



Forest restitution and protected area effectiveness in post-socialist Romania

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ARTICLE INFO

Article history:

Received 13 May 2011

Received in revised form 7 December 2011

Accepted 16 December 2011

Available online 9 January 2012

Keywords:

Protected area

Effectiveness

Collapse of socialism

Forest restitution

Illegal logging

Deforestation

Remote sensing

Landsat

Central and Eastern Europe

Romania

ABSTRACT

The effectiveness of protected areas can diminish during times of pronounced socio-economic and institutional change. Our goals were to assess the effectiveness of Romanian protected areas at stemming unsanctioned logging, and to assess post-socialist logging in their surrounding landscapes, during a time of massive socio-economic and institutional change. Our results suggest that forest cover remained fairly stable shortly before and after 1990, but forest disturbance rates increased sharply in two waves after 1995 and 2005. We found substantial disturbances inside protected areas, even within core reserve areas. Moreover, disturbances in the matrix surrounding protected areas were even lower than inside protected area boundaries. We suggest that these rates are largely the result of high logging rates, triggered by rapid ownership and institutional changes. These trends compromise the goals of Romania's protected area network, lead to an increasing loss of forest habitat, and more isolated and more fragmented protected areas. The effectiveness of Romania's protected area network in terms of its ability to safeguard biodiversity is therefore most likely decreasing.

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1. Introduction

The world has failed to meet the 2010 target of halting biodiversity decline and species continue to be lost at an alarming rate (Butchart et al., 2010; CBD, 2010; Hoffmann et al., 2010). Protected areas are the cornerstone of conservation efforts (Cantu-Salazar and Gaston, 2010; Joppa et al., 2008; Myers et al., 2000), but land-use changes can trigger habitat loss and fragmentation outside protected areas, and may affect ecosystem processes within them (Hansen and DeFries, 2007). Analyzing land use changes in and around protected areas is therefore critical for assessing the effectiveness of this common biodiversity conservation strategy.

Protected area effectiveness is often compromised during periods of rapid socio-economic or institutional change, which can

trigger widespread land use changes and predatory resource use (Dudley et al., 2002; Irland, 2008). For example, the collapse of socialism in the former Soviet bloc and transitions from planned to market economies generated drastic land use changes (Bau-mann et al., 2011; Ioffe et al., 2004; Kuemmerle et al., 2007). At the same time, much of the infrastructure for nature protection eroded (Wells and Williams, 1998), institutions weakened, and illegal logging and poaching increased (Henry and Douhovnikoff, 2008; Soran et al., 2000; Vandergert and Newell, 2003). More recently, a substantial number of Eastern European countries joined the European Union (EU), requiring them to significantly enlarge their protected area network (Oszlanyi et al., 2004; Young et al., 2007). How these trends have affected the effectiveness of the regions' protected areas, however, remains poorly understood.

The Carpathians in Eastern Europe are of outstanding importance for nature conservation. The region has remained relatively undisturbed compared to Western Europe, is rich in biodiversity, and provides a refuge for large mammal populations (Anfodillo et al., 2008; UNEP, 2007). It comprises Europe's largest mountain range and also largest continuous temperate forest ecosystem (UNEP, 2007).

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In some Carpathian countries, most notably Romania, large areas of forest land shifted from public to private ownership, including areas officially residing within protected areas. Implementing sustainable forest management and EU nature protection regulations in this new multi-ownership landscape is a formidable challenge (Strimbu et al., 2005). Yet, how logging rates and patterns have changed during the transition from socialism to market-economies, and how forest ownership changes have affected protected area effectiveness in the Carpathians remains unexplored.

Assessing the status of forests in this region is often impaired by outdated forest resource information. In Romania, the last national forest inventory was carried out in 1984 (Brandlmaier and Hirschberger, 2005; Marin et al., 2010). The lack of information about forest change is worrisome because Romania has some of Europe's last and most extensive old-growth, primary forests (400,000 ha in 1984; remaining 218,500 ha in 2004) (Veen et al., 2010) and harbors the largest European populations of brown bear (*Ursus arctos*), gray wolf (*Canis lupus*), and lynx (*Lynx lynx*) (Ioras et al., 2009).

