Land Use Policy 38 (2014) 685–697

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Forest and agricultural land change in the Carpathian region—A meta-analysis of long-term patterns and drivers of change

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ARTICLE INFO

Article history:
Received 29 July 2013
Received in revised form 17 January 2014
Accepted 22 January 2014

Keywords:
Long-term historical land use
Land use legacies
Deforestation
Reforestation
Agricultural expansion
Abandonment
Drivers of land change

ABSTRACT

Humans have altered land cover for centuries, and land-cover change is a main component of global change. Land use transition trajectories, such as the forest transition theory (i.e. switch from deforestation to stable or increasing forest cover), relate long term changes in land use to gradual changes in underlying drivers, such as economic development, demographic change, and urbanization. However, because only few studies examined land change over centuries, it is not clear how land cover changes during very long time-periods which are punctuated by shifts in socio-economics and policies, such as wars. Our goal here was to examine broad land change patterns and processes, and their main driving forces in Central and Eastern Europe during distinct periods of the past 250 years. We conducted a meta-analysis of 66 publications describing 102 case study locations and quantified the main forest and agricultural changes in the Carpathian region since the 18th century. These studies captured gradual changes since the peak of the Austro-Hungarian Empire up to the accession to the European Union of most of the formerly socialist countries in the study region. Agricultural land-use increased during the Austro-Hungarian Empire in 70% of the case studies, but dropped sharply during and especially after the collapse of the Socialism (over 70% of the cases). The highest rates of abandonment occurred between 1990 and 2000. The Carpathian region experienced forest transition during the Interwar period (93% of the cases), and the forest expansion trend persisted after the collapse of Socialism (70% of the cases). In terms of the drivers, institutional and economic factors were most influential in shaping deforestation and agricultural expansion, while socio-demographics and institutional shifts were the key drivers of land abandonment. Our study highlights the drastic effects that socio-economic and institutional changes can have on land-use and land-cover change, and the value of longitudinal studies of land change to uncover these effects.

Introduction

Land-cover change is a main component of global environmental change (Foley et al., 2005), affecting climate, biodiversity and

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http://dx.doi.org/10.1016/j.landusepol.2014.01.012

ecosystem services, which in turn, affect land-use decisions (Ojima et al., 1994). Humans have altered land cover for centuries, but recent rates of change are higher than ever (Foley et al., 2005; Goldewijk, 2001; Hansen et al., 2010). The temporal dimension of change is particularly interesting because land-use legacies may persist for centuries (Foster et al., 2003). Over long time periods though, land-use transition theories predict gradual changes, primarily as a function of demographic and economic factors (DeFries et al., 2004; Foley et al., 2005). For example, forest transition theory postulates that gradual economic and demographic change leads to agricultural specialization and reforestation of marginal lands, and defines the transition point as the time of the lowest forest cover in a given country or region (Mather, 1992; Meyfroidt and Lambin, 2011). Different regions may experience these transitions at different points in time, depending on economic, political or institutional condition (Meyfroidt and Lambin, 2011) or go through multiple transition phases (Yeo and Huang, 2013), as land systems respond to institutional and economic changes (Lambin et al., 2001). Shifts in political systems, and the related socio-economic adaptations, such as those following the collapse of the Soviet Union, greatly affect land trends (Hostert et al., 2011). The question is though first, how land cover changes over long time periods, and how these changes vary depending on economic, institutional and social factors. Regional land change patterns are the combined result of changes at much finer scale, that are driven by complex economic, policy and institutional, demographic and market forces (Lambin and Meyfroidt, 2010; Verburg et al., 2009). These localized changes, in turn, are constrained by interacting broad- and local-scale driving forces, especially in crisis situations (Cioroianu, 2007). While, the local-scale drivers of land-use change can be understood from case-studies (Foley et al., 2005), the variation of these drivers across regions can only be understood from a broader perspective.

Capturing land change under successive distinct economic periods and documenting change processes over large areas and long time periods (e.g., centuries) is often impossible due to the lack of consistent, broad-scale and long-term data. When that is the case, a meta-analysis can be a valuable tool for synthesizing knowledge and extracting broader scale patterns and drivers of change (Poteete and Ostrom, 2008; Rudel, 2008). Meta-analyses have been applied to assess, for example, long-term urban growth across the globe (Seto et al., 2011), desertification (Geist and Lambin, 2004), deforestation (Geist and Lambin, 2002), and tropical agriculture (Keys and McConnell, 2005). In regard to forest change, such a meta-analysis showed that tropical deforestation is a result of interacting proximate causes and underlying driving forces, which vary geographically and with historical context (Geist and Lambin, 2002). Another meta-analysis focusing on forest cover in Mexico showed that cattle ranching and outmigration cause deforestation in lowland areas, while highland regions with outmigration experience forest cover increase (Rudel, 2008). Dryland degradation globally has been attributed to the combined effects of climate, economies and institutions which drive cropland expansion, overgrazing and infrastructure development (Geist and Lambin, 2004). In Central Eastern Europe, Kozak (2010) analyzed land change across a number of local case studies to describe forest transition in the Polish Carpathian Mountains as occurring between the two World Wars (WW). However, while most meta-analyses examined broad spatial extents and explain spatial variation, their temporal scale has been limited to decades, which limits the ability to isolate effects and legacies of major socio-economic shifts across time and space. Furthermore, most meta-analyses of land change processes included only case studies that were published in English (Geist and Lambin, 2004; McConnell and Keys, 2005; Seto et al., 2011), thus not including local research and knowledge.

Broad scale, long term comparative studies across countries of Eastern Europe are still lacking (Björnsen-Gurung et al., 2009), despite the availability of a high number of local, regionally published studies. Given its long land-use history and multiple social, political and economic shocks, the Carpathian region represents a "natural experiment" (Gehlbach and Malesky, 2010) to examine long-term land-use change and to develop a broader synthesis of land-use histories.

Our overall goal was to identify and quantify broad-scale and long-term land change patterns and processes during times of shocks, and the main driving forces of these changes. To do so, we conducted a meta-analysis of historical land change studies for the Carpathian region, reaching as far back as 1790s.

Specifically, our objectives were to:

(1) Assess and quantify the main forest and agricultural changes in the Carpathian region for politically and economically distinct time periods over the past 250 years;
(2) Assess the heterogeneity of the local-scale studies across the region;
(3) Identify the main drivers of long-term land-use change and the impact of major socio-economic shocks on forest and agricultural change.

Methods

Study area

We studied the 350,000 km^2 Carpathian region in Eastern Europe, which comprises two major eco-regions: the Carpathian Mountains and the Pannonian Plains. The study area includes parts of the Czech Republic, Poland, Ukraine and Romania, and all of Hungary and Slovakia (Fig. 1), has a temperate climate, and landscapes consisting mostly of a mosaic of forests, pastures, and agricultural fields. The region harbors some of the largest contiguous temperate forests in Europe (Knorn et al., 2009; Kuemmerle et al., 2007) alongside high nature conservation value farmland (Paracchini et al., 2008). The Pannonian plains also represent one of the most fertile regions in Europe (Schiller et al., 2010). The Carpathian eco-region is a global biodiversity hotspot, particularly regarding plant diversity, and harbors rare old-growth and alpine meadow ecosystems and many wildlife species of conservation concern (e.g., brown bear, wolf, lynx, European bison (Salvatori et al., 2002).

