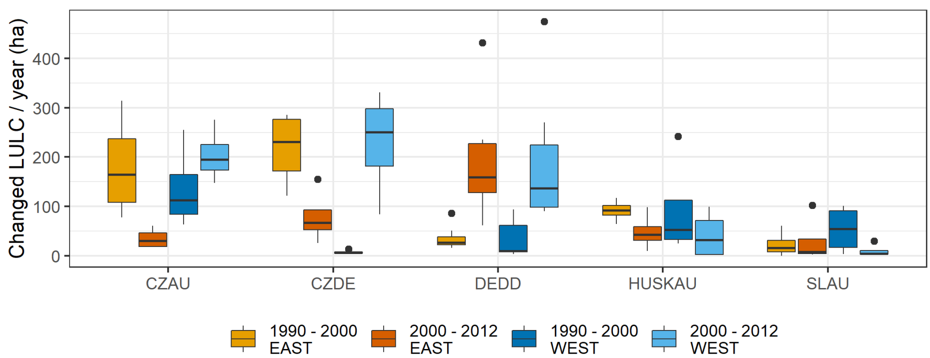


Fig. 14: Comparison of the rate of changes (hectare change per year) between individual segments of the Iron Curtain; note: SLAU – Slovenia-Austria; HUSKAU – Hungary/Slovakia-Austria; DEDD – West-East Germany; CZDE – Czechia-Germany; CZAU – Czechia-Austria; SLAU – Slovenia-Austria. Black dots indicate the presence of outlying values (sampling plots with significantly higher changed areas, more than 1.5 * IQR). The boxplot shows the median, Q1 and Q3. Whiskers represent 1.5 * IQR.

were recorded for the afforestation dynamics, which was, compared to the Western part, higher in three out of five segments in the East (all but the West-East German and Slovenian-Austrian) parts of the border. The volume of dynamics of Agricultural internal conversion significantly differed between the sides of the border only for the Czech-German and West-East German parts of the border. The deforestation dynamics was also higher on the Eastern side of the Czech-German border when compared to the Western side. The opposite trend, i.e., a higher dynamics in the West, was observed for the Slovenian border. The last process was urbanisation, the dynamics of which was generally higher in the Czech-Austrian segment of the borders than in the others with a higher rate of changes observed in the West.

No significant REGION*BORDER interaction (the segment of the Iron Curtain vs. East/West) was detected for the afforestation dynamics (Table 13; Fig. 16), the detailed scale therefore indicates more or less an equalisation of the results in the individual border regions between the

Table 12: Differences in the dynamics of the processes in the individual regions (Iron Curtain segments, e.g. Czechia - Austria) – Iron Curtain segments in the first period (1990 – 2000)

1990 - 2000	CZAU	SLAU	HUSKAU	DEDD	CZDE
Afforestation	*****	n.s.	*	n.s.	*****
Agricultural internal conversion	n.s.	n.s.	n.s.	*	*****
Deforestation	n.s.	*	n.s.	n.s.	*****
Deurbanisation	n.s.	n.s.	n.s.	n.s.	n.s.
Urbanisation	n.s.	n.s.	n.s.	n.s.	n.s.

Asterisks express the significance levels as follows: *p < 0.05; **p < 0.01; ***p < 0.001; ***p < 0.0001; *****p < 0.00001; note: all results have to be significant in both Wald test and ANOVA-type statistics (ats) to be considered significantly different.

Table 13: Differences in the dynamics of the processes in the individual regions (Iron Curtain segments, e.g. Czechia - Austria) – Iron Curtain segments and East/West classification for the second period (2000 – 2012)

2000 - 2012	CZAU	SLAU	HUSKAU	DEDD	CZDE
Afforestation	n.s.	n.s.	*****	n.s.	n.s.
Agricultural internal conversion	*****	n.s.	n.s.	n.s.	***
Deforestation	**	n.s.	n.s.	n.s.	*
Deurbanisation	*****	*****	***	n.s.	*****
Urbanization	*	n.s.	n.s.	n.s.	*****

Asterisks express the significance levels as follows: *p < 0.05; **p < 0.01; ***p < 0.001; ***p < 0.0001; *****p < 0.00001; note: all results have to be significant in both Wald test and ANOVA-type statistics (ats) to be considered significantly different.

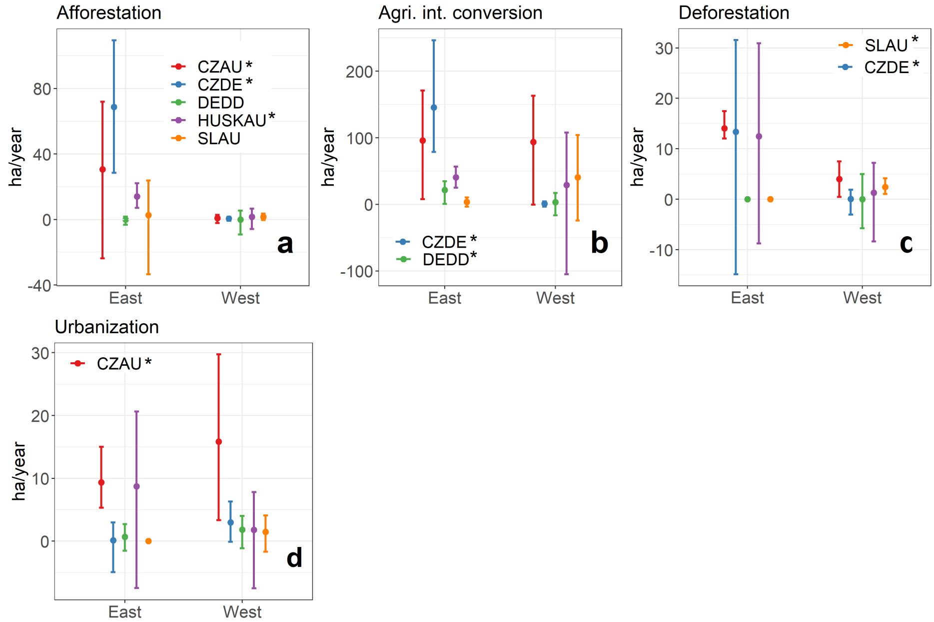


Fig. 15: Comparison of the rate of changes between individual segments of the Iron Curtain – the segments in the first period (1990 – 2000); Note: Median values with 95 % confidence interval are based on the bootstrap method (normal method, R=10 000); Asterisks indicate significant differences between the East and West (significance of results based on Table 12).

East and the West. The only different part was the Slovakian/Hungarian-Austrian part where a higher afforestation dynamics could be observed in the East. The opposite trend, deforestation, differed significantly between Eastern and Western side of the border for both regions of the Czech border. In both, we can see a lower deforestation rate in the East than in the West. Surprising results were revealed by analysing the Agricultural internal conversion. In the second period, the East-West sides of the Czech-Austrian and Czech-German borders differed in this aspect. In both regions, the decrease of the dynamics in the East and its increase in the West were apparent (Fig. 16 b). In the second period, differences were also detected in the border segments as far as the deurbanisation processes were concerned. A higher dynamics can be observed in the Western part at the Czech borders (both "Czech" segments) than in the East. On the other hand, this process was somewhat more intensive on the Eastern side of the border (albeit to a minor extent) in the Hungarian-Slovakian segment of the border. The opposite – the increase in urban and urban-like areas – was recorded on the Western side of the border in both "Czech" segments of the Iron Curtain.

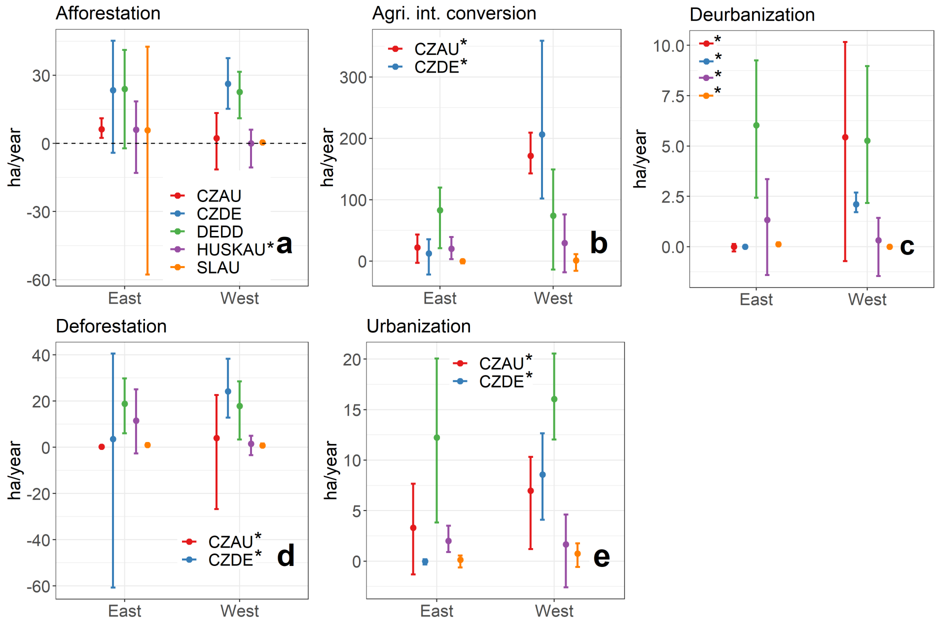


Fig. 16: Comparison of the rate of changes between individual segments of the Iron Curtain in the second period (1990 – 2000); Note: Median values with 95 % confidence interval are based on the bootstrap method (normal method, R=10 000); Asterisks indicate significant differences between the East and West (significance of results based on Table 13).

5.1.4 Detailed comparison of the results on the borders of the former East and West Germany (DEDD)

As the previous Chapter indicates, the differences in the transition processes between the former West and East Germany are not too big. We can practically only discuss the changes in the Agricultural internal conversion in the first period. These changes, or rather their similarity in the second period, are demonstrated by Fig. 17. The graph indicates a similar pattern of the changes and an almost ten times increase in the volume of changes in the second period.

The first period, poorer as far as the rate of changes is concerned, indicates notable differences in the utilisation of the agricultural land. First, in the East, a two-way conversion between arable land and pastures (almost non-existent in the West), can be observed. From the perspective of the agriculture, a notable drop in the arable land areas is apparent in the West (and, to a lesser degree, in the East). The second period indicates a strong increase in the volume of changes (Fig. 14). For this period, a generally higher volume of changes in most sampling plots can be observed, in particular due to the increase in the area of pastures; the data

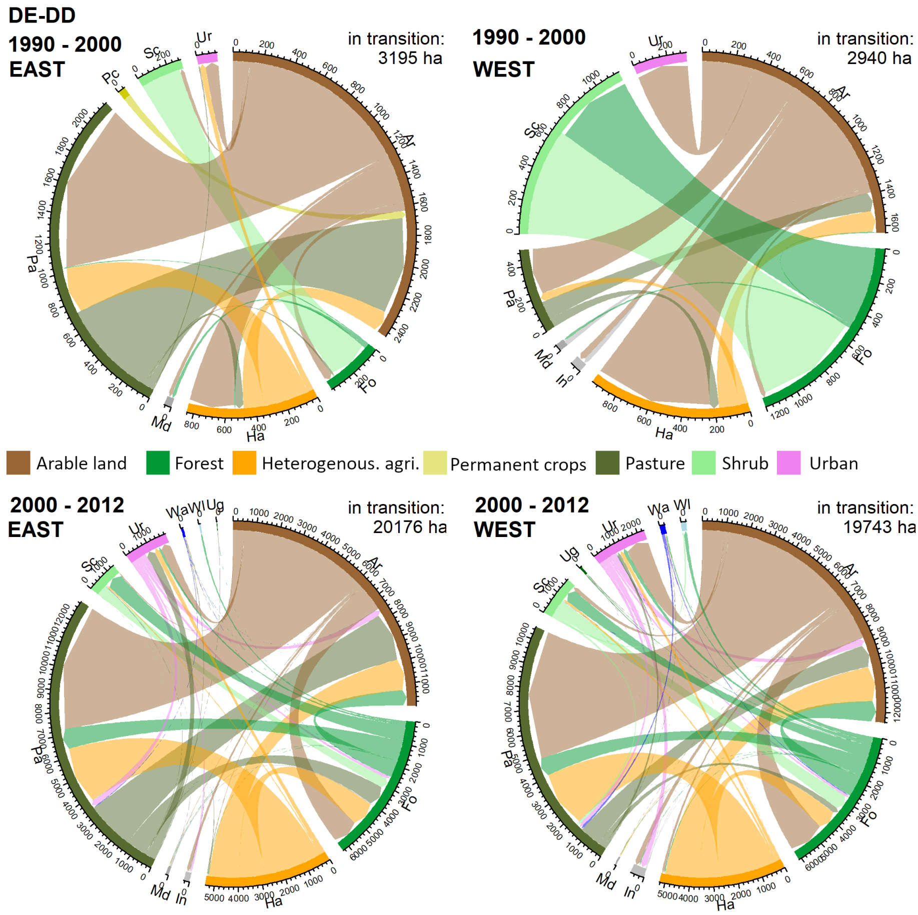


Fig. 17: Transition scheme for LULC classes for the former East Germany-West Germany region on both sides of the border (East, West) and both time periods (1990-2000, 2000-2012). Circles represent area under transition. The colour of the perimeter represents a particular LULC class. Inner bands represent the portion of the LULC class transitioning to another LULC class (to a different perimeter colour e.g. a brown band from a brown perimeter to a pink one means the volume of the arable land to urbanised area transition). Ar – Arable land; Fo – Forest; Ha – Heterogeneous agriculture; In – Industrial; Md – Mine, dump; Pa – Pastures; Sc - Shrub; Pc – Permanent crops; Ur – Urban, Wl – Wetland; Wa – Water.

are however affected by an outlier represented by a sampling site on the borders of Schleswig-Holstein and Mecklenburg where a conversion of a large area (West = 51 %, East = 46 % of the particular sampling site), predominantly from the arable land to pastures, occurred. This sampling site is responsible for 25 % of all changes in the East Germany-West Germany segment in the second period.

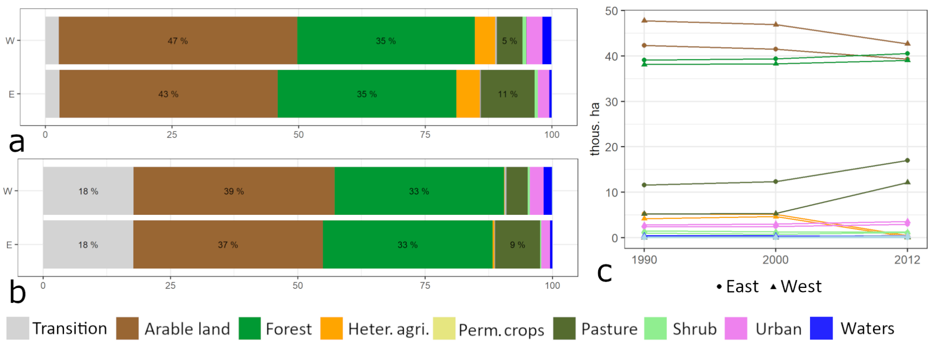


Fig. 18: The evolution of the LULC categories in the East Germany – West Germany part of the border a) the rate of the permanent LULC types and the rate of changes at the borders between 1990 – 2000, b) 2000 – 2012, c) evolution of individual LULC categories.

The comparison of the permanent LULC types (Fig. 18) and of the rate of the transformed LULC types provided three basic results: (i) the Eastern parts in general had a higher rate of pastures serving as a reserve for conversion into the arable land, (ii) this reserve was lower in the West and was to some degree compensated by heterogeneous agriculture, (iii) over the course of the entire studied period, the category of heterogeneous agriculture practically disappeared, (iv) the trajectory (Fig. 18 c) of individual LULC categories in the West and East are very similar and can be characterised as gradual abandonment of arable land and of heterogeneous agriculture in favour of pastures.

5.1.5 Detailed comparison of the results from the Czech - German borders (CZDE)

A more detailed look at the Czech-(West)German part of the border reveals marked differences between the first and second periods. The agricultural internal conversion and deforestation are the only processes for which differences between the Eastern and Western sides of the border were observed across both periods. In the first period, we observe notable differences in the dynamics of afforestation and in the second, differences in urbanisation and deurbanisation between both sides of the border. The total volume of changes in the Western part of the borders steeply grew in the second period while on the Czech side, the trend was opposite (i.e., a higher total extent of changes in the first period and a lower in the second).

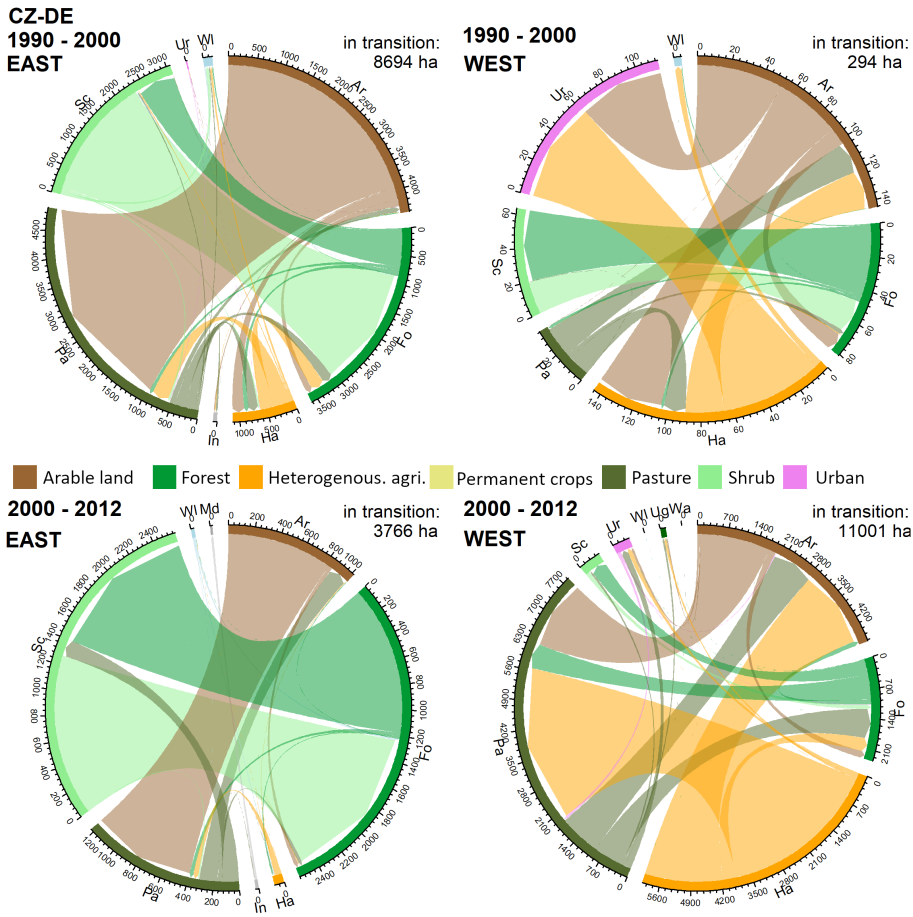


Fig. 19: Transition scheme for LULC classes for the former Czech - German region on both sides of the border (East, West) and both time periods (1990-2000, 2000-2012). Circles represent area under transition. The colour of the perimeter represents a particular LULC class. Inner bands represent the portion of the LULC class transitioning to another LULC class (to a different perimeter colour e.g. a brown band from a brown perimeter to a pink one means the volume of the arable land to urbanised area transition). Ar – Arable land; Fo – Forest; Ha – Heterogeneous agriculture; In – Industrial; Md – Mine, dump; Pa – Pastures; Sc - Shrub; Pc – Permanent crops; Ur – Urban, Wl – Wetland; Wa – Water.

The higher afforestation rate in the East over the course of both periods (Fig. 19) was caused by a higher degree of conversion from shrubs to forests. This process was also apparent on the Western side but in the first period, the volume was negligible (300 ha in the West vs almost 9,000 ha in the East). In the second period, no differences were observed in afforestation but there was a significant difference in deforestation. The process of deforestation differed between both sides of the border – the

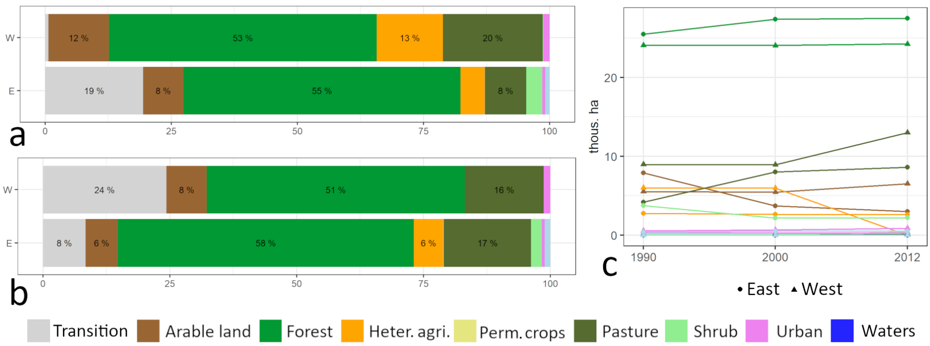


Fig. 20: The evolution of the LULC categories in the Czech - German part of the border a) the rate of the permanent LULC types and the rate of changes at the borders between 1990 – 2000, b) 2000 – 2012, c) evolution of individual LULC categories.

deforestation in the favour of shrubs continued in the East in the second period; in the West, it was in favour of shrubs and pastures. As far as the overall representation of forest areas is concerned, however, it was relatively stable on both sides of the border across time (Fig. 20).

