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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.

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 km^2) 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).

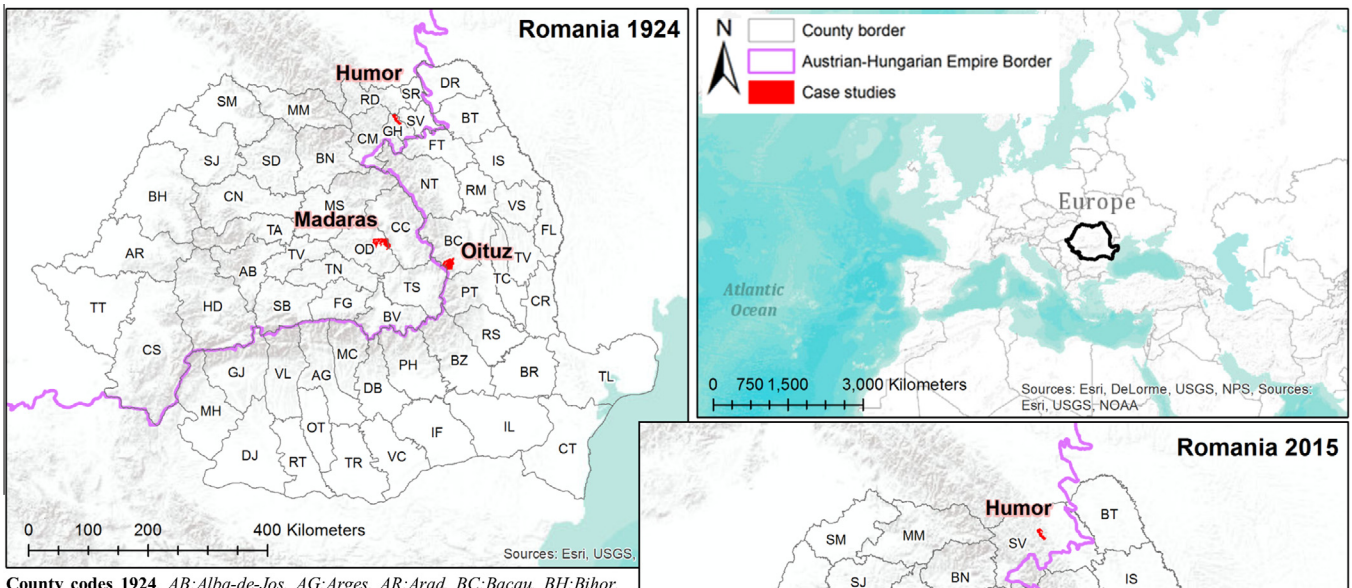
After the Second World War (WWII) all land was nationalized and managed by the state. Soviet policies heavily influenced forest management leading to widespread clear cuts and planting of fast-growing species. With the collapse of the Soviet Union in 1990, land was partially returned to former private 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

compare historical and contemporary management at a finer spatial resolution. All studies were situated at elevations between 700 and 1100 m and had a total area of 14,000 ha (Fig. 1). The three case study areas are characterized by similar ecological conditions (temperate climate, average yearly temperature around 7 Celsius, average precipitation of 800 mm, dominant soil class of Cambisol, (Institutul de Cercetări şi Amenajări Silvice Bucureşti, 1951; Ministry of Agriculture and Forestry, 1945; Romanian Church Forest Administration, 1926) and hence similar historical forest composition (beech and mixed beech, fir, and spruce forest). Forest management practices and policies were homogeneous since the 1950s until the early 1990s in all three areas because they were under state management, but forests in Humor are currently mostly state managed and in Oituz and Madaras mostly privately managed (Institutul de Cercetări şi Amenajări Silvice Bucureşti, 1951; Ministry of Agriculture and Forestry, 1945; Romanian Church Forest Administration, 1926). Furthermore, our case study areas differed highly in their historical policy, management practices and ownership structures because they were situated on either side of the Ottoman–Austrian–Hungarian border (Table 1). This means that the case study areas captured a variety of historical forest management types and hence provide a great opportunity to examine the role of forest management legacies on current forest composition, structure and disturbance patterns.

2.2. Overview of long term forest dynamics

We analyzed long-term forest dynamics in Romania in relation to major socio-economic shifts and ownership changes based on an extensive literature review and national-level statistics. We relied on forest cover statistics about major forest types (coniferous, beech, oak, other) for the years 1924, 1954, 1964, 1980, 1985,1994, 2006 and 2010 (Directia Centrala de Statistica, 1985, 1980, 1964; Directiunea Statisticei Generale, 1954; Institutul National de Statistica, 2010, 2006, 1994; Ministerul Agriculturii şi Domeniilor, 1924). We used average disturbance data reported in the 1924 forestry statistic for the decade of 1912–1922, in combination with age structure data to reconstruct average disturbance for the decade of 1902–1912. We only extrapolated the age structure for young forest classes because this method will result in estimates with high uncertainties for mature forests. The disturbance value for 1870 is reported in the literature (Nicolau-Barlad, 1944). For the years 1960–2014 we calculated disturbed areas based on FAO harvest volume data (FAO (United Nations Food and Agriculture Programme), 2015), which we converted to area estimates (ha) using an average volume/ha value of 400 cubic meters. The conversion factor was chosen based on average dendrometric values for contemporary forests of harvestable age in Romania (i.e., forests 80 years of age or older) (Rusu and Cojinovschi, 2014) and is comparable to timber volumes for clear-cuts in other parts of the



County codes 1924. *AB:Alba-de-Jos, AG:Arges, AR:Arad, BC:Bacau, BH:Bihor, BN:Bistrita-Nasaud, BR:Braila, BT:Botosani, BV:Brasov, BZ:Buzau, CC:Ciuc, CM:Campulung, CN:Cojocna, CR:Covurlui, CS:Caras-Severin, CT:Constanta, DB:Dambovita, DJ:Dolj, DR:Dorohoi, FG:Fagaras, FL:Falciu, FT:Falticeni, GH:Gura-Humorului, GJ:Gorjiu, HD:Huniedoara, IF:Ilfov, IL:Ialomita, IS:Iasi, MC:Muscel, MH:Mehedinti, MM:Maramures, MS:Mures-Turda, NT:Neamtu, OD:Odorhei, OT:Olt, PH:Prahova, PT:Putna, RD:Radauti, RM:Roman, RS:Ramnicul-Sarat, RT:Romanati, SB:Sibiu, SD:Solnoc-Dobaca, SJ:Salaj, SM:Satu-Mare, SR:Siret, SV:Suceava, TA:Turda-Aries, TC:Tecuci, TC:Tulcea, TN:Tarnava-Mare, TR:Teleorman, TS:Trei-Scaune, TT:Timis-Torontal, TV:Tarnava-Mica, TV:Tutova, VC:Vlasca, VL:Valcea, VS:Vaslui.*

County codes 2015. *AB:Alba, AG:Arges, AR:Arad, B:Bucuresti, BC:Bacau, BH:Bihor, BN:Bistrita-Nasaud, BR:Braila, BT:Botosani, BV:Brasov, BZ:Buzau, CJ:Cluj, CL:Calarasi, CS:Caras-Severin, CT:Constanta, CV:Covasna, DB:Dambovita, DJ:Dolj, GJ:Gorj, GL:Galati, GR:Giurgiu, HD:Hunedoara, HR:Harghita, IF:Ilfov, IL:Ialomita, IS:Iasi, MH:Mehedinti, MM:Maramures, MS:Mures, NT:Neamt, OT:Olt, PH:Prahova, SB:Sibiu, SJ:Salaj, SM:Satu-Mare, SV:Suceava, TL:Tulcea, TM:Timis, TR:Teleorman, VL:Valcea, VN:Vrancea, VS:Vaslui.*

Fig. 1. Location of study area in Europe, imperial boundaries from 1900s, the location of 3 cases studies in the Carpathian Mountains and county borders for 1924 and 2015.