The region has a long land-use history, with centuries of agricultural and forest land use being influenced by changes in political, economic and demographic dynamics (Verburg et al., 2009). Land-cover changes during recent decades (since 1980s), have been captured by remote sensing analyses of the entire region, and showed overall increases in forest cover and agricultural abandonment (Griffiths et al., 2014; Kuemmerle et al., 2008). However, our understanding of long-term land-use trends remains scattered across numerous local-scale case-studies dispersed across the region (e.g., Feranec and Ot'ahel, 2009; Kaim, 2009; Ostafin, 2009) and a synthesis of these studies is lacking.

Theoretical land change predictions

In order to understand land-use trends in the region, we examined agricultural and forest change during five historical periods with distinctive socio-economic, political, technological and cultural characteristics, that were demarcated by several large-scale shocks: (1) the Habsburg and Austro-Hungarian Empires (K.u.K. Monarchy), a time of agricultural modernization and the beginning of the industrial revolution, which ended with World War I (WW I), (2) the Interwar period, characterized by the emergence of several nation-states, industrialization and intensification up to World War II (WW II), (3) the Socialist period,

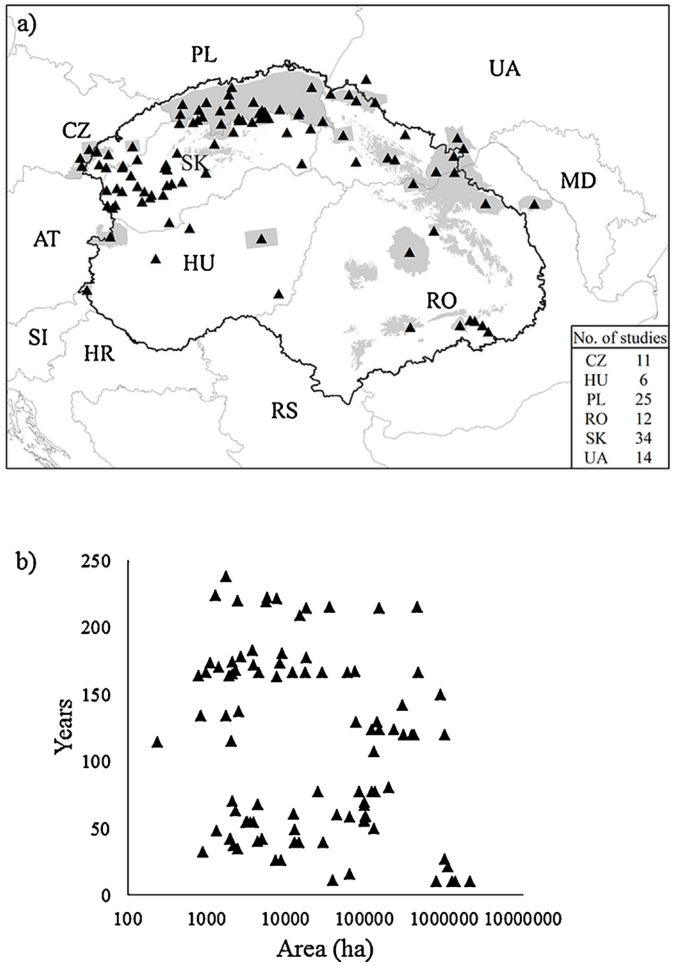

Fig. 1. (a) Study area, including spatial extent of case studies (gray) and centroids for 102 case study locations (triangles). Country codes: AT: Austria, HU: Hungary, PL: Poland, CZ: Czech Republic, SK: Slovakia, UA: Ukraine, RO: Romania, MD: Moldova, HR: Serbia, SI: Slovenia. (b) Spatio-temporal distribution of 102 study locations (one location may include multiple case-studies).

defined by intensification, centrally planned economies and land reforms leading to nationalization and collectivization, which ended around 1990 in the Carpathian countries, (4) the Transition when countries established market economies and land reforms took place, which lasted roughly until 2000, and lastly (5) the Accession of most countries to the EU in either 2004 and 2007 (except Ukraine), a period influenced by EU's trade, agricultural, and economic policies. We considered this last time period to start in 2000 because that is when most countries already adjusted their regulations and legislation according to European standards.

We formulated a set of expected land change trends for each period, based on overall socio-economic and technological trends during the respective time periods. Specifically, we predicted that the expansion of the Austro-Hungarian Empire, and the industrial revolution, led to homogenization and specialization of land use practices (Bičík et al., 2001), manifested as an increase in agricultural lands and a decrease in forest cover up to WW II. Under socialism, natural resource use intensified (Cioroianu, 2007), and we hypothesized that agricultural expansion, intensification and in some countries collectivization, led to an increase of agricultural land, especially in lowland areas, while abandonment of marginal lands allowed for forest recovery. We expected that the collapse of socialism, followed by the changes in ownership structure and the establishment of market economies led to a decrease in agricultural lands due to abandonment and forest re-growth during the Transition period (Baumann et al., 2011; Kuemmerle et al., 2009a,b; Prishchepov et al., 2013). We also expected that the effects of the EU macro-economic policies would result in the increase of agricultural lands due to subsidies (Björnsen-Gurung et al., 2009) and continued forest transition (Lambin and Meyfroidt, 2010). We hypothesized thus increases in both agricultural lands (over previously abandoned fields) and forest cover after 2000 (Csaki and Jambor, 2009). For a summary of these expected trends, see Table 1.

Data

We collected case study information on forest and agricultural change both from peer-reviewed articles and gray literature. We used Google Scholar and regional scientific databases using combinations of "historic", "land-use/land-cover change", and "maps" in English and the regional languages (Romanian, Slovakian, and Ukrainian) and complemented this information with traditional library research in the respective countries plus references from local experts in the Czech Republic, Hungary, Ukraine, Poland, Romania and Slovakia. For 85 publications, we extracted information about the study area, land cover at different time periods, and the main drivers of change. In approximately half of the cases, data was provided directly by authors of the paper. For the remaining publications we extracted the data using a structured form. From the total of 85 publications, we selected and analyzed those 66 papers (listed in Appendix 1) that (1) were based on spatially-explicit data (historic maps, aerial photographs, and satellite imagery) and not only statistics; (2) examined land cover at least two points in time, and (3) included spatial data regarding the study location or coordinates of the study region. We excluded papers that did not meet at least one of the three criteria (Appendix 2). We hereafter refer to a case study as being a single geographical location at which either forest or agricultural (or both) land cover was reported during a given time period. Some papers contained several case studies, reporting land-cover change in multiple locations. We did not include in our meta-analysis recent broad-scale remote sensing land change studies based on Landsat data (Alcantara et al., 2012; Baumann et al., 2011; Griffiths et al., 2014; Knorn et al., 2012, 2009; Kuemmerle et al., 2011, 2009a, 2008, 2007; Prishchepov et al., 2012), due to their significantly different spatial extent, frequent overlap among studies, and generally short duration, but we considered them in the discussion of change drivers. In sum, the 66 papers contained a total of 102 case study locations, for which change rates were calculated for one or more time-periods (Fig. 1 and Table 1). The spatial extent of the individual studies spans from 240 ha (Wolski, 2001) to over 2 million hectares (Grekov, 2002), with the median at 12,500 ha (Fig. 1b). On a temporal scale, the shortest time period covered by all case studies at a single location was 10 years (Grekov, 2002), and the longest 238 years (Mojses and Boltižiar, 2011). The mean time covered was 105 years.

