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Spatial determinants of abandonment of large-scale arable lands and managed grasslands in Slovakia during the periods of post-socialist transition and European Union accession

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ABSTRACT

Agricultural land abandonment represents one of the most significant processes affecting today's European landscapes. This process occurs more intensively in the post-socialist Central and Eastern European countries, where the adoption of a market-oriented economy after the era of socialism and the implementation of EU policies were the greatest challenges of recent decades. In this article, we analyse the spatial determinants of abandonment of large-scale arable lands and grasslands in two time periods: the transition period (1990–2000) and the EU accession period (2000–2006). The analyses were performed on a country-wide and region-specific scale. The abandoned fields were identified based on CORINE land cover change analyses, then the role of morphometric, biophysical, distance and demographic variables was analysed with the use of logistic regression estimations and AUC (Area Under Curve) statistics. Similar to other studies from post-socialist countries we observed much higher rates of abandonment during the transition period. The abandonment was more likely to occur on fields with lower soil quality located on less accessible areas close to non-farmed land. Particularly in the transition period we found that the abandonment was largely influenced by the migration and changes of population structure in rural areas. Fewer determinants played a role during the EU accession period compared to the transition period. The dominance of abandonment in the mountainous region and changes in the determinants underline the importance of topographic disaggregation in the region-based modelling of agricultural land-use change.

Introduction

Abandonment of agricultural land is a widespread phenomenon in Europe (Gerard et al., 2010; Hatna & Bakker, 2011; MacDonald et al., 2000; Rey Benayas, 2007; Verburg & Overmars, 2009) especially in post-socialistic countries (Alcantara, Kuemmerle, Prishchepov, & Radeloff, 2012; Griffiths, Müller, Kuemmerle, & Hostert, 2013; Müller, Leitão, & Sikor, 2013; Munteanu et al., 2014). Generally, land abandonment is understood as alteration in land-use from a traditional or recent pattern to a less intensive form (Baudry, 1991) or a termination of the use of managing soils (Sluiter & de Jong, 2006). The negative effects of agricultural land abandonment may include loss of particular biodiversity (Bolliger et al., 2011); increased spread of fire, particularly in the southern latitudes; and an increase in rural out-migration (Müller, Kuemmerle, Rusu, & Griffiths, 2009). Abandonment also encourages loss of landscape attractiveness and landscape heterogeneity, as well as its cultural heritage (Baránková et al., 2011; Höchtl, Lehringer, & Konold, 2005; Tasser, Walde, Tappeiner, Teutsch, & Noggler, 2007). On the other hand, agricultural land abandonment also has numerous positive effects, such as a decline in fragmentation related to the forest succession; an increase in carbon sequestration potential (Bolliger et al., 2011); regulation of heat and terrestrial albedo (Munroe, van Berkel, Verburg, & Olson, 2013); an increase in undisturbed habitats (Kuemmerle et al., 2010); improvements in non-farm biodiversity (EEA, 2004; Kampmann, Lüscher, Konold, & Herzog, 2012); reduced erosion (Renwick et al., 2013); stabilisation of hydrological cycles (Otero et al., 2011); promotion of soil conservation (Southworth & Nagendra, 2010). Especially in mountainous areas agricultural abandonment significantly affects the provision of ecosystem services (cultural, provisioning, regulating

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and supporting) that contributing to both highland and lowland economies (Morán-Ordóñez, Suárez-Seoane, Calvo, & de Luis, 2011). In many cases, the overall impact may be very difficult to determine because it largely depends on the context and choice of measurements, as well as spatial and time scales (MacDonald et al., 2000). If we consider the extent of abandoned land then agricultural land abandonment is a challenging issue for scientists, policy makers and stakeholders.

Although no general land abandonment theory exists, many authors assume that the least economically desirable lands with poor biophysical conditions are abandoned first and then, as an agricultural enterprise is transformed, further abandonment proceeds (Baudry, 1991). The critics of this assumption have argued that several studies in this field of research are based on anecdotal or circumstantial evidence or are biased towards marginal areas (Hatna & Bakker, 2011). Abandonment of croplands on productive sites was found, for example, in the Ukraine (Baumann et al., 2011). In countries with a high proportion of mountainous landscapes, the remoteness, physical disadvantages, reduced competition, limited technical and structural adaptations, as well as the increasing proportion of older people are often reported as important factors in land abandonment (MacDonald et al., 2000; Mottet, Ladet, Coqué, & Gibon, 2006; Müller & Kuemmerle, 2009). It is also important to consider the magnitude of changes in the institutions governing agricultural land-use (Prishchepov, Radeloff, Baumann, Kuemmerle, & Müller, 2012). Various national policies, location features and historical backgrounds may largely differentiate the processes that drive land abandonment on a transnational level. Regional and country-wide studies, particularly in contrasting regions of Europe, are therefore necessary to confirm or deny the general assumptions regarding the factors influencing land abandonment, and to understand the conditions under which past land transitions may be reversed (Munroe et al., 2013). The development of explicit models of land-use change allows scientists to analyse, evaluate and infer the characteristics of locations where abandonment occurs (Müller & Munroe, 2008; Prishchepov, Müller, Dubinin, Baumann, & Radeloff, 2013). In the case of agricultural abandonment, factors derived from digital elevation models, soil characteristics or accessibility conditions are commonly used (Bakker & van Doorn, 2009; Corbelle-Rico, Crecente-Maseda, & Santé-Riveira, 2012; Rey Benayas, 2007).

