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Land use change in Southern Romania after the collapse of socialism

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Abstract The drastic socio-economic and political changes that occurred after the breakdown of socialism in Eastern Europe triggered widespread land use change, including cropland abandonment and forest cover changes. Yet the rates and spatial patterns of post-socialist land use change remain largely unclear. We used Landsat TM/ETM+ images to classify land cover maps and assess landscape pattern changes from 1990 to 2005 in Argeş County, Southern Romania. Cropland abandonment was the most widespread change (21.1% abandonment rate), likely due to declining returns from farming, tenure insecurity, and demographic developments during transition. Forest cover and forest fragmentation remained remarkably stable during transition, despite widespread ownership transfers. Cropland abandonment provides opportunities for increased carbon sequestration, but threatens cultural landscapes and biodiversity. Continued monitoring is important for assessing whether abandoned croplands will eventually reforest or be put back into production and to better understand the consequences of post-socialist land use change for ecosystems and biodiversity.

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Introduction

Cropland expansion has been the main cause for widespread conversions of natural to human-dominated landscapes (Klein Goldewijk 2001; Ramankutty et al. 2002). This has enabled the continued provision of some essential ecosystem services (e.g., food, fiber), but also degraded other services (e.g., climate and soil stability, water quality), altered ecosystem functioning, and caused extinctions via habitat loss (DeFries et al. 2004; Foley et al. 2005; MA 2005). While cropland expansion continues to be a significant global land use change (Lepers et al. 2005), socio-economic and demographic changes have reversed land use trends in some regions and resulted in the reforestation of formerly cultivated land (Mather 1992; Mather and Needle 1998; Rudel 1998). This provides opportunities for restoring some properties of natural ecosystems, for mitigating climate change through increased carbon sequestration, and for increasing habitat connectivity (Bolliger et al. 2007; Rudel et al. 2005; Silver et al. 2000). Assessing land use change in areas that undergo rapid political or socio-economic change is therefore important (GLP 2005; Lambin and Geist 2006), but there are large regional monitoring gaps, and the rates and spatial patterns of cropland abandonment and reforestation often remain unclear (Rudel et al. 2005).

The transition from command to free-market-oriented economies in Eastern Europe after the fall of the Iron Curtain in 1989 drastically changed the region's political, socio-economic, and demographic structures. State-support and markets for agriculture disappeared, new land

management policies were issued, and land reforms resulted in massive land ownership transfers (Lerman et al. 2004; Mathijs and Swinnen 1998). This strongly affected land use decisions and triggered widespread land use change (Bicik et al. 2001; Lerman et al. 2004), including cropland abandonment and reforestation at unprecedented rates (Ioffe et al. 2004; Kozak 2003; Müller and Sikor 2006; Nikodemus et al. 2005), and increased logging (Achard et al. 2006; Kuemmerle et al. 2007). However, while general land use trends in Eastern Europe during transition are well acknowledged, detailed data on these trends are largely lacking (GLP 2005).

Romania is a particularly interesting country for study because its agricultural sector is among the largest in Eastern Europe, it is among the most populous countries in Europe, and Romania recently joined the European Union. Romania is also rich in traditional cultural landscapes that harbor unique farmland biodiversity and have high recreation potential and aesthetic value (Cremene et al. 2005; Palang et al. 2006). Moreover, Romanian borders include a major part of the Carpathians, Europe's largest continuous temperate forest ecosystem and mountain range (Ioras 2003; Oszlanyi et al. 2004). Carpathian ecosystems harbor exceptionally high biodiversity, many endemic species, and viable populations of endangered large herbivores and carnivores (Ioras 2003; Webster et al. 2001).

Post-socialist land use change may pose both threats to and opportunities for Romania's ecosystems, their biodiversity, and the services they provide. For example, the decreasing profitability of farming, the restructuring of the agricultural sector, and demographic changes all likely led to declining human pressure in rural areas, but cropland abandonment and reforestation threaten the persistence of cultural landscapes and may result in biodiversity loss (Cremene et al. 2005). New forest management policies promote sustainable forestry (Kissling-Naf and Bisang 2001), but ownership transfers, weakened institutions, and economic difficulties may have increased illegal logging and forest fragmentation (Bouriaud and Niskanen 2003; Turnock 2002; Webster et al. 2001). Yet, although much is at stake, little is known about how post-socialist land use change has affected Romania's rural landscapes and ecosystems.

This lack of detailed information is not surprising, because fine-scale, multi-temporal land use maps or agricultural census data are often unavailable or of unknown reliability (Filer and Hanousek 2002; Peterson and Aunap 1998). Mapping post-socialist land use change based on satellite images is a solution in such cases, and Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data are particularly well-suited for this purpose. Images from before and after 1989 exist and the spatial resolution of Landsat TM/ETM+ data allows for fine-scale mapping of the rates and spatial patterns of post-socialist landscape dynamics (Kozak et al. 2007b; Kuemmerle et al. 2007; Peterson and Aunap 1998).

Yet despite these advantages, only a handful of peer-reviewed satellite-based assessments of post-socialist land use change exist for the Carpathian ecoregion. Visually interpreting a Landsat image and historic maps revealed marked village structure changes in southeast Poland (Angelstam et al. 2003). In the tri-country border of Poland, Slovakia, and Ukraine, forest disturbance rates increased after 1989 in all countries (Kuemmerle et al. 2007). Elsewhere in the Polish and Slovak Carpathians, forest land increased by 4% between 1987 and 2000 (Kozak et al. 2008, 2007b). Forest also became more fragmented during transition in the northern Carpathians (Kozak et al. 2007b; Kuemmerle et al. 2007). To our knowledge, only two studies have examined the fate of Romania's landscapes in post-socialist times: Dezso et al. (2005) compared coarse-scale Global Land Cover Characterization (GLCC) and Moderate Resolution Imaging Spectroradiometer (MODIS) land cover, which showed an 18% forest cover decrease in a sub-catchment of the Tisza River in northern Romania; Mihai et al. (2007), focusing on alpine vegetation in a small study region in the southern Romanian Carpathians, examined Landsat images from 1986 and 2002, which showed only moderate changes, most notably the regeneration of vegetation on barren lands and secondary succession on grassland. To date, no study has assessed the rates and spatial patterns of cropland abandonment, forest cover change, and forest fragmentation in Romania at fine scales or for larger regions.

