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Spatiotemporal Analysis of the Controlling Factors of Forest Cover Change in the Romanian Carpathian Mountains

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Forest cover change is driven by complex processes that depend on political, conservation, and biophysical conditions. At present, mountain areas worldwide are undergoing intense forest cover change. Local-scale studies exist, but policy makers lack reliable and consistent information at the regional scale about long-term trends, controlling factors, and the success of existing policy measures. Long-term forest cover change data based on advanced image preprocessing procedures have recently become available. This study explores the potential of such data for a regional-scale analysis of forest cover change in mountain areas by analyzing forest cover change in the Romanian Carpathian Ecoregion (about 107,000 km^2) between 1985 and 2010. It shows that (1) extrapolations from local to regional scale are inaccurate, (2) European forest protection policies have been unsuccessful, and (3) the Romanian Carpathians are greening due to land abandonment in remote areas.

Keywords: *Forest cover change; image preprocessing; logistic regression; controlling factors; European Union conservation policies; mountain areas; Carpathian Mountains; Romania.*

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Introduction

The Carpathian mountain range connects 8 Eastern European countries, from Serbia and Romania in the south to Austria, the Czech Republic, Hungary, Poland, Slovakia, and Ukraine in the north (Björnsen et al 2009). In Romania, several natural and anthropogenic factors have influenced forest cover changes. Changes in land zoning and ownership regimes are considered to be the major drivers of forest cover changes during the past decades. Land reforms following the collapse of the communist regime in Romania in 1989 affected large areas of forest land that were transferred from state to private ownership. Both protected and unprotected forest areas changed owners during the 3 restitution phases in 1991, 2000, and 2005 (Abrudan et al 2009; Knorn et al 2012b).

Studies focusing on forest cover dynamics during these transition periods have reported both increasing and decreasing deforestation rates (Table 1). The scale of these studies varies from national (Strimbu et al 2005; Abrudan et al 2009; Dutca and Abrudan 2010; Ioja et al 2010), to mountain range (Olofsson et al 2011; Griffiths et al 2012, 2013a, 2013b, 2013c; Vanonckelen et al 2015) to local (Kuemmerle et al 2008b; Müller et al 2009; Knorn et al 2012a, 2012b; Müller et al 2013), with a clear dominance of local studies. These studies show that 4 factors explain increased logging rates after the implementation of forest restitution laws. First, the economic recession provided an incentive for the new owners to immediately clear-cut their forests for short-term returns (Strimbu et al 2005; Ioras and Abrudan 2006). Second, Romania's forest restitution was a slow and complex process, with many new owners fearing that their property rights were not permanent (Sikor et al 2009), which also led to rapid deforestation. Third, the postsocialist period in Romania was characterized by weak institutions and law enforcement, which resulted in increased illegal logging (Strimbu et al 2005; Ioja et al 2010). Fourth, new forest owners often lacked capacity and knowledge for sustainable forest management and nature conservation, which triggered an unintended degradation of the forest resources (Knorn et al 2012b).

Although these local-scale case studies have provided new insights into the causes of deforestation, questions remain. It is unknown to what extent the deforestation rates they identified are representative of the whole Romanian Carpathians, since researchers tend to focus on hot spots of forest cover change. Also, it is unclear to what extent national forest protection programs had a significant impact. In order to address these questions, a national-scale analysis is essential. This, however, is possible only if forest cover change can be accurately mapped for the entire Romanian Carpathians over

TABLE 1 Studies of forest cover dynamics in Romania.

Study area	Time frame	Forest cover change	Reference
Carpathian ecoregion	1985–2010	Decrease	Griffiths et al 2012
		Not applicable	Griffiths et al 2013c
		Decrease	Griffiths et al 2013a
		Increase	Griffiths et al 2013b
Northern Romania	1987–2009	Decrease	Knorn et al 2012b
Argeş County	1990–2005	Stable	Kuemmerle et al 2008b
Argeş County	1990–2005	Not applicable	Müller et al 2009, 2013
Romania	1991–2008	Not applicable	Abrudan et al 2009
Romania	1993–2003	Not applicable	Strimbu et al 2005
Romania	1998–2009	Not applicable	Ioja et al 2010
Romania	1990–2006	Increase	Dutca and Abrudan 2010
Carpathian Mountains	1990–2010	Decrease	Olofsson et al 2011
Northern Romania	2000–2010	Decrease	Knorn et al 2012a
Carpathian ecoregion	1985–2010	Not applicable	Vanonckelen et al 2015

several decades. Until recently, reliable data at those scales were unavailable. Recent breakthroughs in the automatic processing of medium-scale satellite imagery in mountain areas, such as improved topographic correction and compositing of individual image footprints (eg Balthazar et al 2012; Griffiths et al 2013a, 2013c; Hansen et al 2013; Vanonckelen et al 2013, 2014, 2015), have made regional-scale analysis possible.

The objective of this study was to detect, quantify, and explain national trends in forest cover change in the Romanian Carpathians. The multitemporal land cover dataset for the Romanian Carpathians (1985–2010) developed by Vanonckelen et al (2015) was used as a starting point for the detection of longer-term forest cover change patterns. Next, the relative importance of several possible controlling factors of forest cover change—accessibility, demographic change, land-use policy, and the biophysical environment—was evaluated to detect controlling factors and policy impacts.

Materials and methods

Study area

The regional-scale study area is the Romanian Carpathian Ecoregion (Figure 1), about 107,000 km^2 of mountainous terrain with elevations up to 2544 m. It has a temperate-continental climate, with a mean annual temperature of about 7°C and a mean annual rainfall between 750 and 1400 mm (Mihai et al 2007; Müller et al 2009). Major soils include Podzols in the mountain zone and Cambisols in the foothill zone (FAO, UNESCO, and WRB 1988).

Three elevation zones are present in the Romanian Carpathian Mountains (Figure 2): a foothill zone, with mixed and broadleaved forests (eg *Betula pendula, Carpinus betulus,* and *Fagus sylvatica*; Figure 2A), between 250 and 1500 m; a mountain zone between 1500 and 2200 m with coniferous forests (eg *Abies alba, Picea abies,* and *Pinus mugo*; Figure 2B); and an alpine zone above 2200 m (the tree line), dominated by *Carex curvula, Festuca supina,* and *Juncus trifidus* (Figure 2C) (Enescu 1996; Mihai et al 2007; Kuemmerle et al 2008b; Vanonckelen et al 2014).

Mapping forest cover change in the Romanian Carpathian Ecoregion

Three maps of forest cover in the study area were constructed for the target years 1985, 1995, and 2010 (Figure 3) by compositing and classifying Landsat imagery. Imagery was selected from the Landsat archive based on 2 criteria. First, all available Thematic Mapper and Enhanced Thematic Mapper Plus images with a standard precision terrain correction and less than 70% cloud cover were considered (Griffiths et al 2013c). Second, all images acquired between mid-February and mid-November within a 2-year range of the target years (1985, 1995, and 2010) were retained. The range of months was limited to avoid low sun angles, shadowing, and high snow coverage.

