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# Using annual time-series of Landsat images to assess the effects of forest restitution in post-socialist Romania

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ABSTRACT

The increasing availability of the Landsat image archive and the development of approaches to make full use of these data provide novel insights into the drivers and dynamics of land use systems change. Focusing on Romania, we asked how the drastic institutional and socio-economic transformation after the collapse of socialism in Eastern Europe affected forestry. We used an annual time series of Landsat images to investigate how three phases of forest restitution affected forest disturbances (due to both, natural events and forest management). We employed the LandTrendr (Landsat-based detection of trends in disturbance and recovery) set of change detection algorithms to perform temporal segmentation and fitting of the Landsat time series, and derived annual disturbance maps (95.72% overall accuracy) along with recovery dynamics. Our change map suggested that forest disturbances increased substantially since the collapse of socialism in 1989, with 75,000 ha of disturbed forest land (4.5% of the total studied forest area). Whereas the late socialist years were characterized by relatively low disturbance levels (12% of all detected disturbances), disturbances increased especially after each of the restitution laws were passed in 1991, 2000, and 2005 (34%, 21% and 32% respectively). Non-state ownership regimes (i.e. private owners vs. public property of local communities) and species composition of restituted forests were two important factors determining disturbance levels. The widespread disturbances we found also raise concerns about timber overexploitation in many areas of the Romanian Carpathians. Our study demonstrates the value of the temporal depth of the Landsat archive and highlights that trajectory-based change detection approaches can be highly beneficial for gaining insights on the effect of institutional shocks on land use patterns.



## 1. Introduction

Land use change is among the primary drivers of global environmental change, affecting ecosystem services and biodiversity, and thus ultimately human well-being (Foley et al., 2005; Millennium Ecosystem Assessment, 2005). Until recently, land use changes were assumed to occur gradually, with land use systems transitioning from one state to another, often following similar intensification pathways as economic development progresses (DeFries et al., 2004). New paradigms for land use change are now evolving, recognizing that land use transitions (i.e., fundamental shifts in land use systems) can also occur very rapidly, sometimes following long periods of relative stability (DeFries et al., 2004; Lambin and Meyfroidt, 2010).

Sudden changes in land systems are particularly frequent in the case of drastic institutional or socio-economic transformations, for example, in the case of revolutions (Kuemmerle et al., 2007; Mueller et al., 2009), economic shocks (Sunderlin et al., 2001), failing states (Irland, 2008), technological breakthroughs (Zak et al., 2008) and warfare (Dudley et al., 2002; Machlis and Hanson, 2008). Although remote sensing has been instrumental for understanding patterns of land use and land cover change, most change detection approaches (Coppin and Bauer, 1996; Coppin et al., 2004) are not well-suited to detect such sudden changes or tipping points as they focus on the comparison of two points in time. Separating gradual changes from sudden ones, however, is challenging using such bi-temporal approaches, and this represents a major obstacle for determining how and why land systems change (Dearing et al., 2010).

The recent opening of much of the global Landsat archive by the United States Geological Survey (USGS) provides new opportunities to advance land use science and has sparked the development of new methodological approaches. For example, change detection

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methods based on annual Landsat time series (i.e. trajectory-based change detection methods) such as the Landsat-based detection of Trends in Disturbance and Recovery (LandTrendr) and the Vegetation Change Tracker (VCT) (Huang et al., 2010; Kennedy et al., 2010) make better use of the temporal depth of the Landsat archive to reconstruct forest disturbance histories with annual resolution and to map trends, such as forest regeneration and succession. Likewise, annual time series of Landsat images can help to separate sudden from gradual vegetation change in rangelands (e.g., fires vs. grazing pressure — Hostert et al., 2003; Röder et al., 2008; Sonnenschein et al., 2011). New change detection approaches based on time series of Landsat images offer several methodological advantages, including robustness against spectral variations arising from topography and phenology. Data availability issues are alleviated by choosing the best suited pixel from potentially many cloud-obscured images. Overall, trajectory-based methods should thus also provide opportunities to assess the effects of socio-economic disturbances, such as rapid political and institutional changes, on land use systems, but to our knowledge no study has used annual stacks of Landsat images for this purpose.

The changes initiated by the collapse of socialism led to fundamental restructuring of the political-, social and economic systems in Central and Eastern European countries (Lerman et al., 2002; Swinnen, 1999). This triggered widespread transformations in the countries' land use systems, resulting for example in agricultural abandonment and extensification, rural depopulation and increased illegal logging of forests (Henebry, 2009; Kuemmerle et al., 2009). The question of land ownership and the re-privatization of formerly collectivized agricultural and forest land was among the key issues during the post-socialist phase and countries followed different strategies. Regarding forest ownership, Romania opted for restitution to historically entitled owners or their heirs.