Table 1
The three case studies, including name, area, historic region, type of management and forest ownership.

Case study	Area (ha)	Historic region	Historical management	Historical ownership	Contemporary ownership
Humor	3500	Bucovina	Austrian	Institutional (church)	Public (state)
Oituz	9000	Moldova	Romanian	Private	Private
Madaras	1500	Transylvania	Hungarian	Private	Private

world (Masek et al., 2011). We cross validated these estimates with annual disturbance rates reported in remote sensing analysis (Griffiths et al., 2014; Potapov et al., 2014) and found differences of only 1–2% in disturbance of forest areas for the overlapping years. However, our estimation is rather conservative because we assumed that harvest volumes stayed constant over time for the period 1960–2014. Volume density may have increased in recent years (Rautiainen et al., 2010; Vliet et al., 2015) and if this was the case for Romania too, our estimates of disturbance may underestimate the amount of historical harvest.

We analyzed national ownership patterns based on 1924 statistical data at the county level (Ministerul Agriculturii şi Domeniilor, 1924) and national statistics for 2010 and 2014 (Curtea de Conturi a Romaniei, 2013). We relied on bibliographical sources on ownership data for 1940 and for the socialist period (1948–1990) (Bouriaud and Popa, 2008; Giurescu, 1981; Nicolau-Barlad, 1944). We compared the proportions of three ownership types in each time periods: public (state owned), institutional, and private.

Since the mid-19th century Romania experienced five major land privatization events concomitant to socio-economic and political shifts such as wars and revolutions. In 1872 serfs were liberated and received land for farming, and in 1921 WWI soldiers received land as war compensation. After WWII all land was nationalized and managed by the state. Following the collapse of the Soviet Union in 1990, three restitution laws, ensured that forest passed back into private ownership in 1991, 2000 and 2007 (Ioras and Abrudan, 2006).

2.3. Historical and contemporary spatial data

Our spatial analysis was largely based on forest inventory data for two spatial scales (country level and forest management unit) and focused on two time periods: early 20th century when the study region was under influence of the Habsburg and the Ottoman Empire (hereafter historical) and following the collapse of the Soviet Union and EU accession (hereafter contemporary). In order to analyze forest extent, composition, age classes and disturbances we relied on county-level forest inventory statistics for the historical period (Ministerul Agriculturii şi Domeniilor, 1924) and aggregated spatial and statistical data at the county level for the contemporary time period. We digitized forest statistics on age classes and forest composition for 1924 and yearly forest disturbance for the decade 1912–1922. Data was available for the 60 historical counties of Romania according to the 1930 administrative boundaries (Max Planck Institute for Demographic Research, Chair for Geodesy and Geoinformatics, 2015) (Fig. 1). For the contemporary time period, we integrated four major data sources: two national statistics (Institutul de Cercetări şi Amenajări Silvice Bucureşti, 2015; Institutul National de Statistica, 2015b) and two spatial broad scale data sets, one on forest disturbance (Hansen et al., 2013) and one on forest composition (Brus et al., 2011). We aggregated these data at the county level using administrative boundaries of the 42 Romanian counties of 2014 (Fig. 1). In order to limit effects of inconsistencies in our data sources and ensure comparability, we used the baseline of national statistics, to which we assigned disturbance rates and species composition from the spatial datasets (Table 2).

At the forest management unit level, we obtained forest extent, composition, age and disturbance from forest management plans dated from 1926 to 1945 (Table 2). Contemporary forest management plans for the years 2008–2014 were available in GIS format and we compared them with digitized historical records to assess shifts in composition, disturbance and age structure.

2.4. Forest disturbance

For our analysis, we define disturbance as loss of forest cover due to forest harvest and natural disturbances (which are in Romania most commonly followed by salvage logging). At the national level we relied on historical disturbance data from 1912 to 1922 from forestry statistics (Ministerul Agriculturii şi Domeniilor, 1924). Historical data on forest harvest was reported by foresters in the field and subsequently centralized for each county, and we expect that this data could underestimate the amount of historical harvest. For the contemporary period (2000–2013) we mapped disturbance at county level using remote sensing data (Hansen et al., 2013) complemented with county level statistics for selective and shelterwood logging, because remote sensing data does usually not capture fine-scale disturbances (Kittredge et al., 2003). At the forest management unit level we compared the historical and contemporary occurrence of disturbance based on the forest management plans.

2.5. Forest composition

For all of Romania, we compared historical and contemporary extent of four major tree species (beech, oak, fir, and spruce) at the county level using the 1924 and 2014 statistics and reported change as percentage of the total forested area. 1924 data was summarized by 1930 administrative regions. For the contemporary dataset we compiled two data-sources of species distribution: statistical data on the area covered by major forest type (coniferous, deciduous and mixed) at the county level (Institutul National de Statistica, 2015b) and spatial information on the distribution of tree species groups in Europe at 1×1 km (Brus et al., 2011). We calculated percentage of tree species per county and assigned them to major forest types. We finally summarized tree species areas by county in order to obtain more detailed statistics. At the forest management unit level, composition is reported as percentage species in a given stand. For the three case studies, we compared historical and contemporary extent and percentage of species for each forest management unit.

2.6. Forest age

Across Romania, statistical data on age class distribution was available to us only at regional level for 2014 (Institutul de Cercetări şi Amenajări Silvice Bucureşti, 2015), and at the country level for 1964 (Directia Centrala de Statistica, 1964) and 1924 (Ministerul Agriculturii şi Domeniilor, 1924). We aggregated all data at the national scale and analyzed changes over time. At forest management unit level, we compared shifts in age distribution between the historic and contemporary time periods at the stand level.

Table 2
Data sources for forest extent, composition, age classes and disturbances for three time periods and at two spatial scales.

	Historical (1924–1945)	Contemporary (2000–2014)
Spatial scale: Romania, at county level		
Disturbance occurrence	Ministerul Agriculturii şi Domeniilor (1924)	Hansen et al. (2013) and Institutul National de Statistica (2015b)
Forest ownership	Ministerul Agriculturii şi Domeniilor (1924)	Institutul de Cercetări şi Amenajări Silvice Bucureşti (2015)
Age class distribution	Ministerul Agriculturii şi Domeniilor (1924) and Nicolau-Barlad (1938)	Institutul de Cercetări şi Amenajări Silvice Bucureşti (2015)
Species composition	Ministerul Agriculturii şi Domeniilor (1924)	Brus et al. (2011), Institutul de Cercetări şi Amenajări Silvice Bucureşti (2015)
Spatial scale: Forest management unit: Humor, Oituz, Madaras		
Disturbance occurrence	Institutul de Cercetări şi Amenajări Silvice Bucureşti (1951), Ministry of Agriculture and Forestry (1945), Romanian Church Forest Administration (1926)	Forest Design (2010) and Institutul de Cercetări şi Amenajări Silvice Bucureşti (2008, 2006)
Age class distribution	Institutul de Cercetări şi Amenajări Silvice Bucureşti (1951), Ministry of Agriculture and Forestry (1945), Romanian Church Forest Administration (1926)	Forest Design (2010) and Institutul de Cercetări şi Amenajări Silvice Bucureşti (2008, 2006)
Species composition	Institutul de Cercetări şi Amenajări Silvice Bucureşti (1951), Ministry of Agriculture and Forestry (1945) and Romanian Church Forest Administration (1926)	Forest Design (2010), Institutul de Cercetări şi Amenajări Silvice Bucureşti (2008, 2006)