Moreover, Romania's protected areas network has undergone several fundamental changes following the collapse of socialism in 1989 (Iojă et al., 2010; Oszlanyi et al., 2004; Soran et al., 2000). Most importantly, Romania has implemented the EU Birds- and Habitat Directive (NATURA 2000), aimed at enlarging and connecting protected area networks. Today, about 20% of Romanian territory and about 10% of the country's forests are under some form of protection, including 13 national parks and 14 nature parks (Iojă et al., 2010). Most of Romania's protected areas are managed by the National Forest Administration Romsilva (Abrudan et al., 2009). While the recent increase in protected areas is a milestone for biodiversity conservation in Romania, considerable concerns about the status of nature protection remain: protected areas are sometimes subject to illegal logging and poaching, and many protected areas lack professional management, financing, and scientific support (Iojă et al., 2010; Soran et al., 2000).

Satellite images, particularly those from the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors, offer great opportunities to assess the effectiveness of protected areas, because they can capture forest disturbance (defined here as full canopy removal due to either natural disturbances, such as wind or insects, or anthropogenic disturbances, such as logging) and allow for robust comparisons across protected area boundaries (Fraser et al., 2009; Huang et al., 2009; Young et al., 2006). Since forest cover is correlated with species habitat and carbon storage (Keeton et al., 2010), forest disturbance is an indirect indicator for protected area effectiveness (Joppa and Pfaff, 2010). We thus use Landsat images to conduct the first assessment of how forest changes have affected protected areas in Romania. We used satellite images to measure forest disturbance and compared disturbance rates inside and outside protected areas across a 30,000 km² region in northern Romania. Specifically, we ask the following research questions:

1. What were the rates and spatial patterns of forest cover change in the post-socialist period (1989–2009)?
2. Were protected areas effective in safeguarding the forests from logging within their boundaries?
3. What was the effect of forest restitution on logging rates and patterns?

2. Study Area

Our study area was one Landsat-scene footprint (34,225 km²) in the northern part of Romania, bordering Ukraine (Fig. 1). Elevations in the study region range from ~200 m to >2300 m above sea level (a.s.l.) and climate is transitional temperate-continental. Natural vegetation occurs in altitudinal belts (Donita and Roman,

1976). A deciduous forest belt consists of four sub-belts (from low to high altitudes): a Sessile oak (*Quercus petraea*) belt (300–600 m a.s.l.); a European beech (*Fagus sylvatica*)-durmast belt (600–1000 m a.s.l.); and a mixed forest belt with beech, Silver fir (*Abies alba*) and Norway spruce (*Picea abies*) (1000–1200 m a.s.l.). Higher altitudes (up to 1800 m a.s.l.) encompass a Norway spruce belt. Above the timber line, a sub-alpine belt (1800–2000 m a.s.l.) with dwarf pine (*Pinus mugo*) and juniper (*Juniperus communis* ssp. *nana*), and an alpine belt (>2000 m a.s.l.), dominated by dwarf shrubs and short-grass meadows prevails (Cristea, 1993; Feurdean et al., 2007; Muica and Popova-Cucu, 1993).

Our study region contains three large protected areas that collectively cover about 204,500 ha: Maramures Mountains Natural Park, Rodna Mountains National Park, and Calimani National Park. All three reserves are forest-dominated, but differ in their management history, size, and protection status. Maramures Mountains Natural Park (hereafter referred to as “Maramures”, ~150,000 ha) was established in 2004 and is Romania's second largest protected area. It is embedded in the Maramures Mountains in Romania's North, consists of 66% forests, 30% meadows and alpine pastures, and 4% agricultural land. As an IUCN category V protected area, limited human activities are allowed inside Maramures. About 19,000 ha are strictly protected in a so called ‘integral protection zone’. Rodna Mountains National Park (hereafter “Rodna”, 46,400 ha) was established in the 1930s, as a 183-ha protected area around the Pietrosu Mare peak. After several extensions, the park now covers almost the entire Rodna Mountain Range, and has been officially administrated since 2004 (Szabo et al., 2008). About 60% of Rodna is forested, while alpine pastures and dwarf pine cover most of the remaining area. Rodna falls into IUCN category II (Dumitras and Pop, 2009) and has a core zone of about 20,800 ha (APNMR, 2010). Calimani National Park (hereafter “Calimani”, 24,000 ha) was officially created in 1990 but did not become operative until 2003 (Toader and Dumitru, 2005). It is part of the Calimani Mountains, the least populated montane region in Romania. Calimani is also classified as IUCN category II and is comprised of 58% old-growth Norway spruce and mixed beech-conifer forest. The core zone (i.e., strictly protected areas) covers an area of about 16,800 ha.

