



Historical forest management in Romania is imposing strong legacies on contemporary forests and their management



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ABSTRACT

Historical forest management can heavily affect contemporary forest management and conservation. Yet, relatively little is known about century-long changes in forests, and that limits the understanding of how past management and land tenure affect current forestry practice and ecosystem conservation. Our goal here was to examine the relationship between historical forest management (as depicted by historical forest cover, species composition, age structure and harvesting data) and contemporary forest patterns in Romania. Romania represents an ideal case-study to examine the effects of historical forest management, because it experienced multiple shifts in forest management regimes since the 1800s due to Austro-Hungarian, Ottoman, Romanian, Soviet and later EU policy influences, and because it is both a conservation hotspot harboring some of the largest old-growth forest in Europe, and an important source of timber for international markets. We reviewed forestry literature and statistics since the 19th century to reconstruct a time-series of forest cover, composition, disturbance patterns, and ownership patterns and interpreted these data in light of institutional changes. We further assessed changes in forest cover, forest harvest, species composition and age structure between two points in time (1920s and 2010s) at the county level, using a combination of historical forest statistics, remote sensing data and modeled forest composition. We complemented our national data with three case studies for which we had stand-level historical and contemporary forest management data. We found that forest area increased in Romania since 1924 by 5% and that the annual rate of forest harvest between 2000 and 2013 was half of the annual rate between 1912 and 1922, which indicates high potential for forest biodiversity conservation. However, the composition, distribution, and age structure of contemporary forests is also substantially different from historical forests. We found an overall increase in coniferous species and several deciduous species (such as *Tilia*, *Populus*, *Betula*, *Alnus* sp.), a spatial homogenization of species composition, and more even-aged stands. We also observed a drop from 14% to 9% in the relative abundance of old forests (>100 years). Spikes in forest harvest coincided with times of widespread forest privatization, and drastic institutional changes, such as agrarian reforms, or the onset and collapse of the Soviet Regime. Overall, our results suggest that effects of past management, land ownership and institutional changes can persist for centuries, and affect forest ecosystem composition, health and structure, and consequently ecosystem services and habitat availability. Our findings are scientifically important because they provide evidence for legacies of past management and for the effects of forest privatization on harvesting rates. Our findings are also relevant to forest management and conservation practice, because they highlight that environmentally sound management over long time periods is essential for sustainable forestry and old-growth forest protection in Europe and elsewhere.

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1. Introduction

Land use dynamics have transformed the Earth's ecosystems to an unprecedented extent (Foley et al., 2005). Long-term forest

changes, in particular, have major consequences for ecosystem functioning, carbon storage, climate regulation and biodiversity (DeFries et al., 2004; Newbold et al., 2015). Globally, forest cover loss increased from roughly 7% in 1700 to over 21% in 1990 (Ellis et al., 2013; Goldewijk, 2001) although several countries in Europe and Asia experienced forest transition (Mather, 1998) in late 19th and early 20th century (Meyfroidt and Lambin, 2011) and are

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currently increasing in forest cover, and carbon sequestration (Erb et al., 2013; Rautiainen et al., 2010). Even though deforestation is declining in some countries (Gold et al., 2006), forest loss due to harvesting and natural disturbances remains high in many areas of the globe (Hansen et al., 2013; Potapov et al., 2014). Forest change is clearly related to socio-economic, political, institutional and environmental drivers (Lambin et al., 2001) but uncertainty about the role of past land uses, also referred to as path dependency, remains a concern for land change assessments. Long term human influence on forests can create legacies that may affect ecosystem functioning, structure and management of ecosystems for centuries (Foster et al., 2003; Munteanu et al., 2015) but the link between past and contemporary land management practices is still poorly understood.

Historical land management decisions affect contemporary landscape patterns across the globe (Foster et al., 2003) and land use legacies can manifest themselves in many aspects of forest ecosystems such as occurrence of disturbance, composition or age patterns. In Eastern Europe, forest disturbance occurs more frequently in areas that were not forested a century ago, indicating that disturbance patterns are affected by past land management (Munteanu et al., 2015). Similarly, past forest fires and harvests diminish the coniferous forests in the Russian Far East (Cushman and Wallin, 2000) and historically farmed forests in Western Europe show a higher abundance of species that colonize abandoned land, and fewer poor dispersers (Dupouey et al., 2002; Plue et al., 2009). Furthermore, the intensity of historical farming affects forest species composition (Atkinson and Marín-Spiotta, 2015; Plieninger et al., 2010), indicating that effects of past management may persist for a long time into the future. Finally, age structure can also be a reflection of past land management, because age-patterns established by harvesting can persist for multiple rotation cycles, even under different management practices (Wallin et al., 1994). In summary, this highlights the persistence of land use legacies even after changes in land use type (Munteanu et al., 2015; Thompson et al., 2013) indicating that past land management may constrain forest management for centuries thereafter.