The Romanian part of the ecoregion is covered by 9 Landsat footprints (Figure 1), which were composited using a pixel-based algorithm developed by Griffiths et al (2013c), whereby the best pixel available in the archive is

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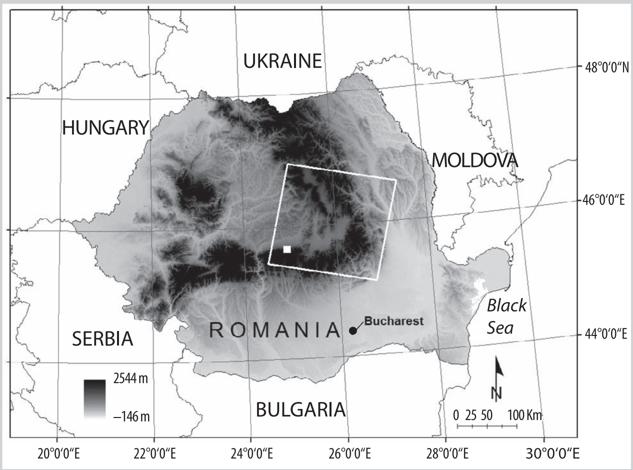
FIGURE 1 Location of Romania in Eastern Europe with the Romanian Carpathian Ecoregion (irregular polygon), the 9 Landsat footprints comprising the Romanian Carpathian Ecoregion (rectangles), Shuttle Radar Topography Mission elevation data for Romania.



selected. The resulting image was then topographically corrected using a pixel-based process proposed by Vanonckelen et al (2014). Forest was defined as land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds in situ (FAO 2010).

Next, 3 forest cover types—broadleaved, coniferous, and mixed—were detected with a Support Vector Machine classifier (Figure 3). The classifier was trained based on randomly stratified points that were sampled using high-resolution imagery from Google Earth. For each forest cover class, at least 900 training points were sampled. The resulting forest cover maps were validated with a different set of points that were sampled independently based on randomly selected ground control points (GCPs) from 2 sources: collection during field visits (May 2010 and July 2011) and identification on high-resolution satellite imagery (WorldView-2, 8 bands, 46 cm resolution, acquired on 13 October 2010).

Based on the 3 forest cover maps, forest cover change maps were produced for 1985–1995 and 1995–2010 (Figure 4), showing areas of stability, afforestation, deforestation, and disturbance. Following the FAO (2010) definition, *afforestation* was defined as transformation from nonforest to forest, either by planting or by natural succession, and *deforestation* was defined as "the conversion of forest to another land use or the long-term reduction of the tree canopy cover below the minimum 10 percent threshold" (FAO 2001: 23). Thus, deforestation included forest loss due to expansion of agricultural land, clear-cuts, and forest die-backs, while afforestation included forest gain due to land abandonment, natural regrowth, and forest plantations. The disturbance class contains the conversions from one forest class into another forest class, eg from broadleaved to coniferous forest (Vanonckelen et al 2015).

Potential controlling factors of forest cover change

Variables that could explain observed land cover changes between 1985–1995 and 1995–2010 were selected based on 2 criteria. First, observed land change processes were linked with possible explanatory variables suggested in the literature. This resulted in the formulation of 4 hypotheses on possible controlling factors, which were related to accessibility, demography, land-use policy, and the biophysical environment. A second criterion was the nationwide availability of categorical and numerical data that could be considered as proxy variables for the controlling factors.

Hypothesis 1 about accessibility: The more accessible an area is by road, the more deforestation will occur. Various studies have identified accessibility as an important controlling factor of both deforestation and afforestation. The spatially explicit land-use model of von Thünen (1826) demonstrated that physical accessibility of the land can control land cover, since periurban farmers' profits depend on the cost of transportation to the market. This has been confirmed by many local-scale studies reporting higher rates of deforestation along roads (eg Chomitz and

FIGURE 2 Typical vegetation types in the elevation zones in the study area: (A) foothill zone (1020 m); (B) mountain zone (1640 m); (C) alpine zone (2360 m) above the tree line. (Photos by Steven Vanonckelen)

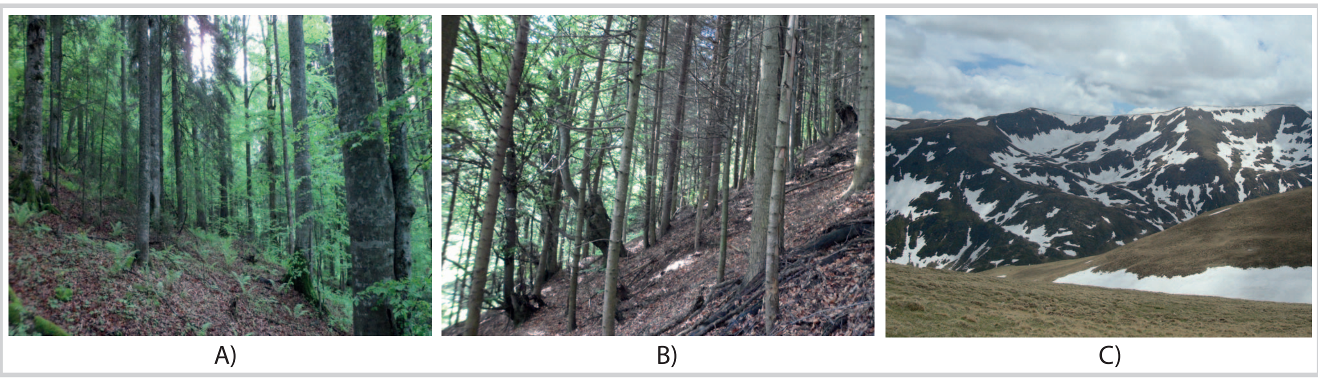
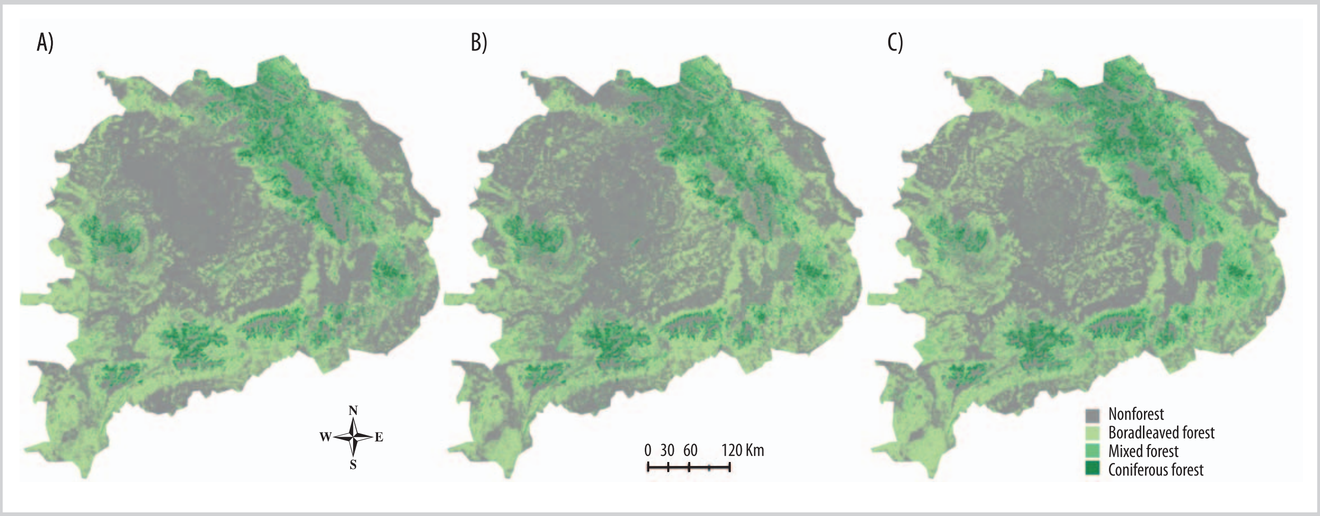


FIGURE 3 Forest cover maps of the Romanian Carpathian Ecoregion showing topographically corrected Support Vector Machine classification composites in the Romanian Carpathian Ecoregion. (A) 1985; (B) 1995; (C) 2010. (Data source: Vanonckelen et al 2015)



Gray 1996; Wilkie et al 2000). In this study, the shortest distance to the nearest settlement and primary and secondary road was calculated for each pixel. The location of roads and settlements was extracted from the 2003 Nomenclature of Territorial Units for Statistics database (European Commission 2013).