As far as the agricultural conversion is concerned, decrease in the arable land was observed in the East across both periods, which is also apparent from the total area of the persisting arable land (Fig. 20). The differences in the structure of the transition of this LULC class can be rather observed in the dominant transition of the arable land to pastures in the East. In the West, this trend set in only in the second period and was complemented with the trend of abandonment of heterogeneous agriculture in favour of arable land and pastures. This resulted practically in dissolution of the heterogeneous agriculture in the second period (similar to the observation along the borders between the former East and West Germany). The last processes showing differences in this segment of the Iron Curtain are urbanisation and deurbanisation. The differences in the rate of these processes are however predominantly caused by the lack of urbanised areas in the East. In the West, the increase of the urban areas is predominantly observed (only urban, not other subtypes such as mining, industry, etc., in particular at the expense of pastures and heterogeneous agriculture.

5.1.6 Detailed comparison of the results on the Czech-Austrian border (CZAU)

In the first period, the Czech-Austrian border segment showed differences between the East and West in the higher dynamics of afforestation (higher in the East) and urbanisation (higher in the West). The second period differed for all processes with the exception of afforestation dynamics in this segment; in general, the volume of the transition processes was higher in the West.

In the first period, a higher rate of afforestation is observed in the East, caused in particular by the conversion of shrubs into forests (Fig. 21). The same cannot be observed on the Western side of the border; on the Western part of the border, a stable amount of forests in the sense of minimum conversion of forest stands was found (Fig. 22). The urbanisation rate in the West was higher than in the East, the total area in transition on both sides of the border was nevertheless very low. The urbanisation in the West was especially at the expense of agricultural areas (heterogeneous agriculture, arable land and pastures). The overall quantity of changes in agriculture was similar on both sides of the border, although they differed in quality. In the East, the transition from arable land to pastures was dominant while in the West, it was the transition of heterogeneous agriculture into pastures and arable land.

In the second period, the highest volume of changes related to the internal agricultural conversion (Fig. 21). In the West, the trends were similar to those in the previous period (but with almost twice as high volume of changes). The transition of the heterogeneous agriculture into the arable land and pastures was still dominant – in this period, the transition was also into permanent crops. The opposite direction of internal agricultural conversion can be to a smaller extent also observed. Contrary to the West, the total volume of changes in the East grew smaller in the second period. The main conversion process between classes of agricultural use was still from arable land to pastures and permanent crops.

The deforestation dynamics also differed between both sides of the border. The Eastern part can be considered stable or negligibly growing as far as the area of forests is concerned while in the West, a decrease in the forest area is observed, in particular in favour of heterogeneous agriculture and arable land (Fig. 21). Other significantly different processes – urbanisation and deurbanisation – are only minor as far as the

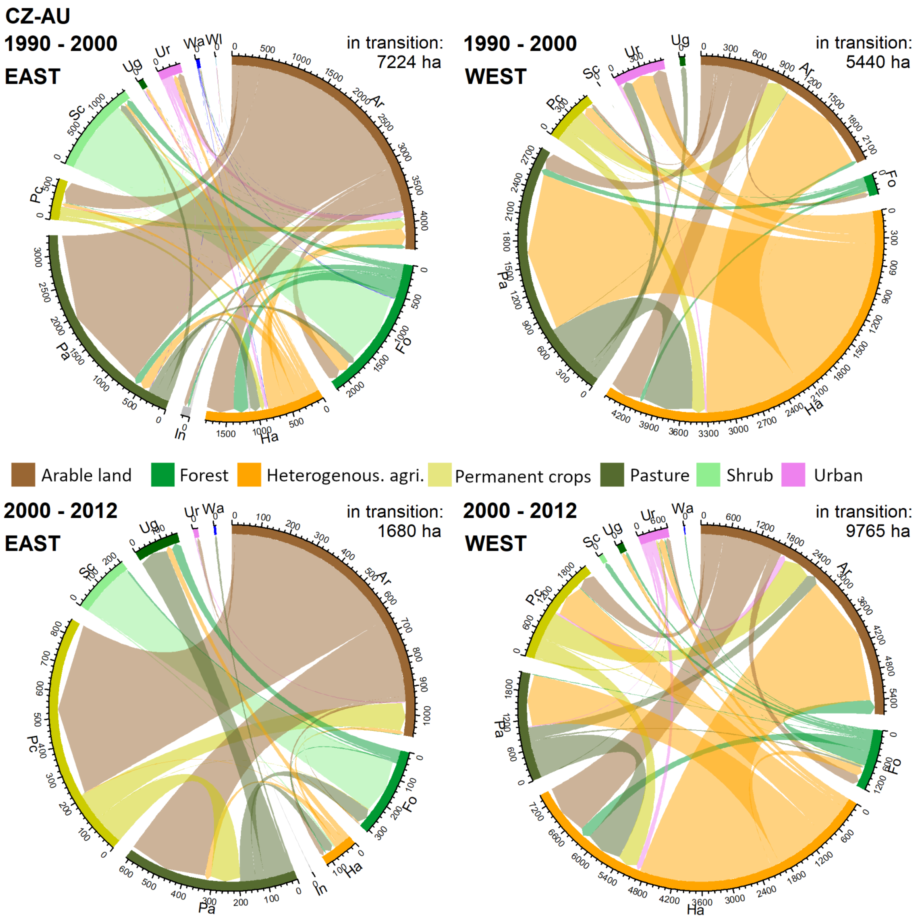


Fig. 21: Transition scheme for LULC classes for the Czech - Austrian region on both sides of the border (East, West) and both time periods (1990-2000, 2000-2012). Circles represent area under transition. The colour of the perimeter represents a particular LULC class. Inner bands represent the portion of the LULC class transitioning to another LULC class (to a different perimeter colour e.g. a brown band from a brown perimeter to a pink one means the volume of the arable land to urbanised area transition). Ar – Arable land; Fo – Forest; Ha – Heterogeneous agriculture; In – Industrial; Md – Mine, dump; Pa – Pastures; Sc - Shrub; Pc – Permanent crops; Ur – Urban, Wl – Wetland; Wa – Water.

total extent is concerned. The trend from the first period, i.e., new urban areas growing at the expense of heterogeneous agriculture and of arable land, however continues in the West. Besides this process, the opposite trend (of approximately the same extent), i.e., conversion of urban areas back into the heterogeneous agriculture, pastures and arable land, can be observed.

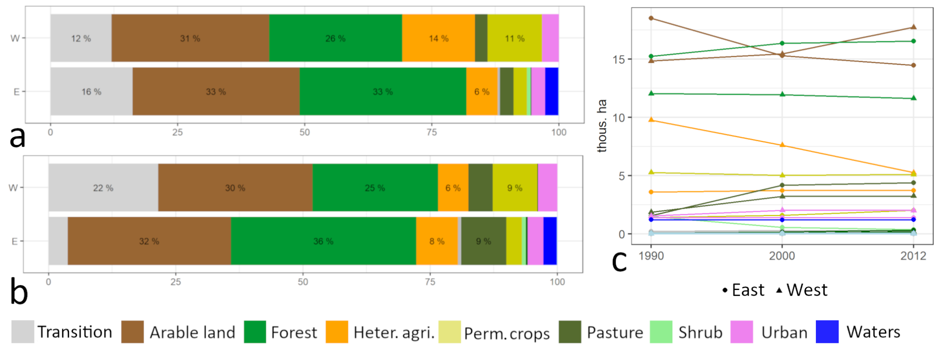


Fig. 22: The evolution of the LULC categories in the Czech - Austrian part of the border a) the rate of the permanent LULC types and the rate of changes at the borders between 1990 – 2000, b) 2000 – 2012, c) evolution of individual LULC categories.

5.1.7 A detailed comparison of the results on the borders of Slovakia and Hungary – Austria (HUSKAU)

For the Slovak/Hungarian-Austrian segment of the borders, differences in the afforestation volume was observed in both periods, in the second period also in the volume of deurbanisation. The general structure of the transition of forests (Fig. 23) depends on the higher representation of the forest areas in the East (Fig. 24).

As mentioned before, the afforestation dynamics is higher in the Eastern part of the border. For both periods, there is however a similar transition pattern in the East. Forests are predominantly formed from shrubs, similar to other segments (e.g. the Czech segments), followed by arable land and to a lesser extent from the heterogeneous agriculture. This fact, i.e., the conversion of shrubs into forests in the East, is predominantly given by the higher representation of this LULC type in the East (it is almost non-existent in the West)

Besides the afforestation dynamics, differences in the volume of deurbanisation processes have also been detected (again, the total volumes are low, hectares per year). This low volume makes then the percentage differences between the East and West more pronounced. The values are somewhat higher in the East, in particular due to the categories Mine and Dump, transformed into new water surfaces. The transition of the urbanised areas into the arable land is similar in the second period for both sides of the border.

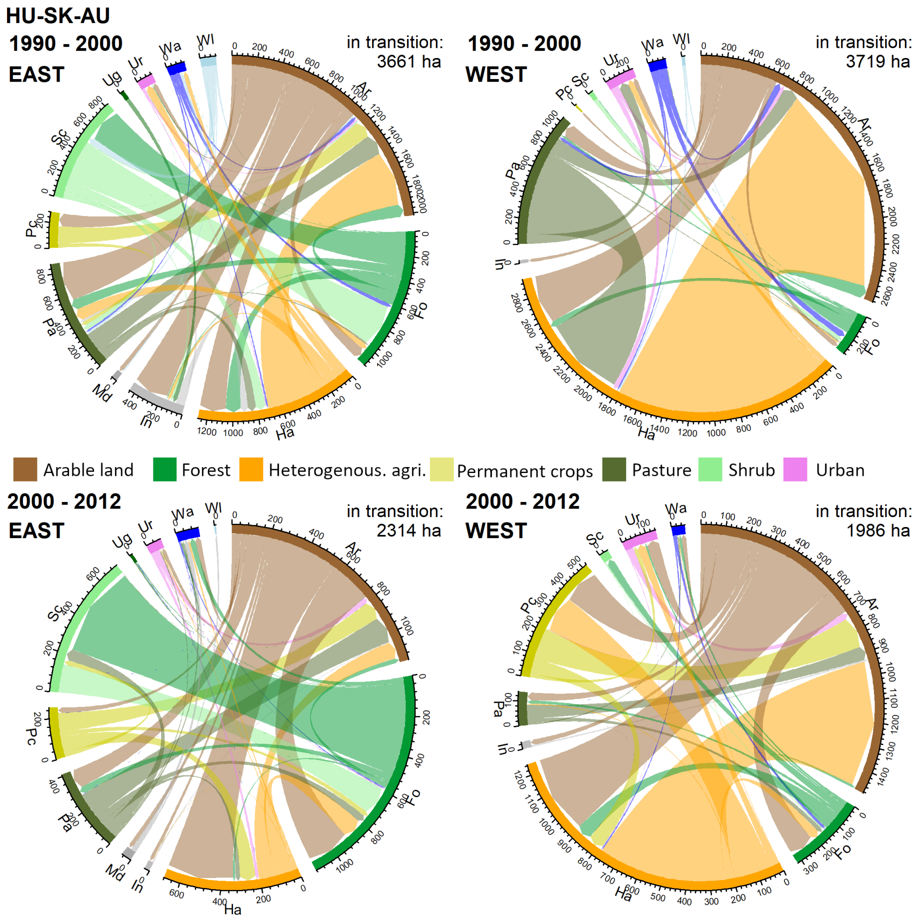


Fig. 23: Transition scheme for LULC classes for the Slovak/Hungarian - Austrian region on both sides of the border (East, West) and both time periods (1990-2000, 2000-2012). Circles represent area under transition. The colour of the perimeter represents a particular LULC class. Inner bands represent the portion of the LULC class transitioning to another LULC class (to a different perimeter colour e.g. a brown band from a brown perimeter to a pink one means the volume of the arable land to urbanised area transition). Ar – Arable land; Fo – Forest; Ha – Heterogeneous agriculture; In – Industrial; Md – Mine, dump; Pa – Pastures; Sc - Shrub; Pc – Permanent crops; Ur – Urban, Wl – Wetland; Wa – Water.

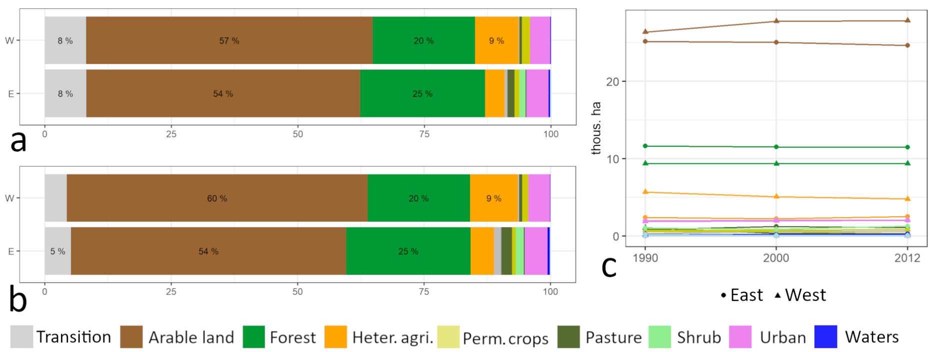


Fig. 24: The evolution of the LULC categories in the Slovak/Hungarian - Austrian part of the border a) the rate of the permanent LULC types and the rate of changes at the borders between 1990 – 2000, b) 2000 – 2012, c) evolution of individual LULC categories.

5.1.8 A detailed comparison of results on the borders of Slovenia and Austria (SLAU)

Slovenian-Austrian border, despite being comparable with other segments of the Iron Curtain as far as the number of sampling plots is concerned, shows the least amount of changes (two thousand ha at most; Fig. 25). Comparison of both sides of the border reveals a different dynamics as far as the deforestation processes in the first period and deurbanisation in the second are concerned.

The deforestation processes in the first period are mostly present in the West where (although a small total amount) of forests gave way to pastures, mines and dumps. In the East, this trend does not show and as far as the representation of individual LULC classes is concerned, the segment is more or less stable on both sides of the border (Fig. 26). The difference (at the level of tens of hectares) is caused by a transition from "others" areas into forest areas in the East.

The structural differences in the agricultural internal conversion and in the forest areas are quite interesting (although their volume does not differ between the East and West). In the first period, a two-way transition between heterogeneous agriculture and arable land was observed; in the West, it was only in favour of the arable land and a two-way exchange between heterogeneous agriculture and pastures. In the second period, the changes are much smaller in the West, the dominant transition is transition from permanent crops to arable land (but in all, it is only 300 ha). In the West, it was a transition from shrubs to forests.

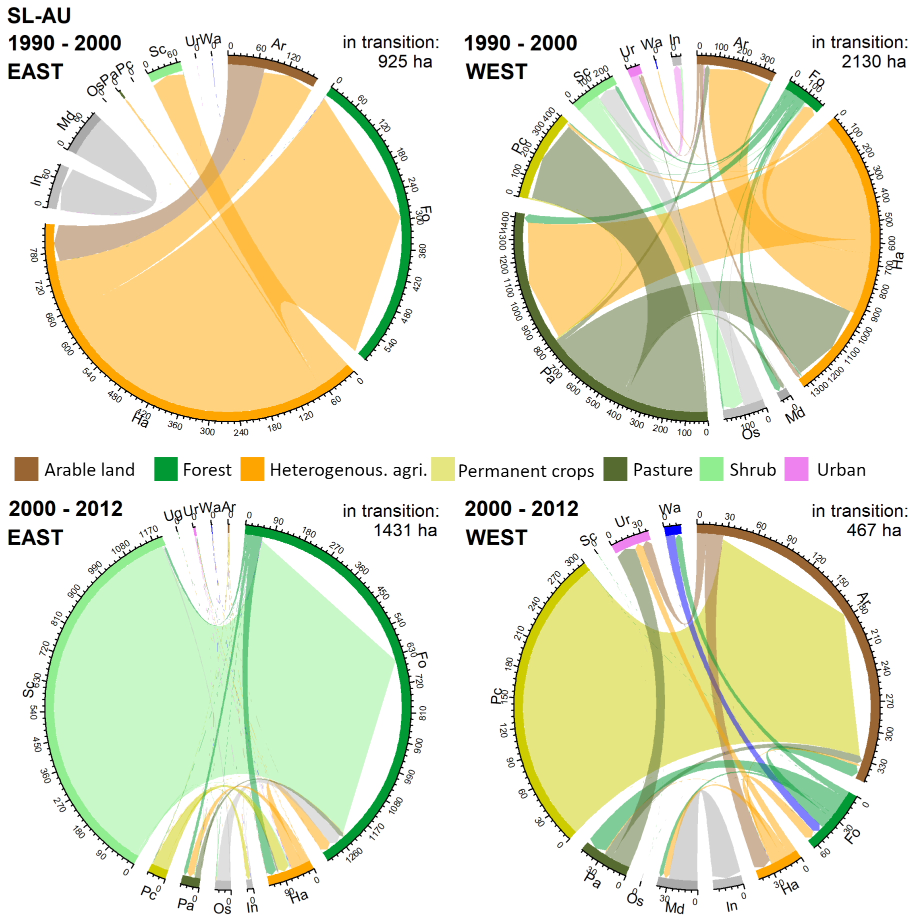


Fig. 25: Transition scheme for LULC classes for the Slovenian - Austrian region on both sides of the border (East, West) and both time periods (1990-2000, 2000-2012). Circles represent area under transition. The colour of the perimeter represents a particular LULC class. Inner bands represent the portion of the LULC class transitioning to another LULC class (to a different perimeter colour e.g. a brown band from a brown perimeter to a pink one means the volume of the arable land to urbanised area transition). Ar – Arable land; Fo – Forest; Ha – Heterogeneous agriculture; In – Industrial; Md – Mine, dump; Pa – Pastures; Sc - Shrub; Pc – Permanent crops; Ur – Urban, Wl – Wetland; Wa – Water.

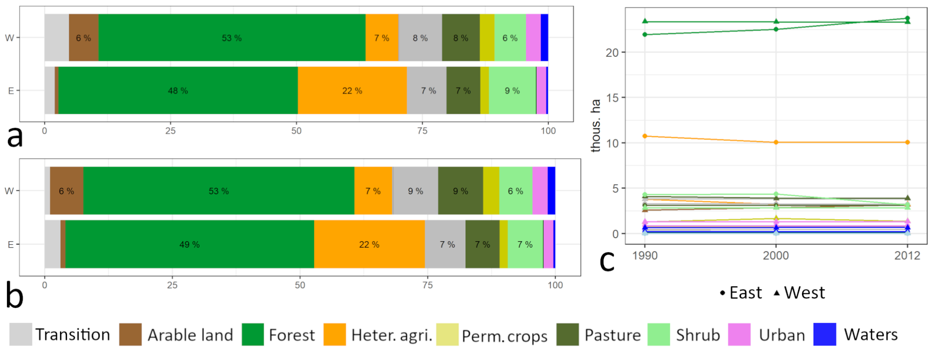


Fig. 26: The evolution of the LULC categories in the Slovenian - Austrian part of the border a) the rate of the permanent LULC types and the rate of changes at the borders between 1990 – 2000, b) 2000 – 2012, c) evolution of individual LULC categories.

5.2 Results of the meso-scale study (the case study of the Czech borderlands)

The change of the political regime (REGIME) in Czechia in 1989 significantly ($p < 0.05$) affected the dynamics of changes of all detailed LULC classes (thematic resolution LC2) as well as of changes in the LUCC structure heterogeneity along the Czech border (Table 14) with the exception of (a) the LULC patch border density expressed as Edge Density metric in all levels of thematic resolution and (b) forest LULC class. The factor describing the political regime in the neighbouring state at the times of imagery acquisitions (NEIGHBOR) affected substantially fewer response metrics (four class level and one landscape level metric) than the change of the political regime in Czechia.

The regime in the neighbouring state in combination with the regime in Czechia (NEIGHBOR*REGIME) affected the dynamics of changes just in the single heterogeneity metric in the detailed thematic resolution (SHDI LC2). The dynamics of two LC1 classes (forest and non-forest near-nature vegetation) was significantly affected by the growing region classification (GR). The interaction of the political regime in Czechia, regime in the neighbouring country and growing region (GR*REGIME, NEIGHBOR*GR, NEIGHBOR*GR*REGIME) influenced the dynamics of farmland and near-nature herbaceous vegetation, as well as the heterogeneity metric. In all, the change of the political regime in Czechia in 1989 affected (individually or in conjunction with other socio-economic or environmental factors) the rate of changes of almost all studied landscape metrics (Table 14). The changes of individual landscape characteristics and their driving forces are described below.

Table 14: The effect of predictors and their interactions on the rate of changes in the landscape metrics and particular LULC classes. Note: *n.s. – non significant.

