Land Use Policy 28 (2011) 552–562

Contents lists available at ScienceDirect

Land Use Policy

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

Patterns and drivers of post-socialist farmland abandonment in Western Ukraine

Matthias Baumann[a,*], Tobias Kuemmerle[a,f], Marine Elbakidze[d,e], Mutlu Ozdogan[a], Volker C. Radeloff[a], Nicholas S. Keuler[c], Alexander V. Prishchepov[a], Ivan Kruhlov[d], Patrick Hostert[b]

[a] *Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, 1630 Linden Drive, Madison, WI 53706-1598, USA*
[b] *Geography Department, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany*
[c] *Statistics Department, University of Wisconsin-Madison, 1300 University Avenue, Madison, WI 53706, USA*
[d] *Geography Department, Ivan-Franko University, Str. Doroshenka, 41, 79000 Lviv, Ukraine*
[e] *Faculty of Forest Sciences, Swedish University of Agricultural Sciences, PO Box 43, SE-739 21 Skinnskattenberg, Sweden*
[f] *Earth System Analysis, Potsdam Institute for Climate Impact Research (PIK), PO Box 60 12 03, Telegraphenberg A62, D-14412 Potsdam, Germany*

ARTICLE INFO

Article history:
Received 13 August 2010
Received in revised form 4 November 2010
Accepted 8 November 2010

Keywords:
Land-use transitions
Fallow fields
Carpathians
Remote sensing
Support Vector Machines
Regression analysis

ABSTRACT

Farmland abandonment restructures rural landscapes in many regions worldwide in response to gradual industrialization and urbanization. In contrast, the political breakdown in Eastern Europe and the former Soviet Union triggered rapid and widespread farmland abandonment, but the spatial patterns of abandonment and its drivers are not well understood. Our goal was to map post-socialist farmland abandonment in Western Ukraine using Landsat images from 1986 to 2008, and to identify spatial determinants of abandonment using a combination of best-subsets linear regression models and hierarchical partitioning. Our results suggest that farmland abandonment was widespread in the study region, with abandonment rates of up to 56%. In total, 6600 km^2 (30%) of the farmland used during socialism was abandoned after 1991. Topography, soil type, and population variables were the most important predictors to explain substantial spatial variation in abandonment rates. However, many of our *a priori* hypotheses about the direction of variable influence were rejected. Most importantly, abandonment rates were higher in the plains and lower in marginal areas. The growing importance of subsistence farming in the transition period, as well as off-farm income and remittances likely explain these patterns. The breakdown of socialism appears to have resulted in fundamentally different abandonment patterns in the Western Ukraine, where abandonment was a result of the institutional and economic shock, compared to those in Europe's West, where abandonment resulted from long-term socio-economic transformation such as urbanization and industrialization.

Introduction

Land-use change strongly affects ecosystems, their services and biodiversity, and ultimately human well-being (Foley et al., 2005). A better understanding of the patterns of land-use change and what drive these spatial patterns is therefore a key challenge for landscape ecology and land-use science (Global Land Project, 2005; Turner et al., 2007). Trajectories of intensifying land use, particularly agricultural expansion in the tropics, are fairly well understood (Geist and Lambin, 2002; Hansen et al., 2008). However, land use can also become less intense as societies industrialize and urbanize, resulting in landscapes characterized by farmland abandonment and reforestation (Lambin and Meyfroidt, 2010; Rudel et al., 2009, 2010). Such shifts of socio-ecological systems characterized by deforestation to systems with forest increase have occurred in Western Europe (Gellrich et al., 2007; Mather et al., 1999) and North America (Kauppi et al., 2006; Rhemtulla et al., 2009) during the 19th and 20th centuries, and more recently in parts of Central America (Marin-Spiotta et al., 2009), and southeast Asia (Fox et al., 2009). Overall though, farmland abandonment rates and patterns remain unclear in many regions worldwide.

This is worrisome, because land abandonment affects ecosystems profoundly (Rey Benayas et al., 2007; DLG, 2005). For example, abandonment decreases soil erosion (Tasser et al., 2003), increases carbon sequestration (Marin-Spiotta et al., 2009; Vuichard et al., 2008), improves water quality (Kramer et al., 1997), and may allow biodiversity to recover (Chazdon, 2008). Conversely, abandonment decreases agricultural production often permanently, because recultivation is expensive once forests have established (Larsson and Nilsson, 2005). In places with long land-use histories, farmland abandonment also threatens cultural identity and bio-

* Corresponding author. Tel.: +1 608 265 92 19; fax: +1 608 262 99 22.
E-mail address: mbaumann3@wisc.edu (M. Baumann).

0264-8377/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.landusepol.2010.11.003

diversity associated with traditional land-use practices (Elbakidze and Angelstam, 2006; Palang et al., 2006; Plieninger et al., 2006).

Eastern Europe and the former Soviet Union are a prime example of a region with widespread farmland abandonment. The breakdown of socialism in 1991 and the shift from centralized planned towards market economies resulted in a profound restructuring of Eastern Europe's agricultural sector (Lerman, 1999; Mathijs and Swinnen, 1998). Prices for inputs and agricultural products were liberalized, budget constraints introduced, guaranteed markets within the Eastern Block disappeared, and foreign competition emerged (Ioffe and Nefedova, 2004; Lerman et al., 2004; Turnock, 1998; Lerman and Shagaida, 2007). Massive ownership transfers of land and capital assets occurred, often resulting in tenure insecurity (Mathijs and Swinnen, 1998). Moreover, substantial migrations away from rural areas occurred (Ioffe et al., 2004). Not surprisingly, official statistics suggest this triggered farmland abandonment at unprecedented rates (DLG, 2005; Henebry, 2009; Ioffe and Nefedova, 2004; Kuemmerle et al., 2008).

The problem is that agricultural statistics for the former Soviet Union are often outdated or difficult to compare before and after 1989 and of doubtful quality. Remote sensing is a well known alternative to assess large scale land-use change (Potapov et al., 2008), and especially Landsat satellites are known to be well suited to assess abandonment rates. For example, Landsat Multispectral Scanner imagery (MSS) showed that 32% of the farmland used in Estonia during socialism was abandoned between 1990 and 1993 (Peterson and Aunap, 1998). Similarly, Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images revealed abandonment rates of up to 21% between 1989 and 2000 in the northeastern Carpathians (Kuemmerle et al., 2008), 52% between 1989 and 2000 for the Smolensk region in European Russia (Prishchepov et al., submitted for publication), 12% between 1991 and 2001 in the greater Olomouc region, located in the northeast of the Czech Republic (Vaclavik and Rogan, 2009) and 21% in southern Romania from 1990 to 2005 (Kuemmerle et al., 2009b). Visual interpretation of high-resolution imagery also showed that 50% of all farmland in Latvia was abandoned during the first 10 years of the transition period (Nikodemus et al., 2005), but abandonment rates were only 7% in Albania for the period of 1988–2003 (Müller and Munroe, 2008). Although these studies emphasize the potential of remote sensing to map post-socialist abandonment, almost all existing work has focused on small study regions in only a handful of Eastern European countries. Thus, abandonment rates in many regions remain unquantified.

Existing work also showed that abandonment rates differed substantially, both within and among countries (Ioffe et al., 2004; Kuemmerle et al., 2008; Müller et al., 2009), and that raises the question about the drivers of these patterns. Quantitative evidence from Eastern Europe to answer this question is scarce, but studies elsewhere in Europe suggest that mainly four categories of variables determine spatial patterns of abandonment. First, environmental variables such as topography and soil quality determine the suitability of farming and can therefore be important determinants of abandonment (Gellrich et al., 2007; MacDonald et al., 2000; Rey Benayas et al., 2007). Remote fields and pastures often require disproportional management effort because fields are dispersed. An increasing distance to markets also diminishs land rents (Baldock et al., 1996; Gellrich and Zimmermann, 2007; Müller et al., 2009). Thus, fields located in remote areas likely have a higher tendency to become abandoned once declining subsidies stop compensating non-profitable farming in such areas. Third, population change is an important driver of farmland abandonment, because rural population decline results in a decreasing farmland demand and a diminishing rural workforce (Verburg and Overmars, 2009; Yeloff and van Geel, 2007). Finally, changes in the input intensity of farming (e.g., fertilizer, and mechanization) can have marked effects on abandonment rates. High-intensity farming typically manages large arable areas and focuses on the most productive sites, thus triggering abandonment in marginal areas (Baldock et al., 1996; Plieninger, 2006).