The primary goal of our study was to investigate whether the political and economic transition after 1989 triggered cropland abandonment and forest dynamics and how this affected Romania's rural landscapes. We decided to use Landsat satellite images to map land cover and landscape patterns changes between the breakdown of socialism and Romania's accession to the European Union. As a case study region, we selected Argeş County in Southern Romania, because the county covers a wide range of environmental conditions (from the mountains in the north to agricultural plains in the south). Moreover, the area is characterized by a heterogeneous farming structure ranging from mainly small-scale farms in the mountains, to relatively large agricultural enterprises in the southern plains. Our specific objectives were:

1. to map changes in the proportions of forest, cropland, and grassland, as well as landscape pattern changes in Argeş County based on Landsat TM/ETM+ images from 1990, 1995, 2000, and 2005;
2. to compare landscape changes among zones of differing altitudes, slopes, and access to market centers; and

3. to interpret the observed changes by considering the political and socio-economic developments that occurred in Romania after the breakdown of socialism.

Study area

Argeş County is located in Muntenia, south-central Romania (44.40–45.60N; 24.40–25.35E), and covers an area of 6,824 km^2. Elevations range from 100 to >2,500 m above sea level, the mean annual temperature varies between 9°C in the plains to 1°C in the highest mountains, and annual rainfall ranges between 550 and 1,100 mm (Romanian National Institute for Meteorology, Hydrology, and Water Management, http://www.hidro.ro). These variations result in four zones of potential natural vegetation: an alpine zone (>2,200 m) above the tree line dominated by *Carex curvula, Festuca supine*, and *Juncus trifidus*; a mountain zone (1,500–2,200 m) with coniferous forests (e.g., *Pinus mugo, Picea abies, Abies alba*); a foothill zone with mixed and broadleaved forests between 250 and 1,500 m with *Fagus silvatica, Betula pendula*, and *Carpinus betulus*; and a zone of thermophilous oak forests in the plains (<250 m, main species include *Quercus petraea, Q. robur, Q. frainetto, and Q. ceri*) (Enescu 1996; Mihai et al. 2007). The predominant geology of the study region is crystalline rocks, with occasional limestone in the mountains and tertiary sediments in the plains (i.e., clays, sandstone, and loess). Major soils include *Podzols* in the mountain zone, *Cambisols* in the foothill zone, and *Argillic soils* in the plains.

Land use has substantially altered natural vegetation communities in most areas of the study region. Today, the foothill zone is characterized by a mix of semi-natural beech forest, pastures, orchards, and small-scale agriculture surrounding villages. Animal husbandry is important in these areas, while intensified large-scale agriculture dominates in the plains. Typical crops in the southern plains include maize, sunflower, and wheat and mixed crops, with a large share of potatoes in the hilly and northern plateaus. Cattle are distributed relatively uniformly across Argeş County, whereas sheep husbandry is concentrated in the north and pig production in the south. Similar to other regions in Romania, the rural economy of Argeş is characterized by the co-existence of subsistence and market-oriented agriculture. The total population of Argeş County is 646,320 people, of which 171,070 live in the capital Piteşti (NIS 2006), the major market center and home to the largest employers in the region.

After 1989, land reforms restituted cropland and forests in three phases and led to a substantial restructuring of farming in the county. In the first two phases (restitution laws in 1991 and 2000), a maximum of 50 ha of cropland and 10 ha of forest land per family were given back to former owners, while the remaining land was redistributed to former cooperative workers (Parliament of Romania 2000). About 35% of Romania's forests were targeted for restitution in this period. The third phase (restitution law of 2005) targeted another 30% of the forest land for privatization (Ioras and Abrudan 2006) and former owners can now potentially receive all of their collectivized land. In Argeş County, about 201,000 ha of agricultural land has been restituted to former owners, while the restitution of forest land is still in progress.

Data and methods

Datasets used

We acquired Landsat images from 1990, 1995, 2000, and 2005. Two different Landsat scenes cover the full extent of the study region (path/row 183/28, and 183/29; covering 5 and 94%, respectively). Clouds were frequent in the highest mountains in the north of the study region and we used images from the overlapping adjacent scene (path/row 184/28) to fill clouds (in 1995), and where suitable images from path/row 183/28 did not exist (in 2000 and 2005). In total, we used nine Landsat TM/ETM+ images (Table 1). Four of these images were from the orthorectified Geo-Cover dataset (Tucker et al. 2004) and the remaining images were co-registered to these images using collinearity equations and correlation windows for automatic tie point search (Kuemmerle et al. 2006). Positional accuracy was well below 0.5 pixels (15 m) for all image pairs.