Prior to 1948, forests belonged to the state (28%), were in private possession (23%) or were owned by local communities, religious or educational institutions or by forms of communal ownership (about 50%, so called public property) (Ioras and Abrudan, 2006). During socialism (1948–1989), Romania's forests were almost entirely owned by the state (here and in the following, 'state' refers to the federal/central government). Restitution was implemented in three distinct laws: law 18/1991 returned up to one ha to historically entitled private individuals (350,000 ha in total), irrespective of historic location or extend (Vasile and Mantescu, 2009). The second law was passed in 2005 and favored public owners while constraining the restituted forest area for individuals (10 ha), churches (30 ha), and community members (20 ha). Since 2005 the third law aims at returning all remaining pre-World War II not state-owned forest property. Once complete, up to 70% of Romanian forests will have been restituted, increasing the number of non-state forest owners to 800,000 (Ioras and Abrudan, 2006; Lawrence, 2009; Lawrence and Szabo, 2005). However, it remains unclear how the end of socialism and the restitution process have affected rates and spatial patterns of forest cover change.

Realization of the restitution proved to be complex, often leading to confusion and frustration among prospective owners (Abrudan et al., 2005; Vasile and Mantescu, 2009) and concern has been expressed about forest utilization through new non-state owners (e.g. immediate felling). Today, forests can either be (1) state property, (2) public property owned by local communities, (3) private property of local communities or (4) private property of individuals or legal entities (associations, schools, churches) (Stancioiu et al., 2010). All forests are grouped into two functional categories: (1) protection forests and (2) protection and production forests (Anfodillo et al., 2008; Stancioiu et al., 2010). Protection forests serve important ecological functions (e.g. along water bodies) and limit economic benefits for owners. New forms of forest management include private forest districts (PFDs). These are associations of non-state forest owners providing coordinated management across larger areas of at least 3000 ha. Currently, 126 of such associations exist.

Our main goal was to use a trajectory-based change detection approach (LandTrendr) in order to assess the effects of the collapse of socialism and the Romanian forest restitution on forest disturbances. Disturbances here refer to intermediate to high intensity canopy disturbances caused by either natural events (e.g. wind throw, fire or spruce dieback) or forest management (e.g. clear cut harvesting, sanitary logging). Temporal segmentation and fitting of annual Landsat time series (LTS), the core features of the LandTrendr approach, provide great opportunities to better understand forest dynamics in Romania during recent decades, and thus will help researchers better understand how land systems respond to drastic institutional changes. Specifically, we ask the following research questions:

- How have forest disturbance rates and patterns changed after the collapse of socialism?
- How have the three individual forest restitution phases affected disturbance patterns?
- Are there differences in forest disturbance rates and patterns between state, community, and privately owned forest land?

## 2. Methods

### 2.1. Study region

Our study region comprises one Landsat footprint (path/row 183/028) in central-eastern Romania including large parts of the Transylvanian basin (Fig. 1). Elevations extend up to 2545 m in the Fagaras Mountains in the southern Carpathians and up to 1700 m in the Eastern Carpathian Mountains, whereas the Transylvanian basin has hilly terrain with elevations between 500 and 800 m. The bedrock comprises crystalline schist, sedimentary rocks and some volcanic strata. The region is characterized by temperate continental climate. Average temperature is about 8 °C and annual precipitation is about 650 mm but can be as high as 2000 mm in the alpine zone. The majority of the study region's land cover comprises forests and forestry has traditionally been an important component of the regional economy and a major source of rural income (Ioras and Abrudan, 2006). Forests can be stratified by elevation into an alpine zone (>2200 m) dominated by mountain meadows, a subalpine zone (1800–2200 m) with mostly dwarf pine (*Pinus mugo*) and juniper (*Juniperus nana*), a coniferous zone (1300–1800 m) and a deciduous and mixed forest zone below 1300 m (Mihai et al., 2007). Coniferous forests are dominated by Norway spruce (*Picea abies*) and silver fir (*Abies alba*), whereas deciduous forests consist mostly of European beech (*Fagus silvatica*) with some birch (*Betula pendula*), hornbeam (*Carpinus betulus*) and Pedunculate oak (*Quercus robur*).

### 2.2. Image data and preprocessing

We acquired a near-annual time series of Landsat TM/ETM+ images for the period 1984–2010. We selected only images from the peak growing season (early June–mid September) and acquired multiple images from the same year if a cloud-free image was not available. Clouds and cloud shadows were masked from all images in the time series based on image differencing with a cloud-free reference image (Kennedy et al., 2010). For some years, (e.g. 1984–1991) cloud cover was extensive and we therefore also incorporated some spring/autumn images and used images from adjacent footprints (184/028 and 182/028, 35% across-track overlap). We also included Landsat 7 SLC-off images for years after 2003, omitting scan line observations with missing values.

Most images had already been orthorectified (L1T) by the USGS. For the period 1996–1999, only one suitable L1T image was available. We therefore acquired three additional images from the European Landsat archive and co-registered them to the L1T images. This was