2.7. Comparison of historical and contemporary data with alternative data sources

Because the reliability of historical forestry statistics is often questionable (Kuemmerle et al., 2011; Schelhaas et al., 2003), we compared the historical datasets used in our analysis with other values reported in the literature and with statistical surveys carried out in the same region by other actors. For the contemporary time period we compared our data with remote sensing estimates and alternative national statistics for Romania (Table 3). Overall, we found only small differences between datasets, indicating that datasets used in our analysis captured the status of Romanian forests well. We found the smallest difference between the French forestry statistics from 1900 (Ministere de L'Agriculture du Commerce de L'Industrie ed des Domaines, 1900) and the Romanian forestry statistic dated 1924, with a 0.4% percentage difference (Ministere de L'Agriculture du Commerce de L'Industrie ed des Domaines, 1900; Ministerul Agriculturii şi Domeniilor, 1924) (Table 3). The largest difference between datasets occurred in the case of forest disturbance between 1900 and 1924 by 12.5% percent, but this is very likely due to the difference in the reporting year (Table 3a). We also checked the correlation of datasets available on contemporary forest cover, disturbance and composition and observed a maximum correlation of 0.98 for disturbance estimates and a minimum correlation of 0.81 for species distribution (Table 3b).

3. Results

3.1. Overview of long term forest dynamics

Historical forest management, in particular past, extensive forest harvest, is strongly reflected in contemporary age structure, composition and disturbance patterns across Romania. Overall, forest area increased in Romania by roughly 308,000 ha since 1924, and the country experienced forest transition (i.e., the shift from

Table 3
Data sets used in our analysis and comparison to values from other sources such as forestry literature, statistical yearbooks and remote sensing estimates for historical (a) and contemporary (b) time periods.

Compared content	Value used in analysis	Cross-reference in literature	Extent of comparison	Difference in %
(a) Historical				
Percentage of forest in Romania	25.472% (Ministerul Agriculturii şi Domeniilor, 1924)	25.875% (L'Office Central de Statistique Du Royaume Hongrie, 1904; Ministere de L'Agriculture du Commerce de L'Industrie ed des Domaines, 1900)	Country level	−0.403%
Forest species composition 1900s and 1920s	Coniferous – 25% Oaks – 23% Deciduous – 52% (Ministerul Agriculturii şi Domeniilor, 1924)	Coniferous – 21% Oaks – 26% Deciduous – 53% (L'Office Central de Statistique Du Royaume Hongrie, 1904; Ministere de L'Agriculture du Commerce de L'Industrie ed des Domaines, 1900)	Country level	Conif + 4% Oaks – 3% Decid – 1%
Forest disturbance (ha)	524,698 (Ministerul Agriculturii şi Domeniilor, 1924)	590,327 (Ministere de L'Agriculture du Commerce de L'Industrie ed des Domaines, 1900)	Valahia and Moldavia State and Communal Forest	−12.5%
Local Oituz Forest area (ha)	9008 (Forest Design, 2010)	9275 (Ministerul Agriculturii şi Domeniilor, 1924)	Forest management unit	−2.96%
	Data used in analysis	Cross-checked with data	Extent of comparison	*R*-squared
(b) Contemporary				
Percentage of county covered by forest	Institutul National de Statistica (2015b)	Hansen et al. (2013)	*N* = 42 counties	0.97
Area covered by major species	Brus et al. (2011) and Institutul National de Statistica (2015b)	Institutul de Cercetări şi Amenajări Silvice Bucureşti (2015)	*N* = 15 (5 species, 3 regions)	0.81
Disturbance area	Hansen et al. (2013) and INS (2013)	Griffiths et al. (2014), INS (2013), and Potapov et al. (2014)	*N* = 28 counties 91% of total forest cover	0.98

decreasing to increasing forest area) in the first half of the 20th century. The lowest forest cover occurred sometime between 1920s, when disturbance was particularly high (93,000 ha) and 1955 when forest inventory area was as its minimum (5,735,000 ha). Forest harvest reached its highest point in the late 19th century (with over 100,000 ha being harvested in one year, Figs. 2 and 3). The contemporary Romanian forest inventory reports 6.3 mil ha of forest, which does not include shrub encroachment and forest succession on abandoned lands (estimated at 2.2 mil ha, Hansen et al., 2013). Overall, annual forest disturbance decreased from 1.40% of the total forest cover in 1924 to 0.71% in 2013.

Forest composition also changed substantially in Romania, with the proportion of deciduous forests decreasing strongly since 1924, when beech accounted for 39% and oak for 22% of the total forest cover. The maximum coniferous cover was reached in Romania in the mid-1980s (31%) (Fig. 2).

Forest ownership changed drastically during several historic land reforms and post-socialist privatization. Our data indicated that in Romania in 1924, land ownership was divided between private land owners (3,298,000 ha), state (1,556,000 ha) and other institutions (1,217,000 ha), i.e., roughly 54%, 26% and 20% respectively. Privately owned land decreased by 1940 to 48% of the total forest area. In 1948 all forest was passed into state ownership (Ioras and Abrudan, 2006). Total state ownership lasted until 1991 when following the collapse of the socialism land started being privatized. Post socialist statistics report a shift in ownership to 30% private, 53% state and 17% other institutions, with a higher percentage of publicly owned forests than before WWII (Fig. 2). In 2014, private forests represented roughly one third of the private forest in 1924. The cross-tabulation of forest disturbance and ownership patterns showed that in 1924, 54% of the forests were privately owned, but as much as 66% of the disturbances occurred in privately owned forests and only 20% in state forests. Spatial information on disturbance by ownership type for 2010 was not available to us.

3.2. Forest disturbance

Forest area increased in Romania since 1924 (when it covered 6,072,000 ha) by 5% and the annual amount of forest harvested (clear cuts and final cuts) between 2000 and 2013 dropped by 50% (~42,000 ha/year) compared to 1912–1922 (~85,000 ha/year). Historically, forest harvest was concentrated in the more accessible, lowland areas of Romania, especially in the south and east of the country, where individual counties had annual harvesting rates between 4% and 6% of their forest cover (Constanta, Ilfov, Vlasca, Olt and Covurlui). Contemporary forest harvesting is concentrated mostly in Northern Carpathians and the northern half of Transylvania (Suceava, Bistrita-Nasaud, Harghita, Covasna, Cluj, Mures, Neamt, Bacau), as well as in the south-east of the country (Calarasi, Ialomita), where forest cover was low to begin with (10% of the county territory). In contrast to overall lower harvesting rates across Romania, in some of the Eastern Carpathian counties, contemporary forest disturbance was higher than historic forest disturbance (Fig. 3).

At the local level, disturbance decreased in all cases, but most prominently in the case of Humor, where there was almost no disturbance in the period 2000–2010. For the Madaras and Oituz cases, the difference in the amount of harvest was small, but the disturbances were historically clustered in space and more evenly distributed in the contemporary time period. (Fig. 4).