Analysis

We developed a common land-cover class catalog, which was applied to all studies. In most instances, this necessitated the aggregation of classes (e.g., 'permanent' and 'seasonal crops' were combined into 'agriculture'). The final product was land-cover data for 'forest', 'agriculture' and 'other' land covers. We calculated the annual rate of change for each land-cover class following the model of FAO forest change assessments (Pandey, 1995) which uses a formula based on the compound interest law in order to compare among sites (Puyravaud, 2003):

$$Ann_{\text{change}} = \left(\frac{A_2}{A_1}\right)^{1/(t_2-t_1)} - 1 \qquad (1)$$

Table 1
Time periods, their duration, the expected land changes and the number of studies that report land change for the specific period. The first number (*) indicates that the annual rate of change has been calculated for only one period. The second number (**) indicates that the case-study spans at least two time periods, and the annual rate of change is calculated based only on land cover at the beginning and end of the considered time span.

Time period	Duration	Expected land change process		Number of case studies	
		Forest	Agricultural	Forest (n)	Agriculture (n)
K.u.K Monarchy	1750–1914	–	+	31*/51**	24*/43**
Interwar	1914–1945	–	+	29*/72**	28*/46**
Socialist	1945–1990	+	+	46*/96**	37*/63**
Transition	1990–2000	+	–	46*/84**	42*/68**
EU accession	2000–2012	+	+	37*/60**	26*/47**

A_1 and A_2 represent the area of land cover of interest (forest or agriculture land) at the times t_1 and t_2. When a case study reported multiple rates within one of the five analyzed time-periods, we calculated weighted averages. Studies that reported a single rate of change across multiple time periods were mapped using a different symbol, as these depict change only between the beginning and end of the first and last period, missing variation within the selected time window. We defined change rates between ±0.1% change/year as 'stable' land use. Centroids were digitized to represent the location of each study and rates of change were calculated for each study and time period under investigation (Fig. 1).

To identify the main drivers, we conducted a qualitative review, categorizing the major types of driving forces as suggested by Geist and Lambin (2004) and Bürgi et al. (2005): institutional, economic, social-demographic, cultural, and climatic. Because our analysis only captured changes in land cover and not in land-use intensity, technological drivers, such as the introduction of fertilizers, or mechanization, which would mostly lead to increased yields or crop rotation, where considered jointly with the economic factors. For each case study, we identified the two most important drivers of change as described by paper authors and regional experts. We counted the number studies that mentioned each driver and qualitatively reviewed each driver across case-studies and the four land change processes of interest (deforestation, reforestation, agricultural expansion, and agricultural abandonment).

Case study representativeness and robustness check

The case studies ranged widely in extent (240 ha to 2.1 million ha) and duration (from 2 to 180 years). We tested for correlation between the absolute values of the annual rate of change and (a) the size of study area, (b) the temporal extent of the studies and (c) the percentage cover at the beginning of the study, but found only weak associations (adjusted R-squares of 0.036, 0.018, and 0.033 respectively). Spatially, land change research was concentrated in the Carpathian Mountains, while lowland areas were underrepresented, except in Ukraine. The highest density of studies was in Poland and Slovakia (Fig. 1). Since 2000, case-studies on agricultural and forest change were relatively sparse due to the short time period under consideration (12 years).

In order to check if case studies represented the general conditions of the respective country's share of the study area, we examined three physical variables, mean elevation, mean slope, and dominant soil type, for each case study and compared mean values of the case-studies with the mean of country's share of the study area. We found that the dominant soil across all countries was Cambisol, as was the case for most of the case-studies, except in Hungary where Luvisols and Fluvisols were overrepresented (Fig. 2). In terms of slope and elevation, case studies in the Czech Republic, Slovakia and Ukraine studies represented their country's physical conditions well. In Poland and Romania, many studies were carried out at higher-than-average elevations and slopes, but the means for the country's share of the study area fall close to the 1st quartile of the case studies distribution in all cases (Fig. 2).

Results

Forest cover increase was the most common land-cover change over the past 250 years in the majority of studies. Among the time periods, we found the highest proportion of case studies reporting decreases in forest cover during the K.u.K. Monarchy (over 22% of studies). However, even during this period, stable forest cover was the most common pattern (mean annual change +0.08%). Forest cover increased during all other periods, especially during the Transition and EU period (mean annual change +1.07% and +0.89%). In the Interwar period, 92% of studies reported stable or increasing forest cover (mean annual change 0.35%, Fig. 3). A high proportion of studies reported forest cover increase (65%) for the Socialist period, in particular in the northern part of the Carpathians (annual mean 0.33%), followed by continuing increasing forest cover during Transition and EU accession periods (73% and 72% respectively). After 2000, forest cover increased (annual mean 0.89%), but in Romania we found high rates of forest cover loss (Figs. 3 and 4).

Agricultural change was generally complementary to forest change, where forests increased, agriculture decreased, and vice versa. However, during the K.u.K Monarchy period, agriculture increased (70% of studies, mean annual increase of 0.12%), while forest cover was mostly stable (45% of studies), indicating agricultural expansion into other land covers (Figs. 3 and 5). The mean annual change of agricultural land during the Interwar period was −1.28%, despite relatively stable agricultural cover (55% of studies, ±0.1% annual change) reported in most studies. After 1945, most studies (>75%) reported a decrease of agricultural land-cover. During the Transition and EU accession periods, there were substantial decreases in agricultural cover (mean annual change of −1.61% and −1.20% respectively). Across time periods, the proportion of studies documenting loss of agricultural land increased constantly until 2000, but dropped slightly after the EU accession (Fig. 3).

There were interesting regional patterns of change though: forest decreased during the K.u.K. Monarchy in the Romanian, Ukrainian, and Slovakian Carpathians, while it increased in the Polish Carpathians, and was stable in the Czech Republic (± 0.1% annual change). During the Interwar period the majority of the forest change case-studies (48%) reported stable or increasing (44%) forest cover (>0.1% annual change) but most of them were in Slovakia, and Poland, while cases of forest loss occurred in Hungary, Romania and Slovakia. Thus, across the region, forest transition occurred during the Interwar period, though we caution that patterns at elevations over 1000 m in Ukraine and Romania were different (Shandra et al., 2013). The most rapid forest increase during the Socialist period occurred in the border region between Poland, Ukraine, and Slovakia (Fig. 4), while deforestation occurred