	Main thematic resolution LC1	Detailed thematic resolution LC2	REGIME	NEIGHBOR	GROWING REGION (GR)	NEIGHBOR* REGIME	NEIGHBOR* GR	GR* REGIME	NEIGHBOR* GR* REGIME
Class level	Forests								
	FOREST		n.s.	**	*****	n.s.	n.s.	n.s.	n.s.
	Farmland								
	FARM		*****	n.s.	n.s.	n.s.	n.s.	*	n.s.
		CROP	**	n.s.	n.s.	n.s.	n.s.	**	n.s.
		GRASS	*****	**	n.s.	n.s.	n.s.	n.s.	n.s.
	Near-nature vegetation								
	NNVEG		*****	*	*	n.s.	n.s.	n.s.	n.s.
		WOOD	*	*	n.s.	n.s.	n.s.	n.s.	n.s.
		HERBS	**	n.s.	n.s.	n.s.	*	*	n.s.
Landscape level	Edge Density								
	ED_LC1		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		ED_LC2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Heterogeneity								
	SHDI_LC1		**	*	n.s.	n.s.	n.s.	n.s.	n.s.
		SHDI_LC2	*	n.s.	n.s.	*	n.s.	**	*

Asterisks express the significance levels as follows: *p < 0.05; **p < 0.01; ***p < 0.001; ***p < 0.0001; *****p < 0.00001.

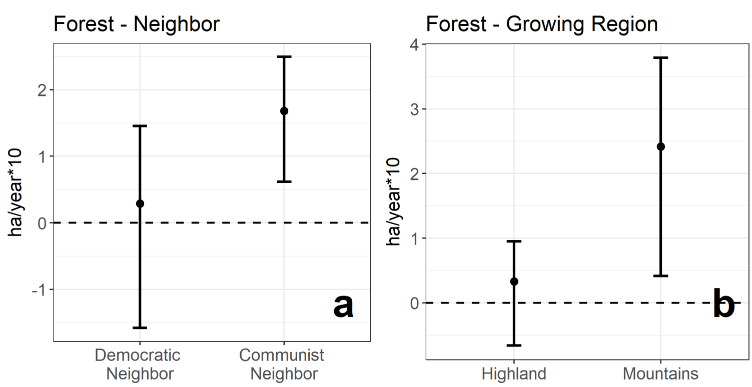


Fig. 27: The effect of socio-economic and environmental factors on the rate of change in the total area of forests (significant level only). The vertical axis shows the rate of increase (positive values) or decline (negative values) of the forested areas; the zero line indicates stable forestation. (a) The effect of the NEIGHBORing country regime, (b) Effect of the growing region typology on sampling sites. Note: Median values with 95 % confidence interval for median based on the bootstrap method (normal method, R=10000).

5.2.1 Forests

The dynamics of change in forested areas in the Czech borderlands was not affected by the change of the political regime in Czechia (REGIME) on itself but it was affected by the regime in the neighbouring state (NEIGHBOR, Fig. 27 a), as well as by the growing region (GR, Fig. 27 b). While the total area of forests increased at the borders with other communist states, a different behaviour of the forest class (lower but variable values) was observed in sampling sites located on the borders with the democratic states. The factor of growing region (Fig. 27 b) divided the sampling sites into higher located sampling sites (mountains) with clear increase in afforestation tendency and lower (highland) sites with an almost steady rate of change in forest class.

5.2.2 Farmland

The changes in the total area of farmland (main thematic resolution LC1) were affected by the political regime in Czechia (Fig. 28 a). The greatest decline of the farmland areas was recorded in the communist period. After the change of the regime in 1989, the rate of decrease of the farmland slowed down and the total area stabilised. In detail, we can observe differences in the trajectory of the farmland class between different growing regions under different political regimes in Czechia. We observed higher losses of farmland in higher located (mountain) sampling sites compared to lower situated (highland) sites during the communist regime (Fig. 28 b). The decreasing tendency in both growing types later (during the democratic period in Czechia) practically disappeared.

Cropland and agricultural grassland

Similarly to the farmland level, more detailed Cropland level shares the same factors (REGIME, GR*REGIME) that influence the rate of change of this particular class. In the communist period, the overall cropland area (Fig. 28 c), regardless of the growing region (Fig. 28 d), shows less variability (more stability), while the democratic period records marked losses of cropland areas in the mountain growing regions. In other words, the variability in the behaviour of cropland changes during the democratic period (Fig. 28 c) is driven by significant losses in higher mountain sampling plots.

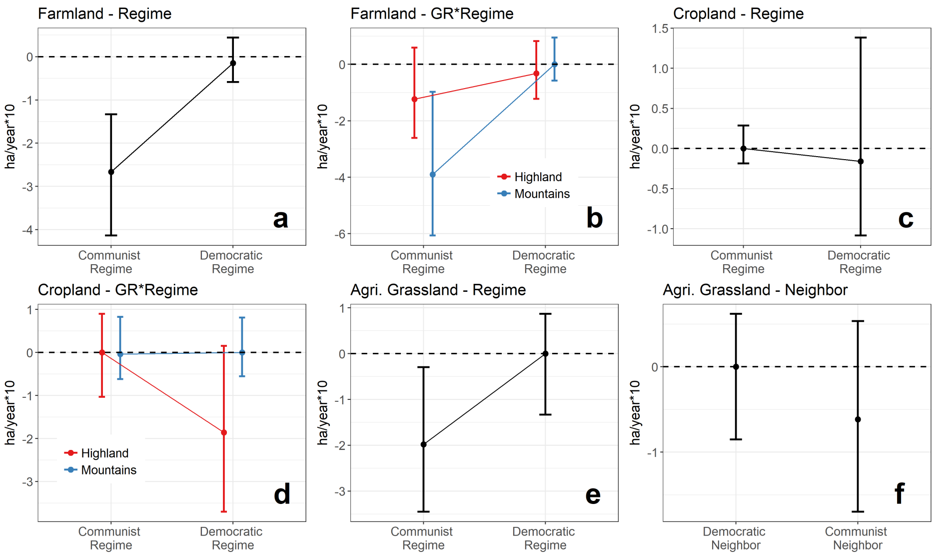


Fig. 28: The effect of socio-economic and environmental factors on the rate of change of the total area of farmland (significant level only). The vertical axis shows the rate of increase (positive values) or decline (negative values) of the farmland area; the zero line indicates no change of the farmland area. (a) The effect of the change of the political regime in Czechia on farmland at the main (LC1) thematic resolution, (b) effect of the interaction of the political regime in Czechia and biophysical factors (growing region, GR). (c–f) Detailed thematic resolution LC2. (c) Effect of the political regime in Czechia on cropland changes (d) Effect of the interaction of the political regime in Czechia with growing region on cropland changes (e) Effect of the political regime in Czechia on agricultural grassland change, and (f) Effect of the political regime in the neighbouring country on agricultural grassland. Note: Median values with 95 % confidence interval for median based on bootstrap method (normal method, R=10000).

The changes of the meadows and pastures area (GRASSLAND) were substantial both before and after the change of regime (REGIME), they however changed direction after 1989 (Fig. 28 e). While there was a significant drop in the area of meadows and pastures during the communist era, their representation grew since democracy was re-established. This reaction on the change of the political regime is not interacting with any other predictor and, hence, is the same all over the study area. Overall, there is a decrease in the total area of grassland in the sampling plots bordering with communist countries; this decrease however cannot be observed in the neighbourhood of former democratic countries where the area of the agricultural grassland is more or less stable (Fig. 28 f).

5.2.3 Non-forest near-nature vegetation

A significant effect of the change of the political regime in Czechia on the changes of the area of non-forest near-nature vegetation (NNVEG) category (encompassing both woody and herbaceous non-forest vegetation) implies a clear increase of the class representation during the communist era and loss in the democratic period. (Fig. 29 a). Although no interaction of variables for this main class is significant, differences were observed for the factors of the growing region (GR, Fig. 29 b) and political regime in the neighbouring country (NEIGHBOUR, Fig. 29 b). Comparing the behaviour of the NNVEG class, the sampling sites neighbouring on the democratic countries tended to increase the acreage of NNVEG. Conversely, a decrease of this category was found on the sites bordering with former communist states. Although the data were variable, a difference was found between highlands (increase) and mountains (decrease) of the NNVEG area.

Woody and herbaceous near-nature vegetation

A more detailed thematic resolution reveals that the political factors (two political regimes - REGIME, interaction of REGIME with GROWING REGION and NEIGHBOR with GROWING REGION) affected in particular the dynamics of non-agricultural herbaceous vegetation (HERBS). The variable dynamics of the total area for this particular class was slightly decreasing towards democratic period (Fig. 29 d) with marked differences (Fig. 29 f) between rather stable lower-situated sampling plots (highlands) and variable decrease in higher parts (mountains). The interaction of the neighbouring country regime with a growing region confirmed the difference in dynamics in highland sampling plots where the increase was associated with the democratic and decrease with the communist neighbouring country (Fig. 29 e). In the mountain growing regions, the situation was rather stable (but markedly varying in case of democratic neighbours).

Differences in the rate of change for non-forest woody vegetation were observed for the regime and neighbour predictors. The representation of this land class slightly increased during the communist regime in Czechia while in the democratic period, a slight decrease was recorded (Fig. 29 g). The neighbour predictor showed association of a slight – but more variable – increase at the borders with democratic states and slight decrease at the sampling plots on the borders with communist neighbours (Fig. 29 h).

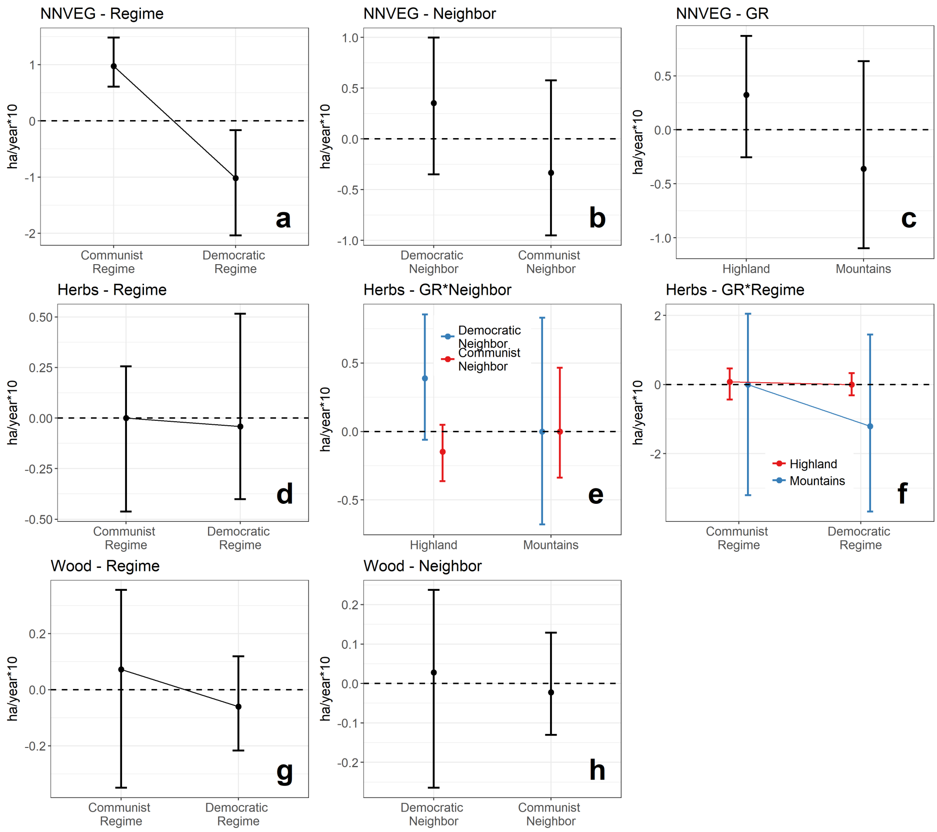


Fig. 29: The effect of socio-economic and environmental factors on the rate of change of the area of near-nature vegetation (significant level only). The vertical axis shows the rate of increase (positive values) or decline (negative values) of the near-nature vegetation; the zero line indicates no change. The effect of the (a) political regime in Czechia, (b) political regime in the neighbouring country and (c) growing region on the near-nature vegetation (NNVEG) at the main thematic resolution LC1. (d–h) Detailed thematic resolution LC2. (d) Changes of the herbaceous vegetation as a function of the political regime in Czechia, (e) of interaction with the political regime in the bordering country and growing region and (f) changes in the herbaceous vegetation as a function of interaction of growing regions and political regime in Czechia. Changes of non-forest wooded vegetation influenced by (g) the political regime in Czechia and (h) in neighbouring country. Note: Median values with 95 % confidence interval for median based on bootstrap method (normal method, R=10 000).

5.2.4 Landscape heterogeneity (Shannon heterogeneity index)

The effect of the political system change on the rate of the changes in landscape heterogeneity was significant for the heterogeneity index (Shannon heterogeneity index, SHDI) calculated for both the main (LC1) and detailed (LC2) thematic resolution. While during the communist period, the landscape heterogeneity was relatively stable or increasing (Fig. 30 a), it is

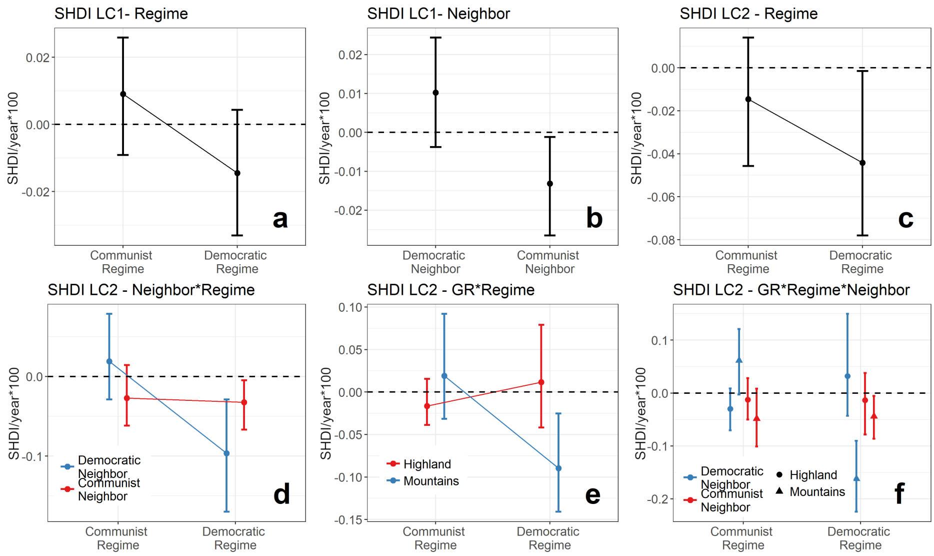


Fig. 30: The effect of socio-economic and environmental factors on the rate of change of the landscape heterogeneity (significant level only). The vertical axis shows the rate of increase (positive values) or decline (negative values) of the heterogeneity; the zero line indicates no change. (a-b) Main thematic resolution LC1. (a) Heterogeneity changes on the LC1 level as a function of the regime change in Czechia and (b) of the political regime in the neighbouring country. (c–f) Detailed thematic resolution LC2. (c) Heterogeneity changes on the LC2 level as a function of the political regime in Czechia, (d) of the interaction of political regime in Czechia and regime in neighbouring country, (e) of the interaction of the political regime in Czechia and growing region and (f) interaction of all predictors. Note: Median values with 95 % confidence interval for median based on bootstrap method (normal method, R=10 000).

on the decline in the democratic era. The same pattern is reflected in the detailed thematic resolution (Fig. 30 c), with only minuscule differences – a slight decline in the communist and a marked decline in the democratic regime, respectively. Marked differences were found for the neighbour predictor in the main thematic resolution. Here, the increase in heterogeneity was found for sampling plots with democratic neighbours and marked decrease for those with socialist neighbour (Fig. 30 b).

At the detailed level of the thematic resolution (LC2), the interaction of predictors yielded significant differences in SHDI for a majority of predictor combinations. As shown in Fig. 30 d, the communist neighbour sampling plots presented a stable decrease in both periods, while those neighbouring on democratic states are stable during the communist period and rapidly decrease during the democratic regime in Czechia. Similarly, the interaction of the regime and growing region (Fig. 30 e) resulted in a rather stable SHDI with a slight increase or decrease for both mountains and highlands during the communist period. A marked difference was revealed in the democratic period where losses in heterogeneity for mountain plots and slight increase for highland plots were observed. Finally, the heterogeneity metric for detailed thematic resolution was significantly affected by the interaction of all employed predictors. As Fig. 30 f shows, there is a difference between the evolution of the landscape in the mountain regions neighbouring on democratic countries in the communist period (slight increase in heterogeneity) and democratic period (relatively higher drop), which cannot be observed in respective highland areas.

5.3 Results of the case study at the microscale level (Zubrnice case study)

5.3.1 Change of land use/land cover and its drivers

Following the aims of the micro scale study, we designed a specific approach to analyse and present the results of the land use/land cover dynamics in this section. The approach puts emphasis on the social and environmental transitions between the individual periods. This is in contrast to the current studies that mostly establish time horizons (years) as milestones with an abrupt impact on landscape dynamics. We, therefore, consider these time horizons to be representative of the transitions between two more or less distinct periods (Fig. 31). While the landscape structure in each of these time horizons (years) is documented with detailed quantitative data, these data must be considered a probe into the period of a specific continuous transition rather than its beginning or the end. At the same time, we intentionally avoid a precise determination of the outer boundaries of these periods of transition.

5.3.2 Agricultural-industrial transition

The transition period spans from the agricultural state that was characterised by the intensive use of the agricultural land (Fig. 9 c), predominantly represented by permanent cultures (orchards and hop yards) and arable land. Since the 19^{th} century, the whole area prospered due to the fruit and hop production. In the case of Zubrnice village, this was catalysed by the proximity to a transport corridor, the nearby Labe River valley, and later by railway connection (since 1890). The site was predomi-

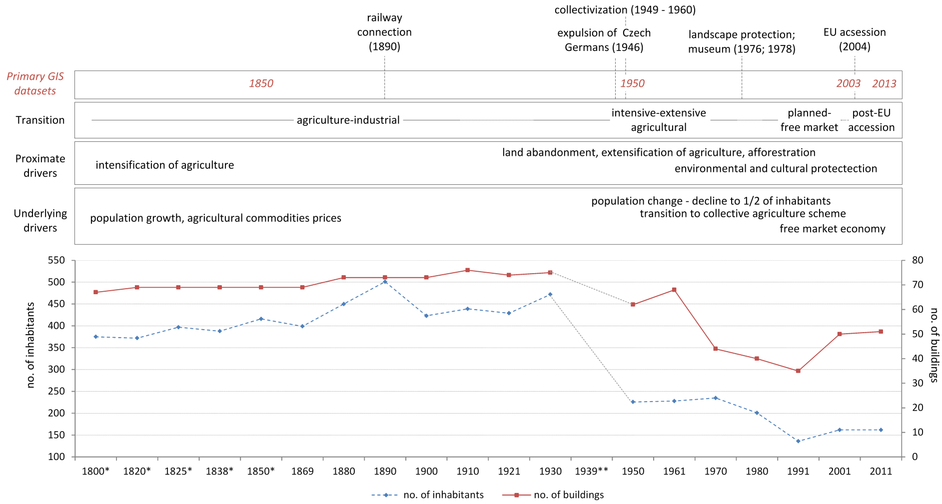


Fig. 31: Proximate and underlying drivers of the LULC change between 1850 – 2013 and transitions used in the text, note: * precensal data: based on Jančárek, 1994, ** missing data.

nantly inhabited by Czech Germans living in the small villages of Zubrnice (where the population increased from 375 in 1800 to 500 inhabitants in 1890) and Stará Homole (with 82 inhabitants in 1869 steadily declining to 54 in 1921).

Towards the time of industrialisation of the region, the population slightly rose due to the intensification of agriculture and the related need for human resources (Fig. 31). The dynamics of the land-use change was relatively low due to the necessity of maintaining continual agricultural output. The era of the industrial shift affected the village of Zubrnice since the first half of the 19th century by the changing employment structure due to the nearby industrial centre of Ústí nad Labem (Jančárek, 1994). The landscape in this time segment exhibited the highest share of intensive land use (46% identified as arable land), high diversity of land use (Table 15) and a differentiated landscape mosaic with the presence of linear wooded and shrub formations (Table 15, Fig. 9 c). The share of permanent cultures (7%; 12 thousand fruit trees as recorded by Stark, 1907) and meadows and pastures (20%) were higher than the average of Czechia (Fig. 32 a) at that time; on the other hand, the forested area (21%) was lower. Official cadastral records for 1896 (Statistische Zentralkommission, k.k., 1904) depicted the stability of the share of arable land, forests, meadows, pastures and permanent cultures. The relative stability of the land use structure continued through the economic rise in the newly established Czechoslovakia (as one of the succession states of the Habsburg Monarchy following the First World War) towards the abrupt changes starting with the post-1929 crisis and the Second World War (UAZK, 2018).

Table 15: Landscape metrics calculated for individual time points (1843 – 2013).