Hypothesis 2 about demography: *The denser the population is in an area, the more deforestation will occur.* Demographic variables can also be linked with deforestation and afforestation. Normally, changes in population density are related to accessibility; for example, people migrate from inaccessible to accessible places. Census data show that Romania's population increased substantially between 1960 and 1992, stimulated by the family policy of the central government (NIS Romania 2013). During the communist regime, a major part of the rural population abandoned their land and moved to the cities (Turnock 1991). After the fall of communism in 1989, the migration to urban areas continued. However, this trend was reversed after 1997, and a net urban–rural movement was detected, with people returning to rural areas when city life became more expensive and job uncertainty increased (Guran-Nica et al 2010). In this study, data on population density in 1986 and 2010 (NIS Romania 2013) were analyzed at the communal (ie parish) level (Solovastru 2010).

Hypothesis 3 about land-use policy: *The better an area is protected, the less deforestation will occur.* Romanian land-use policy has undergone several phases: the communist period with a centralized policy and collective farming was followed by a transition phase, the start of a free-market system, and finally accession to the European Union (EU). These transitions initially created uncertainty about land tenure, since a new forest protection system was established following EU guidelines. The 3 restitution laws of 1991, 2000, and 2005 affected large forest areas, and both protected and unprotected forest changed owners during the 3 transition phases. The consequences of this transitional period have been described for other countries in Eastern Europe (Van Rompaey et al 2007; Kuemmerle et al 2008a; Szilassi et al 2010). Under Law 18/1991, approximately 353,000 ha of forestland were returned to about 400,000 pre-1948 individual owners (up to 1 ha per owner). In 2000, another land restitution law (Law 1/2000) was passed, and according to this law all community, town, and communal forests should be restituted to their former owners. The third restitution law (Law 247/2005) was passed in 2005; according to its provisions, all forests (including protected areas) should be restituted to the former owners irrespective of size, location, and ownership type (Abrudan et al 2009).

In Romania, cropland abandonment between 1990 and 2005 was mainly triggered by policy reforms whereby steep lands at high elevations were the first to be taken out of production (Kuemmerle et al 2008b; Müller et al 2009, 2013). Land ownership data are still stored at the communal level, and it was therefore impossible to compile a national-scale landownership map for this study. The analysis of possible policy effects on forest-cover dynamics was therefore restricted to the evaluation of the forest protection areas imposed by the European Natura 2000 protection program, which established 2 types of protection zones: special protection areas and areas of special conservation interest. A Special Area of Conservation (SAC) is defined in the European Union's Habitats Directive and ensures measures to conserve natural habitats (European Commission 2009). SACs complement Special Protection Areas (SPAs), which have the duty to safeguard the habitats of migratory birds and certain particularly threatened birds (European

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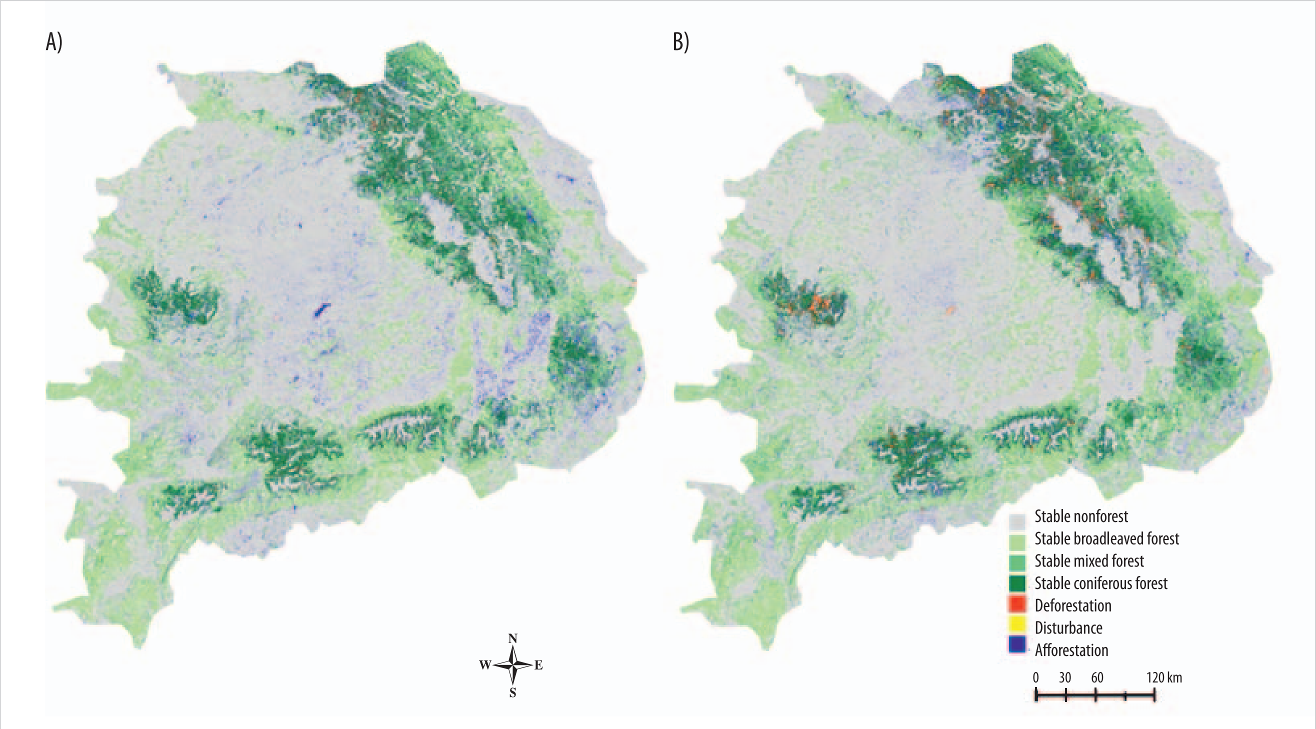
FIGURE 4 Maps of the Romanian Carpathian Ecoregion showing forest cover change trends in the Romanian Carpathian Ecoregion. (A) 1985–1995; (B) 1995–2010



Commission 2009). Together with SACs, the SPAs form a network of protected sites across the EU.