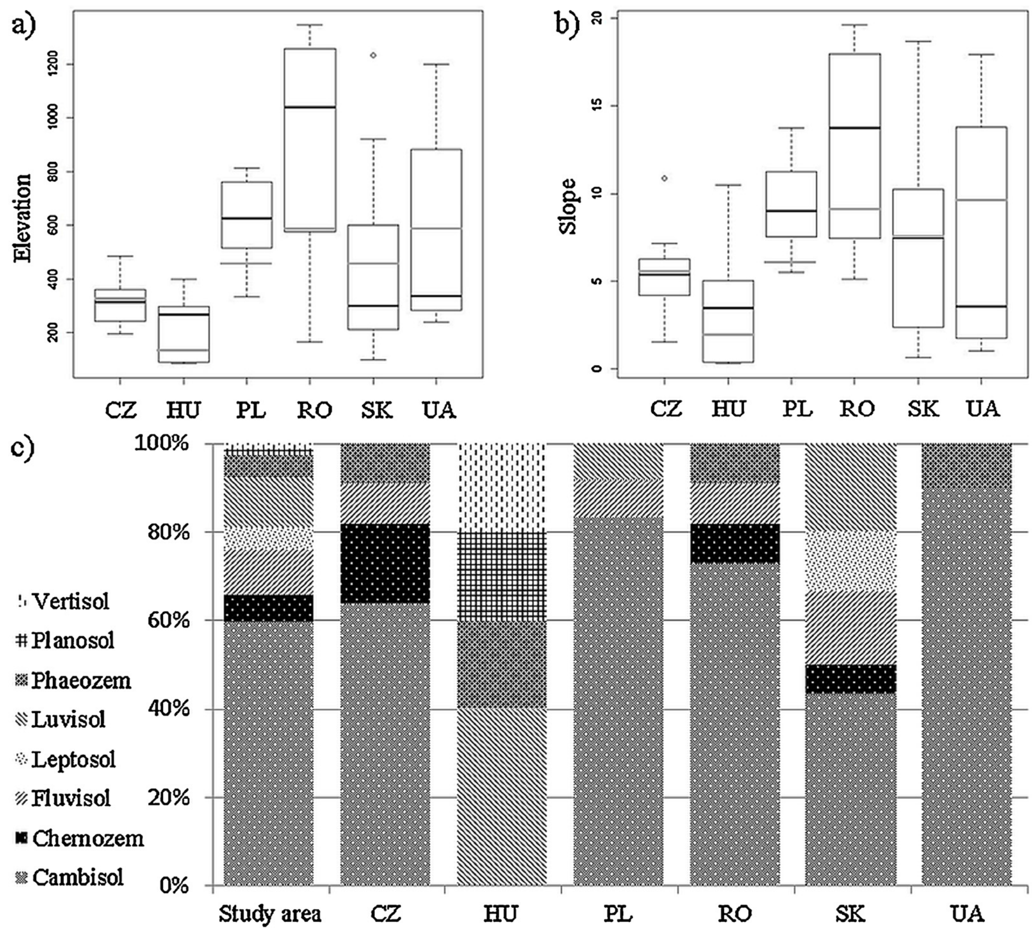

Fig. 2. Representativeness check of case studies biophysical characteristics for the country's share of the study areas: comparison of (a) elevation and (b) slope. The gray line indicates the mean value for the country's share of the study area. (c) Soil type distribution for the case studies in each country and for the region as a whole. Country codes: CZ: Czech Republic, HU: Hungary, PL: Poland, RO: Romania, SK: Slovakia, UA: Ukraine.

in lowland areas (e.g., Hungary) as well as in the mining district of central Slovakia. After 1990, forest cover increased across Poland, Slovakia, Czech Republic and Hungary, but there were still cases of forest loss in the Eastern Romanian Carpathians and southwestern Slovakia.

Agricultural change varied regionally: during the K.u.K. Monarchy, agriculture expanded mostly in the lowlands of Hungary, Czech Republic, and Ukraine, concurrent with forest loss, while agriculture decreased in the mountains of Slovakia and Poland. In the Interwar period agricultural land use peaked in parts of Hungary and southwest Slovakia, while agriculture declined in parts of the Polish Carpathians and northern Slovakia. During the Socialist time period, low but positive annual rates of agricultural expansion occurred in Romania and southeast of Hungary. In Slovakia and the Czech Republic, agriculture decreased slowly, whereas in Poland, agricultural land decreased by up to 5% per year (Woś, 2005). Since 1990s, agricultural decrease was least pronounced in the lowlands of Hungary, Ukraine, and the Czech Republic. In mountain areas, lower abandonment rates were reported in Ukraine, contrasting with higher rates for Romania and Slovakia (Fig. 5). Since 2000 agriculture declined in 69% of the studies, but we caution that there are only few studies for this period.

Our analysis of the main drivers of land change examined the number of times at least one of the selected drivers of change (institutional, economic, socio-demographic, cultural, and climatic) was deemed important by the case-study authors and collaborators for each of the change processes. We found that institutional and economic factors were the most important drivers of agricultural expansion and deforestation, jointly accounting for more than 75% and 65% respectively of the case studies. This class of drivers also included the technological developments that led to agricultural intensification and support forest transition, but our focus on land-cover areas did not allow to examine technological drivers in detail. In contrast, socio-demographic factors like migration or sector employment were more important for agricultural abandonment (42% of cases) and forest succession (36% of cases, Fig. 6). Physical factors were also mentioned as drivers of change, for example climate supported forest succession on abandoned mountain pastures, where the timberline shifted to higher altitudes (Mihai et al., 2006; Shandra et al., 2013). Overall, abandonment of agriculture was largely driven by socio-demographic (42%) and institutional (31%) factors, with the economy playing a less important role (24%) (Fig. 6).

Discussion

We identified temporal and spatial patterns of land-cover change and their driving forces over the last 250 years across the Carpathian Basin. Our results showed that forest change was closely related to agricultural dynamics and that rates and patterns of change were heterogeneous among politically distinct time periods, and varied regionally. Deforestation was less widespread than we had expected, and the observed changes differed from our expectations in particular during the K.u.K. Monarchy and