Until the end of the first decade of the 21st century, the determinants of post-socialist agricultural abandonment remained unexplored (Kuemmerle et al., 2008; Müller et al., 2009). The adoption of a market-oriented economy after the era of socialism and the implementation of European Union (EU) policies and subsidy systems during and after EU accession were the greatest challenges faced by these landscapes in recent decades. Abrupt termination of state subsidies and competition in an open European market lowered farming profitability and triggered enormous level of land abandonment. Compared to typical gradual transformations, these rapid social and institutional changes offer a unique opportunity to understand the drivers and processes of land-use change. Recently, there have been large contributions to this area of research from regional studies in Eastern Europe (Prishchepov et al., 2012), Albania (Müller & Munroe, 2008), Romania (Müller & Kuemmerle, 2009; Müller et al., 2009), Ukraine (Baumann et al., 2011; Kuemmerle et al., 2011) and post-Soviet European Russia (Prishchepov et al., 2013).

Afforestation and extensification of agriculture most significantly affected European landscapes during the period of 1990–2000 (Feranec, Jaffrain, Soukup, & Hazeu, 2010). These two processes, that comprise agricultural land abandonment, were most visible in post-socialist countries. Slovakia was the fifth most afforested country (1.45% of the area) with an extensification rate in sixth place (0.64% of the area) (Feranec et al., 2010). A case study review from the Eastern Europe Carpathian region indicated an annual decrease in agriculture land of 1.61% during the transition period (1990–2000) and 1.20% during the EU accession period (2000–2012). Changes in the agricultural landscape in the administrative regions of Slovakia during 1990–2000 are presented by Feranec et al. (2005). The forest area increased in these two time periods by 1.07% and 0.89% annually (Munteanu et al., 2014). A more detailed analysis of agricultural land change from the Carpathian region is presented by Griffiths et al. (2013). According to the classified Landsat images, during the period 1985–2000, about 24% of cropland area (in Slovakia 13.1%) was converted to other uses, while about 11% of the 1985 cropland area (in Slovakia 5.5%) was abandoned in 2010. The forest area increased in the whole Carpathian region by 3.4% during the first period (in Slovakia 2.2%) and by 2.3% (in Slovakia 1.7%) during the second period. The same trends were reported in country-wide descriptive studies (Bezák & Mitchley, 2014; Izakovičová & Oszlányi, 2012; Kanianska, Kizeková, Nováček, & Zeman, 2014) as well as in many local case studies (Boltižiar & Olah, 2013; Cebecauerová, 2007; Feranec, Ot'aheľ, & Husár, 1997; Mojses & Petrovič, 2013; Špulerová et al., 2014).

Despite high rates of agricultural change in Slovakia, no research using spatial models of agricultural land change at the country level has been performed. Our aim was to identify and analyse the determinants of agricultural land abandonment at the country-wide and naturally regionalised level in Slovakia. Using morphometric, biophysical, socio-economic and specific proximate factors, we analysed the abandonment of the two most prominent agricultural land classes: arable lands and grasslands. We investigated the differences in abandonment during two time periods that reflected the most important governmental transitions in recent decades: the breakdown of socialism and the accession to the European Union. Our objectives were as follows:

- to identify the determinants of abandonment of large-scale arable lands and grasslands in Slovakia,
- to establish a spatially explicit modelling framework of country-wide and region-specific abandonment of arable lands and grasslands during the periods 1990–2000 and 2000–2006,
- to analyse the role of selected determinates in the abandonment of arable lands and grasslands during the transition and EU accession period

Data and methods

Study area

Agriculture in Slovakia is largely dependent on landscape-ecological conditions, such as geo-relief, soil and bioclimatic properties. Georelief characterises the mountain arch of the Western Carpathians with its typical alternation of varied mountain ranges (flysh, crystallinic, carbonate and volcanic rocks). The relief culminates in the alpine parts of central High and Low Tatras in the northern part of central Slovakia and progressively descends in the SW and SE. The average temperature and the average amount of rainfall in the mountainous regions range from −3.9 °C to 9.7 °C and from 642 mm to 1756 mm, respectively. The dominant soil types in mountains are the cambisoils and podzols (IUSS Working Group WRB, 2007). The lowland and basin landscapes (51% of Slovakia) cover the southern part of the country and comprise the dominant proportion of arable land and grassland. They are mostly covered by fertile soils (haplic luvisol, fluvisols, chernozems; IUSS

Table 1
Selected explanatory factors, their presence in corresponding models and overall AUC statistics.

Variable	Unit	National models		Regional models			
		1990–2000	2000–2006	1990–2000		2000–2006	
				R1	R2	R1	R2
Elevation (elevation)	metres						
Slope (slope)	degrees	+					+
Global solar radiation (radiation)	W/m^2						
Topographic position index (TPI3, TPI10)	–						
Topographic wetness index (moisture)	0–1				+		
Soil quality (soil)	Class (1–9)	+	+	+	+	+	
Temperature (temp)	°C			–			
Area not covered by croplands and grassland in 1970 (not70)	1/0	+			+		
Rainfall (rainfall)	mm						
Distance to main water course (water)	metres				+		
Distance to main road (road)	metres		+				
Distance to large city (city)	metres						
Distance to county centre (county)	metres		+			+	+
Distance to town (town)	metres	+			+		
Distance to village (village)	metres	+		+	+	+	
Distance to forested area (forest)	metres			–			
Distance to area covered by shrub (shrub)	metres	–	–	–	–		–
Emigration rate (EMI)	%	+			+		
Age index (age)	%			+		+	
AUC statistics (mean)		0.841	0.845	0.856	0.752	0.881	0.732
AUC statistics (coeff. of variation)		0.002	0.005	0.003	0.004	0.006	0.009

± the overall (positive/negative) influence of significant determinants on the agricultural abandonment.

Working Group WRB, 2007). The average temperatures range from 4.1 °C to 10.4 °C and the average rainfall ranges from 525 mm to 1070 mm.