To our knowledge, only three studies have assessed determinants of farmland abandonment quantitatively. In southern Romania, topography and local market access were the main determinants of farmland abandonment, whereas population parameters did not influence abandonment patterns substantially (Lakes et al., 2009; Müller et al., 2009). Conversely, population density and marginality for farming explained abandonment in Albania (Müller and Munroe, 2008). In addition to these studies, descriptive analyses suggest that topography, population density, migration, ownership regime, and land reform strategies also may have influenced post-socialist farmland abandonment (e.g., Kuemmerle et al., 2008; Sitko and Troll, 2008). A comprehensive assessment of post-socialist farmland abandonment drivers across larger areas in Eastern Europe, however, is missing.

Western Ukraine is a particularly interesting region to study patterns and drivers of post-socialist farmland abandonment, because it comprises a large variability in environmental conditions, including areas of favorable farming conditions (i.e., fertile soils and long growing period) and marginal farming (e.g., mountain regions). Likewise, the region is characterized by varying socio-economic conditions and different cultural traditions in use of natural resources. Field evidence also suggests that farmland abandonment in Western Ukraine was widespread after 1991, when Ukraine became an independent state.

The overarching goal of our study was to (a) map post-socialist farmland abandonment in Western Ukraine and (b) relate abandonment patterns to environmental, accessibility, population, and land use intensity variables. Specifically, we tested four hypotheses: post-socialist farmland abandonment rates are higher:

1. in areas of higher elevation, steeper slopes, and poorer soils;
2. in remote areas afar from market centers;
3. in areas with decreasing (rural) population density;
4. where the intensity of farming decreased most.

Methods

Study area

Our study region in Western Ukraine covers about 48,000 km^2 and consists of three oblasti (i.e., Ivano-Frankivska, Lvivska, and Zakarpatska) with 47 rayons. Rayons are district-level administrative units in Ukraine (equivalent to the NUTS-3-level in the European Union, or the county-level in the United States). Elevation in the study region varies from 75 to 2061 m and the region contains almost the entire Ukrainian Carpathians as well as adjacent plains (Fig. 1). Main rivers in the regions are Dniester, Prut, and Tysmenytsia. Soils vary throughout the study region with Cambisols and Podsols dominating in the mountains, and albeluvisols, phaeozems, and fluvisols in the lowlands. Climate is temperate continental with slightly warmer conditions in the southwest (e.g., mean temperature of 9.6 °C in Uzgorod) compared to the northeast (7.2 °C in Lviv), while annual precipitation is around 740 mm (Kruhlov et al., 2008; NESDIS, 2009).

Approximately 5.2 million people live in the study region, one-third in cities (State Statistics Committee of Ukraine, 2001). The plains and Carpathian foothills are relatively densely settled. Agriculture is the main land use in the plains and foothills, and forestry

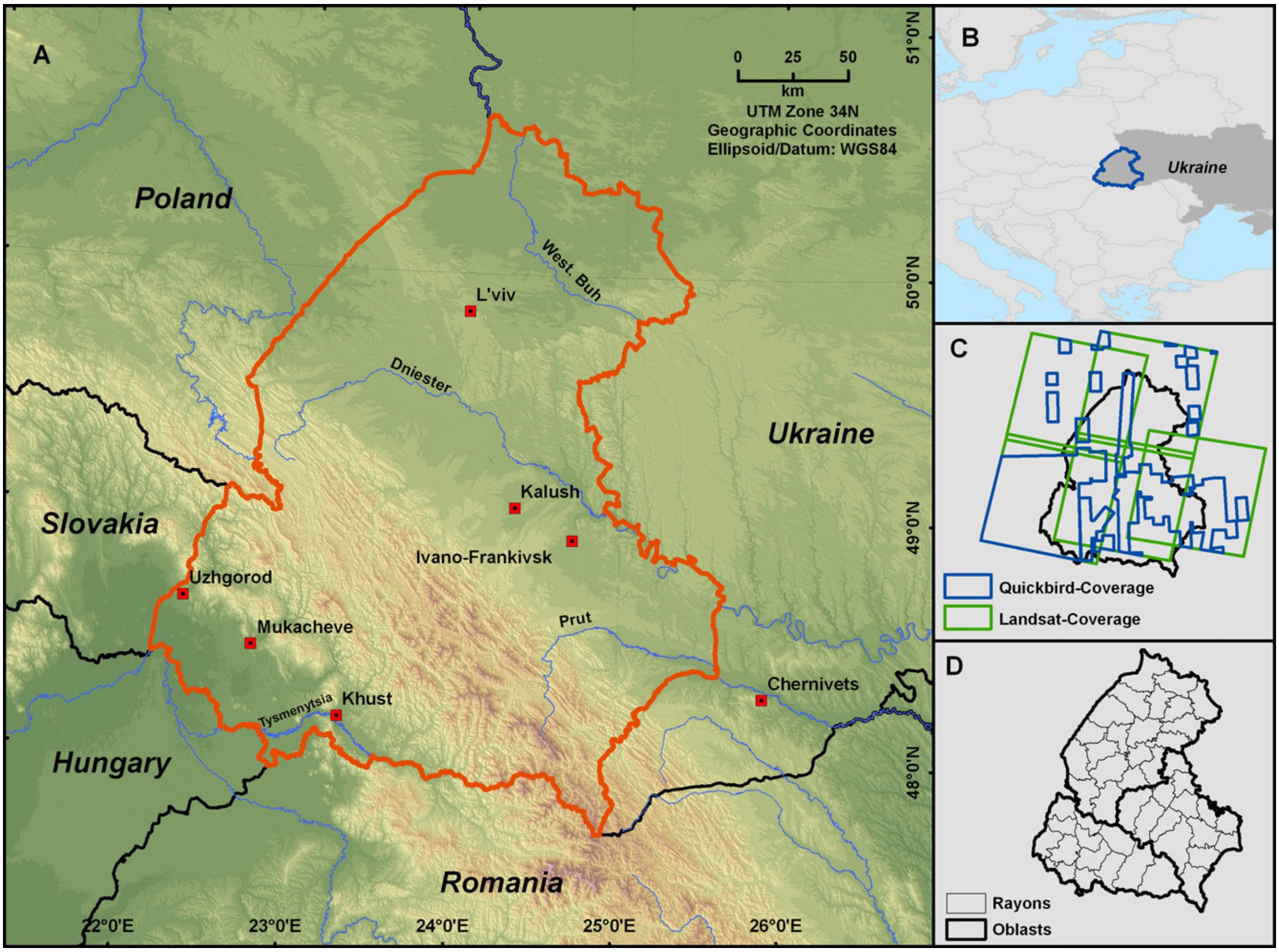

Fig. 1. Study region in the Ukrainian Carpathians. (A) Study region boundaries (red), topography, and major population centers. (B) Location of the study region in Europe. (C) Landsat TM footprints (green) and Quickbird footprints (blue) used. (D) Oblast (bold) and rayon (fine) boundaries. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

and smallholder agriculture prevail in the mountains (Augustyn, 2004). Wheat, corn, oil crops, dairy, and meat are the main agricultural products (Elbakidze and Angelstam, 2006; Sitko and Troll, 2008; Turnock, 2002).

During Soviet times, all agricultural lands were collectivized and managed in large-scale enterprises. Mechanization and inputs (e.g., fertilizer) increased markedly, and some forests were converted to croplands and pastures (Kozak et al., 2007). The breakdown of socialism in 1991 resulted in a substantial restructuring of Ukraine's agricultural sector. Many state farms went bankrupt (Lerman, 1999) and the farmland was distributed among former collective farm workers. Yet, most farmland is still managed by large-scale agricultural enterprises, because of slow land reforms and a missing land market (Lerman, 1999; Lerman et al., 2004).

Satellite images

To map abandonment, we used Landsat TM images (Fig. 1C). For each of the five footprints, we acquired two images from 1986 to 1989, characterizing land use during socialism, and two images from 2006 to 2008, representing current land use (i.e., four images per footprint). This resulted in a total set of 20 Landsat images (Table 1). For each time period, we used one summer and one spring or fall image from different years to capture phenology differences between permanent farmland and abandoned farmland (Kuemmerle et al., 2008; Prishchepov et al., submitted for publication). Seventeen ortho-corrected images were acquired from the United States Geological Survey (USGS) and the other images were co-registered to these. Average positional error was <0.25 pixels. Clouds and cloud shadows were masked.

Mapping post-socialist farmland abandonment

To map post-socialist farmland abandonment, we used a two-stage approach: first, we mapped farmland in use in 1986–1989; and second, we used a multi-temporal classification approach to assess whether farmland was abandoned or still in use in 2006–2008. We used a Support Vector Machines (SVM) approach for both classifications. SVM are well-suited for mapping farmland abandonment because they handle complex spectral classes well (Foody and Mathur, 2004) and have recently been applied to quantify post-socialist farmland abandonment (Kuemmerle et al., 2008). We used an SVM approach based on Gaussian kernel functions that requires estimating the kernel width γ and the regularization parameter C; and we chose an optimal parameter combination based on cross-validation (Janz et al., 2007).