Hypothesis 4 about the biophysical environment: The better the quality of the soils and the steeper the slopes are in an area, the more deforestation will occur. The biophysical environment is a key variable that controls the spatial pattern of land-use change. During expansion of farmland, the most suitable land will be used first, leaving less suitable land under forest. Conversely, during farmland abandonment, the less suitable fields will be abandoned first. Land-cover studies have described this process over various time scales and in different regions (eg Van Rompaey and Govers 2002; Müller et al 2009, 2013; Szillassi et al 2010). Biophysical factors most frequently linked with suitability for farming are slope, elevation, and soil type. Elevation and slope values were derived from a Shuttle Radar Topography Mission with an original spatial resolution of 90 × 90 m (CGIAR-CSI/NASA 2013). This resolution was resampled to 30 × 30 m by means of a bicubic spline interpolation to match the resolution of the Landsat data (Figure 1; Vanonckelen et al 2015). According to the World Reference Base for Soil Resources 8 main World Reference Base soil types were present in the Romanian Carpathian Ecoregion: Andosol, Cambisol, Fluvisol, Leptosol, Luvisol, Phaeozem, Podzol, and Regosol (FAO/UNESCO/WRB 1998).

Finally, 8 explanatory variables, data on which were available for the whole Romanian Carpathian Ecoregion, were selected and grouped in 4 categories corresponding to the 4 hypotheses: (1) accessibility, (2) demography, (3) land-use policy, and (4) biophysical environment (Table 2).

Detection of significant controlling factors by means of logistic regression

A number of methods are available to evaluate the relation between observed land cover change and potential explanatory variables. The most straightforward approach is based on frequency analysis of cross-tabulation tables in which the observed number of land cover changes in a certain category of an explanatory variable is compared with the expected number of land cover changes (Van Rompaey et al 2001). A significant over- or under-representation of a change type in a given class of a categorical variable can then be interpreted as a correlation. Though this method makes it possible to test individual variables, simultaneous analysis of the effects of multiple variables is often impossible, since correlation between explanatory variables is not allowed in cross-tabulation analysis. A second drawback is the need to categorize each numerical variable, which automatically leads to a loss of information.

An alternative technique is a logistic regression that links a set of explanatory variables (numerical and/or categorical) with the probability of occurrence of a certain event, in this case a specific land cover change (Hosmer and Lemeshow 2000). The advantages of logistic regression analyses are that (1) calibration is possible with

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a relatively limited number of input data, (2) both categorical and numerical variables can be included simultaneously, (3) there is no need to categorize numerical variables, and (4) correlated explanatory variables can be included (Nelson 2001; Serneels and Lambin 2001; Van Rompaey et al 2001; Verburg et al 2004; Van Dessel et al 2008). However, there are also some disadvantages: an implicit assumption of linearity of the land cover change process in terms of the logit function and between dependent and independent variables, the prerequisite of selecting explanatory variables, and the limitation of application to studies using between-subject designs (Tu 1996; Steyerberg et al 2001).

Given the possibilities and drawbacks of the available techniques and data, a logistic regression analysis was selected for further analysis of the observed land cover change in the Romanian Carpathians; a stepwise multiple logistic regression (MLR) was implemented using ArcMap 10 and SAS 9.2. Thereby, an MLR equation was derived for the 2 main observed land cover changes, deforestation and afforestation. The MLR analysis was performed for the 2 time periods, 1985–1995 and 1995–2010. Probabilities for the 2 main land cover change types were assessed using the standard logistic regression equation.

The categorical variables soil type (8 categories) and protection level (3 categories) were coded with binary dummy variables: a value of 0 (absence of the category) or 1 (presence of the category) (Hosmer and Lemeshow 2000). The number of dummy variables was 1 less than the number of categories per categorical predictor, 8 dummy variables for soil type and 2 dummy variables for protection level. The reference category for soil type was Regosol, and the reference for protection level was "no protection." Since the Natura 2000 network in Romania started only in 2001, the predictor "protection level" was not included in the MLR models for 1985–1995. In a stepwise MLR, the model coefficients were assessed by maximizing the likelihood of the observed land cover changes (deforestation and afforestation) through an iterative procedure. Parameters that were not significant at a 95% confidence level were left out, after which new parameters were calibrated for the remaining variables.

Positive values for the coefficients suggest that the probability of land cover change increases with increasing values for the explanatory variable. To calculate the regression coefficients, 25,000 points were selected separately for the 2 dependent variables (afforestation and deforestation). The sampling was based on the land cover changes that were determined in Vanonckelen et al (2015), and the values of the corresponding explanatory variables were extracted for each pixel. Hereby, half of the sample (about 12,500 points) was selected in the area with no land cover change (coded 0) and the other half in the area where land cover change occurred (coded 1).

After the MLR analysis, probability maps were constructed for each MLR model (afforestation and deforestation). Afterward, the goodness of fit was evaluated using a relative operation characteristic (ROC) procedure (Hall et al 1995; Pontius and Schneider 2001; Schneider and Pontius 2001) to evaluate whether the MLR models described the observed land cover changes better than random models. In the ROC analysis, true positives (pixels correctly predicted) were plotted against false positives (pixels incorrectly predicted) for different land cover changes (Pontius and Schneider 2001). The overall ROC value was defined as the area under the ROC curve (AUC), which is an indication of the model performance. Therefore, a significant model is characterized by an AUC value larger than 0.5, while a random model corresponds with an AUC value of 0.5 or lower (Pontius and Schneider 2001).

Results

Land cover change

Figure 4 shows the main land cover change trends between 1985–1995 and 1995–2010; Table 3 breaks down these broad trends into specific land cover change types. During 1985–1995, forest classes remained fairly stable, with about 2 million ha of stable broadleaved forest and about 1 million ha of stable mixed and coniferous forest. Land cover change—deforestation, afforestation, and disturbance—affected relatively small areas: Afforestation occurred on about 426,000 ha, mainly in lower-elevation areas and at the edges of stable forests in higher-elevation areas. Deforestation was even less widespread, covering about 292,000 ha; the Romanian Carpathian Ecoregion was greening during this period.

Between 1995 and 2010, both deforestation and afforestation increased, mainly at the fringes of stable forests. Deforestation was especially prevalent in the southern and western corners of the region and covered about 322,000 ha, while afforestation occurred on about 479,000 ha. The stable nonforest class decreased from 5,545,000 ha between 1995 and 2010 to 5,147,000 ha between 1985 and 1995. Compared to 1985–1995, the stable broadleaved and coniferous forest areas increased in 1995–2010, with about 2.5 million ha of stable broadleaved forest and about 1.25 million ha of stable coniferous forest. However, the second period was 5 years longer than the first, so the comparison is not exact. Forest areas undergoing disturbance accounted for only about 34,000 ha.

Finally, the net forest change was calculated by subtracting the deforested area from the afforested area. The net forest increase was 134,000 ha in 1985–1995 and 156,000 ha in 1995–2010. This corresponds to a forest increase of 13,370 and 10,423 ha/year, respectively.