Romania has restituted (i.e. privatized) almost 45% of its forests prior to 2009 over the course of three phases based on laws passed in 1991, 2000, and 2005 (Abrudan et al., 2009; Strimbu et al., 2005). At the end of the restitution process, about two-thirds of all forest will be in private ownership, corresponding to about 800,000 new forest owners (Ioras and Abrudan, 2006). Since forests were restituted during a period of economic hardship and weak political institutions, incentives for new owners to capitalize on their forest land by over harvesting were high (Nichiforel and Schanz, 2011; Turnock, 2002).

3. Materials and methods

3.1. Datasets used

We used eight mid-summer to early-autumn Landsat TM/ETM+ images from path/row 185/27 to reconstruct forest disturbance histories from 1987 to 2009. We acquired images mainly before and after restitution laws were passed, and before and after protected areas were established (images from 8 September 1994, 4 July 2002, 4 September 2004, 11 October 2006, and 15 July 2009) and complemented our time series with images spanning the time period of 1986–1989 (18 September 1986, 7 October 1987, and 8 July 1989) to establish a baseline representing the forest cover of the late socialist period. Landsat images have 30-m resolution and are well-suited for mapping forest cover changes in the Carpathians at landscape scales (Kozak et al., 2008; Main-Knorn et al.,

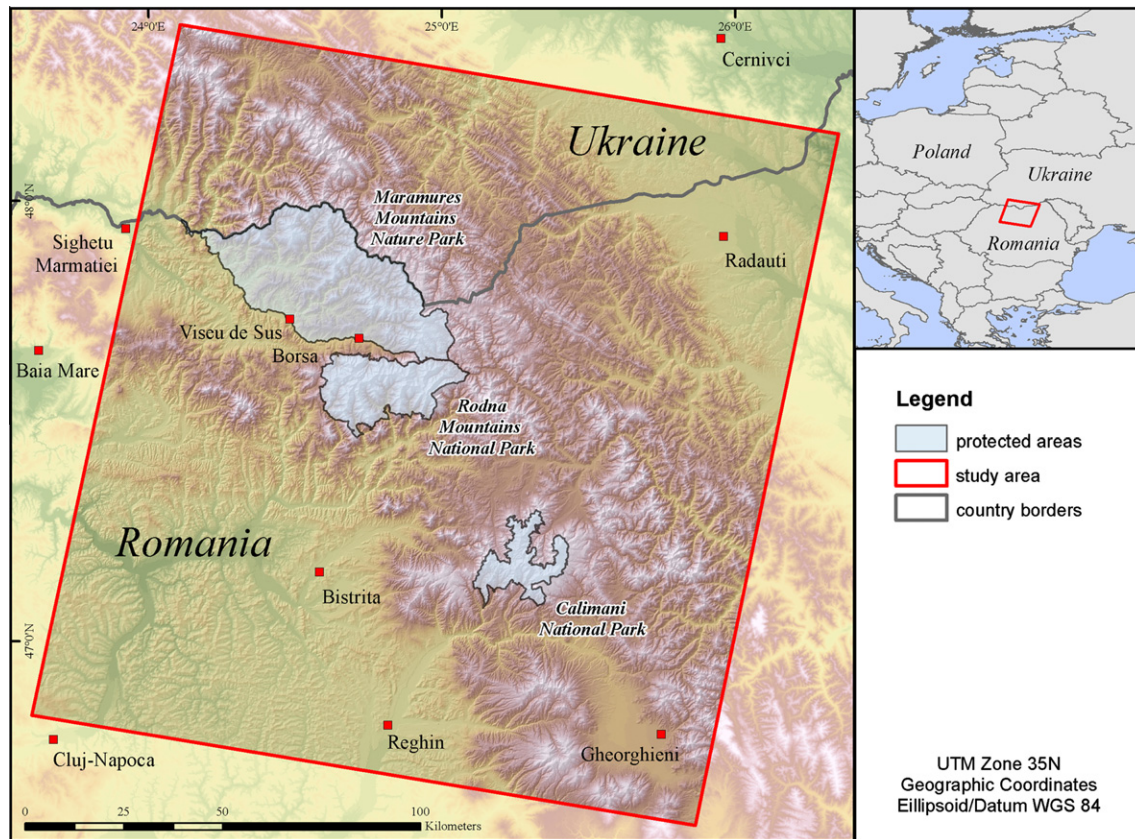


Fig. 1. Study area in the Carpathian Mountains in Eastern Europe including the three protected areas Maramures Mountains Nature Park, Rodna Mountains National Park, and Calimani National Park (Data: SRTM digital elevation model, ESRI Data and Maps Kit).

2009; Olofsson et al., 2011). Of the seven spectral bands, the thermal band was not retained for our analysis. Seven images had already been orthorectified by the United States Geological Survey. One image was obtained from the Global Land Cover Facility (www.landcover.org) and co-registered to the other images. We masked clouds, and cloud shadows (1986: 2572 km²; 1987: 2029 km²; 1989: 1062 km²; 1994: 983 km²; 2002: 1607 km²; 2004 no clouds; 2006: 4897 km²; 2009: 338 km²).

Reference data for training and validation was collected based on high resolution satellite images or air photos available in Google Earth that cover the complete study area (Baudron et al., 2011; Knorn et al., 2009). We sampled 3000 random points and classified those as either forest or non-forest based on visual interpretation. Points were considered forested if tree cover exceeded 60% and forest patches were larger than one Landsat pixel (900 m²) (Kuemerle et