Ground truth for training and validation purposes was mapped in the field and from ancillary datasets. Extensive field visits were carried out in two communes in the summers of 2004 and 2005. Participatory mapping was conducted where local farmers mapped their fields and communal land use by using transparent overlays on a

Table 1 Landsat TM and ETM+ images used to derive land-cover maps for the years 1990, 1995, 2000, and 2005

Path	Row	Sensor	Acquisition dates
183	28	Landsat 5 (TM)	18th August 1989
183	28	Landsat 5 (TM)	2nd July 1995
183	29	Landsat 5 (TM)	21st August 1990
183	29	Landsat 5 (TM)	2nd July 1995
183	29	Landsat 7 (ETM+)	5th June 2000
183	29	Landsat 5 (TM)	29th July 2005
184	28	Landsat 5 (TM)	13th October 1995
184	28	Landsat 7 (ETM+)	7th April 2002
184	28	Landsat 7 (ETM+)	12th June 2000

70 km^2-subset of an IKONOS image (10th September 2004) and a Quickbird image (272 km^2, 23rd July 2004). These maps were later scanned and digitized on screen. We also mapped land use maps for two villages (Bascov and Rateşti), which were generated in 2005 and 2006 and covered an area of approximately 85 and 7,000 ha, respectively. We also obtained topographic maps (produced in the 1970s; scale: 1:100,000) for the entire county.

We acquired the missing-value corrected Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) from the International Centre for Tropical Agriculture (http://srtm.csi.cgiar.org), resampled it to the spatial resolution of the Landsat data and derived slope, aspect, and surface roughness (i.e., the gradient in slope). We also obtained the Coordination of Information on the Environment of the European Union (CORINE) land cover maps for the years 1990 and 2000 (http://dataservice.eea.europa.eu). CORINE land cover maps are of limited use for mapping land use change due to their relatively coarse scale and large minimum mapping unit (25 ha). Thus, we used the CORINE maps for stratifying our study area prior to classifying the image (see "Land-cover classification"). Settlements, roads, rivers, and water bodies were digitized from the topographic maps, and roads were categorized into communal roads, county roads, national roads, European roads, and the highway linking Bucharest and Piteşti. We also acquired the administrative boundaries of the county and the communes. Moreover, we obtained the 1989 and 2003 census data from the National Institute of Statistics, which included various indicators on rural populations and agriculture (NIS 2004).

Land-cover classification

We used automatic image classification to derive individual land cover maps for the time periods 1990, 1995, 2000, and 2005 from the Landsat images. As settlements, roads, water bodies and rivers were not expected to have changed substantially between 1990 and 2005, we masked these areas. The remaining areas were separated into 'forest', 'cropland', and 'permanent grassland' (including shrubland). Cropland referred to plowed land, whereas grassland contained managed and unmanaged grassland, including areas of early successional shrubland. Initial tests suggested high spectral ambiguity between small-scale cropland in mountain valleys (a mixture of household plots, gardens, and orchards) and some forests and grassland in the plains. To avoid misclassifications, we classified small-scale cropland areas separately from the rest of the study area. Small-scale cropland was selected based on the CORINE land cover map (classes 221–222, and 241–243) using the 1990-CORINE map for images from 1990 and 1995 and the 2000-CORINE map for images from 2000 and 2005.

We used a two-stage classification strategy. First, forest and non-forest areas were separated using unsupervised clustering based on Iterative Self-Organizing Data Analysis (ISODATA) and 50–60 clusters. Second, we used a hybrid classification strategy to classify non-forest areas into cropland and permanent grassland. Hybrid classifications combine advantages from unsupervised and supervised approaches and are useful if thematic classes display high spectral variability (e.g., due to crop type variability, phenology, or an elevation gradient, Cihlar et al. 1998; Kuemmerle et al. 2006). We digitized areas of potential training data based on high-resolution images and field knowledge. These polygons were clustered into spectrally homogeneous classes and clusters were assigned to a thematic class based on ancillary information and field knowledge. Ambiguous clusters were subdivided or discarded and all remaining clusters were used as training signatures in a maximum likelihood classification (i.e., guided clustering, Bauer et al. 1994; Stuckens et al. 2000). The 1995 and 2005 images contained clouds (4.1 and 6.5% of the study region, respectively) and we digitized these areas. Clouded areas were classified separately using images from the adjacent path and the same time period.

We combined the different classifications (forest, non-forest, small-scale agriculture, and cloud areas) into a single land cover map per time period. All land cover maps were majority filtered using a 3 × 3 kernel to eliminate noise. We assigned all forest patches below a threshold of 7 pixels to the dominant surrounding non-forest class because such tree-dominated patches (e.g., hedges, riparian stripes, etc.) are, functionally, not forest. A major advantage of deriving land cover maps for each year separately is the ability to rule out some land cover trajectories a priori. We decided that all non-forest/forest/non-forest trajectories represented misclassifications, because a mature forest cannot develop within 5 years. Thus, we assigned these pixels to the dominant surrounding non-forest class. We also labeled all areas above the tree line (1,350 m) as mountain meadows.

To assess the accuracy of the land cover maps, we calculated a stratified random sample (765 locations) based on the land cover map from 2005. All points were categorized into the 'forest', 'cropland', and 'permanent grassland' classes using the field data, participatory maps, and ancillary datasets. To validate the land cover maps from 1990, 1995, and 2000, we checked the temporal consistency of all ground truth points. This was carried out based on field visits, interviewing local experts, and visual assessment of the Landsat images. We retained only those points where land cover had not changed between 1990 and 2005 (603 points) and calculated class-specific and overall accuracy, as well as the Kappa value (Foody 2002). All validation data were gathered independently from the training data.

Change analysis

We used post-classification map comparison to derive change maps for the time periods 1990–1995, 1995–2000, and 2000–2005. Mountain meadows were excluded from the change analysis because tree line changes were assumed to be negligible (Mihai et al. 2007). Change maps were summarized by calculating change rates and the area covered by each change class. We also derived the proportion of forest, cropland, and grassland within five equal frequency groups (quintiles) of the topographic variables elevation, slope, and roughness. To assess the effects of infrastructure and market proximity on land use change, we categorized distance surfaces for two infrastructure categories (A: highways and European roads, subsequently labeled 'major roads'; B: category A, national roads, and county roads, labeled 'all roads'), and commune centers into quintiles, and summarized land cover proportions per quintile. We also tested, on the commune level, whether changes in cropland were related to socio-economic changes and changes in farming practices in the post-socialist period. We calculated Pearson's correlation coefficient between relative changes in cropland and changes in rural population density, the number of cattle, and the number of tractors, respectively, and tested the significance of each correlation.