Classification training data of pre-1990 farmland was based on a random sample of 1000 points per footprint with a minimum distance of 2 km between points to avoid spatial autocorrelation (Table 2). Each point was labeled as 'farmland' or 'other' based on visual interpretation of the Landsat images. Farmland was defined as areas used for crop production or as meadows and pastures

Table 1
Landsat images and acquisition dates.

	Path/row				
	184/026	185/025	185/026	186/025	186/026
I	1987-04-30[a]	1986-10-11[a]	1988-08-21[b]	1987-10-05[a]	1986-10-02[a]
II	1989-07-08[a]	1989-07-07[b]	1988-10-16[a]	1988-07-27[b]	1988-07-27[a]
III	2006-09-25[a]	2006-10-18[a]	2006-10-18[a]	2006-09-23[a]	2006-09-07[a]
IV	2008-08-13[a]	2007-07-17[a]	2007-05-14[a]	2007-07-24[a]	2007-07-24[a]

[a] Landsat TM5.
[b] Landsat TM4.

in one of the images. This was carried out for three footprints (p184r026, p186r025, and p186r026). For the remaining two footprints (p185r025 and p185r026), we sampled 1000 random points per class (i.e., 'farmland' and 'other') from the overlap areas to adjacent footprints (Knorn et al., 2009). We then parameterized the SVM, derived farmland maps for each footprint, applied a 3 × 3 majority filter, and mosaicked all classifications into an area-wide map.

To map farmland abandonment, we selected 1000 random points within the farmland areas of each footprint and labeled these points as 'permanent farmland' or 'abandoned farmland' based on visual interpretation of multitemporal Landsat images as well as high-resolution Quickbird imagery from GoogleEarth (Fig. 1C) (Kuemmerle et al., 2008). Using spectrally rich Landsat imagery and high-resolution imagery in concert can provide reliable ground truth for land cover conversions (Cohen et al., 2010; Kuemmerle et al., 2009c). The Landsat images provide spectral information in the visible, near-, and mid-infrared domains, which is important for agricultural applications. Spectral signatures for farmland in use and fallow fields are known for the study region from extensive field visits (Kuemmerle et al., 2006, 2008, in press), allowing us to assess whether fields are fallow or in use for both time periods (1986–1989 and 2006–2008). We additionally checked ground truth points in recent, high-resolution Quickbird images available in GoogleEarth that provide additional insight into successional stages (e.g., presence of shrubs encroachment). To derive a representative sample of training points, we stratified our sample based on an existing land-cover map for three Landsat footprints (p184r026, p185r026, and p186r026; Kuemmerle et al., 2010, 2006). For the remaining footprints, we clustered the 2006–2008 images into broad land-cover classes using unsupervised classification for stratification. We defined abandoned farmland here as areas that we classified as 'farmland' in our first classification (i.e., farmland mask from 1986 to 1989) and that were categorized as 'fallow' in both of the 2006–2008 images. We derived abandonment maps for each footprint separately, applied a 3 × 3 majority filter, and mosaicked the resulting maps.

Classification accuracy was assessed using a 10-fold nested cross-validation. We divided our dataset randomly into training points (90%) and validation points (10%), classified a land cover map based on the training data, and calculated mean overall accuracy, Kappa, user's, and producer's accuracies based on the remaining validation points (Foody, 2002). This was repeated ten 10 times and we averaged all accuracy measures (Kuemmerle et al., 2009c, in press). Finally, we area-corrected these measures for a possible bias due to our stratified random sampling scheme (Card, 1982). The final map was classified using all ground truth points, meaning that our error estimates represent conservative estimates (Kuemmerle et al., 2009c). Abandonment rates were summarized by rayon (Fig. 1D), elevational zones (100-m bins), and slope zones (5% bins). We also assessed whether abandonment rates differed among the northern and the southern part of the study region (these regions are characterized by slightly different agriculture suitabilities as well as different socio-economic conditions), and we chose the border of the Zakarpatska oblast, which represents the highest ridge of the Carpathians and the main watershed divide, as a boundary.

Table 2
Training samples and classification accuracies for the 1980s farmland classification (top) and the abandonment classification (bottom).

Landsat scene	Contrib. to covered area	Nr. "Farmland points"	User's accuracy (%)	Prod.'s accuracy (%)	Nr. "Non-farmland" points	User's accuracy (%)	Prod.'s accuracy (%)	Overall accuracy (%)	Kappa
184026	0.164	702	95.52	97.00	298	92.68	89.26	94.70	0.87
185025	0.275	998	94.96	96.29	1002	96.25	94.91	95.60	0.91
185026	0.232	992	93.22	95.56	1008	95.52	93.15	94.35	0.89
186025	0.174	623	92.92	96.95	369	94.44	87.53	93.45	0.86
186026	0.154	389	91.09	92.03	526	94.06	93.35	92.79	0.85
Total/Average		**3704**	**93.54**	**95.57**	**3203**	**94.59**	**91.64**	**94.18**	**0.88**
Area weighted			**93.69**	**95.69**		**94.84**	**92.05**	**94.35**	**0.88**
Landsat scene	Contrib. to covered area	Nr. "Abandonm. points"	User's accuracy (%)	Prod.'s accuracy (%)	Nr. "Permanent farmland" points	User's accuracy (%)	Prod.'s accuracy (%)	Overall accuracy (%)	Kappa
184026	0.164	446	87.18	91.48	552	92.83	89.13	90.18	0.80
185025	0.275	332	89.55	90.36	668	95.19	94.76	93.30	0.85
185026	0.232	289	90.29	94.74	711	94.74	96.20	93.50	0.84
186025	0.174	159	87.94	95.93	841	95.93	97.98	94.80	0.80
186026	0.154	201	93.48	85.57	798	96.44	98.49	95.89	0.87
Total/Average		**1427**	**89.69**	**91.62**	**3570**	**95.03**	**95.31**	**93.50**	**0.83**
Area weighted			**89.66**	**91.79**		**95.02**	**95.31**	**93.53**	**0.83**

Table 3
Explanatory variables including their source and *a priori*-supposed direction of influence.

Variable group	Variable name	Time period covered	Hypothesized influence	Source
Environmental variables	Median elevation [m]		+	SRTM
	Median slope [%]		+	SRTM
	Gleysol content [%]		+	FAO
	Podsol content [%]		+	FAO
	Cambisol content [%]		–	FAO
	Phaeozem content [%]		–	FAO
	Regosol content [%]		–	FAO
	Median agricultural suitability (1 = very suitable, 7 = unsuitable)		+	FAO
Accessibility variables	Total length of roads per rayon [km]		–	[b]
	Total length of railways per rayon [km]		–	[b]
	Mean distance to market center [km]		–	[b]
Population variables	Population change [%]	1989–2008	–	[a]
	Urban population change [%]	1989–2008	+	[a]
	# of towns per rayon		+	[b]
	# of villages per rayon		–	[b]
	Changes in unemployment [# people]	1989–2007	+/–	[c]
Agricultural input intensity	# of tractors on farm	2008	+/–	[c]
	Change of aver. # of employees per farm	1989–2007	+/–	[c]

[a] www.ukrcensus.gov.ua.
[b] Geodezkartinformatyka.
[c] State Statistics Committee of Ukraine 2008.

Explanatory variables and their hypothesized influence

Marginal farmland plots are often expected to be abandoned first (Baldock et al., 1996). To proxy marginality, we calculated median elevation and slope for each rayon, based on the Shuttle Radar Topography Mission (SRTM) digital elevation model. Soil quality was incorporated based on (1) the relative coverage of the five main soil types according to the FAO soil map (FAO-UNESCO, 2007), and (2) the median agricultural suitability index, which ranges from 1 (very suitable) to 7 (unsuitable). This index combines physical soil characteristics such as texture, effective soil depth, and soil phases constraining soil management, and relates it to crop requirements and tolerances (Fischer et al., 2008). The index provides therefore additional information about agricultural suitability. Our *a priori* hypotheses were that abandonment rates were higher in regions of higher slopes, higher elevation, and poor soils (Ioffe et al., 2004; Müller et al., 2009).

Our second group of variables captured the accessibility of farmland. We proxied accessibility by calculating (1) km total length of 1st and 2nd order roads per rayon, (2) total length of railways per rayon, and (3) mean distance to major market centers (i.e., cities with a population between 100,000 and 500,000), based on roads, railways, and settlement layers from digital topographic maps (Geodezkartinformatyka, 1997). We hypothesized *a priori* that abandonment rates were higher in remote areas.