	1843	1954	2003	2013
SHDI	1.718	1.258	0.727	0.771
TE (km)	491.874	324.115	203.958	207.427
LPI (%)	6.223	9.978	49.178	50.183
MPS (ha)	0.055	0.058	0.071	0.083

5.3.3 Intensive to extensive agricultural transition

The trend of land abandonment was apparently beginning in 1948, with a decline in the arable land of 50 ha out of approx. 500ha of the entire study area (UAZK, 2018), and continued to later periods (Fig. 32 a). I identify the main drivers for such decline in the expulsion of the entire community of Czech Germans (summer 1945, rest of the population in 1946; Glassheim, 2015) and resettlement by new inhabitants from all of Czechoslovakia after the Second World War (the 1950 population was 226 compared to 472 in 1930). With the political and economic transition in 1948 towards a totalitarian state and planned economy (Bičík et al., 2001), the structure of the land use changed as well. The lack of workforce contributed to the general extensification of the land use with a major shift to afforestation and conversion to meadows, pastures and permanent cultures. This shift included an increase in meadows and pastures by 100 ha reaching a total share of 40%, and an increase of the permanent cultures by 70 ha to a 20% share in 1954. The collectivization of agriculture under the centrally planned socialist economy led to the reshaping of the fragmented ownership and cultivation (in 1939, 52% of the owners possessed less than 5 ha of land) manifested in the establishment of a collective agricultural union in 1949.

Due to the above-mentioned factors, the development of land use in the transition period towards a totalitarian state led to massive abandonment of arable land in favour of forested areas, permanent cultures (often in the state of transition towards forest) and extensive meadows and pastures (see Fig. 32 b). The abandonment accounted for 35 percent points (pp) of the whole area between the second half of the 19th century and the first half of 20th century (Fig. 32 a). The spatial extension of the transition from the arable land to meadows and pastures to a secondary succession towards forest in the later period is characteristic of the northern part of the former Stará Homole settlement (Fig. 33 D). We identified the continuity of the transition from arable land to the current meadows and pastures mainly in the proximity to the urban centre of the researched region with easy access and easier conditions for pasturage in general.

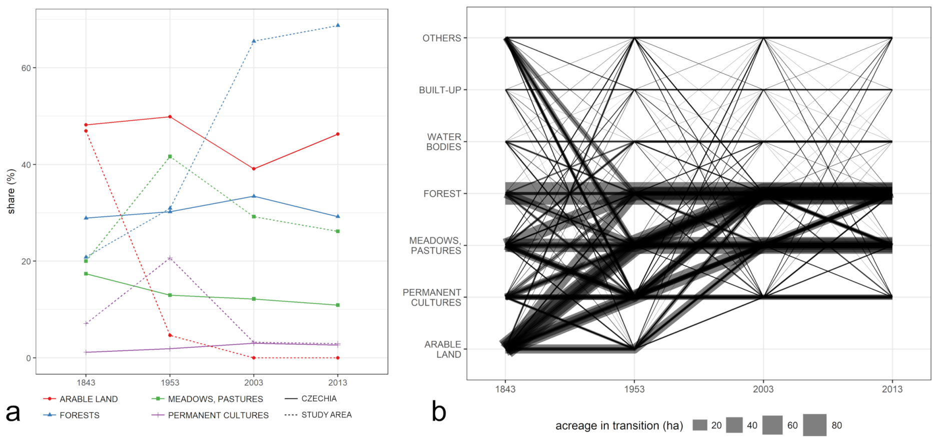


Fig. 32: a: Comparison of the evolution of LULC classes in the Zubrnice study area (dotted lines) and whole Czechia (solid lines) between 1843 and 2013 (share for Czechia calculated for 1845, 1948, 2000 and 2013), b: Transition of LULC classes during the researched period.

5.3.4 Planned to free-market transition

The transition period from planned to free-market economy is discussed in terms of its impact on LULC changes in Central-European post-communist states (Bičík et al., 2001; Kupková et al., 2013; Baumann et al., 2011). Planned economy emphasised the idea of self-sufficient agricultural output. In order to follow the policy of agricultural self-sufficiency, there was a tendency to use land with marginal agricultural output (i.e. worse topographic conditions). The areas with marginal agricultural outputs were often located in the places affected by a dramatic decline of population (typically the areas affected by expulsion of Czech Germans; e.g., Balej et al., 2010). Therefore, the synergetic factors of worse topographic conditions and lack of workforce posed a difficult problem for the sustainability of agricultural management. Despite the efforts for the use of such areas (pasturage), the land often remained abandoned or afforested.

Both these factors manifested in the study area (i.e., worse topographic conditions and depopulation, Fig. 9 a). As described above, the change and decline in population, together with specific and challenging topography, led to extensification of the LULC types. The peripheral location and abandonment of arable land played an important role in establishing a protected landscape area (PLA) in the region in 1976 (IUCN V, 1976). In 1978, this was followed by declaring the area a protected monument zone (aiming to conserve the cultural heritage) and in 1995, the highest category of protection, Rural Monument Reserve (vesnická památková zóna) was established (AOPK ČR, 2018; NPU, 2018). Then, the shift towards a post-productivist agricultural scheme was catalysed by the revolution in 1989, which was significant for restitution of land to former owners. After 1991, a population increase was observed, which was facilitated mainly by secondary housing and recreation (35% of all buildings in 1992). However, the secondary housing had little or no impact on other than the built-up LULC categories.

The spatial extent of the changes in landscape structures could be divided into two categories. Both lead to more extensive methods of land use. The first category is a transition to forest from former meadows and pastures (by 10 pp in the whole area) that indicate the continuing secondary succession in the northern parts (Fig. 33 F) and in the near surroundings of the village of Zubrnice. The other type of transition was from permanent cultures to meadows and pastures (again in the vicinity of the settlement, Fig. 33 E). Abandoning permanent cultures (by 17 pp) resulted in concentration (regression) of that LULC class close to the village (Fig. 33 C). The decline in fruit production (12 thousand fruit trees in 1948) was driven by clearing the fruit trees and orchards (1955 and 1956) from parcels to allow the use and operation of heavy machinery. Continuing abandonment in the form of afforestation (between 1950 and 2003, the area of forest doubled to 327 ha, covering 65% of the study area in 2003) led to a rapid unification of the landscape mosaic manifesting in the changes in landscape metrics such as diversity index, total edge, largest patch index and mean patch size (see Table 15). Combined, these metrics show the unification and the loss in diverse landscapes in the beginning of the transition period.

5.3.5 Post-EU accession transition

The last transition period denotes the short-lived but relatively intense landscape changes related to the end of the post-socialist social and economic transition and the accession to the EU. The key factors in the transition period of pre- and post-accession to the EU are observed in the continuing counter-urbanisation that proliferated in the specific form of secondary housing (Fig. 31). Another strong factor affecting LULC is the Common Agricultural Policy (CAP) that supports the status quo in LULC by a subsidy to management of meadows and pastures. This is in line with CAP measures that use the landscape structure (type, size and management at the individual land use classes) as a primary regulation criterion for subsidies, instead of a focus on ecological functions and processes. While the overall landscape structure displays stability, changes may be observed in its qualitative characteristics. The peripheral unused locations are undergoing further secondary succession and afforestation, while the intensity of use and management practices on permanent grasslands slightly increased as a result of CAP schemes. Finally, the national and regional subsidies and empowerment of local communities as well as further decentralized governing structures (PLA, municipality) help to re-establish and/or renew certain historical landscape structures (paths, alleys, solitary trees) within the centre of the study area as proposed by the first renaturation plan in 1995 (Vráblíková, 1995). These actions were followed by a proposal for the renewal of historic landscape structures of strip fields defined by hedgerows (Ledvinka et al., 1999) and a revitalization plan for Luční Stream (Janda et al., 2000).

5.3.6 Spatial dimension of land-use change trajectories

Following the description of LULC dynamics and its proximate and underlying drivers, the spatial definition of the major trajectories of landscape change are analysed. As each period of transition that affects landscape processes is represented by a certain landscape structure in a given time horizon (year), we present the transition matrix between these horizons to classify the persistence of individual LULC categories. In terms of the trajectories of the LULC changes (Fig. 32 b), the study area contains 17% (83 ha) persistent forest patches (the forest stands identified on the same location at all time points). The major transition (13%; 69 ha) was from arable land at the first time point to meadows and pastures (1954)

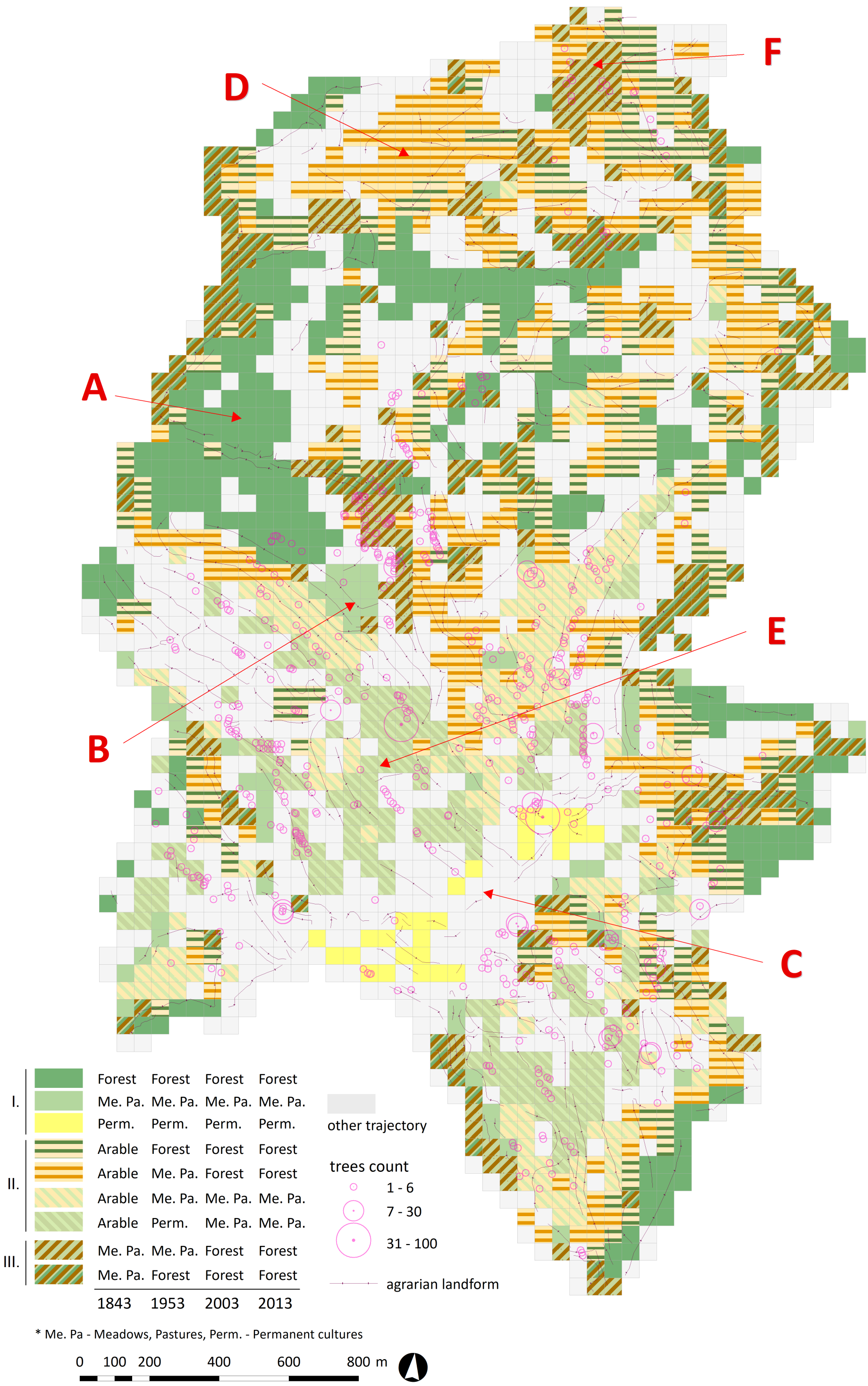


Fig. 33: Localisation and typology of major changes

and finally to forests at the last two time points. The second major transition was from arable land at the first time point to persistent meadows and pastures in the second and subsequent time points (9.5%; 47 ha).

Based on the transition matrix, it was possible to classify individual spatial units (represented as pixels on the map - Fig. 33) into three categories of transitions with different potential for landscape conservation and for their use as narratives of landscape change. These categories include (i) persistent patches, (ii) patches that changed their use but still display landscape relics indicating historical landscape processes and uses (e.g., management practices), and finally (iii) patches that were changed and do not display any relics indicating historical landscape processes and uses. The individual categories of transitions are further explained as follows:

1. Persistent patches: despite the peripheral location and conservation efforts in the study area, only the 23% of the total area was identified as unchanged (Fig. 33 - I. category). The persistent areas were mainly found in the steeper northern parts of the research area with persistent forest stands (Fig. 33 A). We found persistent use of meadows and pastures scattered in the southern part with the only larger patch in the centre of the area (Fig. 33 B). In accordance with our expectations, the permanent agriculture (i.e., orchards) persisted near the currently urbanized centre surrounding Zubrnice village (Fig. 33 C).

2. Changed patches with relics of past use: More than half of the studied landscape was altered by transitions other than forest-meadows/pastures transition (and vice versa) and meadows/pastures-permanent cultures transition (and vice versa). The major transition was based on the massive abandonment of arable land (Fig. 33 – II. category) to afforestation predominantly in northern parts (Fig. 33 D) surrounding the former settlement of Stará Homole (Fig. 9). The second subtype of arable land abandonment was in favour of meadows and pastures that persisted until the present day and that are located mostly in the vicinity of Zubrnice village (Fig. 33 E). Location of the arable land in transition indicates the extensification trend outwards from the village centre as well as the influence of local topography.

3. Changed patches without relics of past use: this category is typical of the transition from meadows and pastures to forest land that persisted until present day. We localized the converted meadows and pastures that predominantly border the current or former persistent forested patches. There is one exception to the minor and scattered succession areas (Fig. 33 F) located in the northern part around the former Stará Homole settlement.

As a supplementary indicator of the past agrarian use, the fruit trees and agrarian landforms were surveyed. Their detailed field survey resulted in the localization of 595 sites with fruit trees (with variable tree counts) and 425 agrarian landforms (mostly terrain levels - dry stone walls) in total. We also analysed the locations of the trees and their coincidence with agrarian landforms (agrarian terrace boundaries) that would indicate the past presence of the agroforest categories. The coincidence of both features is demonstrated by the fact that the mean distance between the trees and the agrarian terrace boundaries is 29 m. In total, 132 trees are located less than 10 m from the surveyed agrarian landforms. Given the mean patch size in 1845 (Table 15), the distances of trees from agrarian landforms indicate the spatial coincidence of both features at individual plots (patches). In 35% of the cases, the localization of surveyed trees coincides with LULC transition from arable land to meadows and pastures. These results confirm the historical abundance of agroforest categories consisting of arable land with trees. Besides trees located on persistent permanent cultures (8%) and persistent meadows and pastures (2%), we found two other significant clusters with fruit tree stands. 20% of persisting fruit trees were found on the afforested arable land, 17% on afforested meadows and pastures. Location of agrarian landforms is self-evidently associated with agrarian LULC categories originating in the first time horizon (69%). We found 30% of all surveyed agrarian landforms on the afforested arable land and 20% on former arable land transformed into meadows and pastures. A minor share (19%) of agrarian landforms is located on the afforested meadows and pastures.

6 Discussion

6.1 Discussion for Part I – Changes in landscape along the Iron Curtain

6.1.1 Dynamics on processes along the entire Iron Curtain

The part of this thesis evaluating landscape changes along the former Iron Curtain builds on the works by (Bičík, Kabrda, & Najman, 2010; Kupková et al., 2013) who analysed the same area and its development between 1990 - 2006. Compared to their studies, I decided to include a longer period (1990 – 2012) and a longer part of the Iron Curtain (the Slovenian part of the Iron Curtain was added). A longer period of observation after the accession of Czechia, Hungary and Slovenia to EU (2004) can better reflect changes resulting from the agricultural (and other) policies adopted by the countries in association with accession. The Slovenian-Austrian part of the border differed from the remaining segments of the border prior to 1989 (more permeable border, absence of physical barriers and a generally more open border than in the rest of the study area, see Chapter 2.6). The Slovenian part can therefore be in a way considered a kind of control area. Another difference between this thesis and the aforementioned studies is a different design of data processing. In the studies by Bičík et al. (2010) and Kupková et al. (2013), a band of 15km from the border is analysed without taking into account the environmental conditions. Those, however, influence (together with other drivers – socioeconomic, political, as mentioned in the Chapter 2.5) the LULC change processes and as such, they should be reflected in the research design (Kuemmerle et al., 2008). A preliminary check of the landscape types in a 15km band from the Iron Curtain revealed differences in the environmental characteristics to the East and West of the border. To prevent bias, i.e., to be able to evaluate the LULC change trajectories under identical environmental conditions, it was decided to use sampling plots placed on the border in a way ensuring an equal representation of landscape types (identical environmental conditions) at the beginning of the study.

Based on the evaluation of the landscape structure in 1990 (the first year of the study period) using the sampling plots on the same LULC type, a similar composition of LULC categories in the West and in the East was revealed. This is in direct contradiction with results reported for the entire 15 km band described above; both studies by Bičík et al. (2010) and Kupková et al. (2013) reported a higher representation of the arable land in the East and of heterogeneous agriculture in the West. The results differ due to the different approaches adopted in the studies, i.e., due to the extent of the processed data. Smaller samples of the landscape such as those used in this study allowed us to use areas with identical environmental conditions (LANMAP), resulting in a better comparability than when using the entire landscape (in which the environmental conditions differ between the sides of the border). The comparability of individual LULC classes in 1990 in the East and in the West can be considered an advantage facilitating an easier monitoring and interpretation of the land change trajectories for periods 1990 - 2000 and 2000 - 2012.

The aforementioned disproportion in the works by Bičík et al. (2010) and Kupková et al. (2013) between the higher area of heterogeneous agriculture in the West and arable land in the East in 1990 is however indirectly observable in my study as well. The evaluation of evolution trajectories of all sampling plots revealed the dominance of different land change processes in the East and in the West. In the West, the transition from heterogeneous agriculture is the main process while in the East, it is the transition from arable land. The differences in the character of those trajectories can be interpreted as a tendency to utilise the dominant agricultural LULC class for conversion into other LULC classes.

An interesting perspective on the results is revealed by the evaluation of convergence of individual processes, i.e., by investigating the question whether or not some processes tend to be harmonised when similar drivers apply, e.g. whether the EU support of extensive use of the farmland is going to lead to similar processes (in this case, conversion into meadows or pastures) on both sides of the border. The detailed assessment reveals that if the border is analysed as whole, the volume of agricultural internal conversion differs significantly for both sides of the border and both periods. The volume of such changes is significantly higher in the second period in the West compared to the East. This can be explained by a higher economical readiness of farmers in the West to react to subsidy policies and agri-environmental schemes such as the Common

Agricultural Policy (CAP). CAP underwent a transformation in the initial year of this study (1990) – a significant change from supporting the volume of production to supporting the farmer's income. This change in the CAP policy was intended as a support for improving the effectiveness (intensification) of production and in principle had two major impacts on the landscape. One of the described paths (van Zanten et al., 2014) led the farmers to already long-awaited and long-expected intensification of production (increase in competitiveness on the world market). The other led to the gradual abandonment of less profitable farmland. Such areas were then transformed into forests or pastures. The pastures are also subject to subventions and despite criticism and change in definition (CAP reform in 2013) towards the support of wood pasture, there is still a major support for their preservation at the supranational (EU) level. (Plieninger et al., 2015).

In accordance with Bičík et al. (2010) and Kupková et al. (2013), I found a higher degree of afforestation in the Eastern parts of the border, the trend even increased in the second period in my study. The character of this LULC change is similar on both sides of the border, namely transition from shrubs. According to the CORINE data definition, shrubs are a transitional forest stage or a more open type of the forest on former pastures. This type of conversion has a higher rate in the East and it can therefore probably be explained by the gradual succession by forests on abandoned plots, intentional increase of forests or a normal forestry cycle (i.e., regular clearing of the forests with subsequent planting of seedlings). Another interesting result at the level of the entire border is the similarity of LULC classes transitioning into forest in the second period, clearly indicating abandonment of certain land use types (arable land, heterogeneous agriculture, pastures) for forest stands. In agreement with (Plieninger et al., 2016; van Vliet et al., 2015), this is typical for the agricultural land abandonment. The transition between arable land and forest stands can be explained by the further tendency to agriculture intensification, which leads to preferring agricultural plots with higher yield. If a smaller number of agricultural plots can result in similar yields due to the intensive agriculture, the less fertile plots can be utilised for extensive land management such as forestry. This phenomenon was found on both sides of the border, it was however more pronounced in the East.