Although forested areas have increased in Europe in the 20th century (Fuchs et al., 2014; Gold et al., 2006; Munteanu et al., 2014), forest disturbance in the past decades is high in Eastern Europe (Griffiths et al., 2014; Hansen et al., 2013) and the forest composition and age structure are altered (Munteanu et al., 2015; Vilén et al., 2012). Contemporary patterns of forest harvesting in Europe vary among countries and have been explained by a suite of factors including site conditions, forest resource availability (Levers et al., 2014), institutional and political context (Baumann et al., 2011; Kuemmerle et al., 2007), ownership structures (Kuemmerle et al., 2009b) and level of protection (Butsic et al., unpublished; Knorn et al., 2012b). However, most of these factors can act at different spatial and temporal scales and their effects can change over time, so that the links between past drivers and contemporary change remain unclear.

Eastern Europe represents a particularly interesting natural experiment for studying the relationship between past and contemporary forest change in relation to land tenure, political systems and conservation efforts because the region has a long history of human use (Giosan et al., 2012), very good data records starting as early as the 18th century (Timár et al., 2010) and experienced multiple shifts in institutions, land tenure, and socio-economic pressures both in time and space (Munteanu et al., 2014). Furthermore, current rates of forest harvesting are high (Griffiths et al., 2014) and controversial (Knorn et al., 2012a; Kuemmerle et al., 2009a), but their relationship to past forest management is still largely unexplored.

Our goal here was to examine the connections between historical forest management (as depicted by historical forest cover,

species composition, age structure and harvesting) versus contemporary forest patterns in Romania. Specifically, we investigated how past and contemporary forest disturbances (harvesting or natural disturbances which are often followed by salvage logging) are related to ownership structures, forest composition and forest age distribution. We explored possible cause-effect relationships based on forestry census data and remote sensing estimate and focused on lingering effects of historical management in contemporary forests, such as altered forest composition, age structure and shifting disturbance patterns related to forest ownership.

2. Methods

2.1. Study area

We studied forest legacies in Romania (238,381 km²) because the region represents an ideal natural experiment of changing forest management over time. Currently all forests in Romania are managed under the same legislation and consistent forest management plans (Ioras and Abrudan, 2006), but the region has historically experienced very different forest management regimes because it was split between the Habsburg and Ottoman Empires during the 18th and the 19th century (Munteanu et al., 2015).

Romania is ecologically highly diverse, including parts of five major vegetation ecoregions: Carpathian Montane Coniferous Forests, Pannonian Mixed Forests, Central European Mixed Forests, East European Forest Steppe and Pontic Steppe (European Environment Agency, 2003). The climate is temperate, with continental influences in the northeast and Mediterranean influences in the south. The mean elevation is 330 m and 27% of the country is covered by forest (National Institute of Statistics, 2012). Romania has a total population of 22 million (National Institute of Statistics, 2012), mostly concentrated in urban regions and a per capita GDP of \$13,200 (Central Intelligence Agency, 2013), among the lowest in the EU. Historically, land tenure in Romania was split between private owners, churches, institutions and state (Bouriaud, 2008). Historical forest management in Romania was mostly focused on natural regeneration. In the early 1900s, roughly 25% of the Romanian forests were coppice forests, and the remaining 75% were either selectively logged or high forests (i.e., even-aged). Of the high forests, about 10% would be usually clear cut, the rest being managed as shelterwood cuts. Even clearcuts had to retain 50 trees/ha for natural regeneration (Antonescu, 1909).

After the Second World War (WWII) all land was nationalized and managed by the state. Soviet policies heavily influenced forest management leading to widespread clear cuts and planting of fast-growing species. With the collapse of the Soviet Union in 1990, land was partially returned to former private owners following three restitution laws in 1991, 2000 and 2007 (Ioras and Abrudan, 2006). In 2007, Romania joined the European Union, which brought with it new regulations to increase nature conservation (Butsic et al., unpublished) and new land management regulations, such as a requirement for management plans for private forests (Ioras and Abrudan, 2006). However, forests experienced high levels of disturbance after 1990, and particularly after 2000 (Griffiths et al., 2014; Potapov et al., 2014), including the loss of valuable ecosystems and old-growth forests (Knorn et al., 2012a). Contemporary forest management in Romania is largely based on natural regeneration (Schulze et al., 2014). In 2014, only about 1% of the forests were clear-cut and about 12% were shelterwood. About a half of the forests are managed solely by sanitary harvests and about 30% were thinned (Institutul National de Statistica, 2015a).

In addition to the national-level analyses, we conducted three case studies situated in the Eastern Carpathian Mountains to

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