The third group of variables captured population change (Elbakidze and Angelstam, 2006) and off-farm income opportunities in cities (Dannenberg and Kuemmerle, 2010; Strijker, 2005). We acquired total population and relative rural/urban population for each rayon for the years 1989 and 2008, plus the change during this period from official census data (State Statistics Committee of Ukraine, 2001). We also incorporated the number of cities (>5000 people), and villages for each rayon based on the digital topographic maps. We hypothesized higher abandonment in areas with higher population declines, and more off-farm income opportunities.

Finally, we acquired variables proxying agricultural input intensity. First, we derived the number of tractors per rayon (for 2008). Higher numbers of tractors potentially reflect a higher market orientation, labor saving, and higher agricultural production. On the other hand, marginal plots, especially pastures, may not be suitable for mechanization. Thus, the effect of tractor numbers was *a priori* unclear (Müller et al., 2009). Second, we derived changes in farm employment between 1995 and 2008 that we hypothesized to be related to abandonment rates. Again, we considered the statistics for each year as well as changes therein. Third, we derived unemployment rates in 2000 and 2007, and changes in between. Higher unemployment could lead to increasing subsistence farming and thus limit abandonment rates or could result in migration of younger population segments, triggering labor scarcity and thus increased abandonment (Müller et al., 2009). The effect of this variable was therefore also unclear *a priori*.

For our statistical analysis, we selected rayons (districts) as our units of observation, because this represented the most detailed level for which most of our socio-economic and demographic predictors were available. Predictors on a finer scale, such as distance to market center or villages were aggregated at the rayon level using median values (distance) or total numbers (villages). We assessed collinearity by calculating Pearson correlation coefficients (r) for each variable pair. When r exceeded 0.7, we retained the variable that was more correlated with abandonment. This resulted in a final set of 18 predictors (Table 3).

Best-subsets regression and hierarchical partitioning

To analyze the relative importance of predictors, we used best subsets regression and hierarchical partitioning. Best-subsets regression performs an exhaustive search for the best linear models ranking all possible models based on goodness-of-fit measures (Miller, 2002). We used the adjusted R^2 as our measure of fit and limited the number of explanatory variables for different models to three, four, and five variables, respectively, to avoid over-fitting due to the moderate sample size (47 rayons). As a measure of variable importance, we summarized how often a variable was included in the 20 best models for each model group (Kuemmerle et al., 2009a; St-Louis et al., 2009).

Hierarchical partitioning (Mac Nally, 2002) quantifies the contribution of a variable to the fit of a multiple linear regression model by comparing the model including this variable to a model without it. This is carried out for each hierarchical level (i.e., model dimensionality), and the improvement in model fit is averaged

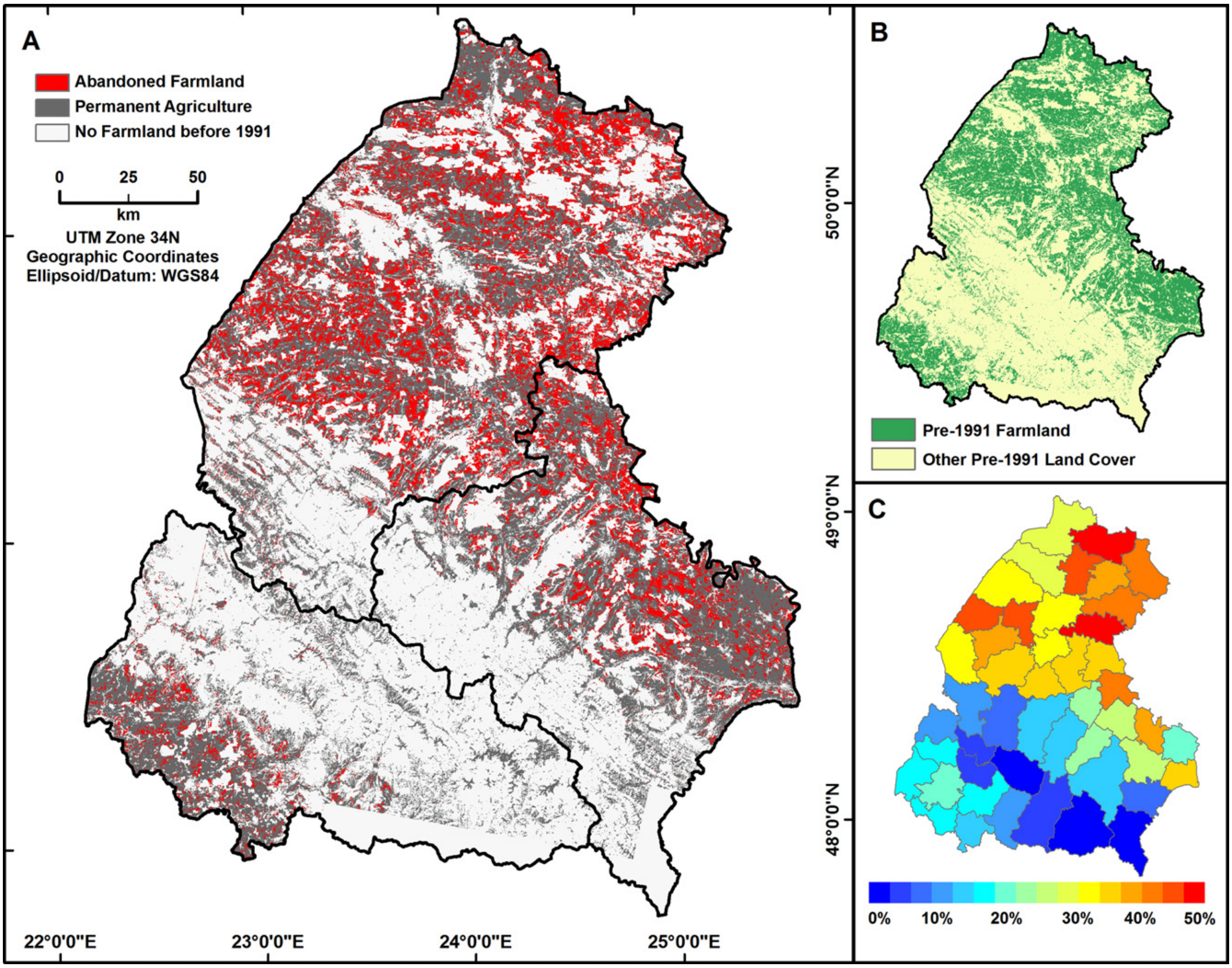

Fig. 2. Results of the remote sensing mapping. (A) Farmland, abandoned after 1990 and active farmland in 2006–2008. (B) Active farmland in 1991. (C) Abandonment rates, summarized at the rayon level.

across all hierarchies, resulting in the independent contribution of this variable (Chevan and Sutherland, 1991; James and McCulloch, 1990). We calculated the average independent contribution of each explanatory variable in our twenty best models for each model group and used the adjusted r^2 values as goodness-of-fit measure.

Results

Patterns of post-socialist farmland abandonment in Western Ukraine

Farmland abandonment was widespread in our study region (Fig. 2). Of the 22,350 km^2 farmed at the end of socialist times (46% of the study region), about 30% were abandoned in 2006 (Fig. 2A and B, 6600 km^2). Overall classification accuracy for the 1980s farmland was 94.4%, (Kappa 0.88), and for the abandonment map 93.5% (Kappa 0.83, Table 2).

Abandonment was widespread in the plains and in the Carpathian foothills, but less abandonment occurred at higher elevations. Abandonment rates were higher closer to the Polish-Ukrainian border and decreased eastwards (Fig. 2A and C). For example, the Peremyshlianski rayon in the north had an abandonment rate of >56%, whereas the Rakhivski rayon in the Carpathians had an abandonment rate of ∼0.2%. On average, 24.44% of the socialist farmland was abandoned on the rayon level (standard deviation of 15.9%), with a median value of 20.69%.

Farmland abandonment rates also differed markedly by elevation and slope (Fig. 3, left column). Abandonment rates were highest between 200 m and 400 m (>35%), and lowest between 1100 m and 1200 m (<2%). Abandonment rates were also higher on gentle slopes and in flat terrain (Fig. 3, left column), and were substantially higher in the northern part of the study region (Fig. 3, right column).

Determinants of post-socialist farmland abandonment

The statistical analysis revealed that environmental and population variables were the best available predictors for explaining farmland abandonment patterns at the district level. Our regression models explained up to 76% of the variability in abandonment rates, and population change, slope, Cambisol content, and unemployment were the most important variables regarding the best-subsets regression and hierarchical partitioning.