Internal agricultural conversion was the process with the highest volume of changes. A relatively stable (higher) volume of changes in the East is a result of the obvious extensification when the arable land transformed into pastures. The same process could be observed in the West (here, heterogeneous agriculture was the source land use type). A strong orientation on the transition into pastures can be attributed to the land extensification here as well (in accordance with the conclusions by Bičík, Kabrda, & Najman, 2010; Kupková et al., 2013). The transition of LULC into pastures is also apparent in the deforestation volume as forests were also partially transformed into pastures. A higher degree of urbanisation in the West was another difference between the sides of the border. This trend can be most likely explained by the limitations to the urban area development before 1989, when most border segments in the East were subject to building limitations preventing new constructions near the Iron Curtain (for details, see Chapter 2.6) and the depopulation of such regions resulted in lack of infrastructure necessary for new urbanisation . Despite a higher rate of urbanisation (although marginal as far as the total area is concerned), the second period was also associated with a higher deurbanisation rate. This can be caused by reclamation and transformation of brownfields/abandoned plots.

6.1.2 Discussion on the dynamics of the processes in the East German-West German segment of the Iron Curtain

None of the analysed segments (regions) shows a degree of similarity of processes on both sides of the border as much as the East-West German border, in particular as far as the volume and structure of the changes in the second period are concerned. The initial political and institutional context was however different in 1990, in particular where agriculture and associated impacts on land use were concerned. The Western part indicated lower volume of the farmland (below 60 %) than the Eastern part (72 %). This was due to the type of farms prior to 1990 where family-run, smaller farms were predominant, compared to the large collective farms in the East (Hennis, 2005). The aftereffects of this are observable till this day in the several times bigger blocs of the arable land in the East compared to the West (Batáry et al., 2017). The increase in the area of the arable land in the entire East Germany in the first period reported by (Hennis, 2005). was not confirmed in the borderland sampling sites where stagnation was rather observed. The trend reported by Hennis (2005) can be explained by a relatively quick adaptation of the collective farms to the commodities with a higher financial profit, which led to homogenization of production with the West and, therefore, a homogenization of the agricultural outputs with the West , which resulted in the need of a small increase in the arable land. Besides the increase in the farmland, I have also observed the opposite process – decline of the arable land, in particular where less fertile "beetroot" growing regions in the higher altitudes (e.g. Brandenburg) are concerned. These areas were very often transformed into pastures (Wollkopf & Wollkopf, 1997). The same process of the transformation of the arable land into pastures was also described in the north of Germany (Schaffert & Steensen, 2017). The abandonment of the higher located arable land was also noted when analysing the smaller samples on the borders of the former Iron Curtain. The greater volume of these changes on the Eastern part described by Schaffert & Steensen (2017) is in accordance with my results.

The trend of arable land abandonment, which was also seen in my results, further increased in the second period (where the transition into pastures was the dominant process). The land abandonment itself is however not a new phenomenon, it continues from as far back as 1970s and is associated with socio-economical changes and industrialisation of the agricultural production. Technological drivers (industrialisation) are represented predominantly by the evolution and improvements of agricultural mechanisation, allowing a higher production with a smaller number of employees, and other technologies leading to the intensification of production (fertilisers, better seed stock). This was further supported by socioeconomic drivers, when ever since the WWII, the number of employees in the agriculture kept dwindling. Together, both drivers resulted in the reducing the total tilled areas while intensifying their use, needing a smaller number of employees.

In the East, this phenomenon is very much catalysed by changes in the socio-economic and political conditions for agriculture after 1990. During 1991 – 1997, over 500 thousand people left agriculture, in particular due to the overemployment in the sector in the East and a rapid machinery modernisation (Hennis, 2005). The above described drivers are more likely to apply in the first studied period. The massive transition between arable land and pastures in the second period is more likely driven by the changes of the subsidy schemes in Germany in 2003 – 2005. According to Sanders et al. (2016), the CAP reform in Germany manifested in particular in the higher subventions of milk production and other associated grazing agriculture (with increased provisions for organic agriculture). A direct impact in the landscape was the logical conversion from the available arable land into pastures. Differences in the volume of changes in the case of forest stands in the West was predominantly between the (transitory) shrubs and forests, it was therefore most likely not a conversion into another type of land use – the structure of the changes corresponds with the usual forestry cycle and management.

6.1.3 Discussion on the dynamics of the processes for the Czech-German segment of the Iron Curtain

In both "Czech" segments, the most prominent changes between the Eastern and Western sides of the border can be observed. The Western part was relatively stable in the first period, with the rate of land changes increasing only in the second period. In the East, the trend was opposite. For that side of the border, certain analogies with the historical context and evolution of the East German side of the border can be found. The Eastern side, i.e., the Czech side of the border, underwent a change of agricultural structure after 1990, with over 400,000 people leaving the sector of agriculture by 2000. Another similarity with the East-West German border lies in the persistence of large farms on the Czech side – former collective farms that remained relatively viable (Bičík et al., 2015). The path leading to the current agricultural condition was much different from the German one and was reflected in the specifics of land use. In Czechia, the agricultural subsidy was significantly reduced (14 % in Czechia compared to 49 % equivalent provisions in other EU countries). This only changed by the end of 1990s and most subventions supported the transformation from arable land into pastures and forestry (which was in particular pronounced for higher altitudes, such as areas studied in this work).

At the same time, privatisation of the state-owned property after 1989 led to notable fragmentation of the land ownership. The original small land blocks were returned to the original owners (or, often, their successors) who however did not use the land for farming themselves but rather rented it to larger farms. The reasons for abandonment of the returned agricultural land rest in the inaccessibility of the particular plots (e.g. a small plot inside a lager block of smaller fields; Sklenička, Janovska, et al., 2014). This, together with the cultural and social changes, led to the fact that the successors of the collective farms survived by renting the land from small owners uninterested in farming themselves (Kupková et al., 2013; Bičík et al., 2015). It can be therefore concluded that the conversion towards permanent grassland and afforestation was by the end of 1990s motivated predominantly by profitability and further accelerated by the lack of interest in farming of the minor land owners.

The above situation is reflected in my results where the transition from arable land into pastures is the dominant transition in the first period. It may be however difficult to tell with any certainty whether the particular plot was indeed used as a pasture or if it was just a secondary succession on the abandoned arable land. The aforementioned emphasis on afforestation (subventions) together with the (normal) transition between the shrubs and forest also explains the higher afforestation rate on the Eastern side of the border.

Kupková et al., (2013) predicted in their contribution (based on a low to almost non-existent dynamics of the changes on the Western side of the border; conclusions drawn from the 2003-2006 data) a further decrease in the intensity of changes in the future. However, as this thesis covered a longer period, it could be observed that the opposite turned out to be true – an increase in the volume of changes and, in particular, a change of the structure in the West. Such marked changes (abandonment of heterogeneous agriculture) can be again explained by the CAP reform in 2003. I assume that the changes caused by this reform have not been recorded in the 2006 CORINE dataset yet as a longer time was needed for processing the changes in the subvention schemes in Germany. On the Czech side, the dynamics of arable land abandonment in favour of pastures slowed down due to the accession of the Czech Republic to EU and related CAP support (Bičík et al., 2015).

6.1.4 Discussion on the dynamics of processes in the Czech-Austrian segment of the border

The historical context for the Czech - Austrian segment is very similar to the previous one. The analysis of historical LULC data revealed that the original condition of the landscape and land use prior to 1948 (change of the political system to central planning in Czechia) was similar on both sides of the border (Rašín & Chromý, 2010). The centrally planned economy manifested its effects in this (and the previous) segment of the Czech border in particular in the extent of individual agricultural blocks that were larger on the Czech side due to collectivisation, mechanisation and depopulation (Sklenička, Janovska, et al., 2014). The evaluation of changes on the Austrian side since 1990s revealed that the dynamics only picked up after 2000, in all likelihood only after 2006 as the conclusions drawn by Kupková et al. (2013) proclaimed stability of the region.

The explanation for the greater volume of afforestation on the Czech side in 1990 - 2000 can be found, similar to the previous segment of the border, in the turbulent changes in agriculture and forestry after 1990. Similar to the previous segment, land abandonment in agriculture and secondary succession or normal forest cycle processes in forestry could be observed here. The structure of changes between the Austrian and Czech sides of the border was however notable in the first period (1990 - 2000). On the Austrian side, the most significant donor land use type was the heterogeneous agriculture, transforming into pastures and arable land. This fact can be explained by changes in the agricultural policies of Austria after 1986, when extensive reforms (eco-social policies supporting multifunctional agriculture) took place. These reforms introduced subventions for new feedstock and energy crops and led to an increase in the area of arable land (Gingrich & Krausmann, 2018). This process was further supported by the accession of Austria to EU (1995) and associated implementation of one of the most complex (and most expensive) agroenvironmental policies in the EU, which lead, among other things, to the extensification of land use (Kurz, 2018). This effect could be observed in the first and second periods as an increase of pastures on the Austrian side of the border. Another factor is the decrease in the number of smaller farms and of "part time" farmers (Kurz, 2018), obvious from the increasing average farm size (1990 – 25 ha; 2015 – 45 ha) in Austria. The general increase in farm size definitely does not contribute towards preservation of heterogeneous agriculture and this trend can present an explanation for the rapid decrease of this category in the West in the second period. A characteristic feature for this segment of the border is the higher area of permanent crops – mostly represented by vineyards.

6.1.5 Discussion on the dynamics of the processes for the Slovak/ Hungarian-Austrian segment of the Iron Curtain

The specifics of the Austrian evolution of land use can be observed in the other "Austrian" segment as well. In all, a smaller dynamics of changes per sampling plot as well as the smaller total volume of changes (e.g. afforestation) shows here. In the first period, one of the four sampling plots represents an outlier as far as the land use change is concerned, namely characterised by the intensity of transition from the heterogeneous agriculture to arable land. A similar trend (albeit to a much smaller extent) can be nevertheless found in other sampling plots in the West in both the first and second period and the land use intensification trends resulting from the reforms of land use policies can be observed here as well (see above). The sites in this segment of the border differ in the afforestation rate in both periods – it is higher in the East than in the West. This trend is identical for Slovakia and Hungary and shares the main drivers. Similar to Czechia, massive agricultural land abandonment is observed for Slovakia after 1990 (Lieskovský et al., 2015), which only decreased after accession of the country to EU associated with agricultural subventions (SAPARD, CAP). The agricultural land abandonment in Slovakia nevertheless led to a higher degree of afforestation (Pazúr & Bolliger, 2017). A similar situation is described in Hungary, where the decrease of arable land and pastures reported by the national statistics since establishing democracy has been steady (in our sampling areas, however, we only observed the arable land abandonment). Besides, a secondary succession on the ever increasing area of uncultivated land is also typical for Hungary (Kohlheb & Krausmann, 2009; HCSO, 2020). In the sampling areas, minor changes in afforestation have been observed, the total acreage of afforested areas is however more or less constant, which can be explained by the position of sampling plots in the fertile Pannonian area.

6.1.6 Discussion on the dynamics of the processes for the Slovenian-Austrian segment of the Iron Curtain

The Slovenian-Austrian part of the border was relatively stable over both studied periods on both parts of the border. This fact was however, to a degree, caused by the location of the sites in higher altitudes with rugged terrain dominated by forest areas. In this respect, only the first period in the West is different as a very similar pattern of changes as in the Pannonian (Slovakian-Hungarian) border was observed – the transition of heterogeneous agriculture into arable land and pastures. A higher volume in transition towards pastures in that site was caused by less favourable conditions for agriculture. Besides, the volume of changes is lower in the East in the first period and only represented by afforestation of agricultural land, which corresponds with the situation in the rest of Slovenia (Gabrovec et al., 2020).

The second period is characterised by stagnation on the Slovenian side of the border. A possible factor contributing to this is the fragmented possession of individual plots that did not yield to the collectivisation pressure, which resulted in a landscape pattern similar to that existing in the 19th century (Bičík et al., 2019). In this period, there was only a minimal volume of changes both in the East and West; if any changes occurred, the most common were afforestation and transition of permanent crops into arable land. In the East, the results are affected by a single sampling location where (after a detailed analysis of airborne imagery) early stages of the forest transition into adult forest occur, the transition is therefore the aforementioned transition from shrubs to forest after replanting or post-calamity development of the forest. In the west, such an outlier is represented by a more fertile (actually, the only fertile) Slovenian sampling plot north of Maribor, where on the slopes, arable land was formed in place of former vineyards. Nevertheless, due to the aforementioned factors such as border permeability, softer approach to collectivisation and in particular environmental conditions, we can conclude that in this segment of the Iron Curtain, the post-communist development did not result in much contrast.

6.1.7 Similar heritage – various transformation paths

The principal aim of the presented first part of the thesis was to compare the development in the border areas representing a unique environment for investigation of the impact of socioeconomic and political drivers in the LULC development. In the initial part of the thesis, different trajectories of changes were assumed; in other words, I hypothesised that there will be a contrast between the Eastern and Western sides of the border and between individual segments of the border representing individual countries. This hypothesis was confirmed.

If we disregard the possibility of incorrect determination of environmental conditions, i.e., if we accept that the sides of the border are comparable, these differences exist. It is therefore necessary to look for driving forces of LULC change. In the previous parts, possible explanations for the differences in the dynamics of individual processes (of land use class conversion) were offered. The initial condition of the land use policy was described for all countries of the Eastern Bloc touching the Iron Curtain, including the obstacles and decline in individual segments (agriculture, forestry and construction) after 1989. Wilson & Klages (2001) studied the changes in agriculture in the former communist states in the Central Europe (CECs) and concluded that the transition from the centrally planned economy with agriculture based on massive subventions (communist era) towards the market economy in the democratic period was basically similar in all those countries. An exception can be observed only in the transition of Poland and Slovenia (the latter can be also observed from our results in the Slovenian part). This transition led in all countries to a period of „transition recession" (see Kornai, 2008 for details) coming with the increase of the income dysbalance and unemployment, but later resulting in a relatively rapid adaptation to the market economy and in an increase in productivity compared to the period prior to 1989 (usually since approx. 1995). Based on the data discussed above (see discussion for individual regions), it is obvious that the transformation process initiated in case of the cross-border comparison (East-West) spatially different changes. To maintain clarity, three transition trajectories will be discussed:

1. The situation is most obvious in the former East-West Germany border regions where the transition was faster, under one leadership and therefore with a stable single political course. These are most likely the principal factors resulting in the similarity of the trends on both sides of the border in case of the West-East German part of the Iron Curtain.

2. The opposite trajectory can be found in the Slovenian-Austrian segment of the border, which is, due to a historical context and specific environmental conditions, relatively stable as far as LULC changes are concerned.

3. The third category includes regions such as Czechia, Slovakia and Hungary. On the borders of these countries with traditional democratic countries, the differences in land use changes between the sides of the border were the highest. This was probably predominantly caused by the significantly worse position of agriculture (especially) in the first period compared to the "Western" countries, which only stabilised following the accession to EU and associated agroenvironmental subvention schemes.

The selected sampling method proved to be effective for investigation of the impact of political decisions. Such political decisions, legislation changes and other socio-economic factors are discussed. I am well aware of the conclusions of studies summarising the principal drivers of land changes in Europe, i.e., that it is rather a complex of factors than individual drivers that affect the landscape evolution (sensu Plieninger et al., 2016). Had we therefore intended to understand the detailed evolution of the landscape in the individual regions, other methods would have to be adopted (such as the approach used in Part III) facilitating a deeper insight into the issues (such as process tracing, in-depth interviews with actors, etc.). Despite this relative simplification, this part of the Thesis can serve as an initial identification of issues for a potential deeper and spatially narrower probe (such as that in Part II).

6.2 Discussion for Part II – the evolution of Czech borderlands

The uniqueness of this part of the study rests in analysing the longer-term development (compared to Part I.) of the landscape in border regions of a transitional/post-communist country. Landscape development both during the communist and democratic periods are compared using a statistical approach and take (among other things) the regime of the neighbouring country into account. Presented results showed that the main drivers of the landscape changes in these regions were represented by the factor of communist/democratic regime, which was further augmented by the political regime in the neighbouring country. These results are in accordance with Sklenička et al. (2014) who have, similarly to here presented findings, reported that socio-economic conditions induce landscape changes more than natural conditions (here, the growing region typology was used as a representative of environmental conditions).

In our study area, the trend of farmland/cropland abandonment was observed, similar to that reported from other parts of Europe (Plieninger et al., 2016) or worldwide (Queiroz et al., 2014), manifesting as reduction of the cropland area and increase of agricultural grassland in the democratic period. Similar trends were observed in Part I. The results of Part II therefore imply that the processes detected in Part I have deeper temporal roots. During the communist period, I have recorded a constant total area of cropland in the borderlands, which differed from the development in the entire Czechia where there was a 16 % decrease in the cropland representation over the communist period and 7 % over the democratic period (Bičík et al., 2001, 2015); in our border regions, the slight decrease only came in the democratic period. The stagnation of the croplands in the former period can be probably attributed to the support and establishment of so called "mountainous collective farms" (1947 – 1949), which were being set up with the purpose of drawing farmers from inland into the borderland regions (Kubeš, 2007) and thus to support agriculture in those regions, dramatically affected by expulsion of the Sudeten Germans after the World War II (see also Glassheim, 2015). Nevertheless, the general trend of land abandonment phenomenon is supported further by the overall decrease in farmland (i.e. total agricultural land – combined cropland and agricultural grassland), especially in the mountains during the communist regime and, in the democratic period, due to a retreat from ineffective cropland cultivation in higher elevations. Land abandonment phenomena is also confirmed by the extensification of the agricultural land use, illustrated by a slight increase in the agricultural land use, namely of the grassland (i.e., meadows and pastures) in the democratic period that was demonstrated for the whole area of Czechia (Bičík, Kabrda, & Najman, 2010). The extensification trend is associated with the abrupt changes in agricultural incentives policies after 1989 (see discussion for Part I).

6.2.1 Effect of the border permeability

A greater dynamics of abandonment of the intensive forms of land use was expected near the borders with democratic neighbours. This expectation was partially confirmed. Bičík & Kabrda (2007) documented practically an identical trend based on the analysis of cadastral reports

– a spatially uniform trend of decline of the area of arable land and increase of the agricultural grassland (pastures) in both periods in their study, together with a continuous increase of forested areas. These trends are more or less in accordance with both studied segments of the Czech border. The abandonment of intensive forms of land management was confirmed in this part of the thesis only partially and with spatial differences. A higher dynamics in afforestation was expected at the borders with "Western" countries. The increase in afforestation was observed there, however an even higher increase was found at the borders with communist neighbours. Besides the afforestation process, the transition of arable land into pastures (agricultural grassland) is another indicator of abandonment of intensive land management forms. This transition was also more pronounced at the borders with socialist countries. To a certain extent, nevertheless, both these categories represent an economic activity. For determining the land abandonment processes, therefore, the categories of non-forest woody vegetation and herbaceous plants (without any economic utilisation) are even more important. Both these categories showed higher dynamics at the borders with democratic countries. This increase can be explained both by the fact that pastural farming only returned into these areas in 1980s and by massive building demolitions in the 1950s (1953 - 1960). It can be assumed that such locations were left to secondary succession – only a small fraction of buildings were rebuilt or avoided demolition and were left for the purposes of border guards (see rak2016cold).

Both parts of the border differ in the landscape diversity represented by the SHDI as well. In general, the diversity over the entire studied area increased near the borders with democratic countries. A closer look however reveals that the diversity declines even there in the democratic period, in particular in the regions with higher altitude (mountains). This can be explained by the aforementioned increase of the non-forest non-agricultural vegetation at the borders with democratic states during the communist period. The diversity however grows lower in the second period, most likely due to the increase of the forest areas and of agriculturally used areas.

The hypothesis about the effect of the guarding regime on landscape development in the Czech borderlands was confirmed. A higher dynamics of land without economic use was found at the borders with democratic neighbours. The effect of more strictly guarded (inaccessible) border is also visible from the results of the diversity index. The similarity of the evolutional trajectories reported in the previous studies can be attributed to the equalisation of results due to the differences in the environmental conditions or due to the characteristic properties of the cadastral records as a data source (discussed in the Introduction in particular in view of the possible problems with errors or delay in changing data).

The hypothesis about the change in the trajectory of the landscape following the change of the political regime in Czechia was confirmed in our study (details in the previous chapter) and are in agreement with those by Bičík & Kabrda (2007). My results are consistent in the evolution of agricultural grassland, i.e., the cessation of the decline (or even slight increase) after reestablishment of democracy. Significant differences between the periods were found in particular in the decline of non-forest vegetation and associated land use diversity. In all, the results for the second period can be considered consistent with those found in Part I, although different data sources were used.

6.3 Discussion for Part III – evolution on the micro-scale

General trends The study area is characterised by a continuous afforestation from the first time horizon to the most recent one (which is in accordance with the results of Part II – a higher afforestation in sampling plots with communist neighbours). In addition to this trajectory, we found a complete loss of the arable land in 2003. In comparison to the general trends in Czechia (Bičík et al., 2001), however, the loss of arable land and afforestation intensity makes the case study area different from the general trends and provides an example of transition in peripheral landscapes (Lasanta et al., 2017; Levers et al., 2018). The structural changes described by the landscape metrics indicate a general decrease in heterogeneity of LULC categories associated with the afforestation trend (and therefore LULC unification). To find representative examples that narrate the evolution of the local landscape, localisation and typological classification of major trajectories were conducted. Only 23 % of the patches in the area were persistent (most of these were forest stands). Dynamic patches explaining the transition in the study area were also identified. The major dynamic trends represented afforestation of arable land and transition of arable land into meadows and pastures. The analysis of the major driving forces led to a strong differentiation of the pre- and post-1950s period. The former period is characterised by stability in housing and population numbers and emerging land abandonment in the last period (see also Balej & Anděl, 2008). The second period was strongly influenced by the devastation and loss of population after the World War II and catalysed the land abandonment, resulting in the extensive mode of agricultural use (see also Bičík & Štěpánek, 1994). We found intensive land-use classes (agricultural) to be concentrically receding in time towards the urban centre of Zubrnice village.