3.3. Forest composition

We found that the total area, proportion and spatial distribution of main tree species changed drastically across Romania since 1924. Forest composition shifted towards higher proportion of coniferous (*Picea* sp., *Pinus* sp., *Larix decidua* and *Pseudotsuga menziesii*) and some deciduous species (*Tilia cordata, Populus* sp., *Betula* sp., and *Alnus* sp.), which are now more homogenously distributed in space. Norway spruce increased in area since 1924 (by 6.75%), currently covering an area of 1,590,000 ha in Romania. Spruce

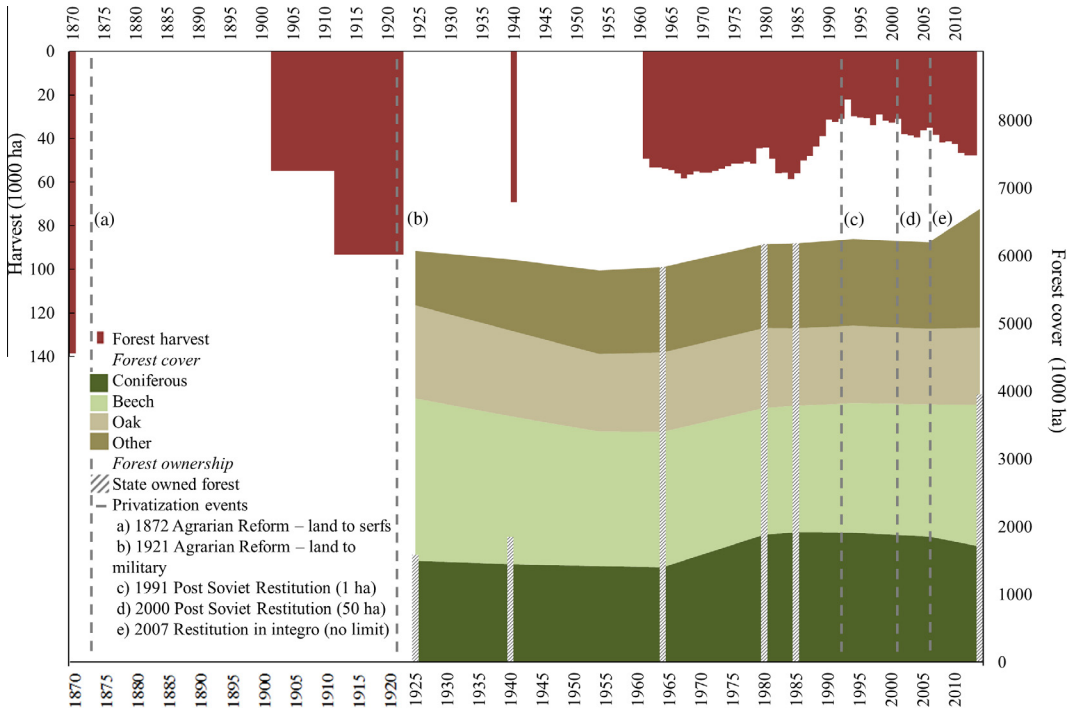


Fig. 2. Overview of the evolution of forest cover, species composition, disturbance and ownership patterns in Romania between 1870s and 2010, in the context of major land tenure changes.

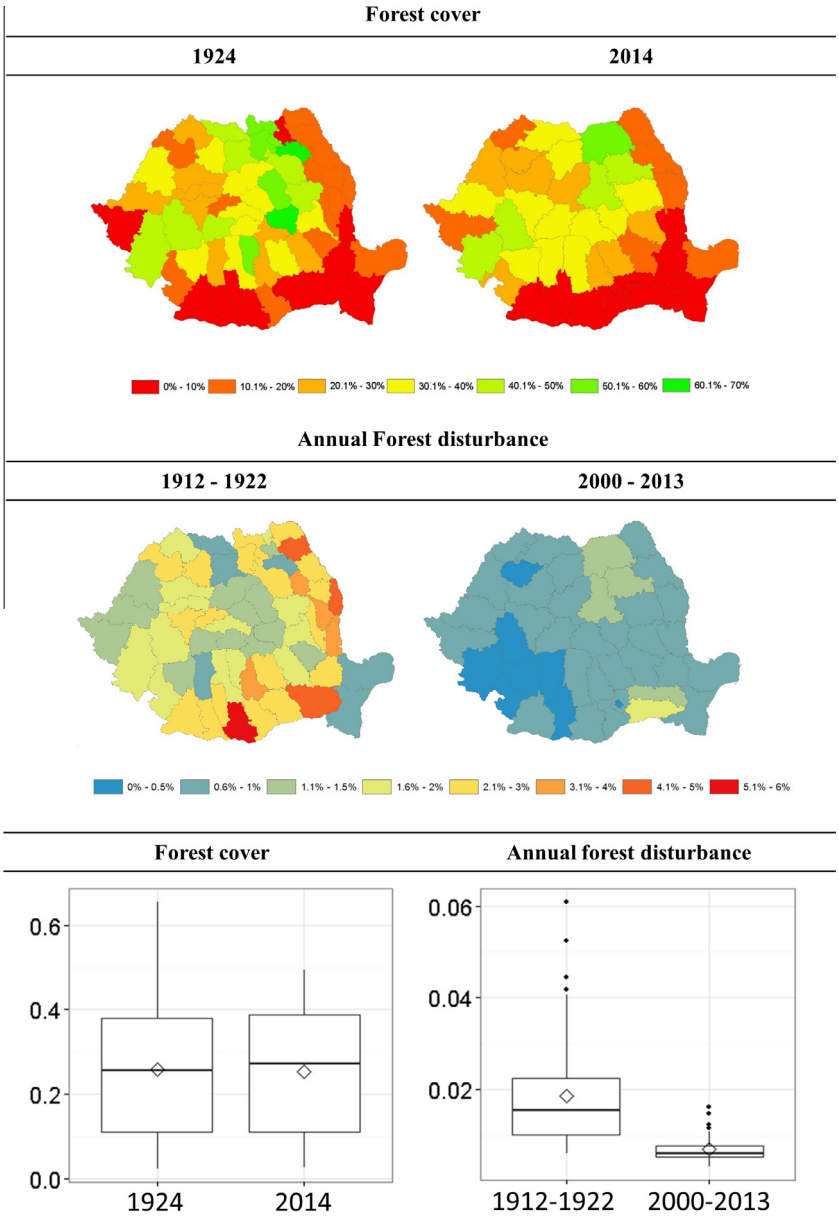


Fig. 3. Percentage forest cover and forest disturbance in Romania historically (n = 58 counties) and contemporary (n = 42 counties).

was historically concentrated at higher elevations and in the northern part of the Carpathians, but is now also found at lower elevations. Beech and fir decreased in area (by 14.66% and 1.05% respectively), losing a total of 861,000 ha, mostly to spruce plantations. For both species, we found a more spatially homogeneous distribution among most counties of Romania: beech declined in the southern Carpathians and the west of Romania and increased slightly in the south of the country. Contemporary oak cover was roughly the same in Romania as in 1924 (ca. 1,400,000 ha, amounting 22% of the forest cover) but the abundance and spatial distribution shifted greatly from a center of their distribution in southern Transylvania and the western part of the country towards the southern and eastern regions of the country. We recorded highest loss of oak from the historic regions of Alba de Jos, Tarnava Mica and Tarnava Mare where oak comprised between 30% and 50% of all forests in 1924 to only 10–20% in 2010 (Fig. 5).