Controlling factors

As Table 4 shows, in the analysis of controlling factors of forest cover change, all MLR coefficients and the *P* values

FIGURE 5 Controlling factors of forest cover change in the Romanian Carpathian Ecoregion: (A) roads and protected areas (SAC is a Special Area of Conservation and SPA is a Special Protection Area); (B) demographic change (change in number of inhabitants per km^2) between 1986 and 2000; (C) soil types. (Sources: [A] European Commission 2013; [B] NIS Romania 2013; [C] FAO/UNESCO/WRB, 1998)

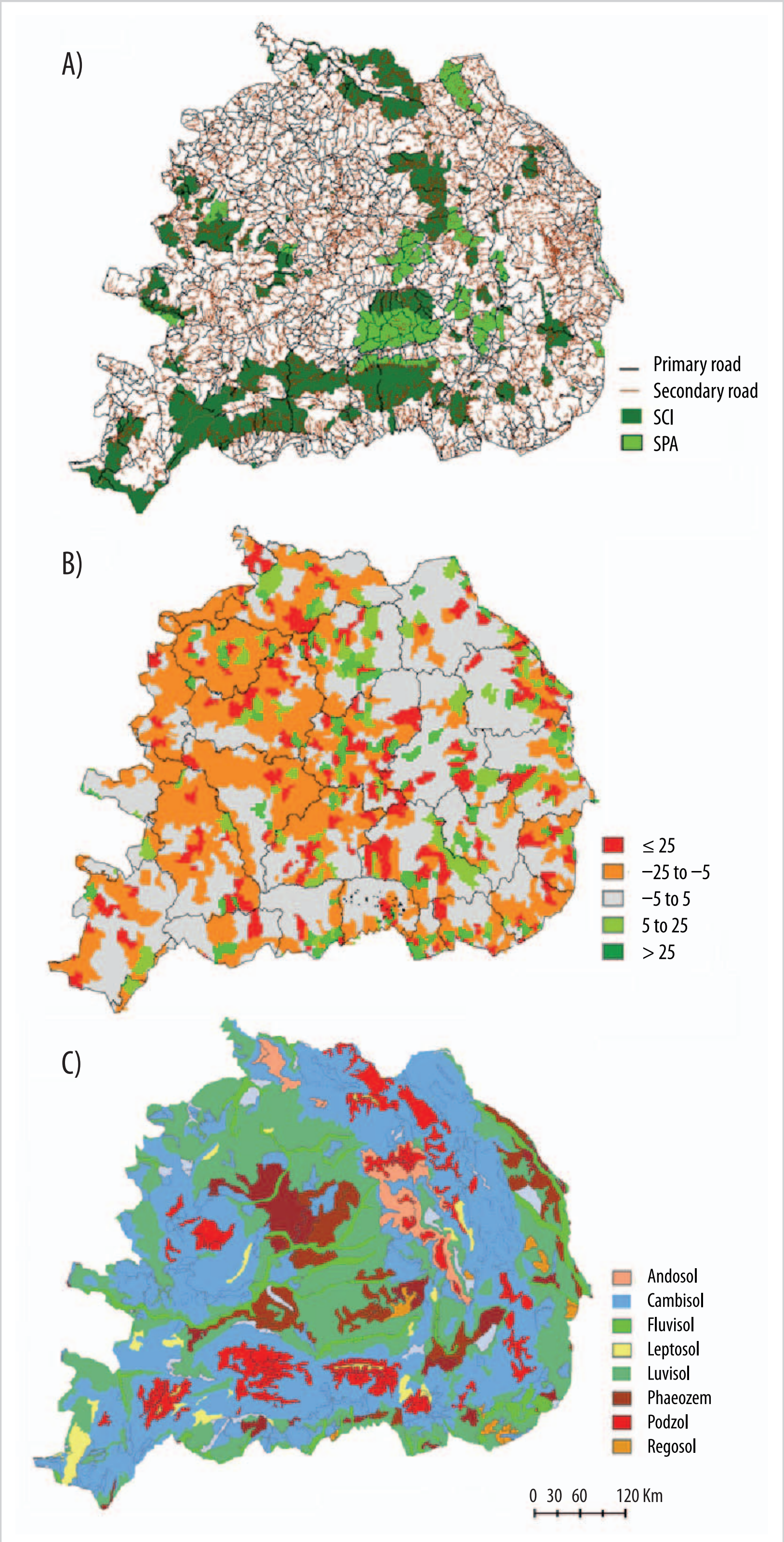

TABLE 2 Explanatory variables.

Variable	Unit	Category
Distance to primary roads	Meters above sea level	Accessibility
Distance to secondary roads	Meters above sea level	Accessibility
Distance to nearby settlement	Meters above sea level	Accessibility
Demographic change (1986–2010)	Change in number of inhabitants/km^2	Demography
Protection level 0 = not protected 1 = special protection area 2 = area of special conservation interest	Categorical	Land use policy
Slope gradient	Degrees	Biophysical environment
Elevation	Meters above sea level	Biophysical environment
Soil type 1 = Andosol 2 = Cambisol 3 = Fluvisol 4 = Leptosol 5 = Luvisol 6 = Phaeozem 7 = Podzol	Categorical	Biophysical environment

for afforestation and deforestation in the study area were calculated for 1985–1995 and 1995–2010. Deforestation and afforestation occurred at the same places, afforestation in the first period and deforestation in the second. For most predictors, a similar correlation with deforestation or afforestation was found for both periods. The sign of coefficients was consistent for 1985–1995 and 1995–2010, with the exception that Podzols were negatively correlated with afforestation in the period 1985–1995 and positively correlated in 1995–2010.

Between 1985 and 1995, afforestation was correlated with 5 explanatory variables at a 95% confidence level—slope, elevation, distance to nearby settlements, and distance to primary and secondary roads. This means that afforestation in 1985–1995 occurred on steep slopes at high elevations, away from settlements and primary roads but near secondary roads. Deforestation in 1985–1995 was positively correlated with elevation and negatively with distance to settlements and to primary and secondary roads. This suggests that forests were mainly removed at high elevations and in relatively accessible places. Furthermore, Podzols were significantly correlated with deforestation. The goodness of fit of the modeling approach was evaluated by calculating AUC values; values of 0.76 for deforestation and 0.71 for afforestation show that the MLR model describes observed transitions better than a random model.

In 1995–2010, afforestation was significantly correlated with 10 explanatory variables, including 5 soil types: slope, elevation, distance to primary and secondary roads, demographic change, and presence of Cambisols, Fluvisols, Luvisols, Phaeozems, and Podzols. This suggests that land units with steep slopes at high elevations, away from primary roads but near secondary roads, have a larger chance of experiencing afforestation. Afforestation in this period was also significantly correlated with population increase. Cambisols, Luvisols, Fluvisols, and Podsols have a larger chance of experiencing afforestation, while Phaeozems have a lower chance of experiencing afforestation. Deforestation in 1995–2010 was significantly correlated with all evaluated predictors except 2 soil types (Fluvisols and Leptosols). The AUC values were higher for this period than for 1985–1995: 0.81 for the deforestation model and 0.80 for the afforestation model.

Discussion

Forest cover change in the Romanian Carpathian Ecoregion

Change detection analysis (Table 3) showed that stable forests were most prevalent on higher elevations. During 1985–1995, afforestation in the study region occurred on about 426,000 ha and was more extensive than deforestation (292,000 ha). A national-scale study by Greenpeace (2012) estimated the total area of deforestation and forest degradation at about 280,108 ha between 2000 and 2011. However, in this study, forest was defined as 20% or greater canopy cover for trees of 5 m or more in height, so the definitions of forest differ and a comparison of the results has to be done with caution. Conversion from nonforest to forest was found to be triggered by the abandonment of cropland and slow

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TABLE 3 Land cover change trends, 1985–1995 and 1995–2010. The sums of all values are not always equal due to rounding.