6.3.1 Implications for conservation efforts and educational use

The biocultural approach to conservation of the landscape heritage lies in the conservation of the processes, thus necessitating better understanding to the past evolution of the landscape trajectories and their contexts (cf. Palang, Spek, & Stenseke, 2011). In this research, we argue that conservation of processes should not be considered as an alternative to the conservation of existing or reconstructed past structures and features, but rather as a complementary approach allowing the reduction of the lack of diachronic depth in rural landscape museums. Using the typology of LUCC transitions in our research, we argue that the changed patches with relics of the past use provide a narrative of landscape transitions that are not clearly identifiable in patches seemingly displaying long-term LUCC stability (as the processes and management regimes may have changed through time). Similarly, the changed patches with relics of the past use may provide a contextualization for sites in landscape museums where past land uses have been reconstructed and conserved. Based on the presented methodological framework, the representative localised samples could be useful for both conservation and educational purposes (i.e., the practical examples of transition from arable land or meadows and pastures to forested areas with emphasis on the relics of the past use). In such areas suitable for conservation, the explanation of proximate and underlying drivers that shaped the local landscape is usually missing. I believe that this unfortunately reduces the educational value of conservation and that the description of such drivers with examples in the landscape, as well as of the role of agricultural relics, would enhance the conservational and educational value of the area. The post-agricultural and ancient forest stands, meadows and pastures were identified in our research area and categorized as changed and/or persistent patches (see Chapter 4.2). These sites are characterised by their distinct flora species composition (Kopecký & Vojta, 2009; Vojta, 2007) due to the higher nutrient legacy on post-agrarian patches. The ancient meadows and pastures are often appraised for high diversity and ecological value (Ihse & Lindahl, 2000). Therefore, we hypothesize that the difference in the general flora assemblages based on different trajectories of change (i.e., transition from meadows and pastures and arable land to forest in comparison to persistent patches) and the effect of fruit tree relics should be further investigated for conservation purposes. Based on the island biogeography concept, the persistent patch size and its connectivity may also play a significant role in the viability of the remnants of ancient meadows and forest stands. Only a single compact patch of a few hectares of persistent meadows and pastures was identified (Fig. 33 B). Despite the limitation in size, the patch is surrounded by permanent cultures and arable land changed to meadows and pastures. The influence of such buffer on increasing the viability and interconnectivity of the respective patch is therefore uncertain. As for ancient forest stands, the compact patch (Fig. 33 A) is larger, connected to afforested patches, and therefore potentially more viable in comparison with meadows and pastures. In terms of conservation and educational potential, the suggested approach benefits from an explicit spatial delimitation of the past use, which could be helpful for the advancement of open-air museums towards a more ecomuseological state. In particular, the approach supports the use of spatio-temporally located landscape features in the conservation effort following the development plan of Vráblíková et al. (1995), which focuses on the re-establishment of stripe fields and orchards together with appropriate modes of farming. The spatio-temporal determination of landscape features supported with the qualitative archival information may be further used to re-establish historical paths for tourism purposes. The use of abandoned buildings and surrounding altered agricultural plots can inform about the post-war population and economic transition in peripheral regions (Fialová et al., 2010), or it can integrate the ecological conservation in the ecomuseum based on the detailed knowledge of past flora assemblages (e.g., pomological potential of fruit trees remnants as a source of old resistant cultivars).

6.3.2 Reliability and applicability of the methodological framework

The methodological framework used in this study (Part III) can be divided into three interconnected steps, i.e., (i) description, (ii) explanation and (iii) selection of representative samples, the replicability of which in other social and environmental settings must be adapted to the specific context. In terms of the descriptive step, the quality of the narratives lies in the density of data sources (i.e., the time horizons) and their limitations (e.g., uncertainties resulting from mapping procedures in the Franziscean cadastre; Forejt et al. 2018). In addition, the variability in LULC transition between the analysed time points can describe the "average" situation between these horizons only, leaving the evolution in-between for further investigation. The explanatory part (i.e., the identification of driving forces behind the change) is highly limited by the availability of archival sources. It is possible to deductively follow the major trends that are described by country-wide (Bičík et al., 2001) or continent-wide (Plieninger et al., 2016) systematic reviews, but problems arise with the specific details in a study area (e.g., strong deviatory intervention by an individual agent or subventions). Finally, the selection process of patches representative for individual trajectories in our study aimed to capture spatially significant trends and could omit samples that are representative on a different (lower) scale. More questions arise from the complementarity of GIS (digitised) and archival cadastral data (see also Harvey et al., 2014). We found minor discrepancies between the data on the proportion of arable fields in different sources of information. We hypothesize that this issue is connected with the delay (Yang et al., 2014) in the change in the land use in the official cadastral records. Additionally, there are methodological questions of the field survey of agrarian landforms and tree localization as well. The agrarian landforms proved to be a relevant predictor for trajectories originating in the arable land evolving into other land-use classes. The fruit trees as an indicator of the past use should be further investigated to gather information about the age of the trees by dendrochronological dating methods (Bürgi et al., 2007). The simple location of fruit trees proved to be a sufficient descriptor in the same way as the agrarian landforms, but the supplementary information could enrich and facilitate the delimitation of representative sites that could support the narratives.

6.4 Discussion summary and methodological limitations

The presented thesis consists of three temporally and spatially linked studies. The general approach utilised in the individual studies followed a "standard procedure for studying driving forces" (Burgi et al., 2005; Fig. 1). This discussion summary will follow this procedure and will be divided into (a) delimitation (spatial extent, temporal extent and landscape elements), (b) analysis (landscape change and persistence, driving forces and actors) and (c) synthesis (relations between driving forces and landscape change). The first step is to define the study area – here, it is border areas. The political border separating the former Eastern and Western Bloc countries in Europe (the Iron Curtain, Part I) was selected to demonstrate the approach to studying LULC change in the border areas. Similarly, nested design approach was further adopted for analysing the internal borders of Czech borderlands (Part II) supplemented with a microprobe of an area in its northern part (Part III). The spatial linking plays an important role in identification of individual drivers/actors of in the landscape, the effect of which can be combined in the same space.

Besides the spatial nested design, nested design was also applied in the temporal scale (see the temporal scale definition in the "standard procedure for study of driving forces"). Here, individual parts of the thesis temporally overlap in the analysed temporal distance from the present, covering a horizon of years (Part I), decades (Part II) to centuries (Part III). The temporal nested design then serves, in combination with its spatial component, for delimitation of the temporal extent (initiation) of individual drivers. Here, for example, the agricultural land abandonment processes were tracked as far back as mid-19th century (Part III) and continue up to the present days (Parts II and III). The spatial delimitation is complemented by the choice of landscape elements (LULC classes) to be analysed. In all parts of the thesis, a similar, relatively coarse, thematic resolution is used (despite slight differences in terminology used for the arable land, permanent cultures, meadows and pastures, forests, waters and urban areas). This intentional unification of the thematic resolution allowed a comparability of outputs and trajectories of the respective LULC classes (e.g. evolution of arable land areas).

Subsequently, individual elements (LULC classes in the respective spatio-temporal extent) are analysed. All parts of the thesis utilise data/

LULC layers created on the basis of aerial imagery or represent derivatives of satellite imagery (CORINE). The derived LULC spatial data were then in the Parts I and II processed to capture the dynamics of landscape changes and persistence and statistically evaluated. In the Part III, the data were not statistically evaluated but the procedure of identification of land changes was similar. The identification of LULC classes in the individual time points and the creation of GIS layers facilitated calculation of landscape metrics for quantification of landscape composition (see below). In all parts of the thesis, the contribution of individual actors and drivers to the land changes were discussed, based on explanations from the sources describing the changes in the political, social and cultural environment.

The analysis of the landscape structure in the individual periods utilised landscape metrics in all parts of the thesis (I-III), i.e., metrics that helped quantify the principal changes at the level of individual LULC classes or of the landscape. Based on the recommendations by (Šímová & Gdulová, 2012), I chose metrics that are not redundant in the sense of a similar behaviours, results or interpretation, and behave consistently even if the size of the study area, grain size or minimal mapping unit and thematic resolution are changed. Individual parts of the thesis (Part I-III) nevertheless do not change the spatial extent of the area of interest – the sampling plots (Part I and II) or area of interest (Part III) remain unchanged through all time points. Similarly, the analysis of grain size or minimal mapping unit cannot be considered subject to change neither where CORINE data (individual layers are harmonised to a minimal mapping unit of 25 ha) nor the research design for Part II (where a variable quality of the airborne imagery could be found; nevertheless, the oldest photographs, i.e. those of the lowest quality, were used to derive the minimum mapping unit) are concerned. A similar approach was adopted in Part III and its grain size.

For determining diversity at the landscape level, the widely used Shannon's diversity index (SHDI) was used. The behaviour of this index is affected by the change of thematic resolution (for details, see Chapter 2.2). We should therefore expect that the higher number of classes are present in the area of interest, the higher is the index. This logical expectation was confirmed in Part II, where the SHDI change across time (e.g. 1953 - 1988) is smaller in the lower thematic resolution LC1 than in the LC2 resolution (with more categories). It is therefore not surprising that the trend of the index (Fig. 30 a,c) is the same for both categories. We must consider that even though the absolute value of the difference of the metrics in the finer LC2 resolution is higher, it denotes a similar level of changes in the landscape (in case of more detailed thematic resolution, SHDI values are bigger and so is their difference). The same index was used for the patch diversity calculation at the landscape level in the Part III. The patch size metric values correspond with the changes in SHDI, which is logical as reduction in diversity is typically associated with increase of the patch size. The metrics in this case clearly illustrate the homogenisation on the landscape level as far as the number of LULC classes is concerned. The simplest metric used in Part I and II was the simple class area (CA) of the individual LULC classes. This metric was opted for as it facilitates further processing in the form of differences between individual years of data acquisition and evaluation of the dynamics of LULC classes. This method (i.e. without calculating the class area proportion, CAP, by dividing the areas by the total area) was chosen due to the identical spatial extent of the sampling plots (identical square areas), which preserved the comparability of the results (sensu Leitão, 2006).

The presented thesis nevertheless shows certain methodological limitations that were partially mentioned in the text already. The first one depends on the data availability and is associated with the segmentation of the landscape evolution into blocks with sharp borders determined by the dates of LULC data acquisition – typically, the segment starting with Franziscean cadastre (1850s) and ending with orthophoto from 1950s (for details, see Dolejš & Forejt, 2019). This approach assumes linearity of the changes within individual periods and disregards any random or intentional interventions of institutions or inhabitants in the land use. The other potential methodical limitation is the approach adopted in particular in the Parts I and II. In the Introduction, this approach is characterised as DF-C (driving force – change, Chapter 2.4.1). This approach intentionally disregards any intervention of an agent – i.e., of an institution or an actor who directly or indirectly cause the land change. In this thesis, including such an actor would be represented for example by a narrower focus on the relationship between the land use change and agricultural subventions. Inclusion of such an institution was however neither planned nor intended and even had we included such factors, we would still have to consider the decision making of individual farmers to be exclusively rational and utility-driven. Back to the choice of the approach – if we discussed the potential drivers and actors instead of their direct effects, such approach would rather serve for defining hypotheses or further research directions. Research directions suggested by my results will be discussed below. Solutions to the limitation represented by the segmentation of the landscape evolution in time can be seen either in a deeper research of historical sources in the older periods or in acquisition of particular actors (which is only possible for studies of a smaller extent). Both options are valid. The use of historical sources was successfully used in Part III and helped in getting a deeper insight into the topic (see also Dolejš & Forejt, 2019). Involvement of particular actors requires the use of the methods of social science where individual persons are concerned (corresponding to DFA-C, A-C approaches). Such involvement is, however, limited by the temporal extent (a human lifespan) or, where institutions (guidelines, laws) are concerned, by the availability of documents.

The conclusions of the review (Chapter 2.4.1) on the frequency of the involvement of individual drivers suggest that the change of a political system, sectoral policies or economical system is a very common driver in landscape change. Other more common drivers include demographic changes and environmental conditions. Both these were identified as key drivers in the presented thesis as well.

In particular, the change of the political regime (in the general sense) proved to be the key driver in the Parts I and II of this thesis focused on the development of the border areas in Central Europe and, in particular, in Czechia. The political change in 1989 was followed, just like in all other countries of the former Eastern Bloc, by a land ownership reform. The land was returned to the original owners or their successors, private agricultural companies (farms) of the western type were being founded. Prischepov et al. (2012) conclude that the speed of the reforms after 1989 and the power of institutions during the transformation period in the countries of the former Eastern Bloc were crucial for the sustainability of agricultural use. In other words, the faster the state (through its institutions) acted, the less land abandonment was observed. This conclusion of the Prischepov's study comparing the transformation of the border areas in Poland, Baltic states and Belarus after 1989 transition can be seen from my results as well. When comparing trajectories of landscape evolution in the West/East Germany and remaining regions (with the exception of Slovenian-Austrian border), the contrast between the land use change on the two sides of borders differs. The former West – East German region shows the highest similarities in the trajectory of changes. The trends in development of the LULC classes and their change converged very quickly on both sides of the border. The contrast between the Eastern and Western sides of the border is however much higher for the remaining regions, in particular in the first period. This is partially due to unique historical context of the region and, in particular, due to different (differently difficult) transformation of land use after 1989. The complexity of transformation was in particular affected by the extent of state-provided agricultural subventions after 1989. For this reason, the change in agricultural policies was another frequently observed driver, which was identified to be a decisive factor in the part of the thesis devoted to the change in border areas along the Iron Curtain (Part I) and of Czechia (Part II). There the most significant changes were observed in the agricultural land use that were most likely associated with the onset (or changes) of subvention policies (CAP, in particular the second period 2000 - 2012).

Kuemmerle et al. (2008) observed in their study the decline in agriculture in Poland, Ukraine and Belarus after 1989, again associated with the interruption of state subventions. This causality is in their case further accelerated by worse topographic conditions and emigration from the agricultural regions. The influence of the topographic conditions on the landscape evolution was studied in particular in the Part II of the thesis devoted to the internal borders of Czechia. I observed a similar rate of agricultural land abandonment in the mountains compared to the highland sites, which was however only true for the communist period (before 1989). A possible explanation was a combination of two drivers – the aforementioned worse topographic conditions together with the devastating depopulation by expulsion of Czech Germans after WWII. Nevertheless, the influence of topographic conditions on the greater depopulation in the mountains was probably caused rather by the worse environmental conditions as the expulsion of Czech Germans occurred in highlands and mountains to the same degree.

Demographic changes are therefore crucial for the evolution of the Czech borderlands (Part II) as was also shown in the case study of Zubrnicko (Part III). Both study areas show a similar decline attributed to the depopulation of the region after WWII (for details, see Glassheim, 2015). In this case, a detailed analysis at the microprobe level of Zubrnicko served very well for understanding the processes (although the generalisation for the entire border is not possible). There, the mechanism of the decline of regions that were more or less prosperous prior to the World War II was also identified based on the detailed archival documents. Biophysical factors also demonstrably affect the change dynamics. The trend of decline in economical activities in the highlands and higher mountain areas during the communist period was also reflected in the microprobe of Zubrnicko; it was brought about in particular by the depopulation and concentration of the agricultural production on more fertile areas.

Comparing the key drivers in the European landscape as defined by Jepsen et al. (2015) with the outputs of this thesis, we find agreement in (a) land tenure reforms (b) associated factors of collectivisation, privatisation and restitution, (c) agro-environmental provisions and (d) changes in the purchase prices of the commodities (described e.g. as a factor of present day evolution e.g. at the Austrian part of the borders). Plieninger et al. (2016) identified the agricultural land abandonment/extensification and, contrary, intensification of land use to be the main processes in Europe. Extensification and arable land abandonment is a typical process observed in all parts of the thesis (and most obvious in the longest temporal extent in Part III). Intensification as a direct driver was only found in Part I (the present day period). The main indirect driving forces behind intensification/extensification were agricultural policies and demographic changes. Looking at the entire extent of the area (Part I), the influence of agricultural policies, in particular reforms and subventions based on the CAP policies was crucial. As however stated above, the changes were usually driven rather by a complex of drivers than by a single driver. The dynamic formation of the landscape is therefore influenced by multiple factors, from biophysical and socioeconomic to political.

7 Concluding remarks

The presented thesis aimed to evaluate the evolution of the landscape in border regions on a general level. In particular, we aimed to determine the degree to which the evolution of land use and land cover is dependent on the permeability of the state border and on other political and socioeconomic factors. For hypotheses testing and for partial aims, three spatial scales represented in the macro scale by the border area along the former Iron Curtain, in the meso-scale by Czech internal borders and on a micro scale by an area of the village Zubrnice located at the northwest border of Czechia. The discussed results imply the following:

- The effect of the border of the former Iron Curtain – division to the Eastern and Western Blocs – can still be observed in the different dynamics of the observed processes from 1990 onwards, in particular where changes in the structure of agricultural land use are concerned.

- The effect of restrictive measures such as border impenetrability and limitation of the urban development is particularly observable in the higher pace of urbanisation in the West after 1990.

- Landscape development as a reaction on common agricultural policy (CAP subventions sensu Burgi et al., 2005) are most clearly observable for Germany. To determine the impact of CAP, however, it would be beneficial to further increase the extent of the study by another period (2012 – 2018 or, better yet, 2022).

- Trajectories of changes vary across regions along the Iron Curtain. The convergence of the volume and structure of LULC changes is only clearly apparent in the case of the former West German-East German borders. This finding was interpreted as a result of a single political focus and administration after 1990, representing a harmonising element.

- The assumption of Slovenia serving as a control area (representing a stagnation of changes) was only partially confirmed. The relatively low dynamics of the observed processes (transition of grouped LULC classes) can be in my opinion rather attributed to environmental conditions unsuitable for agriculture on this border.

- Conclusions presented in the last two bullets contrast with the development on the Czech, Slovak and Hungarian sides of the borders (the "Eastern" side) where the tendency of agricultural land abandonment (especially cessation of tillage) was only stopped by the accession to EU and associated agricultural subventions (CAP).

- For the landscape development in the area of interest, the social and political conditions have the greatest effect (Part I), however where environmental conditions differ (Part II), significant differences in the dynamics of agricultural land use were also observed.

- The effect of reduced border permeability (reduction to exclusion of economic activities in the form of strictly guarded border) was demonstrated at the borders of Czechia with democratic countries; the dynamics of the increase of economically unused vegetation types was higher at the borders with democratic countries than at the borders with communist neighbours.

- The effect of the political system (before and after 1989) was also observed, in particular by stabilisation of agricultural grassland.

- An example of agricultural land abandonment in the Czech borderlands was presented and commented on in a case study on a small area of Zubrnice. This process and this area were especially affected by the expulsion of the Czech Germans after 1945 (that resulted in an almost complete depopulation of the region) and by the transition into a new political and economic system in 1948.

- In case of evolution of the landscape that is subject to cultural heritage protection, I argue for the conservation of the process of land change – i.e., for supplementing the current approach and attempts for reconstruction of a (typically pre-industrial) landscape by examples of areas documenting the landscape evolution, which allow to explain and demonstrate the main drivers of such changes.

- Results and discussion of this thesis reveal clearly identifiable contrasts in the evolution of the landscape in individual regions along the Iron Curtain and in the Czech borderlands. A clear causality between e.g. agricultural subventions and intensification/extensification trends would have to be further confirmed by other methods. Suitable methods could include the methods of social sciences or process tracking of the involvement of actors of the changes (owners, leaseholders, institutions).

References

Antrop, M. (1997). The concept of traditional landscapes as a base for landscape evaluation and planning. the example of flanders region. *Landscape and Urban Planning*, *38*(1-2), 105–117. doi: 10.1016/s0169-2046(97)00027-3

Antrop, M. (2005). Why landscapes of the past are important for the future. *Landscape and Urban Planning*, *70*(1-2), 21–34. doi: 10.1016/j.landurbplan.2003.10.002

AOPK ČR. (2018). *Ústřední seznam ochrany přírody—chko České středohoří [nature conservation catalogue]. http://drusop.nature.cz/.*

Balej, M., & Anděl, J. (2008). Land use changes and environmental stress accounting (case study from northwestern part of the czech-german borderland). *Journal of Geography and Regional Planning*, *1*(5), 97–109.