Identification of samples of abandoned arable land and grasslands

To identify abandoned fields, we used CORINE Land Cover (CLC) data sets for the years 1990, 2000, and 2006, which describe the transition period (1990–2000) and the EU accession period (2000–2006). Arable land (CLC class 2.1) is represented in Slovakia only by class non-irrigated arable land (CLC class 2.1.1), which includes cereals, legumes, fodder crops, root crops and fallow land. Managed grasslands are represented by CLC class 2.3.1 – pastures, defined as dense grass cover of floral composition, dominated by graminaceous not under a rotation system, and is grazed or harvested mechanically (EEA, 2007). These two classes (hereafter, arable land and grassland) cover the majority of agriculturally used fields in Slovakia, except for the permanent agricultural crops (covered by CLC class 2.2) and small-scale mosaic fields (covered by the CLC class 2.4 heterogeneous agricultural areas). Omitting these CLC classes was a decision supported by the strong regional appearance of permanent crops that could have considerably influenced our modelling results and by the difficult sampling of agricultural abandonment from the heterogeneous agricultural areas.

We considered four types of land cover conversions – categorical changes (when one land cover class or its part/s is replaced by another land cover class/es; cf. Coppin, Jonckheere, Nackaerts, Muys, & Lambin, 2004) that represent land abandonment:

- arable land (2.1.) to pasture (2.3.),
- arable land (2.1.) to forest (3.1.),
- arable land (2.1.) to transitional woodland/scrub (3.2.4.),
- pasture (2.3.) to forest (3.1.) and
- pasture (2.3.) to transitional woodland/shrub (3.2.4.).

Since the smallest detected unit in the CLC dataset is 25 ha and the modification of polygons is applied if an area changed in size by more than 5 ha, we captured only the largest areas of abandonment in our analyses. The large-scale fields in Slovakia were the result of agricultural collectivisation so our study could be interpreted as an analysis focused on collectivised arable lands and grasslands. To exclude the fields that exhibit no abandonment in reality (commission error), we additionally checked samples of abandonment locations using available LUCAS survey data (Land Use/Cover Area frame statistical Survey) for the years 2000 and 2006 and aerial photographs for the years 2003 and 2006.

Modelling procedures

Location features that serve as land-cover and land-use change drivers and best quantitatively describe land-use patterns are often selected through the use of regression analysis (Overmars, de Koning, & Veldkamp, 2003). We used logistic regression analyses following the similar analysis at the European scale by Hatna and Bakker (2011). In logistic regression, the binary response variable (with 1 for abandoned and 0 for stable agricultural land) is linked by the logit function to the explanatory factors (determinants), and this linkage can be converted to the probabilities of an event (abandonment) occurrence (Atkinson & Massari, 2011). Moreover, using logistic regression we were able to assess the contribution of explanatory factors to the resulting probability of abandonment occurrence.

The uncertainty and spatial variability of explanatory factors were evaluated iteratively by performing 100 estimations of logistic regression coefficients on 100 samples stratified by the polygons of presence and absence of agricultural abandonment. To prevent possible bias due to the unequal number of abandoned and managed polygons, we took 10% of abandoned pixels and 1% of managed pixels in each sampling iteration. Additionally, we compensated for this bias by employing the rare-event logistic regression approach implemented in the *R* statistics package called Zelig (Imai, King, & Lau, 2007; R Core Team, 2013).

Prior to the case-specific (country-wide, region-specific) regression analysis we removed all determinants with high collinearity (variance inflation factor > 10, Ott & Longnecker, 2010). Additionally, we also checked the mutual correlation of determinants and decided to remove those from each pair of highly correlated determinants (Pearson correlation coefficient > 0.80) that exhibited higher collinearity and higher correlation with some other determinants. To prevent the auto-correlation, we set the minimum distance of sampled pixels to 1000 m. This sampling procedure was performed for both periods and both levels of analysis (country-wide, region-specific). In each case, we recorded the regression probabilities of the occurrence of abandonment and the regression coefficients of the corresponding determinants. The resulting regression coefficients were evaluated using box-plots that suitably expressed the ranges of the coefficients (percentiles and the median values) among the samples. We considered a determinant meaningful if three conditions were met: (1) its regression coefficients had the same sign in at least 95 sampling cases; (2) the significance was confirmed by the Wald statistic test at a *p*-value lower than 0.05; and (3) the analysed determinant significantly contributed to the overall model accuracy measured by the Receiver Operating Characteristic (ROC) Area Under Curve (AUC) statistics comparing the false-positive error rate versus the true-positive rate of estimated probabilities (Galletti, Ridder, Falconer, & Fall, 2013). Those factors that were non-significant (Wald statistics and AUC statistics) were removed from subsequent analyses. AUC statistics was used also for the evaluation of the accuracy of the resulting model. The AUC statistics in this case analyse the probability that the model will correctly allocate the abandoned and managed fields. AUC values usually range between 0.5 (random allocation) and 1 (perfect fit). Generally, land cover and land-use change models are successful if their AUC statistics value exceeds a threshold of 0.75 which indicates that the model can correctly distinguish between two classes (stable managed agricultural land and abandoned agricultural land) with a probability of 75% (Prishchepov et al., 2013).

Determinants of land abandonment

A basic assumption in land cover modelling is that each location has specific characteristics determined by specific conditions. These conditions, so called determinants, may be of a biophysical, economic, social, interactive, neighbourhood, and/or political nature (Verburg, Eck, Nijs, Dijst, & Schot, 2004). As summarised by Renwick et al. (2013), according to Food and Agriculture Organization (FAO) (2006) the various reasons for agricultural land abandonment may be grouped as follows: natural constraints, land degradation, socio-economic factors, demographic structure, and the institutional framework. Determinants in land change models are mostly extracted from the physical attributes of the land. Socio-economic conditions are then expressed by access that a location has to, for example, employment opportunities and facilities (Verburg et al., 2004). Regarding this study, the model is thus not about cause/effect, but rather about determining which types of arable lands and grasslands were most influenced by abandonment.