Land cover change trend	Land cover change types	Area (10^3 ha)[a]	
		1985–1995	1995–2010
Stable broadleaved forest (BL)	BL–BL	2288	2467
Stable mixed forest (MX)	MX–MX	1089	1268
Stable coniferous forest (CF)	CF–CF	1021	997
Disturbance	CF–BL, BL–CF, CF–MX, MX–CF, BL–MX, MX–BL	55	34
Deforestation	BL–NF, MX–NF, CF–NF	292	322
Afforestation	NF–BL, NF–MX, NF–CF	426	479
Net forest change	Afforestation minus deforestation	+134	+156
Stable nonforest (NF)	NF–NF	5545	5147

[a]It is possible that the sum of all values is unequal due to rounding.

afforestation. A similar study by Olofsson et al (2011) in the Romanian Carpathians between 1990 and 2010 showed that grasslands and forests expanded on unused or abandoned farmland after 1989. Griffiths et al (2013b) showed grassland abandonment rates in the Romanian Carpathian Ecoregion between 60% and 70% between 1985 and 2010. Afforestation continued after EU accession in 2007; Griffiths et al (2013b) found that it was especially concentrated in areas favorable for farming in the study area (mainly Luvisols according to Figure 5C).

Areas of deforestation in Romania identified in our study (Figure 4) also overlap with those mapped by other researchers. Knorn et al (2012b), focusing on changes in the northern Romanian Carpathians, found the greatest deforestation near the Ukrainian border between 1994 and 2009, which overlapped with the deforestation patterns we identified between 1990 and 2010. Another study by Knorn et al (2012a) also detected old-growth forest disturbances between 2000 and 2010 near the border of Ukraine and in the northwestern part of the Romanian Carpathian Ecoregion. Griffiths et al (2012) determined areas of deforestation between 1985 and 2010 on a Landsat footprint in central-eastern Romania and observed the largest deforestation during the first restitution phase, 1991–1999, at the borders of the forest and on the plateaus.

Controlling factors of forest cover change

Eight explanatory variables were linked with observed deforestation and afforestation in the Romanian Carpathian Ecoregion for 1985–1995 and 1995–2010, using a logistic regression model. AUC values for model validation ranged from 0.71 to 0.81 and were highest for the deforestation scenario for 1995–2010. The 8 explanatory variables can be grouped into 4 categories—accessibility, demography, land-use policy, and the biophysical environment; the results for these categories are summarized below.

Accessibility: Distances to settlements and primary and secondary roads (Figure 5A) were taken as proxy variables for accessibility. The analysis showed that deforestation mainly occurred in relatively accessible places in both periods. This finding may confirm the von Thünen (1826) model, in which timber is considered as a market product and transportation costs and accessibility are seen as controlling deforestation patterns to a certain extent.

The afforestation process seems to follow a different logic, since afforestation was more probable further from settlements and primary roads in both periods. This may be explained by the fact that afforestation results from the natural regeneration of trees due to forest expansion or regrowth on abandoned fields (Kuemmerle et al 2006, 2008b). Griffiths et al (2013b) observed extensive afforestation in the Romanian Carpathian Ecoregion since accession to the EU. Another explanation is the obligatory replanting of young trees in the second year after a cut when natural regeneration has been insufficient (Dumitriu et al 2003).

Demography: In the first period, demographic change (population growth or decrease) was not significantly correlated with the observed deforestation and afforestation patterns. However, both afforestation and deforestation were positively correlated with population growth between 1995 and 2010, where the main trend was migration from peripheral rural areas to urban areas (Figure 5B). This might be explained by the fact that population increase leads to a more intensive management of the Romanian forest, with frequent clear-cuts followed by replanting, while the landscape in the

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TABLE 4 Positive/negative coefficients for afforestation and deforestation models, 1985–1995 and 1995–2010.

Category	Variable	Afforestation model[a]		Deforestation model[a]	
		1985–1995	1995–2010	1985–1995	1995–2010
Accessibility	Distance to primary roads	+	+	−	−
	Distance to secondary roads	−	−	−	−
	Distance to nearby settlement	+	NS	−	−
Demography	Demographic change	NS	+	NS	+
Land use policy	Special protection area	NA	NS	NA	+
	Area of special conservation interest	NA	NS	NA	+
Biophysical environment	Slope gradient	+	+	NS	+
	Elevation	+	+	+	+
Soil type	Andosol	NS	NS	NS	+
	Cambisol	NS	+	NS	+
	Fluvisol	NS	+	NS	NS
	Leptosol	NS	NS	NS	NS
	Luvisol	NS	+	NS	−
	Phaeozem	NS	−	NS	+
	Podzol	NS	+	−	+

[a]NA = not applicable (the Natura 2000 network of protected areas in Romania started only in 2001); NS = not significant at the 95% confidence level.

depopulating areas is more stable. The mismatch between the available population data (1986 and 2000) and the observed land cover patterns (1985, 1995, and 2010) make further field observations necessary to validate this hypothesis.

Land use policy: The end of the communist regime resulted in new political and economic conditions and a change in land tenure after decollectivization in the 1990s. Crucial changes in the Romanian forestry sector were the implementation of 3 restitution laws between 1991 and 2005, accession to the EU, and the establishment of protected areas. However, weak implementation of property laws resulted in increasing forest disturbance (Griffiths et al 2013c). Therefore, data on the Natura 2000 network of protected areas (special protection areas and areas of special conservation interest) in Romania were used as a controlling factor for the impact of land-use policy (Figure 5A). Since the establishment of protected areas in 2001, they were considered only for the second period (1995–2010). It might be expected they would lead to a slowing of deforestation in the delineated zones. However, they were in fact significantly positively correlated to deforestation; proportionally more forest disappeared inside than outside these zones. A possible explanation for this might be accelerated deforestation between 1995 and 2001, when Natura 2000 was not yet implemented. Furthermore, Biriş et al (2006) reported that the implementation of the Natura 2000 network in Romania has been difficult because of the lack of trained experts, lack of data, and/or the dispersion of data in a nonuniform way in Romanian municipalities.

These findings are also in line with findings from other researchers who analyzed local forest cover dynamics during and just after the fall of the communist regime (Soran et al 2000; Brandlmaier and Hirschberger 2005; Ioja et al 2010; Knorn et al 2012a, 2012b). Knorn et al (2012a) reported a continued loss of old-growth forest in the Romanian Carpathians despite a growing protected-area network. Old-growth forest disturbances were found within protected areas and were partly related to institutional land reforms, insufficient protection, and ownership changes since the collapse of communism in 1989. In another study, Knorn et al (2012b) assessed

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disturbance patterns between 1987 and 2009 in the northern Romanian Carpathians. Forest disturbance rates increased sharply in 2 waves after 1995 and 2005. Substantial disturbances were detected in protected areas and even within core reserve areas. Logging rates were largely triggered by rapid ownership and institutional changes. Finally, Ioja et al (2010) reported an overall decrease in the efficacy of Romania's protected areas following the creation of the Natura 2000 sites. Administrative bodies were generally understaffed and poorly financed, conditions that were reflected in poor enforcement and implementation of conservation goals (Ioja et al 2010).

Biophysical environment: Elements of the biophysical environment (slope and elevation) were positively linked to both afforestation and deforestation (Table 4); in fact, they were the most influential predictors. The results of the MLR showed that both deforestation and afforestation occurred at relatively high elevations and on steep slopes. For afforestation, this observation was in line with the theory that land units less suitable for farming were abandoned first. Following the same logic, deforestation should have occurred at lower elevations and on weaker slopes, which was, however, not the case. A possible explanation is the recent regreening of these slopes after land abandonment. Moreover, the results showed that Phaeozems have a smaller chance of experiencing afforestation, while Podzols have a larger chance of experiencing afforestation (Table 4, Figure 5C). This is in line with the quality of the different soil types. Phaeozems, rich in nutrients and organic material, are highly suitable for pasture and farming (FAO 2006). Podzols, on the other hand, are considered unattractive for farming but suitable for forests (FAO 2006), which made them attractive for new plantations in the period after decollectivization.