To quantify changes in landscape patterns, we calculated landscape indices (McGarigal 1994; O'Neill et al. 1988) for the forest, grassland, and cropland classes for 1990 and 2005. We derived mean and standard deviation patch size, patch density, and the aggregation index. Patch density denotes the number of patches per square kilometer of all unmasked areas. The aggregation index approaches zero when all patches of a class are maximally disaggregated, and equals 100 if the landscape consists of a single patch (McGarigal 1994). All land cover maps had been majority filtered, but this has little effect on simple landscape metrics for small filtering neighborhoods (3 × 3 pixels in our case) (Frohn and Hao 2006). We also assessed changes in forest fragmentation using spatially explicit fragmentation measures that categorize forest pixels as either 'core', 'perforated', 'edge', or 'patch', based on the proportion and connectivity of forest pixels within a moving window (Riitters et al. 2002). We selected a neighborhood size of 9 × 9 pixels based on previous experience (Kuemmerle et al. 2006, 2007), thereby assuming that continuous forest areas >7.29 ha (270 × 270 m^2) represent unfragmented forest.

Results

The satellite-based land cover maps revealed distinct zones of land cover in Argeş County (Fig. 1). The southern plains were dominated by cropland, settlements, and occasional forest patches. In the foothill zone, forests prevailed on the slopes, while valleys and plateaus at intermediate altitudes (500–800 m) were predominantly grassland; cropland in this zone only occurred in the immediate neighborhood of settlements. The mountain zone was mostly forested, although some grassland was found in the valleys (Fig. 1). In total, 38.7% (2,928 km^2) of the study region was forested in 2005; cropland and grassland together had a share of about 50.8% (3,841 km^2); settlements covered 9.7% (732 km^2); and water bodies amounted to 0.8% (58 km^2).

Our classification approach yielded reliable land cover maps for all four time periods. Overall accuracies ranged from 90.6 to 92.5% and kappa values were high (>0.85) for all four time periods (Table 2). Forest areas were classified with the highest accuracies (user's and producer's accuracies of >92%), whereas accuracies for cropland and grassland were moderately lower (ranging between 89–96 and 83–90%, respectively). Any uncertainty was mainly connected to confusion among forest and grassland, as well as among cropland and grassland (Table 2). The accuracy of our change maps, calculated as the product of the accuracies of the individual land cover maps, was 84.48%,
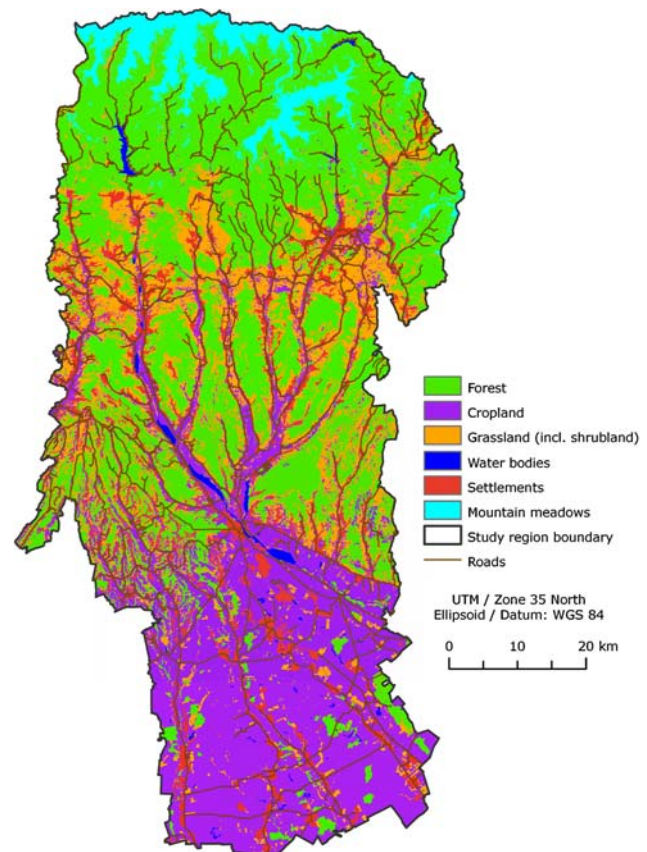

**Fig. 1** Land cover map of Argeş County for 2005

Table 2 Accuracy assessment for the land cover maps from 1990, 1995, 2000, and 2005

	Reference data				
	Forest	Cropland	Grassland	Totals	UAC
1990					
Classified data					
Forest	250	7	14	271	92.25%
Cropland	3	139	12	154	90.26%
Grassland	8	10	160	178	89.89%
Totals	261	156	186	603	
PAC	95.79%	89.10%	86.02%		
CK	0.86	0.87	0.85		
OAC	91.04%				
OK	0.86				
1995					
Classified data					
Forest	251	2	16	269	93.66%
Cropland	2	144	7	153	94.74%
Grassland	8	10	163	181	90.06%
Totals	261	156	186	603	
PAC	96.17%	92.31%	87.63%		
CK	0.89	0.93	0.86		
OAC	92.54%				
OK	0.89				
2000					
Classified data					
Forest	246	1	19	266	92.83%
Cropland	15	139	6	160	95.86%
Grassland	0	16	161	177	83.85%
Totals	261	156	186	603	
PAC	94.25%	89.10%	86.56%		
CK	0.87	0.94	0.77		
OAC	90.55%				
OK	0.85				
2005					
Classified data					
Forest	316	3	22	341	92.67%
Cropland	0	178	11	189	94.70%
Grassland	15	17	203	235	86.36%
Totals	331	198	236	765	
PAC	95.47%	89.90%	85.65%		
CK	0.87	0.92	0.8		
OAC	90.99%				
OK	0.86				