Balej, M., Raška, P., Anděl, J., & Chvátalová, A. (2010). Memory of a Landscape – A Constituent of Regional Identity and Planning? In *Landscape modelling* (pp. 107–121). Dordrecht: Springer Netherlands. doi: 10.1007/978-90-481-3052-8_8

Batáry, P., Gallé, R., Riesch, F., Fischer, C., Dormann, C. F., Mußhoff, O., … Tscharntke, T. (2017). The former Iron Curtain still drives biodiversity–profit trade-offs in German agriculture. *Nature Ecology & Evolution*, *1*(9), 1279–1284. doi: 10.1038/s41559-017-0272-x

Baumann, M., Kuemmerle, T., Elbakidze, M., Ozdogan, M., Radeloff, V. C., Keuler, N. S., … Hostert, P. (2011). Patterns and drivers of post-socialist farmland abandonment in Western Ukraine. *Land Use Policy*, *28*(3), 552–562. doi: 10.1016/j.landusepol.2010.11.003

Beranová, L., Balej, M., & Raška, P. (2017). Assessing the geotourism potential of abandoned quarries with multitemporal data (České Středohoří Mts., Czechia). *GeoScape*, *11*(2), 93–111. doi: 10.1515/geosc-2017-0008

Bičík, I., Gabrovec, M., & Kupková, L. (2019). Long-term land-use changes: A comparison between Czechia and Slovenia. *Acta geographica Slovenica*, *59*(2), 91–105. doi: 10.3986/AGS.7005

Bičík, I., & Štěpánek, V. (1994). Post-war changes of the land-use structure in Bohemia and Moravia: Case study Sudetenland. *GeoJournal*, *32*(3), 253–259. doi: 10.1007/BF01122117

Bieling, C., Plieninger, T., & Schaich, H. (2013). Patterns and causes of land change: Empirical results and conceptual considerations derived from a case study in the swabian alb, germany. *Land Use Policy*, *35*, 192–203. doi: 10.1016/j.landusepol.2013.05.012

Bičík, I., Anděl, J., & Balej, M. (2010). Landscape Function Transformations with Relation to Land-Use Changes. In J. Anděl, I. Bičík, P. Dostál, Z. Lipský, & S. G. Shahneshin (Eds.), *Landscape modelling* (pp. 87–103). Dordrecht: Springer Netherlands. doi: 10.1007/978-90-481-3052-8_7

Bičík, I., Jeleček, L., & Štěpánek, V. (2001). Land-use changes and their social driving forces in czechia in the 19th and 20th centuries. *Land Use Policy*, *18*(1), 65–73. doi: 10.1016/s0264-8377(00)00047-8

Bičík, I., & Kabrda, J. (2007). *Land use changes in Czech border regions (1845-2000)* (Vol. 42) (No. 1-2).

Bičík, I., Kabrda, J., & Najman, J. (2010). Land-Use Changes Along the Iron Curtain in Czechia. In J. Anděl, I. Bičík, P. Dostál, Z. Lipský, & S. G. Shahneshin (Eds.), *Landscape modelling* (pp. 71–85). Dordrecht: Springer Netherlands. doi: 10.1007/978-90-481-3052-8_6

Bičík, I., Kupková, L., Jeleček, L., Kabrda, J., Štych, P., Janoušek, Z., & Winklerová, J. (2015). *Land Use Changes in the Czech Republic 1845–2010*. Cham: Springer International Publishing. doi: 10.1007/978-3-319-17671-0

Brandt, J., Primdahl, J., & Reenberg, A. (1999). Land-use changes and their environmental impact in rural areas in Europe. In R. Krönert, J. Baudry, I. Bowler, & A. Reenberg (Eds.), *Land-use changes and their environmental impact in rural areas in europe* (pp. 81–102).

Breitung, W. (2002). Transformation of a Boundary Regime: The Hong Kong and Mainland China Case. *Environment and Planning A: Economy and Space*, *34*(10), 1749–1762. doi: 10.1068/a3566

Breuer, T., Kolejka, J., Marek, D., & Werner, E. (2010). Convergence of cultural landscape on the Czech-bavarian border in Šumava Mts. *Geografie-Sbornik CGS*, *115*(3), 308–329.

Bürgi, M., Bieling, C., Von Hackwitz, K., Kizos, T., Lieskovskỳ, J., Martín,

M. G., … others (2017). Processes and driving forces in changing cultural landscapes across europe. *Landscape Ecology*, *32*(11), 2097–2112.

Bürgi, M., Hersperger, A. M., Hall, M., Southgate, E. W. B. R., & Schneeberger, N. (2007). Using the Past to Understand the Present Land Use and Land Cover. In *A changing world. challenges for landscape research* (pp. 133–144). doi: 10.1007/978-1-4020-4436-6_9

Burgi, M., Hersperger, A. M., & Schneeberger, N. (2005). Driving forces of landscape change - current and new directions. *Landscape Ecology*, *19*(8), 857–868. doi: 10.1007/s10980-005-0245-3

Bürgi, M., & Turner, M. G. (2002). Factors and processes shaping land cover and land cover changes along the Wisconsin River. *Ecosystems*, *5*(2), 184–201. doi: 10.1007/s10021-001-0064-6

Campbell, D. J., Lusch, D. P., Smucker, T. A., & Wangui, E. E. (2005). Multiple methods in the study of driving forces of land use and land cover change: A case study of SE kajiado district, kenya. *Human Ecology*, *33*(6), 763–794. doi: 10.1007/s10745-005-8210-y

Cherrill, A., & Lane, M. (1995). The survey and prediction of land cover using an environmental land classification. *Applied Geography*, *15*(1), 69–85. doi: 10.1016/0143-6228(95)91063-4

Cihlar, J. (2000). Land cover mapping of large areas from satellites: Status and research priorities. *International Journal of Remote Sensing*, *21*(6-7), 1093–1114. doi: 10.1080/014311600210092

Collier, D. (2011). Understanding process tracing. *PS: Political Science & Politics*, *44*(04), 823–830. doi: 10.1017/s1049096511001429

Congalton, R., Gu, J., Yadav, K., Thenkabail, P., & Ozdogan, M. (2014). Global land cover mapping: A review and uncertainty analysis. *Remote Sensing*, *6*(12), 12070–12093. doi: 10.3390/rs61212070

Copernicus Programme. (2019). *Corine land cover.* Retrieved from `https://land.copernicus.eu/pan-european/corine-land-cover`

Cushman, S. a., McGarigal, K., & Neel, M. C. (2008). Parsimony in landscape metrics: Strength, universality, and consistency. *Ecological Indicators*, *8*(5), 691–703. doi: 10.1016/j.ecolind.2007.12.002

Dale, V. H., & Kline, K. L. (2013). Issues in using landscape indicators to assess land changes. *Ecological Indicators*, *28*, 91–99. doi: 10.1016/j.ecolind.2012.10.007

Dolejš, M., & Forejt, M. (2019). Franziscean cadastre in landscape structure research: a systematic review. *Quaestiones Geographicae*, *38*(1), 131–144. doi: 10.2478/quageo-2019-0013

Ernoult, A., Freiré-Diaz, S., Langlois, E., & Alard, D. (2006). Are similar landscapes the result of similar histories? *Landscape Ecology*, *21*(5), 631–639. doi: 10.1007/s10980-005-5321-1

ESRI. (2019). *Environmental systems research institute, arcgis 10.x, redlands.*

Feranec, J., Soukup, T., Taff, G. N., Stych, P., & Bicik, I. (2017). Overview of Changes in Land Use and Land Cover in Eastern Europe. In *Land-cover and land-use changes in eastern europe after the collapse of the soviet union in 1991* (pp. 13–33). Cham: Springer International Publishing. doi: 10.1007/978-3-319-42638-9_2

Fialová, D., Chromy, P., Kucera, Z., Spilková, J., Štych, P., & Vágner, J. (2010). The forming of regional identity and identity of regions in Czechia - Introduction to the research on the impact of second housing and tourism. *Acta Universitatis Carolinae, Geographica*, *45*(1), 49–60.

Flesch, A. D., Epps, C. W., W., J., Clark, M., Krausman, P. R., & Morgart, J. R. (2010). Potential Effects of the United States-Mexico Border Fence on Wildlife. *Conservation Biology*, *24*(1), 171–181. doi: 10.1111/j.1523-1739.2009.01277.x

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., … Snyder, P. K. (2005). Global Consequences of Land Use. *Science*, *309*(5734), 570 LP – 574.

Foody, G. M. (2002). Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, *80*(1), 185–201. doi: 10.1016/S0034-4257(01)00295-4

Forejt, M., Dolejš, M., & Raška, P. (2018). How reliable is my historical land-use reconstruction? Assessing uncertainties in old cadastral maps. *Ecological Indicators*, *94*, 237–245. doi: 10.1016/j.ecolind.2018.06.053

Forest Management Institute (FMI). (2019). *Oblastní plány rozvoje lesů.* Retrieved from `http://www.uhul.cz/nase-cinnost/oblastni-plany-rozvoje-lesu`

Forman, R. (1993). *Landscape ecology*. New York: Wiley.

Fu, B.-J., Zhang, Q.-J., Chen, L.-D., Zhao, W.-W., Gulinck, H., Liu, G.-

B., … Zhu, Y.-G. (2006). Temporal change in land use and its relationship to slope degree and soil type in a small catchment on the loess plateau of china. *CATENA*, *65*(1), 41–48. doi: 10.1016/j.catena.2005.07.005

Fuchs, R., Verburg, P. H., Clevers, J. G., & Herold, M. (2015). The potential of old maps and encyclopaedias for reconstructing historic European land cover/use change. *Applied Geography*, *59*, 43–55. doi: 10.1016/j.apgeog.2015.02.013

Gabrovec, M., Kumer, P., Ribeiro, D., & Šmid Hribar, M. (2020). Land Use in Slovenia. In (pp. 279–290). doi: 10.1007/978-3-030-14066-3_18

Geist, H. J., & Lambin, E. F. (2002). Proximate causes and underlying driving forces of tropical deforestation. *BioScience*, *52*(2), 143. doi: 10.1641/0006-3568(2002)052[0143:pcaudf]2.0.co;2

George, A. (2005). *Case studies and theory development in the social sciences*. Cambridge, Mass: MIT Press.

Gingrich, S., & Krausmann, F. (2018). At the core of the socio-ecological transition: Agroecosystem energy fluxes in Austria 1830–2010. *Science of the Total Environment*, *645*, 119–129. doi: 10.1016/j.scitotenv.2018.07.074

Glassheim, E. (2006). Ethnic Cleansing, Communism, and Environmental Devastation in Czechoslovakia's Borderlands, 1945–1989. *The Journal of Modern History*, *78*(1), 65–92. doi: 10.1086/499795

Glassheim, E. (2015). Unsettled Landscapes: Czech and German Conceptions of Social and Ecological Decline in the Postwar Czechoslovak Borderlands. *Journal of Contemporary History*, *50*(2), 318–336. doi: 10.1177/0022009414551103

Godet, L., & Thomas, A. (2013). Three centuries of land cover changes in the largest French Atlantic wetland provide new insights for wetland conservation. *Applied Geography*, *42*, 133–139. doi: 10.1016/j.apgeog.2013.05.011

Grešlová Kušková, P. (2013). A case study of the Czech agriculture since 1918 in a socio-metabolic perspective – From land reform through nationalisation to privatisation. *Land Use Policy*, *30*(1), 592–603. doi: 10.1016/j.landusepol.2012.05.009

Grogan, K., Pflugmacher, D., Hostert, P., Kennedy, R., & Fensholt, R. (2015). Cross-border forest disturbance and the role of natural rubber in mainland southeast asia using annual landsat time series. *Remote Sensing of Environment*, *169*, 438–453. doi: 10.1016/j.rse.2015.03.001

Gu, Z., Gu, L., Eils, R., Schlesner, M., & Brors, B. (2014). circlize implements and enhances circular visualization in R. *Bioinformatics*, *30*(19), 2811–2812. doi: 10.1093/bioinformatics/btu393

Hägerstrand, T. (1995). *A look at the political geography of environmental management*. Department of Geography, University College Dublin.

Hampl, M., & Müller, J. (2011). Společenská transformace a regionální diferenciace Česka:příklad vývoje rozmístění pracovních míst a obyvatelstva. *Geografie*, *116*(3), 211—230.

Harvey, F., Kaim, D., & Gajda, A. (2014). Analysis of historical change using cadastral materials in the carpathian foothills. *European Journal of Geography*, *5*(3), 6–21.

Hasselmann, F., Csaplovics, E., Falconer, I., Bürgi, M., & Hersperger, A. M. (2010). Technological driving forces of LUCC: Conceptualization, quantification, and the example of urban power distribution networks. *Land Use Policy*, *27*(2), 628–637. doi: 10.1016/j.landusepol.2009.08.016

Hazeu, G. W., Metzger, M. J., Mücher, C. A., Perez-Soba, M., Renetzeder, C., & Andersen, E. (2011). European environmental stratifications and typologies: An overview. *Agriculture, Ecosystems and Environment*, *142*(1-2), 29–39. doi: 10.1016/j.agee.2010.01.009

HCSO. (2020). *Hungarian central statistical office.* Retrieved from `http://www.ksh.hu`

Heckmann, M., Muiruri, V., Boom, A., & Marchant, R. (2014). Human–environment interactions in an agricultural landscape: A 1400-yr sediment and pollen record from north pare, NE tanzania. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *406*, 49–61. doi: 10.1016/j.palaeo.2014.04.005

Hennis, M. (2005). *Globalization and european integration : the changing role of farmers in the common agricultural policy*. Lanham, Md: Rowman and Littlefield.

Hersperger, A. M., Gennaio, M.-p., & Verburg, P. H. (2010). Linking Land Change with Driving Forces and Actors : Four Conceptual Models. *Ecology And Society*, *15*(4).

Hersperger, A. M., Gennaio, M.-p., Verburg, P. H., & Bürgi, M. (2011). Feedback Loops in Conceptual Models of Land Change : Lost in Complexity ? *Ecology And Society*, *16*(2), 1–3.

Hruška, M., Gimunová, T., Kohlíček, V., Novotný, I., Perglerová, M., Reininger, D., … Voltr, V. (2018). *Situační a výhledová zpráva půda 2018*. MZE.

Ihse, M., & Lindahl, C. (2000). A holistic model for landscape ecology in practice: The Swedish survey and management of ancient meadows and pastures. *Landscape and Urban Planning*, *50*(1-3), 59–84. doi: 10.1016/S0169-2046(00)00080-3

Jančárek, P. (1994). Sňatky v zubrnicích v 19. století (zpráva o archivním průzkumu). *Historická demografie*, *18*, 167–178.

Janda, J., Štiginger, J., Urbanová, M., & Urban, V. (2000). *Revitalizace říčních systémů luční potok, obec zubrnice,*. Praha.

Jeleček, L. (2007). Environmentalizace vědy, geografie a historické geografie: environmentální dějiny a výzkum změn land use Česka v 19. a 20. století. *Klaudyán*, *4*(1), 20–28.

Jepsen, M. R., Kuemmerle, T., Müller, D., Erb, K., Verburg, P. H., Haberl, H., … Reenberg, A. (2015). Transitions in european land-management regimes between 1800 and 2010. *Land Use Policy*, *49*, 53–64. doi: 10.1016/j.landusepol.2015.07.003

Kabrda, J. (2008). The changing spatial structure of agricultural land use in Czechia since the mid-19th century. *Geografický časopis*, *60*(3), 255–278.

Kanianska, R., Kizeková, M., Nováček, J., & Zeman, M. (2014). Land-use and land-cover changes in rural areas during different political systems: A case study of Slovakia from 1782 to 2006. *Land Use Policy*, *36*, 554–566. doi: 10.1016/j.landusepol.2013.09.018

Killeen, T. J., Guerra, A., Calzada, M., Correa, L., Calderon, V., Soria, L., … Steininger, M. K. (2008). Total historical land-use change in eastern bolivia: Who, where, when, and how much? *Ecology and Society*, *13*(1). doi: 10.5751/es-02453-130136

Kohlheb, N., & Krausmann, F. (2009). Land use change, biomass production and HANPP: The case of Hungary 1961-2005. *Ecological Economics*, *69*(2), 292–300. doi: 10.1016/j.ecolecon.2009.07.010

Kolejka, J. (2013). *Nauka o krajině: geografický pohled a východiska*. Praha:

Academia.

Kopecký, M., & Vojta, J. (2009). Land use legacies in post-agricultural forests in the Doupovské Mountains, Czech Republic. *Applied Vegetation Science*, *12*(2), 251–260. doi: 10.1111/j.1654-109X.2009.01023.x

Kornai, J. (2008). The Great Transformation of Central Eastern Europe: Success and Disappointment. In *Institutional change and economic behaviour* (Vol. 53, pp. 1–37). London: Palgrave Macmillan UK. doi: 10.1057/9780230583429_1

Kubeš, J. (2007). Rozdílný vývoj obyvatelstva v sídlech české a rakouské části přeshraničního regionu „Novohradské hory – Freiwald" mezi lety 1869–2001. *Klaudyan*, *4*(1), 32–55.

Kuemmerle, T., Hostert, P., Radeloff, V. C., van der Linden, S., Perzanowski, K., & Kruhlov, I. (2008). Cross-border comparison of post-socialist farmland abandonment in the Carpathians. *Ecosystems*, *11*(4), 614–628. doi: 10.1007/s10021-008-9146-z

Kuemmerle, T., Radeloff, V. C., Perzanowski, K., & Hostert, P. (2006). Cross-border comparison of land cover and landscape pattern in eastern europe using a hybrid classification technique. *Remote Sensing of Environment*, *103*(4), 449–464. doi: 10.1016/j.rse.2006.04.015

Kupková, L., Bičík, I., & Najman, J. (2013). Land Cover Changes along the Iron Curtain 1990-2006. *Geografie*, *118*(2), 95–115.

Kurz, P. (2018). Between Smallholder Traditions and "Ecological Modernisation" – Agricultural Transformation, Landscape Change and the Cap in Austria 1995–2015. *European Countryside*, *10*(1), 158–179. doi: 10.2478/euco-2018-0010

Lasanta, T., Arnáez, J., Pascual, N., Ruiz-Flaño, P., Errea, M., & Lana-Renault, N. (2017). Space–time process and drivers of land abandonment in Europe. *CATENA*, *149*, 810–823. doi: 10.1016/j.catena.2016.02.024

Ledvinka, F., Hušek, P., & Nováková, J. (1999). *The enlargement of mla zubrnice proposal.* Národní památkový ústav, Ústí nad Labem.

Leitão, A. (2006). *Measuring landscapes : a planner's handbook*. Washington, DC: Island Press.

Levers, C., Schneider, M., Prishchepov, A. V., Estel, S., & Kuemmerle, T. (2018). Spatial variation in determinants of agricultural land abandonment in Europe. *Science of The Total Environment*, *644*(July), 95–

111. doi: 10.1016/j.scitotenv.2018.06.326

Lieskovský, J., Bezák, P., Špulerová, J., Lieskovský, T., Koleda, P., Dobrovodská, M., … Gimmi, U. (2015). The abandonment of traditional agricultural landscape in slovakia – analysis of extent and driving forces. *Journal of Rural Studies*, *37*, 75–84. doi: 10.1016/j.jrurstud.2014.12.007

Linnell, J. D. C., Trouwborst, A., Boitani, L., Kaczensky, P., Huber, D., Reljic, S., … Breitenmoser, U. (2016). Border Security Fencing and Wildlife: The End of the Transboundary Paradigm in Eurasia? *PLOS Biology*, *14*(6), e1002483. doi: 10.1371/journal.pbio.1002483

Mahoney, J. (2012). The logic of process tracing tests in the social sciences. *Sociological Methods & Research*, *41*(4), 570–597. doi: 10.1177/0049124112437709

Max Planck Institute for Demographic Research. (2019). *Mosaic project: Historical gis datafiles.* Retrieved from `https://censusmosaic.demog.berkeley.edu/data/historical-gis-files`

McGarigal, K., & Marks, B. (1995). *FRAGSTATS: spatial pattern analysis program for quantifying landscape structure*.

McWilliams, A. (2012). The heritage of a metaphor: archaeological investigations of the Iron curtain. In M. Sarah, O. Hillary, & S. Penrose (Eds.), *The good, the bad and the unbuilt: Handling the heritage of recent past* (pp. 19–28).