Conclusion

Hitherto, studies of land cover change patterns and their controlling factors were conducted at a local scale. These studies were able to reveal certain relations between local conditions and land cover change in general or a specific type of land cover change. However, local-scale studies were limited, since no regional-scale variables were included, such as demographic and regional-level policy changes. This study aimed to produce new insights into the mechanisms of land cover change by including both local- and regional-scale variables. Maps produced with advanced pixel-based compositing techniques were combined to show forest cover changes at a regional scale in an extensive mountain ecosystem. Forest cover change analysis was based on advanced image preprocessing of Landsat images that have recently become available.

The main findings of this study are that overall, the Romanian Carpathians are greening, and that the findings of local case studies on increasing deforestation rates cannot be extrapolated. Change detection analysis showed that both afforestation and deforestation were more extensive in the second period (1995–2010). In contrast, disturbance was more pronounced in the first period (1985–1995), but even then only in a small area. Overall, forest cover in the Romanian Carpathians showed a net increase of 13,370 ha/year in 1985–1995 and 10,423 ha/year in 1995–2010. Deforestation was only observed in local hot spots. Accessible places were preferentially logged, while a gradual greening occurred in more remote locations due to land abandonment.

To acquire better insight into the factors that control the spatial pattern of forest cover dynamics, observed forest cover was linked with 8 explanatory variables. The analysis showed that deforestation has to a certain extent followed the 1826 von Thünen model, whereby transportation costs and accessibility control deforestation patterns. Von Thünen reasoned that accessible places with adequate road systems are logged first, while afforestation occurs in more remote locations, possibly related to the abandonment of remote fields. Land suitability for farming or forestry could be identified as a crucial factor since different soil types were correlated with afforestation and deforestation trends.

Finally, this study showed that the implementation of the Natura 2000 network missed its goal, since more deforestation was observed inside what are now protected areas than outside them during 1995–2010. This could partly be explained by the lawless period after the fall of the communist regime and before the establishment of the protected areas. Another explanation could be the difficulties implementing the Natura 2000 network in Romania and the status of nature protection; policy makers and local politicians must provide more budget and manpower to implement and control the protection of Natura 2000 areas.

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REFERENCES

Abrudan IV, Marinescu V, Ionescu O, Ioras F, Horodnic SA, Sestras R. 2009. Developments in the Romanian forestry and its linkages with other sectors. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 37(2):14–21.
Balthazar V, Vanacker V, Lambin E. 2012. Evaluation and parameterization of ATCOR3 topographic correction method for forest cover mapping in mountain areas. *International Journal of Applied Earth Observation and Geoinformation* 18:436–450.
Biriş IA, Marin G, Stoiculescu C, Maxim I, Verghelet M, Apostel J. 2006. *COST Action E 27: protected forest areas in Europe (PROFOR)—Country report Romania*. Bucharest, Romania: Forest Research and Management Institute ICAS.
Björnsen Gurung A, Bokwa A, Chelmicki W, Elbakidze M, Hirschmugl M, Hostert P, Ibisch P, Kozak J, Kuemmele T, Matei E, Ostapowicz K, Pociask-Katerczka J, Schmidt L, van der Linden S, Zebisch M. 2009. Global change research in the Carpathian Mountain Region. *Mountain Research and Development* 29:282–288.
Brandlmaier H, Hirschberger P. 2005. *Illegal logging in Romania. Report.* WWF European Forest Programme and the Danube Carpathian Programme (DCP). http://assets.panda.org/downloads/finalromaniaillegallogging.pdf; accessed on 19 January 2015.
CGIAR-CSI/NASA [Consultative Group on International Agricultural Research–Consortium for Spatial Information/National Aeronautics and Space Administration]. 2013. SRTM 90m Digital Elevation Database v4.1. http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1; accessed on 16 January 2015.
Chomitz KM, Gray DA. 1996. Roads, land use, and deforestation: A spatial model applied to Belize. *World Bank Economic Review* 10(3):487–512.
Dumitriu G, Pirnuta G, Biris O, Florian GB. 2003. *The Sound Use of Wood and Other Resources in Romania*. Presentation offered at the Seminar on Strategies for the Sound Use of Wood, Poiana Brasov, Romania; available from the corresponding author of the present article.
Dutca I, Abrudan IV. 2010. Estimation of forest land-cover change in Romania, between 1990 and 2006. *Bulletin of the Transylvania University of Brasov* 3(52):1–4.
Enescu V. 1996. *Forest Genetic Resources Conservation in Romania*. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). European Commission. 1992. Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC). http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm; accessed on 16 October 2015.
European Commission. 2009. European Union Directive on the Conservation of Wild Birds. http://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm; accessed on 16 October 2015.
European Commission. 2013. Nomenclature of territorial units for statistics—NUTS 2013/EU-28 http://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/KS-GQ-14-006; accessed on 15 October 2015.
FAO [Food and Agriculture Organization of the United Nations]. 2001. *Global Forest Resources Assessment 2001*. Rome, Italy: FAO.
FAO [Food and Agriculture Organization of the United Nations]. 2006. *World Reference Base for Soil Resources 2006: A Framework for International Classification, Correlation and Communication*. Rome, Italy: FAO.
FAO [Food and Agriculture Organization of the United Nations]. 2010. *Global Forest Resources Assessment 2010*. Rome, Italy: FAO.
FAO/UNESCO/WRB [Food and Agriculture Organization/United Nations Educational, Scientific and Cultural Organization/World Reference Base]. 1998. Soil Map of the World, Revised Legend. *World Soil Resources Report 60*, Rome, Italy: FAO.
Greenpeace. 2012. *Forest Cover Change in Romania in 2000–2011*. http://www.greenpeace.org/romania/Global/romania/paduri/Despaduririle%20din%20Romania/Forestcover%20change%20in%20Romania%202000-2011.pdf; accessed on 17 January 2015.
Griffiths P, Kuemmerle T, Baumann M, Radeloff VC, Abrudan IV, Lieskovsky J, Munteanu C, Ostapowicz K, Hostert, P. 2013a. Forest disturbances, forest recovery, and changes in forest types across the Carpathian ecoregion from 1985 to 2010 based on Landsat image composites. *Remote Sensing of Environment.* http://dx.doi.org/10.1016/j.rse.2013.04.022; accessed on 28 October 2015.
Griffiths P, Kuemmerle T, Kennedy RE, Abrudan IV, Knorn J, Hostert P. 2012. Using annual time-series of Landsat images to assess the effects of forest restitution in post-socialist Romania. *Remote Sensing of Environment* 118: 199–214.
Griffiths P, Mueller D, Kuemmerle, T, Hostert P. 2013b. Agricultural land change in the Carpathian ecoregion after the breakdown of socialism and expansion of the European Union. *Environmental Research Letters* 8:1–12.
Griffiths P, van der Linden S, Kuemmerle T, Hostert P. 2013c. A pixel-based Landsat compositing algorithm for large area land cover mapping. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 5:1–14.
Guran-Nica L, Marin C, Todică-Ştefan N. 2010. Migration movements in the Romanian rural space (1990–2008). *Proceedings of the 5th WSEAS International Conference on Economy and Management Transformation* 2: 503–507.
Hall CAS, Tian H, Qi Y, Pontius G, Cornell J. 1995. Modelling spatial and temporal patterns of tropical land use change. *Journal of Biogeography* 22:753–757.
Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG. 2013. High-resolution global maps of 21st-century forest cover change. *Science* 342(6160):850–853.
Hosmer DW, Lemeshow S. 2000. *Applied Logistic Regression. 3rd edition*. New York, NY: John Wiley & Sons.
Ioja CI, Patroescu M, Rozylowicz L, Popescu VD, Verghelet M, Zotta MI, Felciuc M. 2010. The efficacy of Romania's protected areas network in conserving biodiversity. *Biological Conservation* 143:2468–2476.
Ioras F, Abrudan IV. 2006. The Romanian forestry sector: Privatization facts. *International Forestry Review* 8:361–367.
Knorn J, Kuemmerle T, Radeloff VC, Keeton WS, Gancz V, Biris IA, Svoboda M, Griffiths P, Hagatis A, Hostert P. 2012a. Continued loss of temperate old-growth forests in the Romanian Carpathians despite an increasing protected area network. *Environmental Conservation* 40(2):182–193.
Knorn J, Kuemmerle T, Radeloff VC, Szabo A, Mindrescu M, Keeton WS, Abrudan I, Griffiths P, Gancz V, Hostert P. 2012b. Forest restitution and protected area effectiveness in post-socialist Romania. *Biological Conservation* 146:204–212.
Kuemmerle T, Hostert P, Radeloff VC, van der Linden S, Perzanowski K, Kruhlov I. 2008a. Cross-border comparison of post-socialist farmland abandonment in the Carpathians. *Ecosystems* 11:614–628.
Kuemmerle T, Müller D, Griffiths P, Rusu M. 2008b. Land use change in Southern Romania after the collapse of socialism. *Regional Environmental Change* 9(1):1–12.
Kuemmerle T, Radeloff VC, Perzanowski K, Hostert P. 2006. Cross-border comparison of land cover and landscape pattern in Eastern Europe using a hybrid classification technique. *Remote Sensing and the Environment* 103: 17–32.
Mihai B, Savulescu I, Sandric I. 2007. Change detection analysis (1986–2002) of vegetation cover in Romania: A study of alpine, subalpine, and forest landscapes in the Lezer mountains, Southern Carpathians. *Mountain Research and Development* 27:250–258.
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(1–2):109–129.
Müller D, Leitão PJ, Sikor T. 2013. Comparing the determinants of cropland abandonment in Albania and Romania using boosted regression trees. *Agricultural Systems* 117:66–77.
Nelson A. 2001. Analysing data across geographic scales: detecting levels of organisation within systems. *Agriculture, Ecosystems and Environment* 85: 107–131.
NIS Romania [National Institute of Statistics]. 2013. *Database of Localities*. Bucharest, Romania: National Institute of Statistics. http://www.insse.ro/; accessed on 12 December 2014.
Olofsson P, Kuemmerle T, Griffiths P, Knorn J, Baccini A, Gancz V, Blujdea V, Houghton RA, Abrudan IV, Woodcock C. 2011. Carbon implications of forest restitution in post-socialist Romania. *Environmental Research Letters* 6:1–10.
Pontius RG, Schneider LC. 2001. Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. *Agriculture, Ecosystems and Environment* 85:239–248.
Schneider L, Pontius RG. 2001. Modeling land-use change: The case of the Ipswich watershed, Massachusetts, USA. *Agriculture, Ecosystems and Environment* 85:83–94.
Serneels S, Lambin EF. 2001. Proximate causes of land-use changes in Narok District, Kenya. *Agriculture, Ecosystems and Environment* 85(1–3):65–82.
Sikor T, Stahl J, Dorondel S. 2009. Negotiating post-socialist property and state: Struggles over forests in Albania and Romania. *Development and Change* 40:171–193.
Solovastru E. 2010. *Statistical Yearbook.* http://www.insse.ro/cms/rw/pages/anuarstatistic2010.en.do; accessed on 19 January 2015.
Soran V, Biro J, Moldovan O, Ardelean A. 2000. Conservation of biodiversity in Romania. *Biodiversity and Conservation* 9:1187–1198.
Steyerberg EW, Harrell Jr FE, Borsboom G, Eijkemans R, Vergouwe Y, Habbema JD. 2001. Internal validation of predictive models: Efficiency of some procedures for logistic regression analysis. *Journal of Clinical Epidemiology* 54: 774–781.