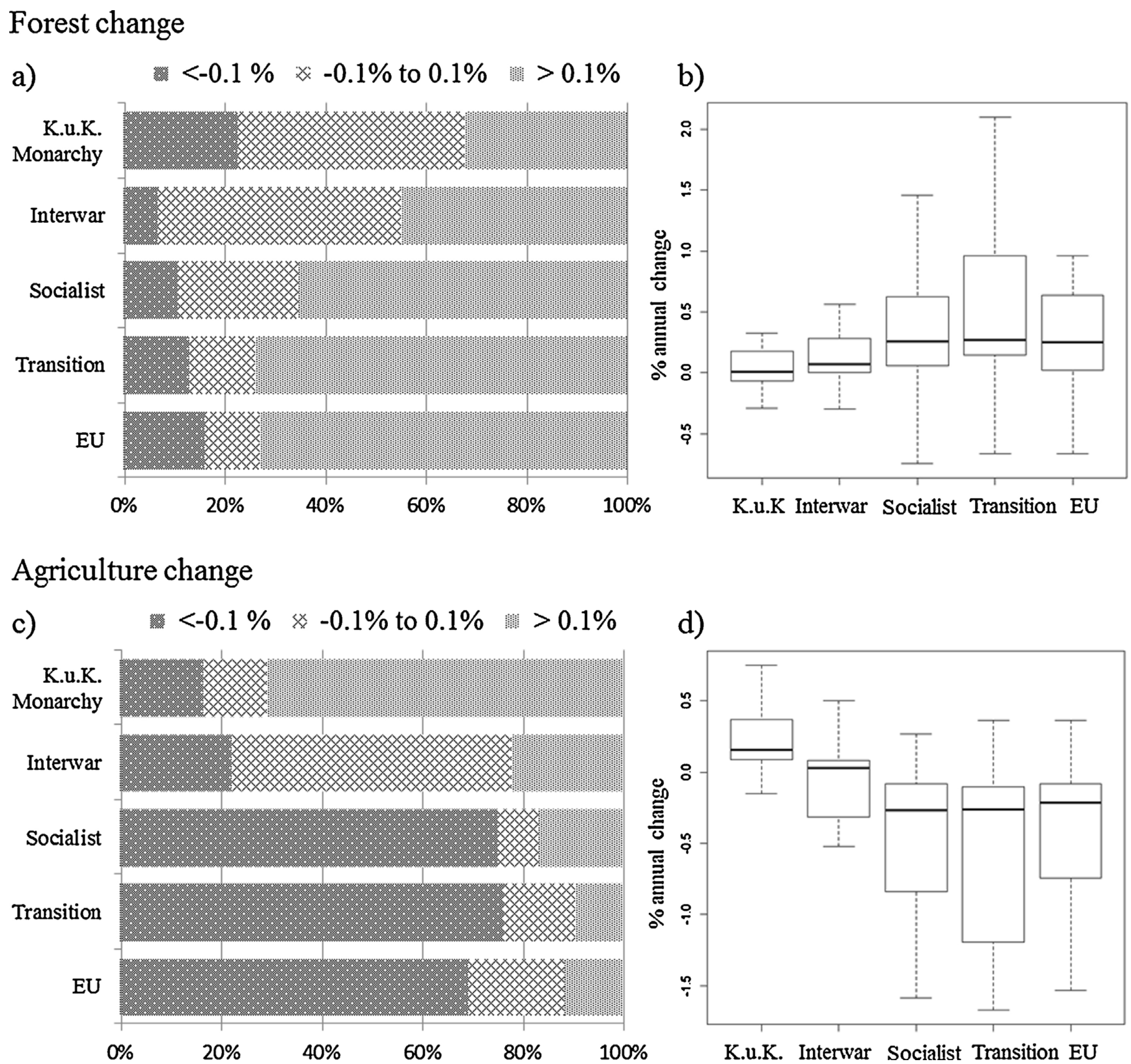

Fig. 3. Proportion of studies reporting decreasing (<−0.1% annually), stable (−0.1% to 0.1% annually) and increasing (>0.1% annually) cover for each time period for (a) forest and (c) agriculture and distribution of annual rates of change per time period for (b) forest and (d) agricultural cover. Country codes: CZ: Czech Republic, HU: Hungary, PL: Poland, RO: Romania, SK: Slovakia, UA: Ukraine.

Interwar periods. Between WW I and WW II, forest cover decrease stopped across the region. Our findings are concurrent with other studies (Kozak, 2003; Kuemmerle et al., 2011), indicating that the region as a whole experienced a forest transition during the Interwar period, despite regional differences (Shandra et al., 2013). After WW II, the observed forest cover increase was in line with our expectations (Table 2). While agricultural abandonment was widespread throughout the 20th century, increase in agricultural cover occurred only during the K.u.K. Monarchy. Contrary to our expectations, agricultural abandonment started early, being a prominent process across the region already during the Interwar and Socialist periods. However, abandonment rates increased after the collapse of the Socialism. In general, forest and agricultural dynamics were complementary, but there were exceptions to this rule due to rapid urban or grassland-related land-cover changes. Agricultural expansion and deforestation were mostly driven by economic and political events, while land abandonment and reforestation were mostly driven by socio-demographic factors.

Table 2
Comparison of expected and observed land changes for each time period and the mean annual rates of change, calculated for all the case studies for which change rates were not spanning more than one period (marked * in Table 1 For these calculations, only studies that report annual change for single periods were considered.

Time period	Expected land changes		Mean annual rate of change		Observed land changes	
	Forest	Agriculture	Forest	Agriculture	Forest	Agriculture
K.u.K Monarchy	–	+	0.08%	0.12%	0	+
Interwar	–	+	0.35%	−1.28%	+	–
Socialist	+	+	0.33%	−0.54%	+	–
Transition	+	–	1.07%	−1.61%	+	–
EU accession	+	+	0.89%	−1.20%	+	–

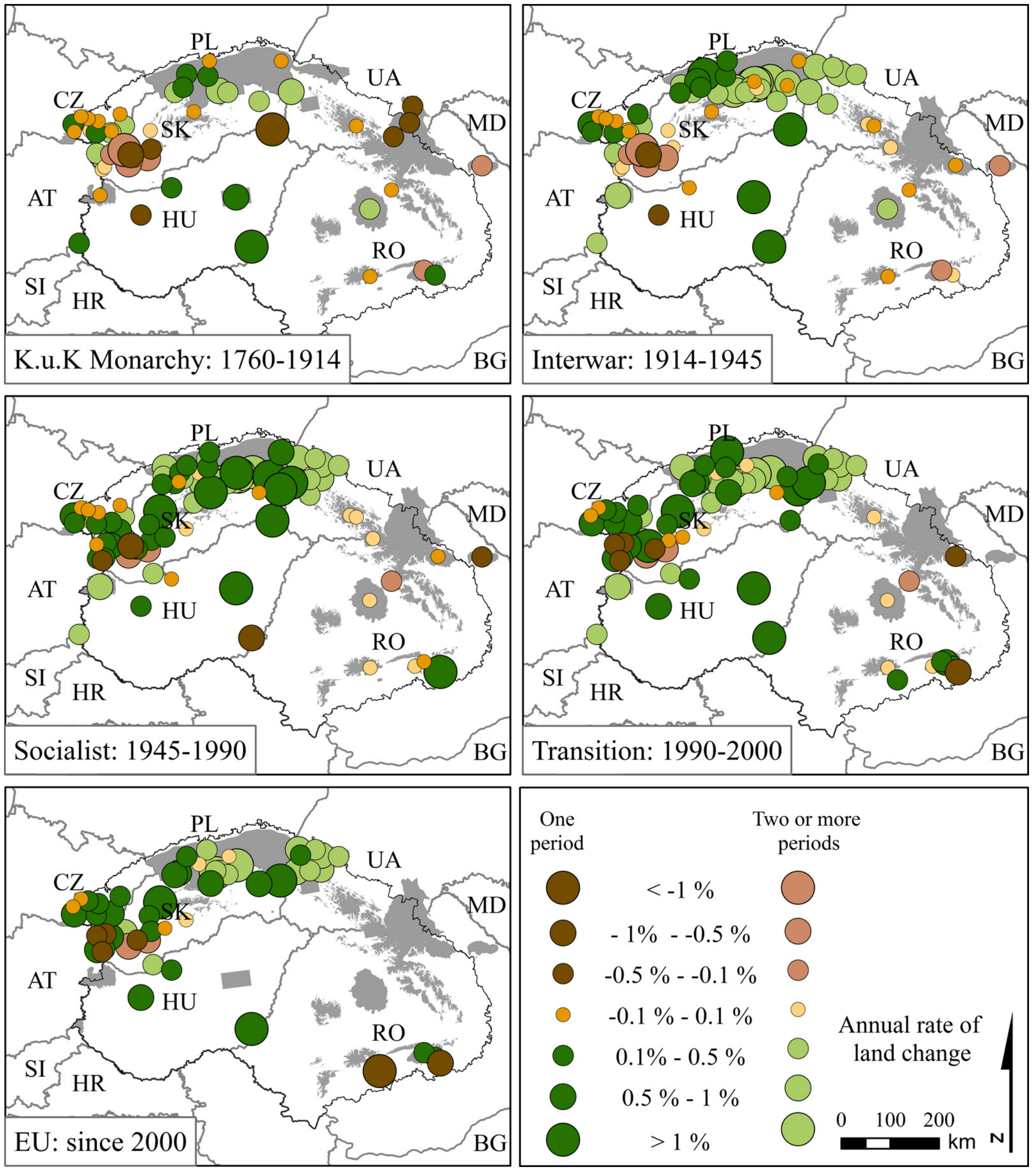

Fig. 4. Spatial and temporal distribution of forest change case studies. Annual rates of change are mapped for each case study and time period. Studies are represented by centroids. The size of the symbols indicate the amount of change, the colors indicate the direction of change (increase/stability/decrease). Shaded colors indicate that annual rates are calculated for more than one time period. Country codes: CZ: Czech Republic, HU: Hungary, PL: Poland, RO: Romania, SK: Slovakia, UA: Ukraine.