At the local scale, our three case studies confirmed the trends observed for Romania as a whole: a drop in the percentage of fir, beech (and oak in Oituz, where it was present to start with) as well as a strong increase in spruce. Overall, forest stands were historically larger and fairly homogeneous in their species composition but became patchier in the contemporary time period. Spruce was more widespread in early 21st century with the exception of Madaras, where forest cover decreased altogether due to contemporary natural disturbances. In the Humor case study, fir area decreased from 1440 ha to 970 ha, being largely replaced by spruce (350 ha) and beech (115 ha). Beech experienced a slight increase from 955 ha to 1030 ha (Fig. 6). In the Oituz case study, the decline of fir, beech and oak was mirrored by an increase in spruce and hornbeam, with generally smaller homogenous stands (Fig. 6).

3.4. Forest age

In contemporary Romania, more forests are even-aged and the area of old forests decreased compared to the historical time

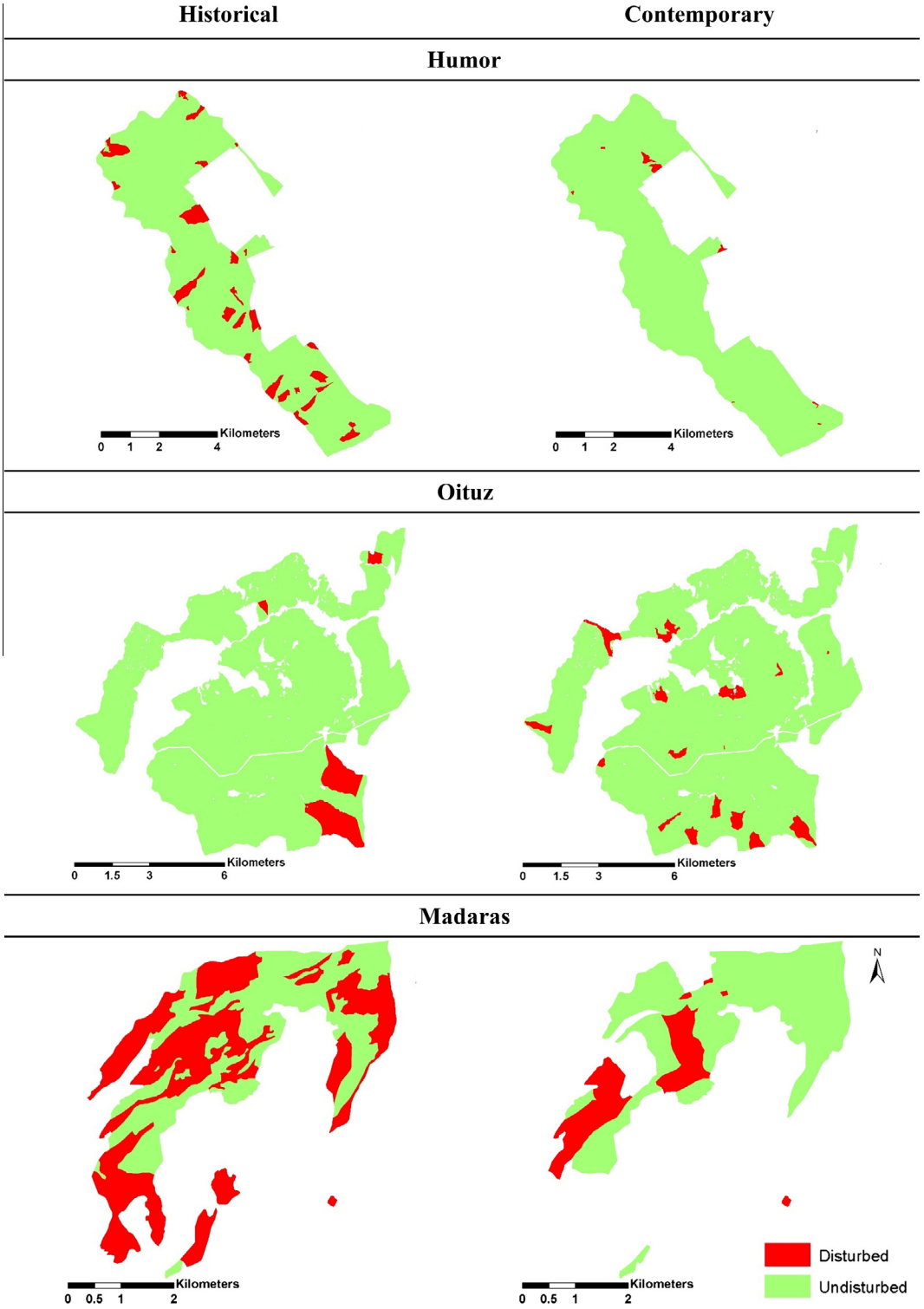


Fig. 4. Historical and contemporary forest disturbance at forest stand level in three case studies: Humor (3500 ha), Oituz (9000 ha) and Madaras (1500 ha).

period. Age structure data was available only at regional level for 2014, and at the county level for 1924. We complemented this dataset with national level statistics for 1964 and aggregated all data to the national level. Old forests (over 80 years) had a higher percentage in 1924 (25% of all forests) compared to 2014 (21% of all forests). In 1924 as much as 49% of all forests were in age classes below 40 years old, with a total of 1,887,000 ha being younger than 20 years old. Overall, we observed an equalization of age structure over time, with roughly 10–17% forest in each age class. Between 1924 and 2014, forests over 100 years declined from 14% to 9% and forests between 80 and 100 increased by 1% (Fig. 7).

When cross-tabulating ownership and age structure, we found that historically the largest proportion of forests under 20 years old (61%) was privately owned, whereas old forest (>100 years) where roughly evenly distributed between state, institutional, and private land owners. In 2014, only a small proportion of old