UAC user's accuracy, *PAC* producer's accuracy, *CK* conditional kappa, *OAC* overall accuracy, *OK* overall kappa
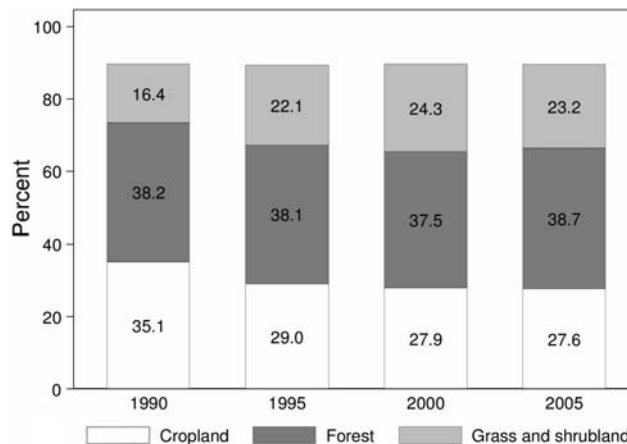
Fig. 2 Share of forest, cropland, and grassland (as percentage of total land) in Argeş County for the years 1990, 1995, 2000, and 2005

throughout the entire study period, equaling a decrease of 512 km^2 (7.5% of the study area), most of which occurred from 1990 to 1995 (6.1%, or 415 km^2). In contrast, grassland increased by 29.4%, from 1,117.6 km^2 (16.4% of the study region) to 1,582.1 km^2 (23.2%) over the 15 years covered by our analysis. The strongest net increase of grassland occurred from 1990 to 1995 (393.8 km^2), right after the change in systems. Forest cover remained relatively stable (38 ± 1%) for all time periods (Fig. 2).

Cropland–grassland conversions also had a profound effect on landscape pattern in our study region. Whereas the number of grassland and cropland patches declined drastically from 1990 to 2005 (by 45 and 43%, respectively), the mean patch size of cropland and grassland increased (from 14.5 to 20.1 ha, and from 3.7 to 10.9 ha, respectively). Cropland-to-grassland patches were largest from 1990 to 1995, and declined throughout the transition period. In the plains located in the south, cropland–grassland conversions occurred in large and highly dispersed patches, whereas cropland–grassland patches were smaller and clustered in mountain valleys (Fig. 3). Cropland–grassland conversions from 2000 to 2005 occurred mainly close to forest edges, particularly in the foothill zone (Fig. 3). Cropland–grassland conversions also led to an increase in grassland aggregation throughout the transition period (i.e., an aggregation index of 82 in 1990, and 89 in 2005; maximum value 100), whereas cropland occurred highly clumped in all time periods (i.e., aggregation index >93).

Forest patches were much larger than cropland and grassland patches, and increased during transition (mean patch size increase from 49.1 to 64.8 ha). Forest fragmentation was relatively high in the study region. Less than 40% of all forest areas were classified as core forest (i.e., unfragmented forest) and the share of edge and patch components amounted to about 60% of the total forest land
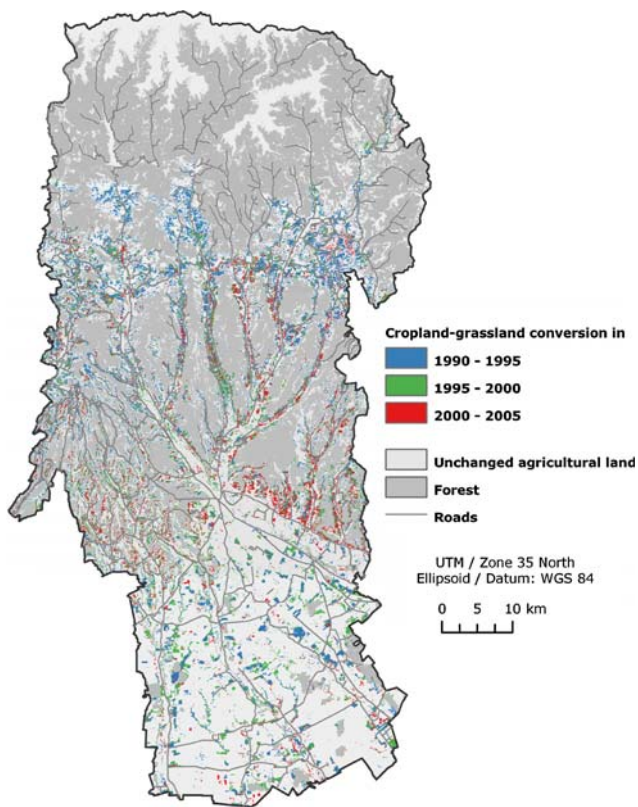
83.79%, 82.39% and for the 1990–1995, 1995–2000, and 2000–2005 maps, respectively.

Land cover changed markedly in Argeş County between 1990 and 2005 (Fig. 2). Indeed, cropland declined by 21.4%

Fig. 3 Cropland-grassland trajectories in the study region between 1990 and 2005 (the class 'unchanged agricultural land' includes both cropland and grassland)

for all time periods. Forest fragmentation did not change substantially from 1990 to 2005.