Our analysis highlighted regional variation in land change patterns, and in the major drivers of change across the study area. We primarily focused on patterns of two broad scale processes: deforestation followed by agricultural expansion and forest cover increase, related to agricultural abandonment. The rise of the Habsburg Empire and Austro-Hungarian Monarchy, which brought German settlers to the Carpathian region, and the industrial revolution of the 19th century, caused significant population growth, increasing demands for agricultural products (Vepryk, 2002). Deforestation for agricultural development was both an economic and a cultural process (Boltižiar and Chrastina, 2006; Mojses and Boltižiar, 2011; Skokanová et al., 2012), and as such, patterns of deforestation varied by land ownership. While Ukrainian smallholders cleared forest patches for agricultural use in lowland areas, large landowners did not deforest, but replaced mixed forest stands with spruce plantations for pulp production at high elevations (Vepryk, 2001). While forest clearing for agriculture was common (Chrastina and Boltižiar, 2010; Konkoly-Gyuró et al., 2011; Vepryk, 2002), deforestation was also related to expanding grassland and urban cover. For example, on Ukrainian mountain meadows, livestock farming increased partly due to Hungarian and Czech investment up to WWII, lowering the timberline (Sitko and Troll, 2008). In the Northern Romanian Carpathians, net forest cover decreased at timberline since 1880s, but generally net forest cover increased at timberline due to decline of transhumance (Shandra et al., 2013).

Similarly, economic growth led to the drainage of wetlands for agriculture in Hungary (Biró et al., 2012; Konkoly-Gyuró et al., 2011; Nagy, 2008), the Czech Republic, and Slovakia (Demek et al., 2008; Drgona, 2004; Gerard et al., 2010, 2006b; Mojses and Bezák, 2010) and to the conversion of grasslands to row crops in Hungary (Chrastina and Boltižiar, 2008), Romania (Schreiber, 2003), and the Czech Republic (Chrastina and Boltižiar, 2008; Havlíček et al., 2011). During the Socialist time, annual forest cover loss was high due to the clearing of forested area of no economic value (small isolated patches and shrubby vegetation)

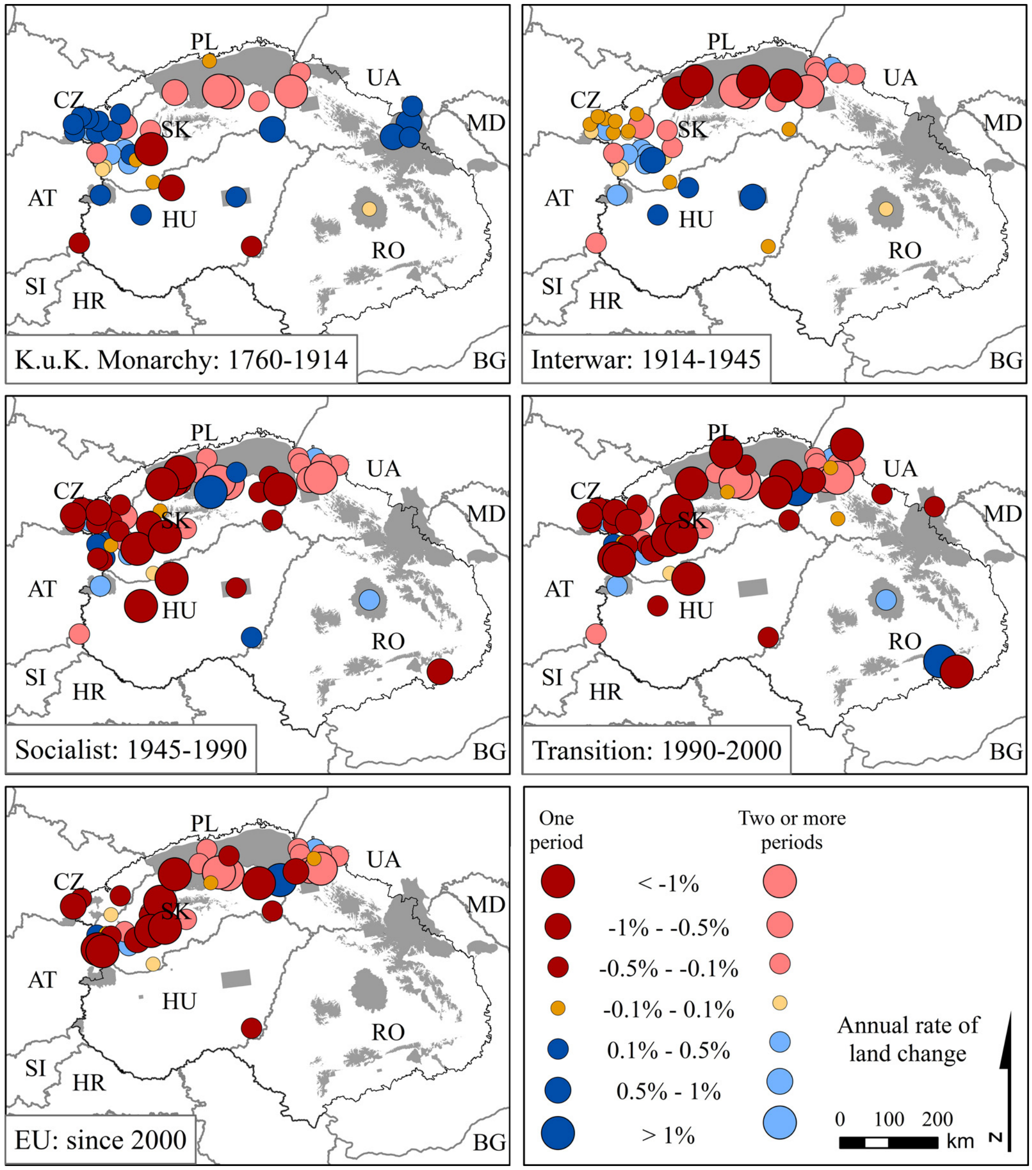

Fig. 5. Spatial and temporal distribution of agricultural change case studies. Annual rates of change are mapped for each case study and time period. Studies are represented by centroids. The size of the symbols indicate the amount of change, the colors indicate the direction of change (increase/stability/decrease). Shaded colors indicate that annual rates are calculated for more than one time period. Country codes: CZ: Czech Republic, HU: Hungary, PL: Poland, RO: Romania, SK: Slovakia, UA: Ukraine.

in Slovakia and the Czech Republic (Demek et al., 2008; Špulerová, 2008; Stránská, 2008). Political goals of increasing agricultural production caused agricultural expansion in the Czech Republic (Demek et al., 2008; Skokanová et al., 2009; Štych, 2007). There was also considerable regional variation related to agricultural expansion: in some mountain areas (e.g., parts of the Polish and Slovak Carpathians) agricultural land remained privately owned and agriculture did not expand (Kozak, 2010; Mojses and Petrovič, 2013), while some agricultural expansion occurred in Romania (where 80% of the population was already employed in agriculture at the time of collectivization), and in the Great Plain of Hungary (about 50% of the population) (Kligman and Verdery, 2011). Deforestation between 1945 and 1990 was, however, not always related to agricultural expansion. For example, tourism and industrial development led to forest cover loss in the Southern Romanian Carpathians (Huzui et al., 2012) and the Tatra Mountains (Gerard et al., 2010, 2006a,b). Similarly, since 1990, selective logging for household needs, illegal harvesting, and large scale clear-cuts due to loopholes in the forest laws of some countries (Irland and Kremenetska, 2009; Kuemmerle et al., 2009a) caused forest losses (Grozavu et al., 2012; Mihai et al., 2007, 2006) with particularly heavy illegal logging reported in Romania (Knorn et al., 2012; Shandra et al., 2013), and Ukraine (Kuemmerle et al., 2009a).