Meyfroidt, P. (2015). Approaches and terminology for causal analysis in land systems science. *Journal of Land Use Science*, *4248*(April), 1–27. doi: 10.1080/1747423X.2015.1117530

Mücher, C. A., Klijn, J. A., Wascher, D. M., & Schaminée, J. H. (2010). A new European Landscape Classification (LANMAP): A transparent, flexible and user-oriented methodology to distinguish landscapes. *Ecological Indicators*, *10*(1), 87–103. doi: 10.1016/j.ecolind.2009.03.018

Munteanu, C., Kuemmerle, T., Boltiziar, M., Butsic, V., Gimmi, U., Halada, L., … Radeloff, V. C. (2014). Forest and agricultural land change in the carpathian region—a meta-analysis of long-term patterns and drivers of change. *Land Use Policy*, *38*, 685–697. doi: 10.1016/j.landusepol.2014.01.012

Niemi, G. J., Johnson, L. B., & Howe, R. W. (2015). Environmental Indicators of Land Cover, Land Use, and Landscape Change. In *Environmental indicators* (pp. 265–276). Dordrecht: Springer Netherlands. doi: 10.1007/978-94-017-9499-2_16

Noguchi, K., Gel, Y. R., Brunner, E., & Konietschke, F. (2012). nparLD : An R Software Package for the Nonparametric Analysis of Longitudinal Data in Factorial Experiments. *Journal of Statistical Software*, *50*(12), 1–23. doi: 10.18637/jss.v050.i12

NPU. (2018). *Památkový katalog, památková rezervace zubrnice [cultural heritage catalogue]. http://pamatkovykatalog.cz/.*

NSRC. (1954). *Národní shromáždění republiky československé, zákon 50/1959 sb. ze dne 9. července 1959 o zemědělské dani (21/1959).*

O'Neill, R. V., Krummel, J. R., Gardner, R. H., Sugihara, G., Jackson, B., DeAngelis, D. L., … Graham, R. L. (1988). Indices of landscape pattern. *Landscape Ecology*, *1*(3), 153–162. doi: 10.1007/bf00162741

Opršal, Z., Šarapatka, B., & Kladivo, P. (2013). Land-Use Changes and Their Relationships to Selected Landscape Parameters in Three Cadastral Areas in Moravia (Czech Republic). *Moravian Geographical Reports*, *21*(1), 41–50. doi: 10.2478/mgr-2013-0004

Overmars, K. P., de Groot, W. T., & Huigen, M. G. A. (2007). Comparing inductive and deductive modeling of land use decisions: Principles, a model and an illustration from the philippines. *Human Ecology*, *35*(4), 439–452. doi: 10.1007/s10745-006-9101-6

Palang, H. (2010). Time boundaries and landscape change: collective farms 1947-1994. *European Countryside*, *2*(3), 169–181. doi: 10.2478/v10091-010-0012-6

Palang, H., Spek, T., & Stenseke, M. (2011). Digging in the past: New conceptual models in landscape history and their relevance in periurban landscapes. *Landscape and Urban Planning*, *100*(4), 344–346. doi: 10.1016/j.landurbplan.2011.01.012

Parker, D. C., Manson, S. M., Janssen, M. A., Hoffmann, M. J., & Deadman, P. (2003). Multi-agent systems for the simulation of land-use and land-cover change: A review. *Annals of the Association of American Geographers*, *93*(2), 314–337. doi: 10.1111/1467-8306.9302004

Pazúr, R., & Bolliger, J. (2017). Land changes in Slovakia: Past processes and future directions. *Applied Geography*, *85*, 163–175. doi: 10.1016/j.apgeog.2017.05.009

Peng, J., Wang, Y., Zhang, Y., Wu, J., Li, W., & Li, Y. (2010). Evaluating the effectiveness of landscape metrics in quantifying spatial patterns. *Ecological Indicators*, *10*(2), 217–223. doi: 10.1016/j.ecolind.2009.04.017

Plieninger, T. (2012). Monitoring directions and rates of change in trees outside forests through multitemporal analysis of map sequences. *Applied Geography*, *32*(2), 566–576. doi: 10.1016/j.apgeog.2011.06.015

Plieninger, T., Draux, H., Fagerholm, N., Bieling, C., Bürgi, M., Kizos, T., … Verburg, P. H. (2016). The driving forces of landscape change in Europe: A systematic review of the evidence. *Land Use Policy*, *57*, 204–214. doi: 10.1016/j.landusepol.2016.04.040

Plieninger, T., Kizos, T., Bieling, C., Dû-Blayo, L. L., Budniok, M.-A., Bürgi, M., … Verburg, P. H. (2015). Exploring ecosystem-change and society through a landscape lens: recent progress in european landscape research. *Ecology and Society*, *20*(2). doi: 10.5751/es-07443-200205

Prishchepov, A. V., Radeloff, V. C., Baumann, M., Kuemmerle, T., & Müller, D. (2012). Effects of institutional changes on land use: Agricultural land abandonment during the transition from state-command to market-driven economies in post-Soviet Eastern Europe. *Environmental Research Letters*, *7*(2). doi: 10.1088/1748-9326/7/2/024021

Prokopová, M., Cudlín, O., Včeláková, R., Lengyel, S., Salvati, L., & Cudlín, P. (2018). Latent Drivers of Landscape Transformation in Eastern Europe: Past, Present and Future. *Sustainability*, *10*(8), 2918. doi: 10.3390/su10082918

Pulec, M. (2006). *Organizace a činnost ozbrojených pohraničních složek, Seznamy osob usmrcených na státních hranicích 1945–1989* (Sešity č.1 ed.). Úřad dokumentace a vyšetřování zločinů komunismu.

Qasim, M., Hubacek, K., & Termansen, M. (2013). Underlying and proximate driving causes of land use change in district swat, pakistan. *Land Use Policy*, *34*, 146–157. doi: 10.1016/j.landusepol.2013.02.008

Queiroz, C., Beilin, R., Folke, C., & Lindborg, R. (2014). Farmland abandonment: threat or opportunity for biodiversity conservation? A global review. *Frontiers in Ecology and the Environment*, *12*(5), 288–

296. doi: 10.1890/120348

R Core Team. (2019). R: A language and environment for statistical computing [Computer software manual]. Vienna, Austria.

Rak, M., Funk, L., & Starková, L. (2016). A cold war conflict landscape in the borderlands of west bohemia. In *Conflict landscapes and archaeology from above* (pp. 267–284). Routledge.

Rašín, R., & Chromý, P. (2010). Land use and land cover development along the Czech-Austrian Boundary. In I. Bičík, Y. Himiyama, & J. Feranec (Eds.), *Land use/cover changes in selected regions in the world* (Vol. 5, pp. 57–65). Japan: Institute of Geography, Hokkaido University of Education, Asahikawa.

Raška, P., Zábranský, V., Dubišar, J., Kadlec, A., Hrbáčová, A., & Strnad, T. (2014). Documentary proxies and interdisciplinary research on historic geomorphologic hazards: a discussion of the current state from a central European perspective. *Natural Hazards*, *70*(1), 705–732. doi: 10.1007/s11069-013-0839-z

Rasul, G., Thapa, G. B., & Zoebisch, M. A. (2004). Determinants of land-use changes in the chittagong hill tracts of bangladesh. *Applied Geography*, *24*(3), 217–240. doi: 10.1016/j.apgeog.2004.03.004

Reid, R. S., Kruska, R. L., Muthui, N., Taye, A., Wotton, S., Wilson, C. J., & Mulatu, W. (2000).
Landscape Ecology, *15*(4), 339–355. doi: 10.1023/a:1008177712995

Röder, A., Pröpper, M., Stellmes, M., Schneibel, A., & Hill, J. (2015). Assessing urban growth and rural land use transformations in a cross-border situation in Northern Namibia and Southern Angola. *Land Use Policy*, *42*, 340–354. doi: 10.1016/j.landusepol.2014.08.008

Rumley, D. (2014). *The Geography of Border Landscapes*. Routledge. doi: 10.4324/9781315746593

SALSC. (2019). *State administration of land surveying and cadastre - web map service for cadastral maps (wms kn) s.* Retrieved from `https://www.cuzk.cz/Katastr-nemovitosti/Poskytovani-udaju-z-KN/Webove-mapove-sluzby-pro-katastralni-mapy-(WMS-KN).aspx`

Sanders, J., Nieberg, H., & Offermann, F. (2016). Impact of the 2003 CAP Reform on Organic Farming in Germany. In A. Sorrentino (Ed.), *The common agricultural policy after the fischler reform* (pp. 231–243). Routledge. doi: 10.22004/ag.econ.44845

Schaffert, M., & Steensen, T. (2017). Land Cover Changes in Northern Germany Between 1990 and 2000 – An East-West Perspective. A study based on CORINE Land Cover data. *Land Ownership and Land Use Development: he Integration of Past, Present, and Future in Spatial Planning and Land Management Policies*, 157–169.

Schubert, F. N. (2011). *Hungarian Borderlands: From the Habsburg Empire to the Axis Alliance, the Warsaw Pact and the European Union*. Bloomsbury Publishing.

Senetra, A., Szczepańska, A., Veteikis, D., Wasilewicz-Pszczółkowska, M., Šimanauskienė, R., & Volungevičius, J. (2013). Changes of the land use patterns in Polish and Lithuanian trans-border rural area. *Baltica*, *26*(2), 157–168. doi: 10.5200/baltica.2013.26.16

Sheffer, E. (2011). *Burned bridge : how east and west germans made the iron curtain*. New York: Oxford University Press.

Šímová, P. (2017). Identifying HNV areas using geographic information systems and landscape metrics. In *Birds as useful indicators of high nature value farmlands* (pp. 37–51). Springer International Publishing. doi: 10.1007/978-3-319-50284-7_3

Šímová, P., & Gdulová, K. (2012). Landscape indices behavior: A review of scale effects. *Applied Geography*, *34*, 385–394. doi: 10.1016/j.apgeog.2012.01.003

Skaloš, J., Weber, M., Lipský, Z., Trpáková, I., Šantrůčková, M., Uhlířová, L., & Kukla, P. (2011). Using old military survey maps and orthophotograph maps to analyse long-term land cover changes – case study (czech republic). *Applied Geography*, *31*(2), 426–438. doi: 10.1016/j.apgeog.2010.10.004

Sklenička, P., Janovska, V., Salek, M., Vlasak, J., & Molnarova, K. (2014, May). The farmland rental paradox: Extreme land ownership fragmentation as a new form of land degradation. *Land Use Policy*, *38*, 587–593. doi: 10.1016/j.landusepol.2014.01.006

Sklenička, P., Molnarova, K., Brabec, E., Kumble, P., Pittnerova, B., Pixova, K., & Salek, M. (2009). Remnants of medieval field patterns in the Czech Republic: Analysis of driving forces behind their disappearance with special attention to the role of hedgerows. *Agriculture, Ecosystems & Environment*, *129*(4), 465–473. doi: 10.1016/j.agee.2008.10.026

Sklenička, P., Šímová, P., Hrdinová, K., & Šálek, M. (2014). Changing rural landscapes along the border of Austria and the Czech Republic between 1952 and 2009: Roles of political, socioeconomic and environmental factors. *Applied Geography*, *47*, 89–98. doi: 10.1016/j.apgeog.2013.12.006

Skokanová, H., Falťan, V., & Havlíček, M. (2016). Driving forces of main landscape change processes from past 200 years in Central Europe - differences between old democratic and post-socialist countries. *Ekológia (Bratislava)*, *35*(1), 50–65. doi: 10.1515/eko-2016-0004

Stark, K. (1907). *Ergebnisse der obstbaumzählung im vereinsgebiete des obst- und gartenbau-vereines für das deutsche elbetal in böhmen: nach dem stande vom jahre 1905*. Henckel.

Statistische Zentralkommission, k.k. (1904). *Gemeindelexikon von böhmen. bearbeitet auf grund der ergebnisse der volkszählung vom 31. dezember 1900*. Wien, k. k. Hof- und Staatsdruckerei.

Strijker, D. (2005). Marginal lands in Europe—causes of decline. *Basic and Applied Ecology*, *6*(2), 99–106. doi: 10.1016/j.baae.2005.01.001

Thapa, G. B., & Rasul, G. (2006). Implications of changing national policies on land use in the chittagong hill tracts of bangladesh. *Journal of Environmental Management*, *81*(4), 441–453. doi: 10.1016/j.jenvman.2005.12.002

Tian, F., Herzschuh, U., Mischke, S., & Schlütz, F. (2014). What drives the recent intensified vegetation degradation in mongolia – climate change or human activity? *The Holocene*, *24*(10), 1206–1215. doi: 10.1177/0959683614540958

Tomson, P., Bunce, R. G. H., & Sepp, K. (2015). The role of slash and burn cultivation in the formation of southern Estonian landscapes and implications for nature conservation. *Landscape and Urban Planning*, *137*, 54–63. doi: 10.1016/j.landurbplan.2014.12.015

UAZK. (2018). *Ústřední archiv zeměměřictví a katastru, výkazy s porovnáním ploch 1845 a 1948. http://archivnimapy.cuzk.cz/.*

Uuemaa, E., Antrop, M., Roosaare, J., Marja, R., & Mander, U. (2009). Landscape metrics and indices : an overview of their use in landscape research. *Living reviews in landscape research*, *3*(1), lrlr-2009-1:1–lrlr-2009-1:28.

Vaishar, A., Šťastná, M., Trnka, P., Dvořák, P., & Zapletalová, J. (2013).

South-Moravian Rural Borderland. *European Countryside*, *5*(2), 115–132. doi: 10.2478/euco-2013-0008

Valipour, M. (2015). Land use policy and agricultural water management of the previous half of century in Africa. *Applied Water Science*, *5*(4), 367–395. doi: 10.1007/s13201-014-0199-1

van der Sluis, T., Pedroli, B., Kristensen, S. B., Lavinia Cosor, G., & Pavlis, E. (2016). Changing land use intensity in Europe – Recent processes in selected case studies. *Land Use Policy*, *57*, 777–785. doi: 10.1016/j.landusepol.2014.12.005

van Dijk, T. (2003). Scenarios of central european land fragmentation. *Land Use Policy*, *20*(2), 149–158. doi: 10.1016/s0264-8377(02)00082-0

van Noordwijk, M., Lusiana, B., Villamor, G., Purnomo, H., & Dewi, S. (2011). Feedback loops added to four conceptual models linking land change with driving forces and actors. *Ecology and Society*, *16*(1).

van Vliet, J., de Groot, H. L., Rietveld, P., & Verburg, P. H. (2015). Manifestations and underlying drivers of agricultural land use change in Europe. *Landscape and Urban Planning*, *133*, 24–36. doi: 10.1016/j.landurbplan.2014.09.001

van Zanten, B. T., Verburg, P. H., Espinosa, M., Gomez-y Paloma, S., Galimberti, G., Kantelhardt, J., … Viaggi, D. (2014). European agricultural landscapes, common agricultural policy and ecosystem services: a review. *Agronomy for Sustainable Development*, *34*(2), 309–325. doi: 10.1007/s13593-013-0183-4

Verburg, P. H. (2014). The Representation of Human-Environment Interactions in Land Change Research and Modelling. In M. J. Manfredo, J. J. Vaske, A. Rechkemmer, & E. A. Duke (Eds.), *Understanding society and natural resources: Forging new strands of integration across the social sciences* (pp. 161–177). Dordrecht: Springer Netherlands. doi: 10.1007/978-94-017-8959-2_8

Vojta, J. (2007). Relative importance of historical and natural factors influencing vegetation of secondary forests in abandoned villages. *Preslia*, *79*(3), 223–244.

Vráblíková, J. (1995). *Perspektivy ekomuzea v zubrnicích: závěrečná zpráva za úkol*. Ústí nad Labem, Univerzita J. E. Purkyně.

Wagner, H. H., & Fortin, M.-J. (2005). Spatial analysis of landscapes:

concepts and statistics. *Ecology*, *86*(8), 1975–1987. doi: 10.1890/04-0914

Walz, U. (2008). Monitoring of landscape change and functions in Saxony (Eastern Germany)—Methods and indicators. *Ecological Indicators*, *8*(6), 807–817. doi: 10.1016/j.ecolind.2007.09.006

Wickham, H. (2009). *ggplot2*. Springer New York. doi: 10.1007/978-0-387-98141-3

Wilson, O., & Klages, B. (2001). Farm restructuring in the ex-GDR: towards a new farm model? *Journal of Rural Studies*, *17*(3), 277–291. doi: 10.1016/S0743-0167(01)00011-0

Wollkopf, M., & Wollkopf, H.-F. (1997). Changes in the Agricultural Structure in the Five New Federal States since the Reunification of Germany. *Geographical review of Japan, Series B.*, *70*(2), 57–73. doi: 10.4157/grj1984b.70.57

Wu, J., & Hobbs, R. (2002). Key issues and research priorities in landscape ecology: An idiosyncratic synthesis. *Landscape Ecology*, *17*(4), 355–365. doi: 10.1023/a:1020561630963

Xie, Y. J., & Ng, C. N. (2013). Exploring spatio-temporal variations of habitat loss and its causal factors in the Shenzhen River cross-border watershed. *Applied Geography*, *39*, 140–150. doi: 10.1016/j.apgeog.2013.01.001

Yang, Y., Zhang, S., Yang, J., Chang, L., Bu, K., & Xing, X. (2014). A review of historical reconstruction methods of land use/land cover. *Journal of Geographical Sciences*, *24*(4), 746–766. doi: 10.1007/s11442-014-1117-z

Yoder, J. A. (2003). Bridging the European Union and Eastern Europe: Cross-border Cooperation and the Euroregions. *Regional & Federal Studies*, *13*(3), 90–106. doi: 10.1080/13597560308559436

Yu, X. J., & Ng, C. N. (2007). Spatial and temporal dynamics of urban sprawl along two urban–rural transects: A case study of guangzhou, china. *Landscape and Urban Planning*, *79*(1), 96–109. doi: 10.1016/j.landurbplan.2006.03.008

Zarina, A. (2010). Path dependency and landscape biographies in Latgale, Latvia: a comparative analysis. *European Countryside*, *2*(3), 151–168. doi: 10.2478/v10091-010-0011-7

Ženka, J., & Kofroň, J. (2012). *Metodologie výzkumu v sociální geografii -*

případové studie. Ostravská univerzita v Ostravě.

Zhao, C., Jensen, J., & Zhan, B. (2017). A comparison of urban growth and their influencing factors of two border cities: Laredo in the US and Nuevo Laredo in Mexico. *Applied Geography*, *79*, 223–234. doi: 10.1016/j.apgeog.2016.12.017

Curriculum vitae

Personal:

Martin Dolejš, born 1986 in the Czech Republic

Affiliations:

Since 2015 Department of Geography, Faculty of Science, Jan Evangelista Purkyně University in Ústí nad Labem, Czechia

Education:

(since 2014): present PhD; Faculty of Environmental Science, Department of Applied Geoinformatics and Spatial Planning, Czech University of Life Sciences Prague; thesis topic: Application of landscape metrics for evaluation of landscape structure development in border areas

(2008 - 2010) Master's degree: Geography, Department of Geography, Faculty of Science, Jan Evangelista Purkyně University in Ústí nad Labem; thesis topic: Recreational potential of suburban forests in the vicinity of Ústí nad Labem

(2009) Semestral Exchange: Landscape Architecture, Suleyman Demirel Universtitesi, Isparta, Turkey

(2008) Semestral Exchange: Baltic Studies, Tallinn University, Tallinn, Estonia

(2005 - 2008) Bachelor's degree: Geography, Department of Geography, Faculty of Science, Jan Evangelista Purkyně University in Ústí nad Labem; thesis topic: Development of Melnik city with a view to urbanistic design, capital build-up and dotation policy

Teaching experience:

(Since 2014) Lecturer of GIS, Geoinformatics, Landscape ecology

(Since 2014) Supervisor and reviewer of Bachelor and Master Thesis (Geography, GIS application)

Participation in research projects:

(2020 - 2023) Grant Agency of the Czech Republic ("GAČR"), Nature and dynamics of local land use conflicts in polyrational environment, land use modelling

(2018 - 2023) OP VVV, SMART CITY, urban vulnerability modelling

(2018 - 2021) COST, LAND4FLOOD: Natural Flood Retention on Private Land (CA16209), flood modelling

(2016 - 2017) Technology Agency of the Czech Republic ("TAČR"), Ecohydrological management of urban microstructures, remote sensing data processing

Other:

Member of Czech Geographic Society, member of academic senate

Impact publications (J_{imp}):

- Dolejš, M., Samek, V., Veselý, M., Elznicová, J. (in press) Detecting World War II bombing relics in markedly transformed landscapes (city of Most, Czechia). Applied Geography.

- Forejt, M., Dolejš, M., Vardarman, J., Raška, P. (in press). Quantifying inconsistencies in old cadastral maps and their impact on land-use reconstructions. Journal Land Use Science.

- Pacina, J., Lenďáková, Z., Štojdl, J., Matys Grygar, T., Dolejš, M. (2020). Dynamics of Sediments in Reservoir Inflows: A Case Study of the Skalka and Nechranice Reservoirs, Czech Republic. ISPRS Int. J. Geo-Information, 9 (258).

- Dolejš, M., Nádvorník, J., Raška, P., & Riezner, J. (2019). Frozen Histories or Narratives of Change? Contextualizing Land-Use Dynamics for Conservation of Historical Rural Landscapes. Environmental Management, 63(3), 352–365.

- Forejt, M., Dolejš, M., & Raška, P. (2018). How reliable is my historical land-use reconstruction? Assessing uncertainties in old cadastral maps. Ecological Indicators, 94, 237–245.

- Raška, P., Dolejš, M., & Hofmanová, M. (2017). Effects of Damming on Long-Term Development of Fluvial Islands, Elbe River. River Research and Applications, 33(4), 471–482.

Scopus publications (J_{SC}):

- Dolejš, M., & Forejt, M. (2019). Franziscean cadastre in landscape structure research: a systematic review. Quaest. Geographicae, 38(1), 131–144.

- Slavík, J., Rybová, K., & Dolejš, M. (2018). Biowaste separation at source and its limitations based on spatial conditions. Detritus, 5(1).

- Dolejš, M., Glorius, B., & Hruška, V. (2016). Motives and barriers of migration to Saxony: the case of migrating health professionals from Czechia. GeoScape, 10(2), 62–77.

- Prekop, M., & Dolejš, M. (2016). Do bypass routes reduce noise disturbances in cities? Case study of Cheb (Western Bohemia, Czech Republic). Geographia Technica, 11(2), 78–86.