al., 2009). Our forest definition thus included orchards (almost absent from our study region), hedgerows, or open shrubland, but not areas with isolated trees. All points were cross-checked visually with the Landsat images to ensure that class labels did not change between 1986 and 2009. Points located in areas covered by clouds or with unclear class membership were discarded. In total, we used 2604 reference points (1280 non-forest, and 1324 forest).

Additional spatial data included an enhanced digital elevation model based on the Shuttle Radar Topography Mission (SRTM, <http://srtm.csi.cgiar.org>), resampled from 90 to 30 m to match the spatial resolution of the Landsat images. We also obtained protected area boundaries (provided by the National Forest Administration of Romania, Protected Areas Department), administrative boundaries (ESRI Data and Maps Kit 2008), core protected zones (provided by the protected area administrations), and areas of old-growth forest (provided by the Romanian Forest Research

and Management Institute – ICAS). Extensive field visits and interviews with protected areas staff and park administrations, stakeholders, NGOs as well as several researchers were carried out in 2008, 2009, and 2010. Field visits served to photo-document and geo-locate examples of forest disturbance sites to identify the causes of these disturbances, facilitated also by local knowledge provided by project partners.

3.2. Forest disturbance mapping

We used the forest disturbance index (Healey et al., 2005; Kuemerle et al., 2007) to map forest cover changes in our study area. Our analysis consisted of two steps. First, we classified forest and non-forest areas for the late 1980s (three images) and 2009 (one image) using Support Vector Machines (SVM) (Knorn et al., 2009; Kuemerle et al., 2009). It was necessary to use three images for the 1980s to obtain an area-wide map due to high cloud coverage in each of these images. SVM delineates two classes by fitting a separating hyperplane based on training samples. This hyperplane is constructed by maximizing the margin between class boundaries and is described by a subset of training samples, so-called ‘support vectors’ (Boser et al., 1992; Cortes and Vapnik, 1995; Foody et al., 2007). SVM require training data that optimize class separation rather than describing the classes themselves (Foody and Mathur, 2006). Using a radial basis function, class distributions with non-linear spectral feature space boundaries can be mapped into a higher dimensional space for linear separation (Huang et al., 2002). A mathematical description of SVM can be found in Huang et al. (2002).