On the other hand, agricultural abandonment and reforestation occurred mostly after WWII, with few local exceptions during earlier times (Patru-Stupariu, 2011). Since 1880, forest cover increased along the timberline throughout the study area (Shandra et al., 2013). During the 19th and early 20th century, marginal agricultural sites in the Polish mountains exhibited the most abandonment due to harsh environmental conditions (Ostafin, 2009), while agriculture expanded in more favorable areas with little terrain, in line with the forest transition theory (Lambin and Meyfroidt, 2010; Lambin et al., 2001). The agricultural decrease was related to a shift of agricultural activities to more productive lands, as well as to industrialization (Gerard et al., 2010, 2006a,b). During the Socialist time period, the forced industrialization of the

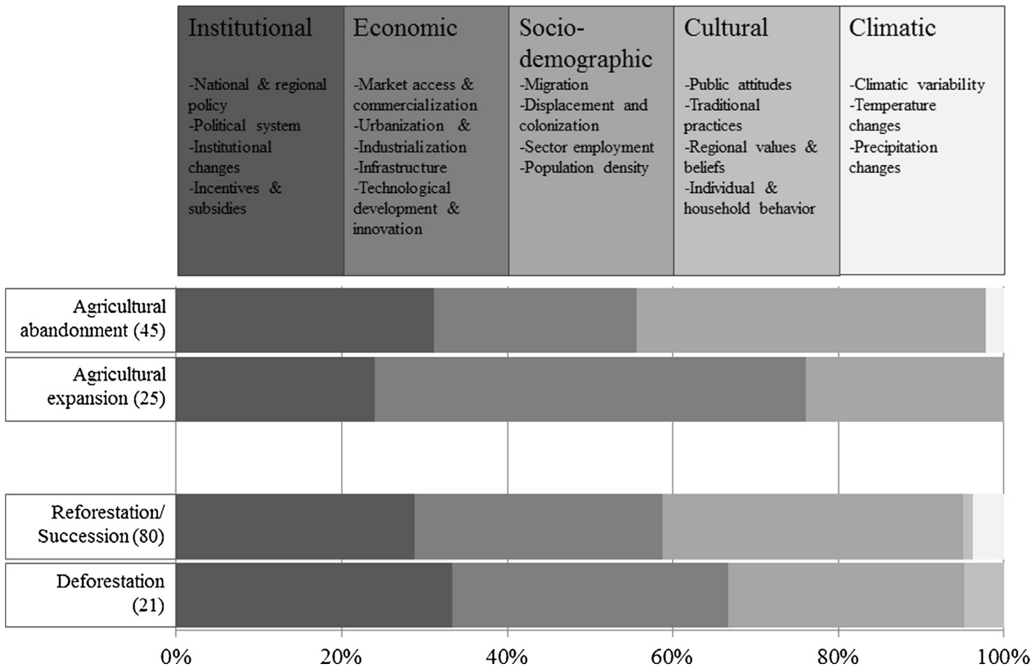

Fig. 6. Main classes of land change drivers and the relative importance of drives for each land change process in the study area. The proportions are calculated based on the number of times a driver was deemed as important in influencing change.

1970s led to migration from rural areas to cities, causing farmland abandonment, for example, in Romania (Schreiber, 2003). In the same period, forests increased along inaccessible areas of the Iron Curtain in the Czech Republic (Skokanová and Eremiášová, 2012), and Slovakia (Kalivoda et al., 2010).

After the collapse of socialism, the lack of agricultural subsidies, decreased profitability (Müller et al., 2013; Prishchepov et al., 2012), and the bankruptcy of most large agricultural enterprises (Petrovič and Hreško, 2010; Turnock, 2002; Zaušková et al., 2011) caused widespread abandonment followed by reforestation (Boltižiar and Chrastina, 2008; Havlíček et al., 2009; Zaušková et al., 2011). Increasing emigration to western Europe (Munteanu et al., 2008; Petrovič, 2006) resulted in decreasing employment in the agricultural sector, reducing pressure on land and allowing forest succession to take place (Kozak, 2003; Kozak et al., 2007; Smaliychuk, 2010). In the Ukraine, after 1990, abandonment occurred mostly on large agricultural fields, while subsistence agriculture reemerged on marginal lands in the mountains (Baumann et al., 2011). Last but not least, nature conservation policies contributed to stabilize or increase forest cover after 1945, and especially since 1990, in parts of Slovakia, Hungary and Poland (Gerard et al., 2006b; Konkoly-Gyuró et al., 2011; Olah and Boltižiar, 2009), even though the effectiveness of protected areas in Romania is uncertain (Knorn et al., 2012). In mountain areas, forest increase was also triggered by decreasing grazing pressure (Mihai et al., 2007; Tirla et al., 2012; Zaušková et al., 2011) and changing climate (Mihai et al., 2006; Shandra et al., 2013; Tirla et al., 2012). On the other hand, after the EU accession, nature conservation and agricultural policies alongside with awareness of the loss of valuable mountain grasslands, resulted in a shift from arable land to high-nature value meadows and from forest to pastures (Bezák and Halada, 2010; Cebecaurová and Cebecauer, 2008; Zaušková et al., 2011).

Most of our case studies reported interactions among the drivers of land change, with broader political decisions being often the underlying factors constraining economic and social conditions (Cebecaurová and Cebecauer, 2008; Janicki, 2004; Sitko and Troll, 2008). The same driver also often caused different land change patterns in different parts of the region: for example during the Socialist time period, national policies led to agricultural expansion on fertile soils in Hungary (Chrastina and Boltižiar, 2008), while forced industrialization as a national policy caused migration and abandonment of agriculture in areas of Romania (Schreiber, 2003). Relative to other drivers of change, the effects of culture on land use may only become apparent at long temporal scales. This means that culture may not have been an important driver at the temporal scale of some of our case studies, which reported change on the order of decades rather than centuries, and culture thus being less prevalent in our summaries than its overall importance would suggest. Furthermore individual effects of drivers were difficult to isolate because of the interplay between social, economic and political elements that lead to local land-use decisions.

It was beyond the scope of our analysis to assess changes in land-use intensity, since most case studies did not map these explicitly. However, across the region, notable changes include agricultural intensification and shifts in forest management. Intensification was driven mostly by economic and technological development throughout the 19th century (Demek et al., 2008; Havlíček et al., 2011; Skokanová et al., 2009), when both crop rotation and industrial fertilizers were introduced. Similarly, Soviet agricultural policies led to intensification (Cebecaurová and Cebecauer, 2008; Mojses and Bezák, 2010; Skokanová et al., 2009) while nationalization of land caused increase in property sizes and the shift from small-scale farms to large state-owned agricultural operations (Boltižiar and Chrastina, 2006; Krivosudsky, 2011; Štych, 2007; Štych et al., 2012). These changes did not necessarily affect the land cover, but let to landscape homogenization (Krivosudsky, 2011; Mojses and Boltižiar, 2011; Špulerová, 2008). Conversely, changes in forest use affected forest patterns and fragmentation: non-native species were planted for timber production (Chrastina and Boltižiar, 2010; Nagy, 2008) and heavy logging and clearcuts occurred during Soviet times in Romania and Slovakia (Boltižiar and Chrastina, 2008; Grozavu et al., 2012; Niculita et al., 2008) due to increased demand for wood. Despite the documented overall forest cover increase after 2000 (0.89% mean annual change), extensive forest disturbances – which do not necessarily alter the land-cover type – occurred in Romania, Poland, Ukraine and the Czech Republic (Griffiths et al., 2014; Kuemmerle et al., 2009a).