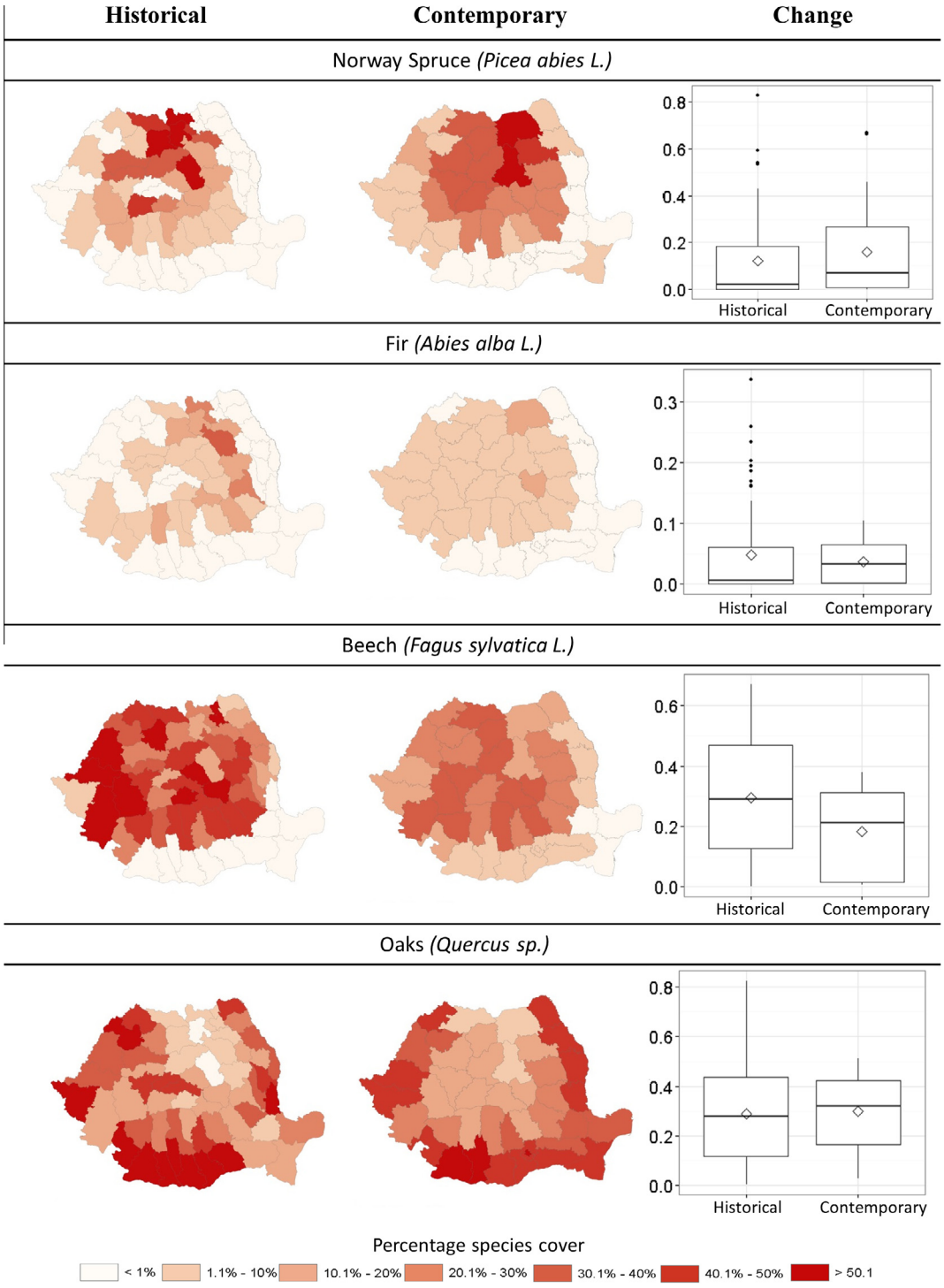


Fig. 5. Percentage of major coniferous species (Picea abies, Abies alba) and major deciduous species (Fagus sylvatica, Quercus sp) within forest cover of Romanian regions in 1924 (n = 58 regions) and in 2014 (n = 42 regions).

forests (17%) was privately owned, and the state owned most of the old forests in Romania, as much as 191,000 ha more than in 1924.

At the local scale, our results indicated that forests were historically older compared to the contemporary period, with the exception of Madaras, where a long history of spruce plantations led to successive wind disturbances and very young forest. In both Humor and Oituz, we found a high loss of forests in age classes older than 100 years, and an overall tendency of even distribution among age classes. In the case of Humor, contemporary stands were mostly 20–60 years old, whereas in Oituz most stands were 100 years or older (Fig. 7).

4. Discussion

4.1. Overview of long term forest dynamics

Our results showed that age structure, composition and disturbance patterns have changed greatly since the early 20th century

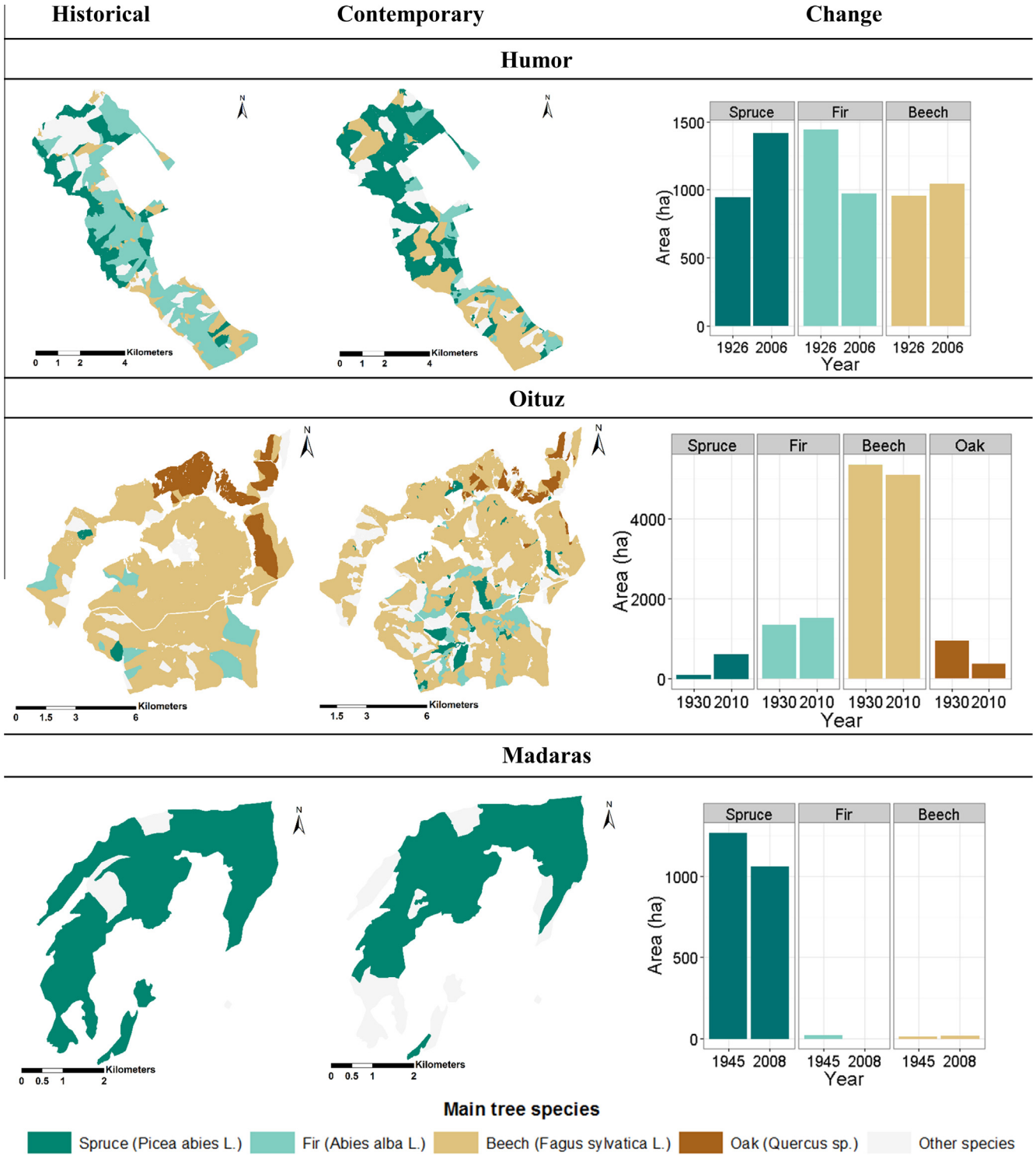


Fig. 6. Species composition at local level in Humor (3500 ha), Oituz (9000 ha) and Madaras (1500 ha) at the beginning of the 20th century and the beginning of the 21st century. Stands with species cover higher than 50% are represented in the graphic.

in Romania and we argue that legacy effects of forest management from nearly a century ago are still greatly reflected in contemporary forests. Forest cover increased in Romania and disturbance is much lower than in early 20th century; but due to intensive management in the past, contemporary forests have a higher percentage of spruce and less beech and oak. We suggest that major shifts in the amount of disturbance and in species composition may be related to changes in governance and land tenure because disturbance peaked around the time of agrarian reforms in the 1920s and post-socialist privatization in the 1990s and 2000s.