Strimbu BM, Hickey GM, Strimbu VG. 2005. Forest conditions and management under rapid legislation change in Romania. *Forest Chronicle* 95: 350–358.
Szilassi P, Jordan G, Kovacs F, Van Rompaey A, Van Dessel W. 2010. Investigating the link between soil quality and agricultural land use change. A case study in the Lake Balaton catchment, Hungary. *Carpathian Journal of Earth and Environmental Sciences* 5(2):61–70.
Tu JV. 1996. Advantages and disadvantages of using artificial neural networks versus logistic regression for predicting medical outcomes. *Journal of Clinical Epidemiology* 49(11):1225–1231.
Turnock D. 1991. The planning of rural settlement in Romania. *Geographical Journal* 157(3):251–264.
Van Dessel W, Van Rompaey A, Poelmans L, Szilassi P. 2008. Predicting land cover changes and their impact on the sediment influx in the Lake Balaton catchment. *Landscape Ecology* 23(6):645–656.
Vanonckelen S, Lhermitte S, Balthazar V, Van Rompaey A. 2014. Performance of atmospheric and topographic correction models on Landsat imagery in mountain areas. *International Journal of Remote Sensing* 35(13): 4952–4972.
Vanonckelen S, Lhermitte S, Van Rompaey A. 2013. The effect of atmospheric and topographic correction methods on land cover classification accuracy. *International Journal of Applied Earth Observation and Geoinformation* 24:9–21.
Vanonckelen S, Lhermitte S, Van Rompaey A. 2015. The effect of atmospheric and topographic correction on pixel-based image composites: Improved forest cover detection in mountain environments. *International Journal of Applied Earth Observation and Geoinformation* 35:320–328.
Van Rompaey A, Govers G. 2002. Data quality and model complexity for regional scale soil erosion prediction. *International Journal of Geographical Information Science* 16(7):663–680.
Van Rompaey A, Krasa J, Dostal T. 2007. Modelling the impact of land cover changes in the Czech Republic on sediment delivery. *Land Use Policy* 24(3): 576–583.
Van Rompaey A, Verstraeten G, Van Oost K, Govers G, Poesen J. 2001. Modelling mean annual sediment yield using a distributed approach. *Earth Surface Processes and Landforms* 26(11):1221–1236.
Verburg PH, Ritsema van Eck JR, de Nijs TCM, Dijst MJ, Schot P. 2004. Determinants of land-use change patterns in the Netherlands. *Environment and Planning B: Planning and Design* 31:125–150.
von Thünen JH. 1826. *Der isolirte Staat in Beziehung auf Landwirthschaft und Nationalökonomie*. [The isolated state in relation to agriculture and national economy; English translation reprinted in 1990] Aalen, Germany: Scientia Verlag.
Wilkie D, Shaw E, Rotberg F, Morelli G, Auzel P. 2000. Roads, development, and conservation in the Congo basin. *Conservation Biology* 14:1614–1622.