Table 1 lists all of the determinants that we hypothesised might influence the abandonment of arable lands and grasslands. Prior to the analysis, we standardised to minimum 0 and maximum 1 according to the following formula: $(y - \min)/(\max - \min)$, where y is the original value and min and max are the minimum and maximum of the original value of the independent variable (Cheng & Masser, 2003). In addition, used polygon-based dataset were rasterized to the cell resolution of 80 m which we found appropriate resolution for using CORINE land cover dataset at the national scale (Pazúr, in review). Aggregation based on average values was used to rescale the raster-based data with resolution finer as 80 m.

Elevation, slope and sun exposure values were derived from a digital elevation model with a resolution of 10 m (Fig. 1a), obtained by the interpolation of the digitised contour lines of the Base Map series at a scale 1:10,000 (GCI, 1990). Contour data were interpolated in ArcGIS 10.1 software by using the Topo to Raster tool that ensures proper preservation of the hydrogeomorphic properties of the output digital elevation model (ESRI, 2012). The insolation was calculated using a direct solar radiation model (ESRI, 2012). Morphometric properties also represented Topographic Position Index (TPI) (Jenness, Brost, & Beier, 2011), which classifies the landscapes into landform categories (e.g., steep narrow canyons, gentle valleys, plains, open slopes, mesas) (Jenness et al., 2011). We derived TPI indexes based on a direct (3 × 3 pixels) neighbourhood and a neighbourhood size of 10 × 10 pixels (81 ha), which we found to be optimal for the classification of most surface distortions. To quantify the topographic control on hydrological processes, we calculated the soil moisture index (Kopecký & Čížková, 2010). Values of this index range between 0 and 1: high values are typical for flat terrains and low values for steep locations.

To incorporate the soil properties, we used a soil quality map derived from the database of the Bonited Pedo-Ecological Units according to Džatko (2002). The soil map was provided by the Soil Science and Conservation Research Institute in Bratislava. The soil quality is categorised into nine categories. The highest four categories represent the most fertile soils that are protected by national legislation (low. num. 220/2004) and can be converted to non-agricultural production only in extreme cases.

Furthermore, we hypothesised that areas that were not agriculturally used at the beginning of the collectivisation process were likely to be not suitable for intensive agriculture. We, therefore, also incorporated in our model also a dummy variable of the presence of arable land and managed grassland into our model, as defined by the CLC 1970 dataset which characterises the beginning of the last, longest period of the agricultural collectivisation process (Bezák & Mitchley, 2014).

To characterise climatic heterogeneity we used the average amount of rainfall and the average temperature during the time period under investigation. The annual measurements of 98 meteorological stations (Fig. 1a) distributed across the whole country were averaged and interpolated by using digital elevation model and geographical weighted regression following the methodology described by Šťastný et al. (2010).

Our database contained several distance variables. We calculated the proximities of important rivers (wider than 6 m); evaluated accessibility as the distance to a main road (quality class I.–III.) and village; isolation as the distance to a large city (over 100,000 inhabitants), county centres (regional centres; Fig 1b) or towns; and proximity to natural areas was assessed as the distance to forested areas and shrubs (CLC classes 3.1. and 3.2.4.; Fig. 1c and d). River and road networks and the location of urban centres were

Table 2
Rates of agricultural land abandonment as measured at a country-wide and region-based level.

Period	Country			Lowland			Mountains		
	(ha)	(%)	NP	(ha)	(%)	NP	(ha)	(%)	NP
1990–2000	15,283	0.74	442	4468	0.27	173	10,815	1.25	370
2000–2006	4927	0.26	185	1844	0.11	81	3084	0.35	152

% – percentage of areas covered by arable land and grassland in particular region and time period.
NP – number of patches.