Variations across the study region were also apparent when comparing land cover along the altitudinal gradient (Fig. 4). Cropland-to-grassland conversion rates were highest between 397 and 1,045 m (the third and fourth elevation quintile) and relatively moderate at lower altitudes (the first elevation quintile, i.e., <243 m). While we found a net decline in cropland from 1990 to 2000, this trend reversed from 2000 to 2005 (3% cropland expansion), mainly at the expense of grassland. Cropland-grassland conversions were also most widespread where steeper slopes and rugged terrain prevailed (Fig. 4). For example, cropland decline in the second, third, and fourth slope quintiles were higher by more than a factor of six compared to flat areas (first slope quintile). Forest cover changes did not show particular variations along physiographic gradients.

Land cover proportions and rates of change during transition also differed substantially among categories of accessibility and distance to commune centers (Fig. 5). As expected, forest cover was much higher in areas of low accessibility than in areas close to settlements and major transportation infrastructure (e.g., about 50% lower in areas

close to commune centers compared to areas further away from these centers). Conversely, cropland was most widespread in areas of good accessibility (Fig. 5). Cropland decline, however, occurred at all accessibility classes for all three parameters investigated. And in some cases, the decline was even larger in areas of good accessibility (Fig. 5). The relationship between cropland decline and socio-economic indicators at the commune level ($N = 102$) was less clear. Cropland-grassland conversions were all only weakly correlated ($R^2 < 0.1$) with changes in rural population density, cattle, and tractor numbers (all correlations were not significant at $p<0.1$).

Discussion

Cropland abandonment in the transition period

Marked land cover changes, most notably the conversion of cropland to grassland, occurred in Argeş County after the collapse of socialism. These land cover trends appear to be most strongly related to the drastic changes in Romania's socio-economic, demographic, and institutional conditions after 1989. While our satellite-based mapping cannot distinguish between unmanaged and managed grasslands, field visits and interviews with farmers and stakeholders suggest that the bulk of cropland–grassland conversions represent permanently abandoned fields, many of which are now undergoing secondary succession. Moreover, livestock numbers have dwindled in Argeş County since 1989 (as elsewhere in Romania, FAOSTAT 2008). Overall, this indicates that cropland-grassland conversions were indeed abandoned fields and not a result of increased livestock breeding.

We suggest that three main factors explain why cultivation ceased in many areas during transition: (1) land reforms and tenure insecurity; (2) decreasing returns from agricultural production; and (3) emigration from rural areas.

Land reforms, the restructuring of the agricultural sector during transition, and the resulting tenure insecurity may have triggered widespread cropland abandonment. In Romania, cropland was restituted to former owners based on the situation in 1947, when the concentration of land ownership had already been reduced by communist land reforms carried out in 1945. The post-socialist Romanian land reform thus led to a fairly equitable allocation of property rights among rural households (Swinnen 1999; World Bank 2000). However, resolving the large amount of claims to land and locating former owners often proved difficult and lengthy (Brooks and Meurs 1994; Turnock 1998). Tenure over particular fields was often unclear (Cartwright 2003), thereby lowering the incentives to

Fig. 4 Variations of the proportion of forest, cropland, and grassland (as a proportion of the sum of these classes) along gradients of elevation, slope and surface roughness. For each gradient, the study region was subdivided into 5 classes of equal area. The *four bars* in each group represent land cover proportions for the years 1990, 1995, 2000, and 2005 (*from left to right*). Correlations among the three variables were all <0.8
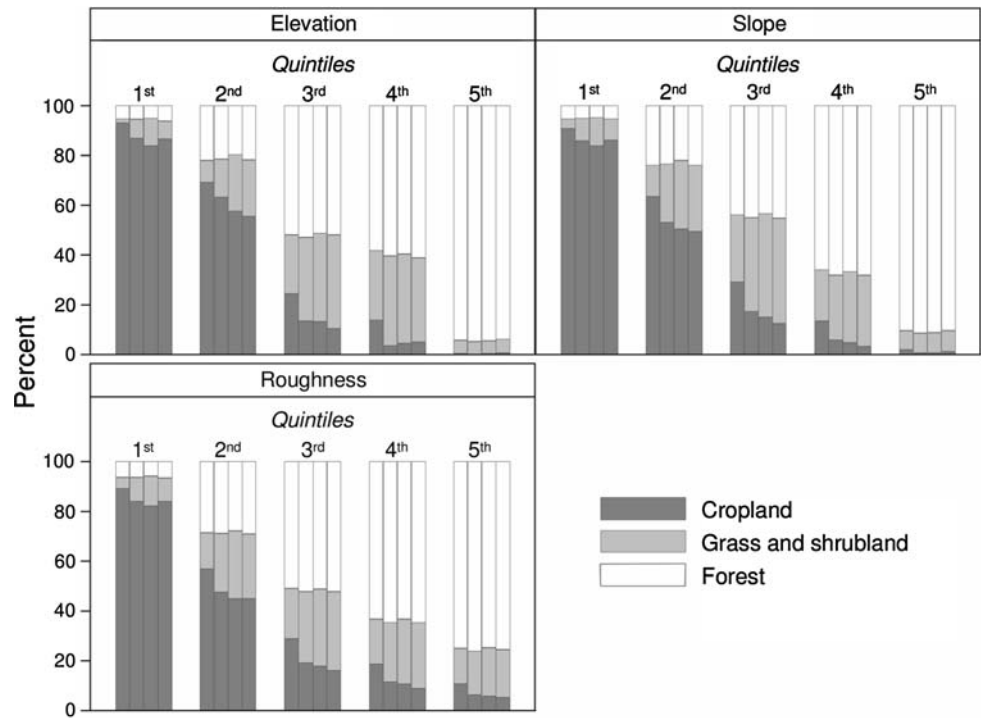