To train and validate the SVM classifier, we used 10-fold cross-validation, where we split all available reference points into training (90%) and validation (10%) samples. We classified each of the

four images (1986, 1987, 1989, and 2009) for all possible splits (i.e., 10 times), calculated accuracy measures for each run, and averaged the error estimates (Knorn et al., 2009; Steele, 2005). We calculated overall accuracy, kappa value, and class-wise user's (error of commission – a pixel is assigned to an incorrect class) and producer's (error of omission – a pixel is omitted from its correct class) accuracies (Congalton, 1991; Foody, 2002). The final forest/non-forest classifications were based on all reference points (Burman, 1989).

We used the forest/non-forest classifications to generate a forest land map by masking all permanent non-forest areas (i.e., non-forest in the late 1980s and 2009). Forests disturbed immediately prior to the acquisition of our earliest image (1986) and which had regenerated by 2009 were thus not assigned to the permanent non-forest class. This means, that areas that were disturbed before 1986 but forested in 2009 are defined as forest land while appropriately assigning the respective disturbances to the late socialist time period. For the resulting forest land map, we used a minimum mapping unit of ~1 ha (10 pixels) based on high-resolution satellite image interpretation and extensive field visits.

Second, we calculated the disturbance index for all forest land pixels and for each image in our time series. The disturbance index is a continuous index based on the Tasseled Cap transformation and emphasizes the difference in spectral signatures between stand-replacing disturbance (high disturbance index values) and all other forest features (low disturbance index values). The DI uses the Tasseled Cap indices by making use of spectral differences between undisturbed forest (high greenness and wetness components, low brightness) and recently disturbed forests (low greenness and wetness, high brightness). Calculating the DI, requires two types of information: first, a forest and non-forest map, and second, the normalization of each Tasseled Cap component relative to the typical reflectance properties of undisturbed forests. Using the three

normalized components the DI is calculated as the brightness minus the sum of greenness and wetness. Separating disturbed from undisturbed forests requires setting a disturbance index threshold for each image. To define this threshold, we randomly selected 30 locations and digitized on screen the two closest disturbances as polygons in each of the Landsat images. Thresholds were determined by extracting the disturbance index range describing the digitized disturbances and setting a disturbance index threshold at the lowest quartile of this distribution. This rather conservative approach was chosen to avoid errors of commission (i.e., overestimation). The result yielded a forest disturbance map for 1987–2009 with the disturbance classes '1987–1989', '1989–1994', '1994–2002', '2002–2006' and '2006–2009'. For this map we used a minimum mapping unit of ~0.4 ha (i.e., 4 pixels) and we excluded disturbances above 1600 m that mainly represented misclassifications due to phenology effects. We then assessed the total disturbed area (in ha) and the annual disturbance rate (in %) for each time period. To validate our final forest disturbance map, we used a stratified random sample of 50 points per disturbance class and 150 points for the permanent forest and permanent non-forest class, respectively. We complied a minimum distance of 1000 m between points to limit spatial auto-correlation. All points were photo-interpreted using Google Earth and the Landsat images (Knorn et al., 2009; Kuemmerle et al., 2009). Finally, an error matrix including area-adjusted user's and producer's accuracies as well as overall accuracies were calculated considering the true area proportions of each class (Card, 1982). Additionally, we calculated 95% confidence intervals around our area estimates (Cochran, 1977).

To assess the effectiveness of protected areas, we summarized disturbances inside and outside the protected areas by calculating annual disturbance rates separately for each zone. Inside protected areas, we also distinguished between core (strictly protected) and