Overall, our analysis provided a synthesis of land change patterns and processes during time periods with very different and rapidly changing political and economic conditions. The strength of our analyses lied in the multi-language data sources as well as in the fact that we complemented this information with traditional library research, accessing a wide base of local knowledge. Furthermore, by synthesizing land changes in 102 case-studies, our analysis improves the understanding of overall trends, and acknowledges regional and temporal differences, rather than extrapolating findings of single micro-scale studies. We showed that rates of change differed markedly over the past 250 years: after the collapse of the Austro-Hungarian Empire agricultural land declined, while the collapse of the socialism accelerated agricultural abandonment and forest cover increase. We also showed that recent land change trends do follow long term land changes in terms of direction of changes but the magnitude of these processes differs substantially across periods, with high rates of change being captured since the collapse of socialism. We acknowledge that some case-studies were focused on capturing change based on unique conditions, such as depopulated areas of Poland (e.g., Maciejowski, 2001; Warcholik, 2005; Wolski, 2001) or flooded villages in Slovakia (Petrovič and Bezák, 2010) so that our analysis might describe the very peaks of observed processes. However, despite the abrupt changes in political and economic systems, which might disrupt gradual land transitions, the forest transition theory holds true in this region with the shift from decreasing to increasing forest cover occurring between the two World Wars for the most case studies.

Our results show that despite repeated shocks, which can alter the intensity of long-term, gradual changes, forest transition theory holds true in the Carpathian region. The change point from forest decrease to forest increase occurred between the two World Wars in most of the areas. Around the world, the forest transition occurred at different points in time, highly dependent on the socio-economic, institutional conditions and global marked dynamics. For example, western European countries like France and Britain experienced forest transition already in the second half of the 18th century (Mather, 1998, 1992) as a function of their land use specialization and developing economies (Barbier et al., 2010; Lambin and Meyfroidt, 2010). Countries, such as India, China, Vietnam, Chile, El Salvador, on the other hand, experienced forest transition recently (second half of the 20th century), driven by governance, global market dynamics and displacement of land use abroad (Mather, 2007; Meyfroidt et al., 2010).

In the Carpathians, the agricultural change was mostly mirrored by forest cover and also involved other land-cover classes, for which data availability was limited. Agricultural expansion up to the early part of the 20th century, coincides broadly with the trends observed during the 19th century in other developed regions such as the US, Canada or USSR, where agriculture expanded mostly over grasslands and forests (Goldewijk, 2001). In developing tropical countries, agricultural expansion and intensification is a more recent process (Keys and McConnell, 2005). Countries like Bhutan, Brazil, Costa Rica or China experience large increases in agricultural covers only in the second half of the 20th century (Meyfroidt et al., 2010). In contrast, during the same time, many post-soviet countries face land abandonment since the collapse of socialism (Alcantara et al., 2012; Prishchepov et al., 2013), a similar trend to the one we observed in the Carpathians. Regional differences were notable, especially due to physical factors and several interacting driving forces, but institutional, policy and economic drivers were most influential in shaping both deforestation and agricultural expansion. Socio-demographic factors like rural population decline were the key drivers for land abandonment. Overall, we highlighted the value of longitudinal studies of land change to reveal the strong effects that repeated socio-economic and institutional changes have on land-use and land-cover.

Acknowledgements

We are indebted and most grateful to all the case-study paper authors who shared their data, and provided additional information. Without their excellent work, our study would not have been possible. We thank P. Culbert, S. Martinuzzi, H. Gibbs, and J. Alix-Garcia for valuable comments at various stages of this study. We are grateful to two anonymous reviewers who provided insightful revisions to our paper. Last but not least, we gratefully acknowledge support by the Land-Cover and Land-Use Change Program of the National Aeronautic Space Administration (NASA), the European Commission (Integrated Project VOLANTE, FP7-ENV-2010-265104 and HERCULES, FP7-ENV-2013-603447), the Einstein Foundation, Berlin (Germany), and the Fulbright Scholar Program.

Appendix 1. List of publications included in the meta-analysis

Boltižiar and Chrastina (2006)
Boltižiar and Chrastina (2008)
Bugár et al. (2010)
Cebecaurová and Cebecauer (2008)
Chrastina and Boltižiar (2008)
Chrastina and Boltižiar (2010)
Dec et al. (2009)
Demek et al. (2008)
Drgona (2004)
Gerard et al. (2006a)
Gerard et al. (2006b)
Grekov (2002)
Grozavu et al. (2012)
Havlíček and Borovec (2008)
Havlíček et al. (2009)
Havlíček et al. (2011)
Hurbánek and Pazúr (2007)
Huzui et al. (2012)
Jančovič et al. (2010)
Janicki (2004)
Kaim (2009)
Kalivoda et al. (2010)
Konkoly-Gyuró et al. (2011)
Kozak (2003)
Kozak et al. (2004)
Kozak et al. (2007)
Kozak (unpublished)
Krivosudsky (2011)
Labuda and Pavličková (2006)
Maciejowski (2001)
Mihai et al. (2006)
Mihai et al. (2007)
Mojses and Bezák (2010)
Mojses and Boltižiar (2011)
Mojses and Petrovič (2013)
Monastyrskiy (2010)
Moyzeová and Izakovičová (2010)
Muchová and Petrovič (2010)
Nagy (2008)
Niculita et al. (2008)
Ostafin (2009)
Ostapowicz and Ostafin (in prep)
Ostapowicz and Kozak (2011)
Patru-Stupariu (2011)
Patru-Stupariu et al. (2011)
Petrovič (2006)
Petrovič and Bezák (2010)
Petrovič and Hreško (2010)
Petrovič and Muchová (2008)
Pietrzak (2002)
Reiser (2006)
Schreiber (2003)
Shandra et al. (2013)
Skokanová et al. (2009)
Špulerová (2008)
Štefunková and Petrovič (2011)
Stránská (2008)
Štych (2007)
Štych et al. (2012)
Vepryk (2000)
Vepryk (2001)
Vepryk (2002)
Warcholik (2005)
Wolski (2001)
Woś (2005)
Zaušková et al. (2011)

Appendix 2. Publications not included in the meta-analysis

Paper not included	Criteria not met
Badea (2011)	1
Bičík et al. (2001)	1
Bochko (2010)	1
Boucníková and Kučera (2005)	1,2
Feranec and Ot'ahel' (2008)	1,3
Feranec et al. (2000)	1,3
Feurdean (2010)	1,3
Kilianová et al. (2008)	1
Konkoly-Gyuró et al. (2007)	3
Korjyk (2001)	1
Kozak (1994)	3
Lavruk (2011)	1
Malahova (2009)	1
Miklovoda and Gazuda (2010)	1
Mulková et al. (2012)	1
Perovych et al. (2011)	1
Sitko and Troll (2008)	1
Slivka and Savjuk (2011)	1,3
Tirla et al. (2012)	3

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