Fig. 5 Land cover proportions per time period in relation to accessibility, represented by distance to commune centers, major roads, and all roads. For each gradient, the study region was subdivided into five classes of equal area. The *four bars* in each group represent land cover proportions for the years 1990, 1995, 2000, and 2005 (*from left to right*). Proportions are given relative to the sum of forest, grassland, and cropland per class. Correlations among the three variables were all <0.8
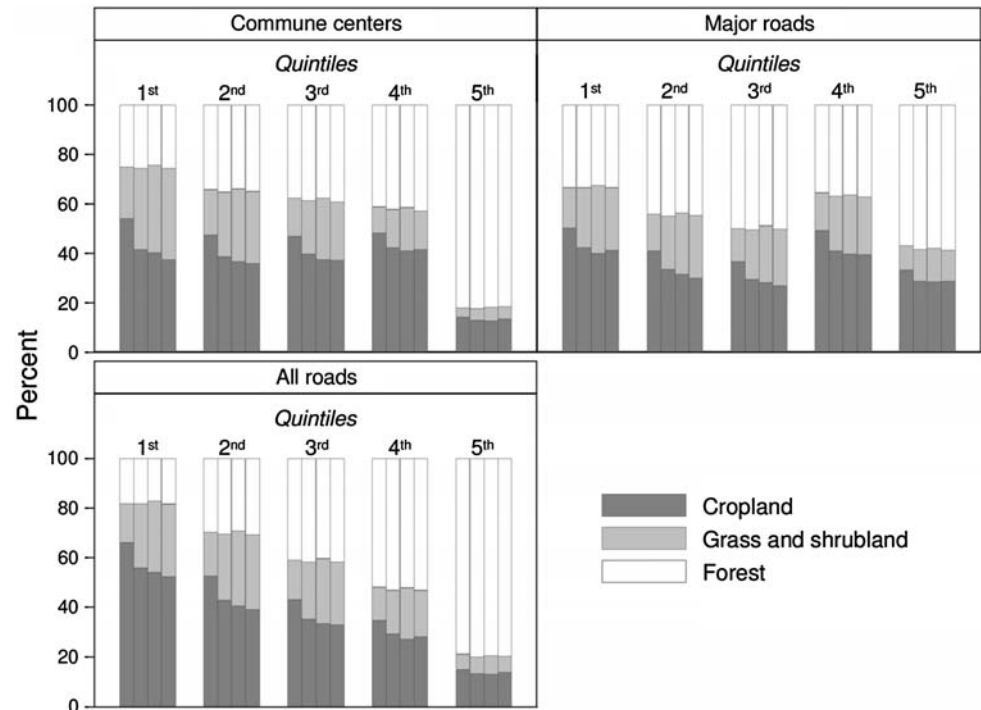
manage them, and such fields were likely abandoned or set aside. Tenure insecurity was strongest in the early years of transition, thus explaining the high abandonment rates we found from 1990 to 1995 (Fig. 2).

Restitution and redistribution of land sometimes also resulted in new owners not knowing the exact location of their land. Also, cropland was allocated to individuals who

were not interested in farming and claimed land purely for speculative purposes (DLG 2005; van Dijk 2003). Both situations likely resulted in the abandonment of cropland. Romania lacked a legal framework to sell and buy restituted land during the first transition years, and until 2004 new land owners were excluded from paying land taxes. This increased the incentives for setting aside land instead of

selling it (Brooks and Meurs 1994; Turnock 1998) and exacerbated the acquisition of additional land for farmers seeking to remain competitive under market conditions. The latter likely contributed to the withdrawal of many people from farming and thus to increased cropland abandonment.

During socialism, Romania intensified agricultural production considerably thanks to subsidies and capital investment by the government, sometimes even pushing cultivation into marginal areas (Turnock 2002). However, after 1989, the situation changed dramatically. State support diminished, former export markets within the socialist sphere of influence disappeared, prices were liberalized, and farmers suddenly faced strong external competition even though they often lacked the necessary inputs (e.g., fertilizer) and technology (e.g., access to machinery) to sustain high yields (Cartwright 2003; Turnock 1998). Along with insecure tenure, these factors substantially decreased the profitability of farming. Many Romanian farmers were not able to compete under these new conditions and agricultural production declined markedly (Trzeciak-Duval 1999; Turnock 1998), thus explaining the high rates of cropland abandonment we found in our study region. Nonetheless, farmers adapted to the new conditions for agricultural production, as we found the highest abandonment rates in the early years of transition (in 1990–1995).

Declining economic returns from agriculture arguably contributed to population changes in Argeş County. Official census data reveal three major population trends (NIS 2004). First, many people moved from rural to urban areas. Second, while total population was relatively stable from 1989 to1996, a substantial population decrease occurred from 1996 to 2003 (more than 5%, equaling >33,000 people). Third, birth rates decreased during transition and rural populations have aged considerably since 1989 (NIS 2004). These trends were likely a response to diminishing livelihood options in rural areas due to the decreasing profitability of agriculture, as well as emerging opportunities in cities and abroad. In Argeş County, just as elsewhere in Central and Eastern Europe, especially the younger demographic segments emigrated (Dorondel 2007; Elbakidze and Angelstam 2007; Palang et al. 2006), which may partly explain the cropland decline. Yet, contrary to our expectations, population changes were only weakly related to abandonment rates at the commune level. People who left agriculture and now commute to cities (Dorondel 2007), as well as emigrants who continue to be registered in their home communes, are two possible explanations for this weak relationship.

The spatial pattern of cropland abandonment

Cropland abandonment in Argeş County was strongly connected to physiographic variables and accessibility indicators, suggesting these are important factors for understanding the allocation of the declining cropland demand, similar to other mountain regions (Baldock et al. 1996; Gellrich et al. 2007; MacDonald et al. 2000; Müller and Munroe 2008). We found the highest abandonment rates on steeper slopes, at higher elevations, and in rugged terrain (Figs. 3, 4), likely because the profitability of farming decreased the most in these areas. Further, rugged terrain is difficult to mechanize, or required specialized machinery that was often unavailable to farmers after 1989.