Univariate correlations between abandonment rates and our predictor variables showed relatively strong linear relationships for Cambisol content (R^2 = 0.56), urban proportion change (R^2 = 0.38), number of villages (R^2 = 0.33), and elevation (R^2 = 0.32) (Fig. 4). Slope and elevation displayed clear negative relationships with

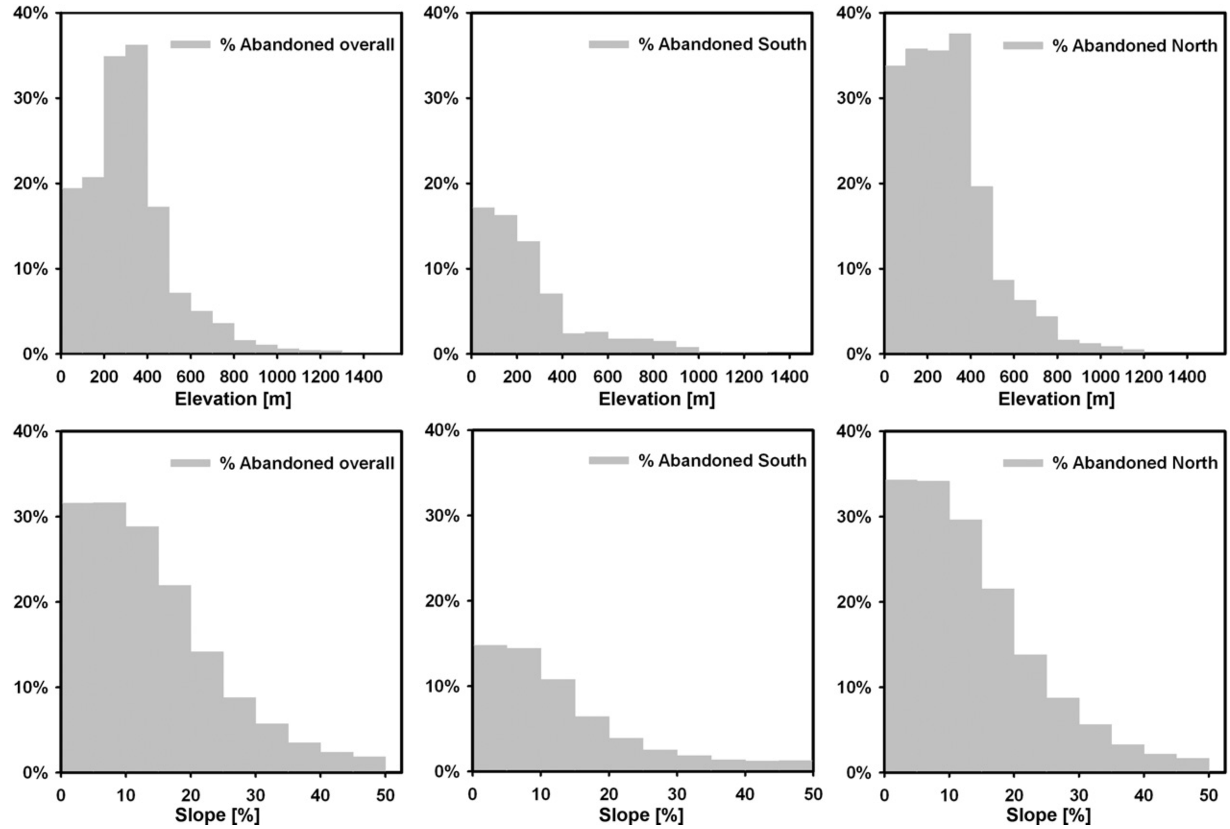

Fig. 3. Abandonment rates by elevation (100 m elevation per class), and slope (5% slope per class).

farmland abandonment. Abandonment rates also decreased with higher Cambisol content, whereas relationships of abandonment rates and the other soil variables were less clear. Besides those already listed, we found additional important relationships: we found higher abandonment rates in regions with decreasing population, in regions with the lowest increase in unemployment, and in regions with decreasing number of employees per farm. We furthermore found lower abandonment rates in regions with lower numbers of villages, in regions with increasing urban population, and in regions with higher total road length.

Average goodness-of-fit of our 60 best models (i.e., 20 models with three, four, and five predictors, respectively) was $R^2 = 0.69$

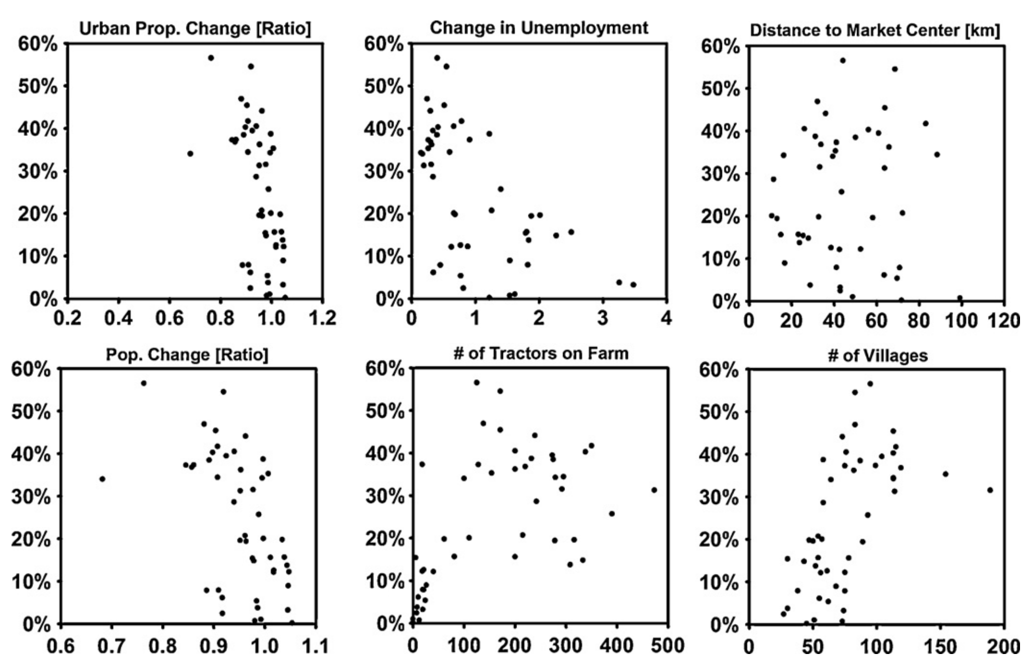

Fig. 4. Relationships between farmland abandonment (%) and selected predictor variables.

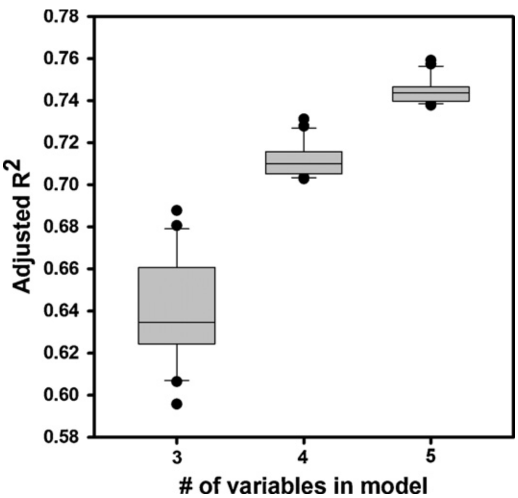

Fig. 5. Boxplots of the explained variance in the best-subsets regression analysis.

(standard deviation of 0.04, median of 0.71). Five-dimensional models had a higher goodness-of-fit (minimum adjusted R^2 = 0.74, mean = 0.74, max = 0.76, median = 0.74) than four-dimensional (0.70, 0.71, 0.73, 0.71) and three-dimensional models (0.59, 0.64, 0.69, 0.63). Our best model had an adjusted R^2 of 0.76 and used five variables (change in unemployment, number of villages, elevation, Podsol content, Cambisol content). However, the difference in the adjusted R^2 between the best and the 20th best five-dimensional model was only 0.02 (0.03 and 0.09 for four- and three-dimensional models, Fig. 5).

The variables that were most often included in the 20 best models were population change (13 of 20 models, 14/20, and 14/20 in the best three-, four- and five-dimensional models), Cambisol content (6/20, 12/20, 18/20), elevation (7/20, 9/20, 11/20), and number of villages (3/20, 10/20, 11/20). Generally, the variables included in the three-dimensional models also entered the four- and five-dimensional ones. With increasing model complexity, all variables appeared in more models, yet the increase was not uniform. For example, Cambisol content and the number of villages had the strongest increase (+12 and +8 respectively), whereas population change, or number of unemployed people only showed moderate increases (+1, +2).