Our study captured several major changes in land tenure systems, and we suggest that forest disturbance was closely related to changes in forest ownership. Specifically, our data captured three land-ownership trends: (a) decrease in private land from 1926 to 1948, following the agrarian reform of 1921 (Ioras and Abrudan, 2006; Ministerul Agriculturii şi Domeniilor, 1924; Nicolau-Barlad,

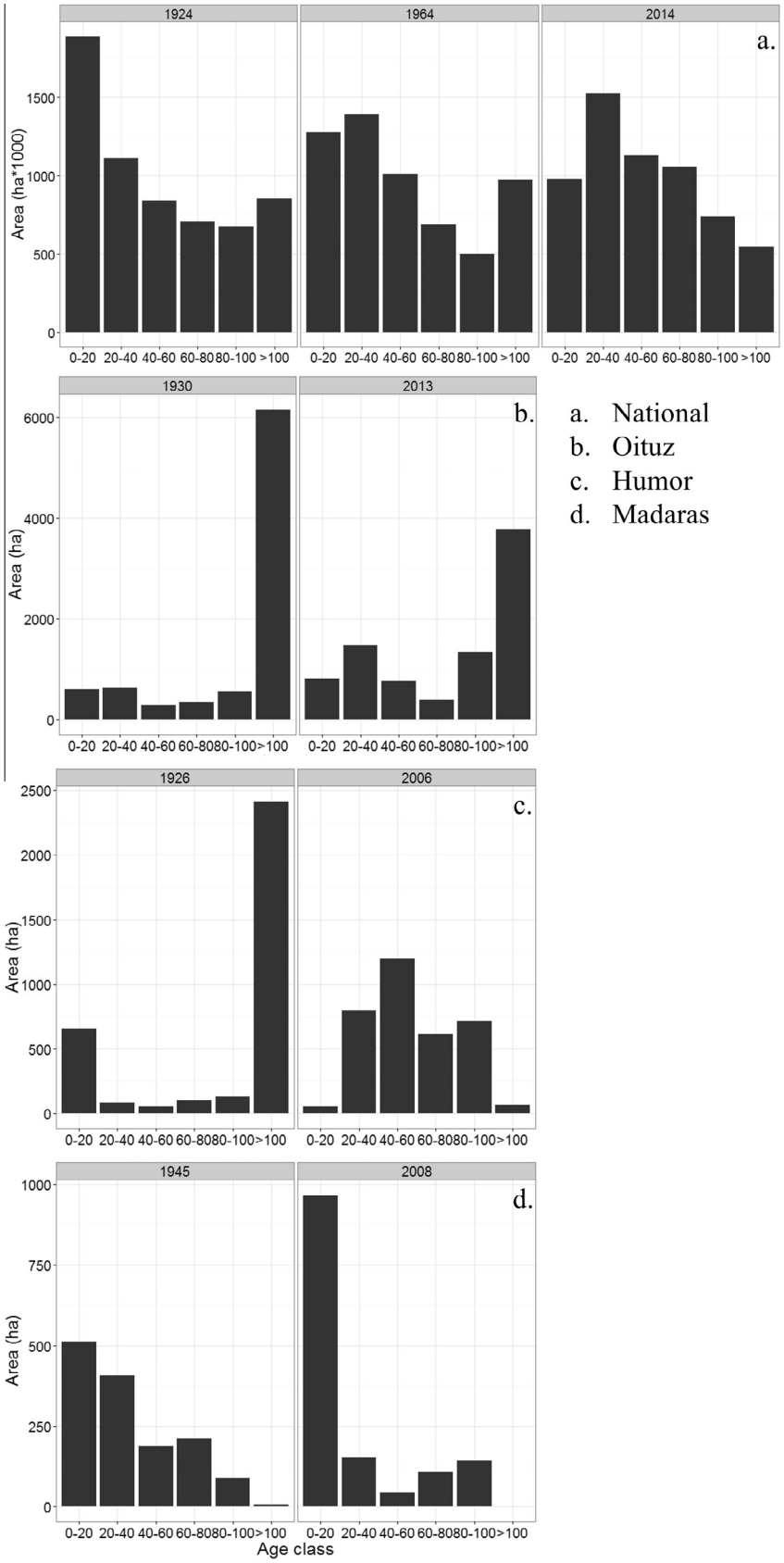


Fig. 7. Forest age distribution in Romania in at (a) national level for the years 1924, 1964 and 2014 and at local case study level in (b) Oituz (9000 ha) between 1930 and 2013, (c) Humor (3500 ha) between 1926 and 2006 and (d) Madaras (1500 ha) between 1945 and 2008.

1944), (b) entirely state-owned land from 1948 to 1989 (Bouriaud and Popa, 2008; Giurescu, 1981; Nicolau-Barlad, 1944), and (c) increase of private land as the result of three privatization laws (Law 18/1991, Law 1/2000 and Law 247/2005) from 1990 to 2014 (Ioras and Abrudan, 2006). These three periods roughly coincide with a decrease, stagnation, and increase in the amount of forest disturbance, suggesting that forest disturbance may be related to changes in land tenure, and specifically to the share of privately owned land. Our results are in line with global forestry literature which indicates that forests with stable ownership have significantly lower rates of harvest (Jin and Sader, 2006), and that harvest rates are higher in private forests (Kittredge et al., 2003). In Romania, missing or unclear regulations and the widespread lack of management plans for privately owned forests may provide a potential explanation for the high rates of contemporary harvesting in private forests that we observed. With 50–75% (roughly 700,000 ha) of its private forests lacking forest management plans, Romania is one of only five European countries in which management requirements are not fully consolidated across land ownership forms (Schmithuesen and Hirsch, 2010). Our results suggest that despite of 50 years of Socialism, when all forests were managed by the state (Ioras and Abrudan, 2006) legacies of historical shifts in governance can affect forest ecosystems far into the future, and may be related to the loss of old growth forests and changes in species composition. Similarly, our results highlighted the importance of stable governance and land tenure in maintaining forest area, age structure, composition and harvest rates.

4.2. Forest disturbance

Based on our results, forest cover increased in Romania since the 1920s and forest transition, i.e., the shift from a decrease to an increase in forest cover (Mather, 1998; Rudel et al., 2005), occurred approximately in the interwar period, consistent with case-studies in the region (Munteanu et al., 2014). Forest area in the current Romanian territory was as high as 10 million ha until 1860s (Nicolau-Barlad, 1944). By 1900 forest cover decreased in Romania by 3 mil ha – (Giurgiu, 2010a, 2010b) due to agrarian reforms at the end of the 19th century, which granted forested land to serfs for farming (Giurgiu, 2010b; Hitchins, 1994). Harvest rates were very high between 1912 and 1922, lowering the total tree cover to a minimum of 5,023,000 ha in the mid-1920s due to high timber needs for war purposes. Another agrarian reform in 1921, caused around 1 mil ha of clearings (Florescu, 1937; Giurescu, 1981; Giurgiu, 2010b; Sabau, 1957). Overall our study suggested that changes in regulations and high demand for agricultural products led to a rapid decrease in forest cover until WWII.