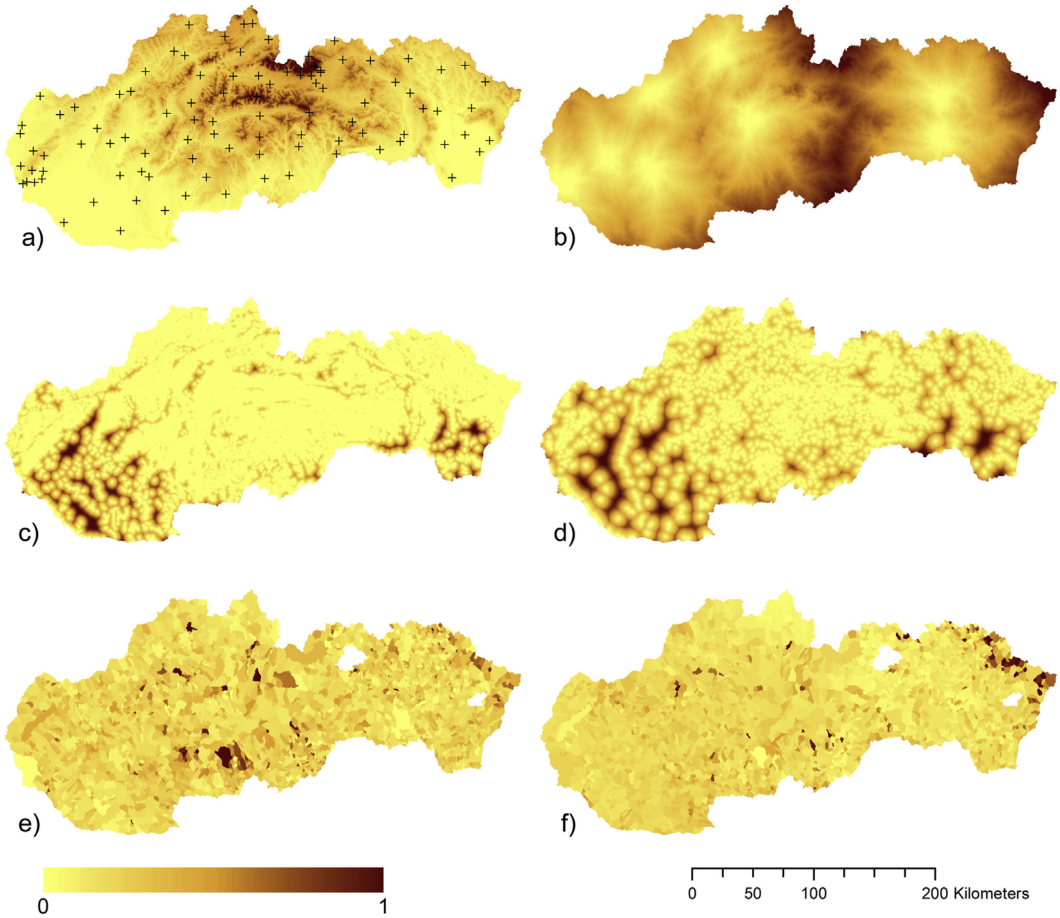

Fig. 1. Example of determinants (normalised explanatory variables) used to model the occurrence of the abandonment of arable land and grasslands: a) digital elevation model with crosshairs depicting the localisation of meteorological station measurements which were used for the interpolation of climatic variables; b) accessibility of county centres (regional centres); c) distances to areas covered by forests; d) distances to areas covered by shrubs; e) average emigration rates in communes for the period of 1990–2000 f) average rates of the ageing index in communes for the period 2000–2006.

derived from the Core Data Basis for GIS (GCI, 2012). The calculated Euclidian distance was weighted by slope as the cost of transportation per unit distance (ESRI, 2012). Additionally, we used road quality classes as a weighting factor for the measurements of the proximity of towns and villages.

We characterised the age structure by an ageing index that expresses the shares of the pre-reproductive and post-reproductive population groups in each commune (Podolák, 2002; Fig. 1f). The emigration rates (Fig. 1e) were calculated as the percentage of people that emigrated from a commune in the time periods under investigation, based on the average annual population counts.

Finally, we attempted to increase the accuracy of our models by relevant thematic and spatial regionalisation (Verburg et al., 2004). In the era of socialist central planning, a specific agrarian policy was determined mostly based on natural conditions. We therefore performed the study of agricultural abandonment at both a country-wide level and a region-specific level, where two broad regions were of primary concern. The first region (hereafter lowland region) considered the landscapes described in the regional geomorphologic division as lowlands and basins, whereas the second (hereafter mountain region) considered all mountainous areas. This regional differentiation is based on the similarities of the distribution of CLC classes in different landscape types (Pazúr, Ot'aheľ, & Maretta, 2012) and was derived from the regional geomorphologic division of Slovakia (GI, 2008).

Results

Locations of abandoned arable lands and grasslands with an area larger than 5 ha, as defined by selected conversions of land cover classes, are shown in Fig. 2. Such abandonment was observed on 15,283 ha (1528 ha annually) during the period of 1990–2000 and on 4927 ha (821 ha annually) in the period 2000–2006 (Table 2). Most of the cases were observed in the central and northern mountainous parts of Slovakia. The most significant trend during the first study period was the conversion of grasslands to transitional woodlands (9776 ha, 91.61% of observations), which likely relates to a massive decline in livestock and sheep production, particularly in the mountainous regions. This trend was the only observed land abandonment transition during the second period (3595 ha). The abandoned fields were clustered across the country, except for the western part.

The factors that were important for abandonment at a country-wide level are summarised in Fig. 3. A low soil quality and proximity to shrubs played a role in both time periods, together with accessibility (expressed by distance to a village in the first period, and distance to the main road in the second period) and isolation (distance to town in the first period and distance to county centre in the second period). Additionally, abandonment in the transition period occurred more often on areas with higher slopes, areas that were not covered by cropland or grassland in 1970, and in villages associated with a higher emigration rate. The average AUC value