The accessibility of a field also strongly determined the spatial pattern of cropland abandonment in the study region (Fig. 5). We propose that access to infrastructural facilities and closeness to local markets strongly affected the profitability of crop cultivation due to higher transportation costs for inputs and outputs. These factors became increasingly important under market conditions and as a result, remote fields were the first to be abandoned. Moreover, even during socialism, some areas in the Romanian Carpathians were considered too remote to be collectivized (Turnock 1998) and we found abandonment to be especially widespread in mountain valleys at high elevations (Fig. 3).

Abandoned fields in mountain valleys often occurred in clusters, whereas abandoned fields in the plains tended to be larger and more dispersed (Fig. 3). One likely explanation lies in the ownership situation prior to socialism. In the mountainous and foothill zone, land concentration was low before 1948, small farms dominated, and a highly fragmented land use pattern prevailed (Brooks and Meurs 1994). The restitution process partly restored this situation and may have hindered the development of economically competitive agricultural structures (Brooks and Meurs 1994; Sabates-Wheeler 2002). In the southern plains, a few large farms owned almost all of the land prior to 1948, fields were larger, and the land use pattern was much less fragmented than in the mountains.

Forest cover trends in the transition period

Forest cover did not change substantially and forest fragmentation remained virtually constant in Argeş County from 1990 to 2005 (Fig. 2). Thus, contrary to concerns at the beginning of the transition period (Turnock 2002; Webster et al. 2001) and in contrast to other regions in the Carpathians and Eastern Europe (Burnett et al. 2003; Kuemmerle et al. 2007; Müller and Sikor 2006), ownership transfers and forest legislation changes after 1989 did not trigger large-scale clear-cutting. We suggest that the 1996 forest code targeting multifunctional forestry, the annually revised harvesting limits for state and private forests (Ioras and Abrudan 2006), and the country's long silvicultural tradition based on selective harvesting were all factors that

helped to prevent large-scale clear-cutting on restituted forest land. Moreover, although cropland abandonment was widespread and field visits confirmed secondary succession on former croplands, most of these areas have not yet reverted back to forests. A 15-year time period is likely too short for a full canopy to develop via natural reforestation, especially since forest expansion in the Carpathians occurs relatively slowly (Kozak et al. 2007a).

Although extensive clear-cutting did not occur from 1990 to 2005, forest degradation and illegal logging may still have been substantial (Strimbu et al. 2005). Overall, forest abuse has been reported to be a major problem in the Romanian Carpathians (Bouriaud and Niskanen 2003; Dorondel 2007; Turnock 2002): economic difficulties in transition led to the increased collection of wood for fuel (Dorondel 2007), corruption has been a problem during transition, and forest legislation has sometimes been neither properly implemented nor enforced (Oszlanyi et al. 2004; Strimbu et al. 2005). In Argeş County, field visits confirmed forest degradation and illegal logging (Dorondel 2007), but forest cover changes were often too subtle to be picked up with medium-resolution Landsat TM/ETM+ images (e.g., sub-pixel clear-cuts or partial canopy removal). Our image analyses may therefore not be able to map the full extent of forest degradation and forest abuse in the study area.

Interviews with forest owners and stakeholders in the mountainous and hilly zone in Argeş County suggest that forest abuse may have been particularly widespread on restituted forest land (Dorondel 2007). The level of control during transition was likely higher and illegal logging lower in communal and state forests compared to private forests (Bouriaud and Niskanen 2003). This highlights the importance of institutional quality in protecting forests from unsustainable use (Deacon 1999; Tucker and Ostrom 2005; Tucker et al. 2007). The privatization of Romania's forest resources is a slow and complex process that is far from being completed (Ioras and Abrudan 2006). Increased privatization will likely exert additional pressure on Argeş' forest resources, and augmented clear-cutting (both legal and illegal) for fast returns may be imminent.

Conclusions and outlook

The sudden socio-economic and institutional changes that arose after the fall of the Iron Curtain immediately translated into land use change in Argeş County, Romania. The most widespread land use change was the abandonment of cropland, likely due to the declining returns of agriculture, changing land ownership, and demographic developments during transition. Topographic variables (e.g., elevation, slope), distance to market centers, and remoteness of cropland were all important for understanding the spatial pattern of cropland abandonment in Argeş County. Forest cover and forest fragmentation remained remarkably stable between 1990 and 2005 despite the widespread ownership transfers of forest resources. Romanian forest policies and institutions likely helped prevent large-scale logging, but fine-scale forest disturbances (e.g., illegal logging or forest degradation) may still have been widespread.

Human pressure has decreased considerably in Romania's rural areas, particularly in marginal areas such as mountain valleys. While the possibility of future forest expansion on abandoned cropland may provide opportunities for additional carbon sequestration, cultural landscapes and their unique biodiversity will be largely lost (Baur et al. 2006; Cremene et al. 2005). Yet it is too soon to speculate on the possible futures for Romania's rural landscapes. Industrialization often triggers large-scale reforestation (Rudel et al. 2005), but post-socialist cropland abandonment has largely occurred due to economic collapse. Considering Romania's accession to the European Union in 2007, Common Agricultural Policy (CAP) payments, rising food prices, increasing biofuel demands, and growing agrotourism are only a few factors that may increase the incentives for putting set-aside cropland back into production, particularly where good farming conditions prevail (DLG 2005). The continued monitoring of land use change in Romania and elsewhere in Eastern Europe will be important for identifying the threats to and opportunities for nature conservation, as well as for informing land managers who strive to balance the competing requirements of immediate human needs and long-term sustainability goals.

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