Following WWII, and especially after 1975, Soviet policies increased forest cover (Marea Adunare Nationala, 1976) by establishing forest plantations outside the historical range of forests (Munteanu et al., 2015). All forest were managed centrally and harvests were planned for 10-year time intervals, making reported forest harvest relatively constant (Marea Adunare Nationala, 1976). We observed a peak in harvest around 1965, partly due to war reparations paid to Russia in oil and timber (Banu, 2004). Disturbance peaked again in 1982–1985 when Romania was paying off loans to the International Monetary Fund (Ban, 2012). Following the collapse of the Soviet Union, disturbance rates were also high in Romania (Griffiths et al., 2014; Hansen et al., 2013; Knorn et al., 2012b; Potapov et al., 2011, 2014) especially following major privatization laws in 1991, 2000, and 2005 (Ioras and Abrudan, 2006). This finding provided further evidence on how institutional instability may increase harvesting patterns (Baumann et al., 2011; Dragoi et al., 2011; Prishchepov et al., 2012). However, we highlight that rates of forest harvesting after 1990 were lower than pre-1990, a fact that is missed by most post-socialist studies.

We found higher historical harvest in the Ottoman and Romanian regions than in the Austrian ones, and attributed this to the increase in exports following the Adrianopole Peace Treaty and the removal of the Ottoman timber monopoly in 1829 (Cojocaru-Ţuiac, 2010). Furthermore, the impact of agrarian reforms was higher in fertile areas than in mountain regions (Giurgiu, 2010a). In Transylvania, counties located closer to Vienna and with less mountains experienced more deforestation. However, the Northeastern Carpathian region was heavily prized for its timber, both by Austrians and Ottomans (Cojocaru-Ţuiac, 2010), and this is where we observed widespread forest harvesting. During the post-socialist period, we found a shift in disturbance patterns, where the mountain regions experienced higher disturbance rates, likely due to more abundant forest resources and increased accessibility.

4.3. Forest composition

Our results indicated an overall homogenization of the spatial distribution of tree species, with an increase in spruce (especially in Transylvania) and a shift in the spatial distribution of oaks (especially to Moldova and Wallachia). Our results also suggested that historical forest management – different across empire borders – may have increased the abundance of conifers on the Austrian and of oak on the Romanian side of the border. During the Austrian forest management of the 19th century, conifers such as spruce and pine were widely planted for pulp, timber and for erosion control in Translyvania (Popa, 2003). In contrast, historical Ottoman and later Romanian forest management was centered on the cut and leave method. This meant that entire watersheds would be clearcut, but at least 50 trees/ha were left standing as seed sources to ensure natural regeneration (Ministry of Agriculture and Forestry, 1945), leading to dominance of beech and oak. In addition, several oak species *(Quercus rubra, Q. frainetto)* were planted historically for erosion control and land reclamation in southern and eastern Romania. However, the increasing percentage of oak and beech in lowland regions coincided with the reduction of the species' ranges in central Transylvania. Although Transylvania still hosts some of the most biodiverse oak wooded pastures (Hartel et al., 2013; Öllerer, 2014), their extent very likely declined severely both during Austrian and Socialist rule (Rus, 2014) due to high value of the timber and because they were cleared for grazing or agriculture (Giurescu, 1981; Rus, 2014).

Socialist forest management also affected the current ecosystem composition. Between 1948 and 1989 large clearcuts were prescribed to pay off war debts (Banu, 2004) and international loans, followed by extensive spruce plantations both within (Cojocaru-Ţuiac, 2010) and outside forest ranges (2 mil ha between 1948 and 1975, (Marea Adunare Nationala, 1976). The area of spruce increased, while that of fir and deciduous species decreased.

Our local case studies provided additional evidence for legacy effects in forest composition. Madaras was mostly deciduous in Austrian military maps of the mid-19th century (Timár et al., 2010) and our data from the early 20th century indicated that spruce plantation occurred in the early 20th century. The area was clear-cut and restocked with spruce several times which may explain the wide-scale wind throws followed by salvage logging which we observed in contemporary management plans. In Humor, the shift from fir to spruce and beech could be a result of spruce plantation which encouraged natural regeneration of beech instead of fir (Damian, 1978; Isciuc, 2010). Finally, in Oituz we found a relatively high proportion of successional species like hornbeam or pines which are a good indication of the effect of the cut and leave management. Beech and oak decreased here, likely because their regenerative power was smaller than that of successional species.

4.4. Forest age

In terms of forest age, Romania has less very young forests (0–20 years) since 1924 but also less forests older than 100 years. A relative equal distribution of age classes is desirable from a management perspective, because it ensures a sustained wood production for timber and pulp (Halbritter and Deegen, 2015). However, old-growth forest have a high natural and conservation value as they provide habitat for a wide range of species, provide ecosystem services and store carbon (Keeton et al., 2010; Wirth et al., 2009) and their loss is unfortunate from a conservation perspective.

Forest management in post WWII Romania aimed to maximize timber production (Banu, 2004; Giurescu, 1981) to pay war debts and economic loans (Ban, 2012; Banu, 2004), and this led to a decrease in old forests, including some of the last old-growth forests of Eastern Europe (Knorn et al., 2012a; Veen et al., 2010). Although consistent with remote-sensing studies indicating the loss of old-growth forests in Romania (Knorn et al., 2012a), our results also highlight that a large proportion of Romanian forests were already managed in the early 20th century despite their old-growth like structure. However, mature secondary vegetation can provide important ecosystem services, have high biodiversity and conservation value (Newbold et al., 2015).

Local scale case studies confirmed the overall loss of old forests, especially in Oituz and Humor, where stands over 120 years old disappeared since 1924, likely as a result of socialist management to maintain equal age classes (Giurescu, 1981). In Madaras, the young forests of 1945 reflect harvests and spruce plantations of the early 20th century, while the contemporary proportion of young stands is likely due to the wind-throws in 1995–1997 (Popa, 2000).

We caution that uncertainty may be introduced in our datasets by elements such as different methods in assembling forest statistics, clear definition of forest disturbance across data sources and ability for clear forest species identification. Overall, we expect that our historic estimates are more accurate in Transylvania and Bucovina, where historic management plans were available (Nicolau-Barlad, 1938; Stinghe, 1939). We expect historic ownership data to be reliable because detailed inventories were required in the course of the agrarian reforms. The historic tree species compositions may include errors depending on surveyors' ability to differentiate between spruce and fir or various oak species.

4.5. Conclusions

Our results suggested that contemporary forests were heavily affected by historical forest management and that changes in institutions and ownership patterns may drastically and rapidly affect disturbance patterns and forest composition. We interpret these results to mean that effects of past management and institutional shifts can linger for centuries, and this is important because many regions of the world are currently experiencing drastic changes in their governance and ownership patterns. Such changes may have snowballing effects on forest systems, their functioning and the services they provide for a long time into the future, making a sound understanding of forest legacies important for both conservation and management. In a regional context, Romania harbors some of the last old-growth forests in Europe, which are in decline across the continent. Romania represents also a major source of timber internationally, although harvest rates have decreased. Our results highlight the need to protect the remaining old forests, which are declining, as well as the need to balance conservation and management goals in the future in order to ensure sustainable forests in Eastern Europe.

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