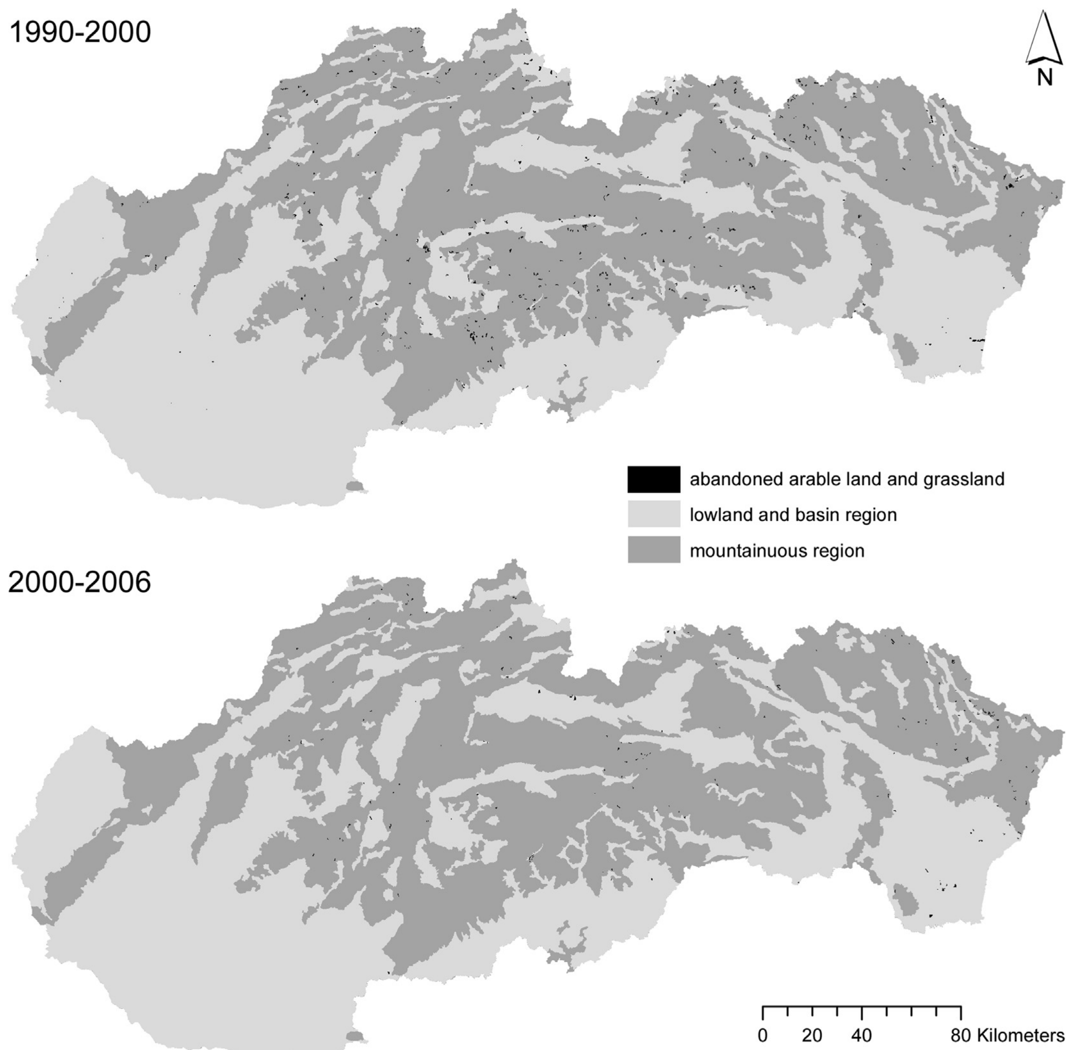

Fig. 2. Areas of the abandoned arable lands and grasslands as identified by the selected transformations of CORINE land cover classes. The colour graduates according to the number of abandonment pixels in focal window of 1 × 1 km. The crosshatch covers areas identified as lowlands or basins.

(0.897 for the first period and 0.888 for the second period) and its low standard deviations (0.003 and 0.003), as measured by our samples, suggest a satisfactory prediction power of the nationwide models in both periods.

Focussing on the case study disaggregated into natural regions reveals case-specific transition trends. Only a few factors were commonly presented in the nationwide and region-specific models. During the first study period, low quality of soils, distance to village and proximity to shrubs commonly increased the probability of abandonment. This finding indicates that the political and economic changes mostly affected less fertile and less accessible locations, that were close to the natural areas.

Among the common factors, the probability of abandonment in lowlands for the period of 1990–2000 increased on sites that were close to the forest, had lower average temperatures and exhibited a high average age of residents. Eight factors determined abandonment in lowlands for the study period of 2000–2006. Apart from the determinants in common with the country-wide model (lower soil quality, proximity to shrubs, and distance to villages), abandonment was more likely to occur here in areas that were further from water sources, more isolated from towns, exhibited a higher moisture level and were not farmed in 1970. The out-migration of the rural population in lowlands had a higher importance than in the country-wide analysis.

Most of the abandoned areas in both time periods (85.65% and 74.14% of the cases, respectively) were observed in mountainous regions. The only common factor observed in both time periods was the distance to a county centre. While abandonment was associated with soil quality, distance to villages and the age index in the first period, and slope and proximity to shrubs were important in the second period.

A comparison of the AUC statistics indicates a noticeably higher accuracy of lowland models during both time periods (Table 1). AUC value increased here from 0.86 to 0.88, respectively, according to the time periods while, in mountainous models, these were just the opposite – decline of model accuracy from 0.75 to 0.73.

Discussion

The analysis that was performed captured the effects of two governmental transitions. The period of 1990–2000 saw major political changes in agriculture and its changing function in the national economy. These changes were accompanied by decreases in agricultural production and economic efficiency, production of