Environmental variables and population variables had the highest independent contribution in the hierarchical partitioning analysis, especially slope (61.8%, 46.8%, and 35.2% for the three-, four-, and five-dimensional models), elevation (47.6%, 34.8%, 25.9%), and Cambisol content (47.4%, 36.3%, 30.3%). The variables with the lowest independent contribution were agricultural suitability index (3.1%, 2.7%, 2.2%), and mean distance to market centers (4.7%, 5.3%, 3.2%). With increasing model complexity the independent contribution of variables decreased. The strongest overall decrease occurred for the variables with the highest independent contribution in three-dimensional models (Fig. 6).

Discussion

The collapse of socialism resulted in widespread farmland abandonment in Western Ukraine, but abandonment rates varied considerably across our study region. What drives these spatial patterns and thus what mediates or amplifies the effects of the high-level causes of abandonment (such as disappearing subsidies and markets, land reforms or tenure insecurity) remains unclear for many regions. Here, we contribute to a better understanding of these drivers by quantifying what determines abandonment patterns in Western Ukraine. Our statistical models showed that soil type, topography, and rural population change explain the spatial heterogeneity of farmland abandonment best at the district level. The relative influence of these variables was sometimes surprising and opposite to what has been observed in Western Europe, suggesting that post-socialist farmland abandonment in Eastern Europe, specifically in Ukraine, followed different rules than so far known.

Our first hypothesis was that abandonment rates would be higher on more marginal sites. Soil type (especially the relative abundance of Cambisols), elevation, and slope were all powerful predictors of farmland abandonment rates at the district-level in our models. Cambisols are generally more suitable for farming than Podsols and Gleysols, and lower abandonment in areas dominated by Cambisols thus seems in line with our first hypothesis at first glance. However, the association with topography was opposite to our expectations, with lower abandonment rates at higher elevations and steeper slopes.

Three factors likely explain these opposite trends. First, the best soils (Cambisols) in our study area occur in the mountains and foothills (Kruhlov et al., 2008). Soils in the plains are often poor or waterlogged, especially in the floodplains of the rivers Dniester and Prut. Much of the abandoned arable land in the plains occurred in these floodplains (Fig. 2). Second, many mountain valleys in the Ukrainian Carpathians are densely populated. During socialism, agriculture there was not as heavily industrialized as in the plains, and traditional subsistence farming as a combination of smallholder crop production and livestock herding has always been important (Süli-Zakar, 1998). During the transition period, traditional subsistence farming became again an important livelihood strategy in such remote regions (Hajda, 1998; Hoshko, 1983). Third, the recent eastward expansion of the European Union reduced border traffic and isolated the lowland close to Slovakia, where we found high abandonment rates (Fig. 2). The bottom line is though that topographic marginality was not a major determinant of abandonment in Western Ukraine.

Our second hypothesis was that there would be higher abandonment rates in less accessible areas. Contrary to our expectation, infrastructure density and distance to local markets were positively related to abandonment rates, although the importance of these variables was low. The low importance and the positive relation of these variables was surprising, because accessibility variables were important predictors in Romania (Müller et al., 2009), suggesting that drivers of post-socialist farmland abandonment patterns may differ regionally.

Our third hypothesis assumed higher abandonment in areas with declining populations and increasing urbanization. Population decline and changes in the proportion of urban population were important to explain the variability of abandonment in our models, and both were positively related to abandonment rates, which was in line with our expectations. Higher abandonment rates in districts with an increasing urban population proportion likely reflect outmigration from rural areas. Often, young population segments are the first to migrate in search for income opportunities and a different life style (Ioffe et al., 2004; Palang et al., 2006). Many villages now have a high proportion of empty households, and a reduced agricultural workforce may have contributed to high abandonment rates. The weak low importance of this predictor may be explained by commuters (i.e., individuals that continue to live in villages, but seek off-farm employment elsewhere) and remittances from family members working abroad, that often help sustain livelihoods in rural areas (Müller and Munroe, 2008).

Our fourth and final hypothesis assumed that abandonment rates were highest where the intensity of farming decreased most.

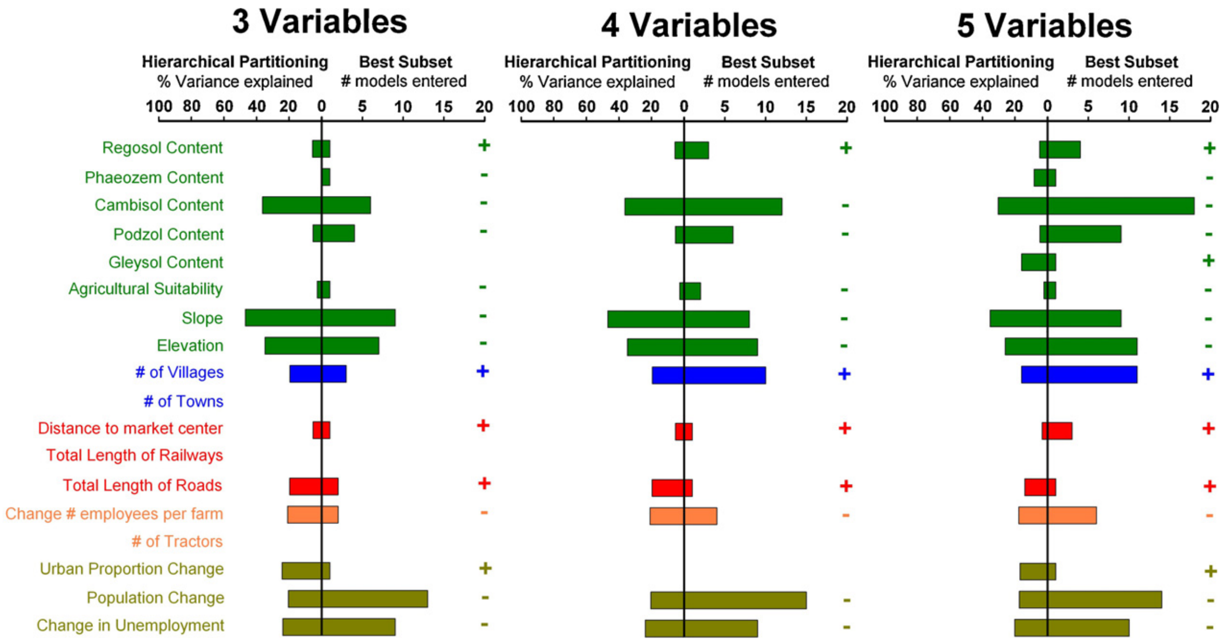

Fig. 6. Average independent contribution of the predictor variables, times they entered into the best regression models, and direction of predictor influence. Environmental predictors are marked in green, settlement predictors in blue, accessibility predictors in red, farm specific predictors in orange, and population predictors in lime. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

The relative importance of land-use intensity variables was overall low though, and the relationship with abandonment was contrary to our expectations. We found lower abandonment rates in areas of higher unemployment, potentially also due to the relatively high importance of traditional subsistence farming and off-farm revenues (e.g., remittances). Abandonment rates were high where mechanization (measured in tractor numbers) was high, indicating a higher market orientation and an abandonment of marginal land not suitable for mechanization (Müller et al., 2009). Overall, our results thus suggest a rejection of our fourth hypothesis.

The rejection of most of our hypotheses suggests that patterns and drivers of post-socialist farmland abandonment in Ukraine differed from those in Western Europe. For example, farmland abandonment in the Alps was higher at higher elevation and on steeper slopes (Gellrich et al., 2007), but we found the opposite pattern. Similarly, abandonment patterns in our study area were probably not mainly determined by crop productivity, and subsistence farming was important in our case, but plays only a minor role in Western Europe (ENRD, 2010). Differences in abandonment patterns between Europe's West and East may reflect fundamentally different underlying causes that triggered abandonment. In Western Europe abandonment appears to be mainly driven by gradual industrialization, market-orientation, and urbanization (MacDonald et al., 2000; Verburg et al., 2010). In contrast, abandonment in Eastern Europe was triggered by the collapse of socialism and the followed radical institutional reforms and economic shocks. Considering that the future of Eastern Europe's farmlands remains highly uncertain, with both, recultivation and a continuing rural exodus being plausible scenarios (DLG, 2005; Verburg et al., 2010), the relatively low importance of variables capturing the market-orientation of farming may indicate that abandonment in Eastern Europe could be considered as a temporal disturbance just as well as a permanent transitions towards forest dominated landscapes. Additionally, the difference of the abandonment pattern in Western Ukraine compared to other Eastern European studies points out that even in regions that suffered from the same shock in surrounding conditions, more precisely the breakdown of socialism, a generalization across countries is hardly possible.