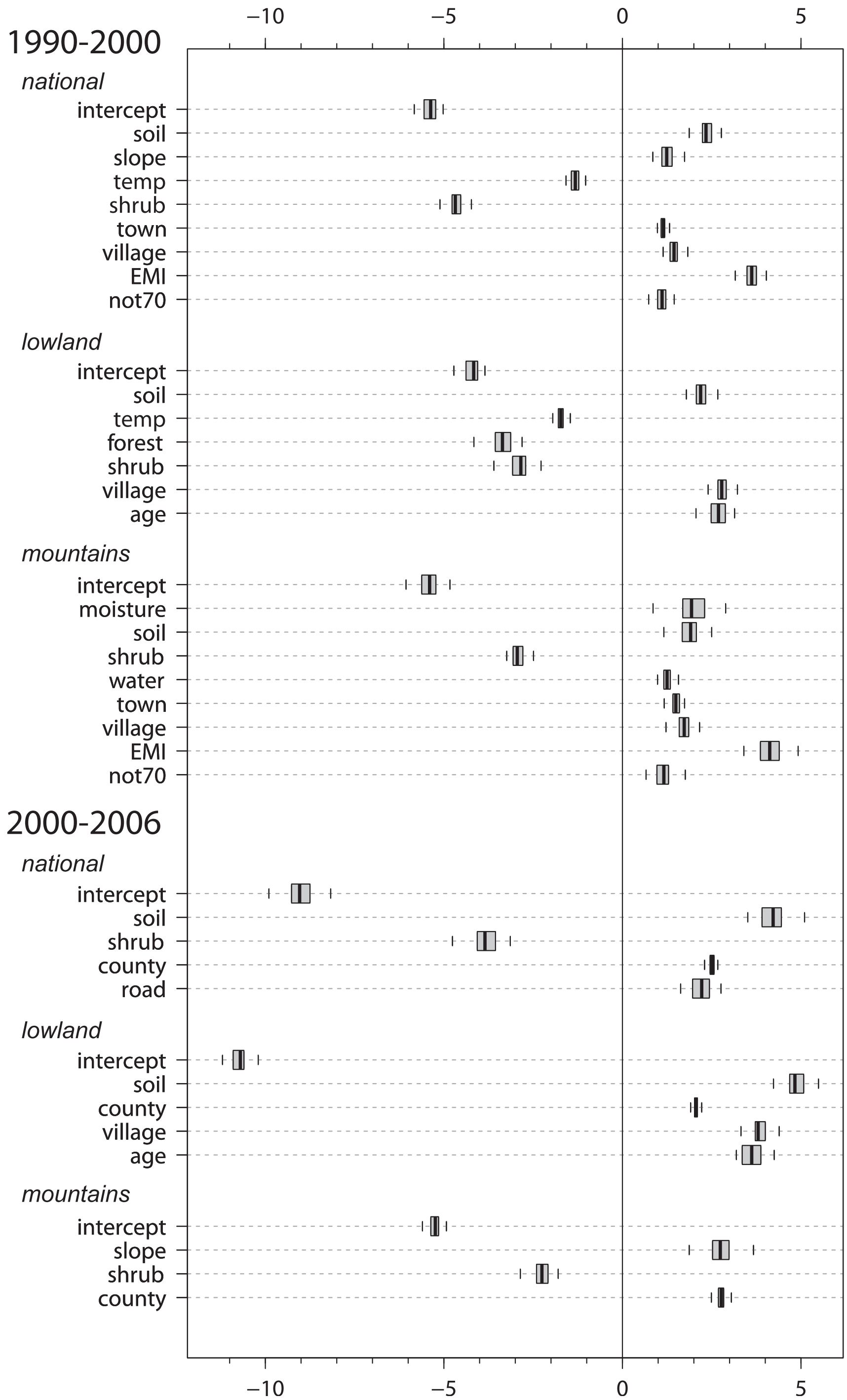

Fig. 3. Contribution of predictors to the abandonment in different time periods analysed on nationwide and region-specific scales. Boxplots show the range of regression coefficients, as measured by the repetition of the rare event logistic regression with multiple samples. Abbreviations: age – age index; county – distance to county centre; EMI – emigration rate; forest – distance to area covered by forest; moisture – topographic wetness index; not70 – area not covered by croplands and grasslands in 1970; road – distance to main road; shrub – distance to area covered by shrub; slope – slope steepness; soil – soil quality; temper – temperature; town – distance to town; village – distance to village; water – distance to main water course.

capital, and employment rates. Additionally, the transition to market-oriented economy largely increased the disparities between the salaries in agriculture and the national average wage. The primary economic causes of these trends lay in the loss of guarantees and incongruities between the costs of agricultural inputs (e.g., labour price, rent of agricultural land) and the prices of agricultural products (Chrastinová, 2004).

Remarkably lower rates of abandonment during the second period reflected a much greater balance in agriculture. The main reasons for the optimisation included: improvements in the system of subsidies (EU pre-accession financial support – Special Accession Programme for Agriculture and Rural Development (SAPARD)), savings in cost factors, an increase in the portion of Gross Domestic Product (GDP) consisting of agriculture, and the implementation of

Common Agricultural Policy (CAP) measures, especially in mountain agriculture (Bezák & Halada, 2010; Kozak, 2010).

We found that soil fertility was the most important factor associated with abandonment, as is also found in western Ukraine (Baumann et al., 2011; Kuemmerle et al., 2008) and in the European part of Russia (Prishchepov et al., 2013). The declined profitability of agriculture after the transition to an open-market economy led to the abandonment of less-productive areas (Bakker, Hatna, Kuhlman, & Mücher, 2011); therefore, the less fertile soils tend to be abandoned first.

Besides fertility, agricultural profitability depends on transport costs. This trend was shown in our study, where the accessibility variables (distance to the road, distance to the village, or slope) were important in all cases. Accessibility was also found to be an important factor of abandonment in the case of the European part of Russia (Prishchepov et al., 2013) and in Albania (Müller et al., 2013).

The role of isolation is ambivalent: the isolation from social and technical modernisation processes could inhibit change (Solymosi, 2011) or could protect local farmers from global competition. On the other hand, a long distance to markets and increased transportation costs could reduce agricultural profitability and cause abandonment. The isolation variables (distance to town or county centre) played an important role in all cases, except in the first period in the lowlands. However, the overall influence of these variables was low, as it was in similar studies (Baumann et al., 2011; Müller & Munroe, 2008).

The proximity of shrubs was influential in all cases, except during the transition period in lowland areas. Shrubs are the typical land cover in early abandoned fields. Areas in the neighbourhood exhibiting similar factors, therefore, are more prone to abandonment. Additionally, seed dispersal in the neighbourhood of shrubs or forests significantly influences reforestation (Tasser et al., 2007).

The association of abandonment with the high out-migration of residents was shown in the country-wide model during the period of 1990–2000, and in the lowland areas for the period of 2000–2006. Since most of the rural jobs are related to agriculture or forestry, this out-migration likely reflected a decrease in job opportunities in these sectors or an increase in opportunities outside agriculture. However, since job opportunities can be endogenous to land cover changes and can be as much of a result as the precursor, such consequences need to be judged with caution (Prishchepov et al., 2013). Nevertheless, agricultural employment and rural out-migration were also common determinants of agricultural land abandonment in other mountainous areas of post-socialist countries, such as in Albania (Müller & Sikor, 2006), Romania (Müller & Kuemmerle, 2009; Müller et al., 2009) and Poland (Kozak, 2010), and has also been observed in Western Europe since the 1950s (FAO, 2006).

A lack of successors in agriculture is a well-known problem (Bruns, Ipsen, & Bohnet, 2000; Elbakidze & Angelstam, 2007; Rescia, Pérez-Corona, Arribas-Ureña, & Dover, 2012; Trell, van Hoven, & Huigen, 2012) and was reflected by the importance of the age index in our region-specific models for the years 1990–2000. However, the overall role of demographic predictors is not as influential as we expected. It may relate to the large inaccuracy of the information on where a person permanently lives and works and where s/he is registered as a permanent resident. Thousands of people that started to work abroad, especially after the accession of the EU in 2004 and the subsequent opening of Western European labour markets, are still registered at their parents' home addresses as permanent residents. We expected to find that economically marginal rural areas were particularly harmed by such an exodus. Our assumption agrees with other studies that indicate high production costs per unit area and depopulation of rural areas as the main drivers of land abandonment (MacDonald et al., 2000; Renwick et al., 2013; Verburg, Eickhout, & Meijl, 2007).

The role of slope steepness was not as influential as it was in other post-socialist regions (Baumann et al., 2011; Kuemmerle et al., 2008; Müller et al., 2013; Opršal, Šarapatka, & Kladivo, 2013) or in Western Europe (MacDonald et al., 2000). However, slope steepness was also used as an input factor for calculation of other predictors that exhibited significant contribution to land abandonment (soil quality, accessibility and isolation variables, topographic wetness index). Similarly, the climate variables (rainfall and temperature) were used in the analysis of soil fertility, and therefore, they did not play an important role in our analyses.

The higher probability of the abandonment of the fields that were not covered by arable land or grasslands in 1970 is likely the consequence of collectivisation in Slovakia (1959–1989), characterised by the improvement of large-scale production and the continuous merging of agricultural farms (Bezák & Mitchley, 2014; Lieskovský et al., 2014) that also occurred in locations that were not suitable for agriculture (especially in mountainous areas) and historically did not exhibit any agricultural usage.

We presented fairly accurate models that reveal the various characteristics of locations where agricultural land abandonment has occurred, and thus we can indicate where this trend is likely. However, agricultural land abandonment as a dynamic process is not reducible to just a single set of factors (Munroe et al., 2013) and we evidently missed some explanatory factors. Experiences from other post-socialistic case studies showed that these intangible reasons for abandonment likely relate to political and economic factors, particularly to changes in land ownership, systems of subsidies, and farmers' decisions. Farmers, often continue farming for a variety of social and cultural reasons (e.g., conservation, tourism, tradition, quality of production) and therefore deviate from the general assumption of deterministic models that landowners make decisions primarily on the basis of economic signals with little time lag (Renwick et al., 2013; Strijker, 2005). Exhaustive field research in the hotspots of abandonment may clarify many other cultural, social and economic aspects that encourage this trend. Comparing the changes in region-based models, we achieved a large reduction in the number of influential factors in the mountainous model, accompanied by a decrease of the resulting model accuracy. This likely relates to the system of subsidies in mountainous agriculture, that supported the maintenance and expansion of agricultural areas in ways that were not predicted by our model. More predictable was abandonment during the EU accession in the lowland region, where only four determinants related to the biophysical properties and accessibility were able to achieve adequate model performance.

The second period was too short for observing the natural succession in the abandoned fields. It is also expected that farmers' responses to the economic and political changes would be more recognisable in the first, longer period. However, considering that the accession of Slovakia to the EU occurred in the middle of the second period, we believe that the agrarian sector exhibited much greater dynamics in the second period because of the (pre)accession investments and policies. These changes relate to agricultural intensification, rather than to agricultural abandonment. It is worth noting that the landscape footprint of agricultural abandonment is considerably slower in comparison to the footprint of agricultural intensification. In addition, shrub and forest cover grows faster in lowlands and basins than in mountainous areas. A reliable answer should include the forthcoming CLC 2012 dataset that may identify more recultivated areas because of the increase of profit opportunities in agriculture caused by rising of commodity prices since 2007.

Conclusions

This paper presents the first nationwide study of agricultural land abandonment determinants in Slovakia. We found that abandonment mostly affected arable lands and grasslands in the transition period of 1990–2000 and was extensive in the central and eastern mountainous parts of Slovakia. With regard to hypothetical determinants, agricultural abandonment predominantly occurred in fields with lower soil quality located on less accessible areas close to non-farmed land. Our results showed that on a national level, increasing the economic attractiveness of agricultural production in villages far from regional centres and towns with a low population of young people and on locations in the hinterland of natural areas may be a good strategy for decreasing agricultural land abandonment. However, the findings of regional models indicated that the pattern of abandonment in the lowland and basin areas largely differed from the patterns in mountainous regions. As much as 85.65% and 74.14% of the area of abandonment of arable land and grasslands was found in the mountains. Using spatially explicit models is, therefore, certainly a superior alternative for the assessment of various policies and financial supports. Moreover, the use of the modelling framework and measured trends also allows an extension of the implications of scenario-based investigations of different forms of future agricultural management.

The continuous abandonment among most of the EU countries demonstrates that the adopted policies have certain limitations. As noted in several studies (e.g., MacDonald et al., 2000; Renwick et al., 2013), focussing only on agricultural support may be the wrong way to view agricultural land abandonment, and a wider cross-disciplinary approach needs to be adopted. Strategic placement of managed and natural ecosystems is necessary for proper regulation of ecosystem services across a landscape mosaic (Foley et al., 2005).

Lack of consideration of local conditions (bottom-up approach), the missing complexity and the involvement of a large bureaucracy render many governmental projects highly ambitious and questionable. This was the case for the Concept of Agricultural Development for Slovakia during the years 2013–2020 (MARD, 2013). Implementing spatially explicit, regional strategies and improving the overall integrity of such projects would certainly target the issue of agricultural land abandonment much more effectively.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.apgeog.2014.07.014.

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