Our study shows the importance of large-area assessments of landscape change, which revealed in our case unexpected spatial pattern of farmland abandonment that differed from other studies in Western Europe. Our statistical analyses suggested that even across Eastern European countries farmland abandonment followed quite different rules, and considering such regional differences seems important when, for example, simulating future land-use patterns or assessing how post-socialist farmland abandonment will affect flows of ecosystem services or biodiversity of Eastern Europe's landscapes.

Acknowledgements

We would like to thank D. Müller for valuable comments at various stages of this study. Two anonymous reviewers are thanked for thoughtful and constructive comments that helped to improve this manuscript. We gratefully acknowledge support by the Alexander von Humboldt Foundation, the Land-Cover and Land-Use Change Program of the National Aeronautic Space Administration (NASA), and the Office for International Relations of Humboldt-University Berlin.

References

Augustyn, M., 2004. Anthropogenic changes in the environmental parameters of Bieszczady Mountains. Biosphere Conservation 6, 43–53.

Baldock, D., Beaufoy, G., Brouwer, F., Godeschalk, F., 1996. Farming at the Margins: Abandonment or Redeployment of Agricultural Land in Europe. Institute for European and Environmental Policy and Agricultural Economics Research Institute, London.

Card, D.H., 1982. Using known map category marginal frequencies to improve estimates of thematic map accuracy. Photogrammetric Engineering and Remote Sensing 48, 431–439.

Chazdon, R.L., 2008. Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science 320, 1458–1460.

Chevan, A., Sutherland, M., 1991. Hierachichal partitioning. American Statistician 45, 90–96.

Cohen, W.B., Yang, Z., Kennedy, R., 2010. Detecting trends in forest disturbance and recovery using yearly Landsat time series: 2. TimeSync—tools for calibration and validation. Remote Sensing of Environment 114, 2911–2924.

Dannenberg, P., Kuemmerle, T., 2010. Farm size and land use pattern changes in postsocialist poland. The Professional Geographer 62, 197–210.

DLG, 2005. Land Abandonment, Biodiversity, and the CAP. Government Service for Land and Water Management of the Netherlands (DLG), Utrecht, the Netherlands.

Elbakidze, M., Angelstam, P., 2006. Implementing sustainable forest management in Ukraine's Carpathian Mountains: the role of traditional village systems. In: IUFRO Conference on Cultural Heritage and Sustainable Forest Management, pp. 28–38.

ENRD (European Network for Rural Development), 2010. Semi-subsistence farming in Europe: concepts and key issues. In: Background Paper Prepared for the Seminar "Semi-subsistence Farming in the EU: Current Situation and Future Prospects", Sibiu, Romania.

FAO-UNESCO, 2007. Soil Map of the World 1:5.000.000. Berkeley University of California.

Fischer, G., Nachtergaele, F., Prieler, S., van Velthuizen, H.T., Verelst, L., Wiberg, D., 2008. Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008). IIASA/FAO, Laxenburg, Austria/Rome, Italy.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309, 570–574.

Foody, G.M., 2002. Status of land cover classification accuracy assessment. Remote Sensing of Environment 80, 185–201.

Foody, G.M., Mathur, A., 2004. A relative evaluation of multiclass image classification by support vector machines. IEEE Transactions on Geoscience and Remote Sensing 42, 1335–1343.

Fox, J., Fujita, Y., Ngidang, D., Peluso, N., Potter, L., Sakuntaladewi, N., Sturgeon, J., Thomas, D., 2009. Policies, political-economy, and swidden in Southeast Asia. Human Ecology 37, 305–322.

Geist, H.J., Lambin, E.F., 2002. Proximate causes and underlying driving forces of tropical deforestation. Bioscience 52, 143–150.

Gellrich, M., Baur, P., Koch, B., Zimmermann, N.E., 2007. Agricultural land abandonment and natural forest re-growth in the Swiss mountains: a spatially explicit economic analysis. Agriculture Ecosystems & Environment 118, 93–108.

Gellrich, M., Zimmermann, N.E., 2007. Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: a spatial statistical modelling approach. Landscape and Urban Planning 79, 65–76.

Geodezkartinformatyka, 1997. Tsyfora topographichna karta masshtabu 1:200.000 Lvivskoyi, Ivano-Frankivskoyi, Ternopilskoyi, Zakarpatskoyi Oblastey (Digital topographic map). Kyiv Geodezkartinformatyka (in Ukrainian).

Global Land Project, 2005. Science plan and implemantation strategy. In: IGBP Report Number 53/IHDP Report Number 1.19. International Geosphere-Biosphere Programme, Stockholm, Sweden.

Hajda, Y., 1998. Turkivshchyna: pryroda i liudy. Uzhhorod (in Ukrainian).

Hansen, M.C., Stehman, S.V., Potapov, P.V., Loveland, T.R., Townshend, J.R.G., DeFries, R.S., Pittman, K.W., Arunarwati, B., Stolle, F., Steininger, M.K., Carroll, M., DiMiceli, C., 2008. Humid tropical forest clearing from 2000 to 2005 quantified by using multitemporal and multiresolution remotely sensed data. Proceedings of the National Academy of Sciences of the United States of America 105, 9439–9444.

Henebry, G.M., 2009. Global change: carbon in idle croplands. Nature 457, 1089–1090.

Hoshko, J., 1983. Boikivshchyna: istoryko-etnographichne doslidzhennia. Kiev (in Ukrainian).

Ioffe, G., Nefedova, T., 2004. Marginal farmland in European Russia. Eurasian Geography and Economics 45, 45–59.

Ioffe, G., Nefedova, T., Zaslavsky, I., 2004. From spatial continuity to fragmentation: the case of Russian farming. Annals of the Association of American Geographers 94, 913–943.

James, F.C., McCulloch, C.E., 1990. Multivariate analysis in ecology and systematics: panacea or pandora's box? Annual Review of Ecology and Systematics 21, 129–166.

Janz, A., van der Linden, S., Waske, B., Hostert, P., 2007. imageSVM—a user-orientated tool for advanced classification of hyperspectral data using Support Vector Machines. In: Proceedings of the 5th EARSeL Workshop on Imaging Spectroscopy, Bruges, Belgium.

Kauppi, P.E., Ausubel, J.H., Fang, J.Y., Mather, A.S., Sedjo, R.A., Waggoner, P.E., 2006. Returning forests analyzed with the forest identity. Proceedings of the National Academy of Sciences of the United States of America 103, 17574–17579.

Knorn, J., Rabe, A., Radeloff, V.C., Kuemmerle, T., Kozak, J., Hostert, P., 2009. Land cover mapping of large areas using chain classification of neighboring Landsat satellite images. Remote Sensing of Environment 113, 957–964.

Kozak, J., Estreguil, C., Troll, M., 2007. Forest cover changes in the northern Carpathians in the 20th century: a slow transition. Journal of Land Use Science 2, 127–146.

Kramer, R.A., Richter, D.D., Pattanayak, S., Sharma, N.P., 1997. Ecological and economic analysis of watershed protection in Eastern Madagascar. Journal of Environmental Management 49, 277–295.

Kruhlov, I., Mukha, B., Senchyna, B., 2008. Natural geoecosystems. In: Roth, R., Nobis, S.V., Kruhlov, I. (Eds.), Transformation Processes in the Western Ukraine. Concepts for a Sustainable Land Use. Berlin Wiessensee Verlag, pp. 81–98.

Kuemmerle, T., Hostert, P., Radeloff, V.C., van der Linden, S., Perzanowski, K., Kruhlov, I., 2008. Cross-border comparison of post-socialist farmland abandonment in the Carpathians. Ecosystems 11, 614–628.

Kuemmerle, T., Hostert, P., St-Louis, V., Radeloff, V.C., 2009a. Using image texture to map farmland field size: a case study in Eastern Europe. Journal of Land Use Science 4, 85–107.

Kuemmerle, T., Müller, D., Griffiths, P., Rusu, M., 2009b. Land-use change in Southern Romania after the collapse of socialism. Regional Environmental Change 9, 1–12.

Kuemmerle, T., Chaskovskyy, O., Knorn, J., Radeloff, V.C., Kruhlov, I., Keeton, W.S., Hostert, P., 2009c. Forest cover change and illegal logging in the Ukrainian Carpathians in the transition period from 1988 to 2007. Remote Sensing of Environment 113, 1194–1207.

Kuemmerle, T., Olofsson, P., Chaskovskyy, O., Baumann, M., Ostapowicz, K., Woodcock, C.E., Houghton, R.A., Hostert, P., Keeton, W.S., Radeloff, V.C., in press. Post-Soviet farmland abandonment, forest recovery, and carbon sequestration in western Ukraine. Global Change Biology, doi:10.1111/j.1365-2486.2010.02333.x.

Kuemmerle, T., Perzanowski, K., Chaskovskyy, O., Ostapowicz, K., Halada, L., Bashta, A.-T., Kruhlov, I., Hostert, P., Waller, D.M., Radeloff, V.C., 2010. European Bison habitat in the Carpathian Mountains. Biological Conservation 143, 908–916.

Kuemmerle, T., Radeloff, V.C., Perzanowski, K., Hostert, P., 2006. Cross-border comparison of land cover and landscape pattern in Eastern Europe using a hybrid classification technique. Remote Sensing of Environment 103, 449–464.

Lakes, T., Müller, D., Kruger, C., 2009. Cropland change in southern Romania: a comparison of logistic regressions and artificial neural networks. Landscape Ecology 24, 1195–1206.

Lambin, E.F., Meyfroidt, P., 2010. Land-use transitions: socio-ecological feedback versus socio-economic change. Land Use Policy 27, 108–118.

Larsson, S., Nilsson, C., 2005. A remote sensing methodology to assess the costs of preparing abandoned farmland for energy crop cultivation in northern Sweden. Biomass & Bioenergy 28, 1–6.

Lerman, Z., 1999. Land reform and farm restructuring in Ukraine. Problems of Post-Communism 46, 42–55.

Lerman, Z., Csaki, C., Feder, G., 2004. Evolving farm structures and land use patterns in former socialist countries. Quarterly Journal of International Agriculture 43, 309–335.

Lerman, Z., Shagaida, N., 2007. Land policies and agricultural land markets in Russia. Land Use Policy 24, 14–23.

Mac Nally, R., 2002. Multiple regression and inference in ecology and conservation biology: further comments on identifying important predictor variables. Biodiversity and Conservation 11, 1397–1401.

MacDonald, D., Crabtree, J.R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Lazpita, J.G., Gibon, A., 2000. Agricultural abandonment in mountain areas of Europe: environmental consequences and policy response. Journal of Environmental Management 59, 47–69.

Marin-Spiotta, E., Silver, W.L., Swanston, C.W., Ostertag, R., 2009. Soil organic matter dynamics during 80 years of reforestation of tropical pastures. Global Change Biology 15, 1584–1597.

Mather, A.S., Fairbairn, J., Needle, C.L., 1999. The course and drivers of the forest transition: the case of France. Journal of Rural Studies 15, 65–90.

Mathijs, E., Swinnen, J.F.M., 1998. The economics of agricultural decollectivization in East Central Europe and the former Soviet Union. Economic Development and Cultural Change 47, 1–26.

Miller, A., 2002. Subset Selection in Regression. Chapman & Hall/CRC, Boca Raton, London, New York, Washington, DC.

Müller, D., Kuemmerle, T., Rusu, M., Griffiths, P., 2009. Lost in transition: determinants of post-socialist cropland abandonment in Romania. Journal of Land Use Science 4, 109–129.

Müller, D., Munroe, D.K., 2008. Changing rural landscapes in Albania: cropland abandonment and forest clearing in the postsocialist transition. Annals of the Association of American Geographers 98, 855–876.

NESDIS [National Environmental Satellite Data and Information Service], 2009. Online Climate Data Directory [online]., http://www.ncdc.noaa.gov/oa/climate/climatedata.html.

Nikodemus, O., Bell, S., Grine, I., Liepins, I., 2005. The impact of economic, social and political factors on the landscape structure of the Vidzeme Uplands in Latvia. Landscape and Urban Planning 70, 57–67.

Palang, H., Printsmann, A., Gyuro, E.K., Urbanc, M., Skowronek, E., Woloszyn, W., 2006. The forgotten rural landscapes of Central and Eastern Europe. Landscape Ecology 21, 347–357.

Peterson, U., Aunap, R., 1998. Changes in agricultural land use in Estonia in the 1990s detected with multitemporal Landsat MSS imagery. Landscape and Urban Planning 41, 193–201.

Plieninger, T., 2006. Habitat loss, fragmentation, and alteration–quantifying the impact of land-use changes on a Spanish Dehesa landscape by use of aerial photography and GIS. Landscape Ecology 21, 91–105.

Plieninger, T., Hochtl, F., Spek, T., 2006. Traditional land use and nature conservation in European rural landscapes. Environmental Science & Policy 9, 317–321.

Potapov, P., Yaroshenko, A., Turubanova, S., Dubinin, M., Laestadius, L., Thies, C., Aksenov, D., Egorov, A., Yesipova, Y., Glushkov, I., Karpachevskiy, M., Kostikova, A., Manisha, A., Tsybikova, E., Zhuravleva, I., 2008. Mapping the World's intact forest landscapes by remote sensing. Ecology and Society 13.

Prishchepov, A.V., Radeloff, V.C., Dubinin, M., Alcantara, C., submitted for publication. The effect of satellite image dates on land-cover change detection and the mapping of agricultural land abandonment in Eastern Europe.

Rey Benayas, J.M., Martins, A., Nicolau, J.M., Schulz, J.J., 2007. Abandonment of agricultural land: an overview of drivers and consequences. CAB Reviews: Perspectives in Agriculture, Veterenary Science Nutrition and Natural Resources, vol. 2, No. 057.

Rhemtulla, J.M., Mladenoff, D.J., Clayton, M.K., 2009. Legacies of historical land use on regional forest composition and structure in Wisconsin, USA (mid-1800s–1930s–2000s). Ecological Applications 19, 1061–1078.

Rudel, T.K., Schneider, L., Uriarte, M., 2010. Forest transitions: an introduction. Land Use Policy 27, 95–97.

Rudel, T.K., Schneider, L., Uriarte, M., Turner, B.L., DeFries, R., Lawrence, D., Geoghegan, J., Hecht, S., Ickowitz, A., Lambin, E.F., Birkenholtz, T., Baptista, S., Grau, R., 2009. Agricultural intensification and changes in cultivated areas, 1970–2005. Proceedings of the National Academy of Sciences of the United States of America 106, 20675–20680.

Sitko, I., Troll, M., 2008. Timberline changes in relation to summer farming in the Western Chornohora (Ukrainian Carpathians). Mountain Research and Development 28, 263–271.

St-Louis, V., Pidgeon, A.M., Clayton, M.K., Locke, B.A., Bash, D., Radeloff, V.C., 2009. Satellite image texture and a vegetation index predict avian biodiversity in the Chihuahuan Desert of New Mexico. Ecography 32, 468–480.

State Statistics Committee of Ukraine, 2001. All Ukrainian Population Census 1989–2000., http://www.ukrcensus.gov.ua/eng/.

Strijker, D., 2005. Marginal lands in Europe—causes of decline. Basic and Applied Ecology 6, 99–106.

Süli-Zakar, I., 1998. Socio-geographical transition in the rural areas of the Carpathian Euroregion. GeoJournal 46, 193–197.

Tasser, E., Mader, M., Tappeiner, U., 2003. Effects of land use in alpine grasslands on the probability of landslides. Basic and Applied Ecology 4, 271–280.

Turner, B.L., Lambin, E.F., Reenberg, A., 2007. The emergence of land change science for global environmental change and sustainability. Proceedings of the National Academy of Sciences of the United States of America 104, 20666–20671.

Turnock, D., 1998. Introduction. In: Turnock, D. (Ed.), Privatization in Rural Eastern Europe. The Process of Restitution and Restructuring. Edward Elgar, Cheltenham, pp. 1–48.

Turnock, D., 2002. Ecoregion-based conservation in the Carpathians and the land-use implications. Land Use Policy 19, 47–63.

Vaclavik, T., Rogan, J., 2009. Identifying trends in land-use/land-cover changes in the context of post-socialist transformation in Central Europe: a case study of the Greater Olomouc region, Czech Republic. Giscience & Remote Sensing 46, 54–76.

Verburg, P., Overmars, K., 2009. Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. Landscape Ecology 24, 1167–1181.

Verburg, P.H., van Berkel, D.B., van Doorn, A.M., van Eupen, M., van den Heiligenberg, H., 2010. Trajectories of land use change in Europe: a model-based exploration of rural futures. Landscape Ecology 25, 217–232.

Vuichard, N., Ciais, P., Belelli, L., Smith, P., Valentini, R., 2008. Carbon sequestration due to the abandonment of agriculture in the former USSR since 1990. Global Biogeochemical Cycles 22, doi:10.1029/2008gb003212.

Yeloff, D., van Geel, B., 2007. Abandonment of farmland and vegetation succession following the Eurasian plague pandemic of AD 1347-52. Journal of Biogeography 34, 575–582.