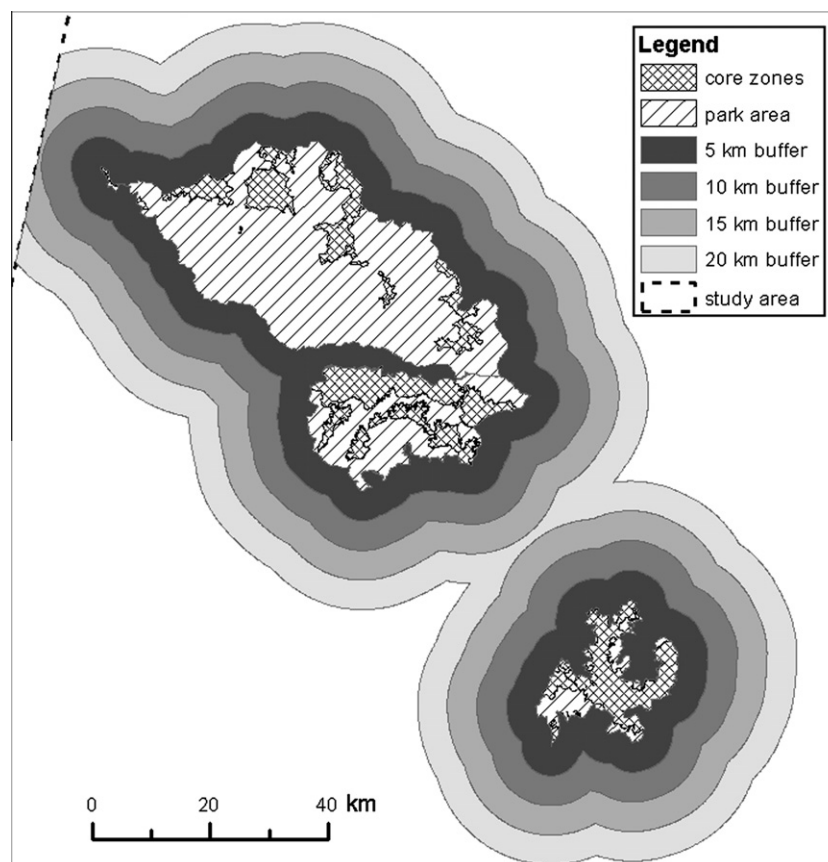


Fig. 2. Buffers and zones of protected areas used to summarize forest disturbance rates.

non-core areas. Outside protected areas we assessed disturbance rates in 5 km buffer zones within 5, 10, 15 and 20 km distance, respectively. We delineated the buffer zones for all protected areas together, i.e. buffers intersecting between neighboring protected areas were merged, thus ensuring that each disturbance was assigned only once to a single buffer zone or protected area (Fig. 2). To assure comparability of disturbance rates between the protected areas and the surrounding buffers, widths of the buffer zones were determined according to the amount of forest land found in all three protected areas summarized (Table 2).

4. Results

The SVM classification resulted in reliable forest/non-forest maps for the individual years, with overall accuracies generally exceeding 90% (1986: 93.4%; 1987: 93.2%; 1989: 92.3% and 2009: 94.6%) and kappa values exceeding 0.85 (1986: 0.87; 1987: 0.86; 1989: 0.85 and 2009: 0.89). The change detection based on the forest disturbance index also yielded a reliable forest disturbance map, with an overall accuracy of 94.9% and relative narrow confidence intervals around the area estimates (Table 1).

Forests covered about 59% of the study region and forest disturbances were widespread between 1987 and 2009, especially for the period 1994–2002 (about 1.7% of the forest land; 30,742 ha) and 2006 to 2009 (about 0.95% of the forest land; 16,993 ha). In

total, 60,945 ha of forest were disturbed over the 22 year time period we studied. Annual disturbance rates were highest between 2006 and 2009 (0.32%; 5664 ha/year).

We found substantial forest disturbance both inside and outside the three protected areas during all time periods (Table 2). In total, 7288 ha of forest cover were lost between 1987 and 2009 in the three protected areas (4.6% of the forest land). This is higher than the disturbances found in the respective buffer zones (Fig. 2) (5 km: 4.0% [6107 ha]; 5–10 km: 3.3% [4617 ha]; 10–15 km: 3.5% [5277 ha] and 15–20 km: 3.3% [5270 ha]). The amount of disturbance differed markedly between time periods though. For instance, disturbance rates for all protected areas were relatively low between 1987 and 1994 (<0.10%), but increased almost 10-fold between 1994 and 2002. This pattern repeated after 2002, with low disturbance rates between 2002 and 2006 (<0.12%) followed by an 8-fold increase after 2006. Of the total disturbed area, 4229 ha (2.69% of the forest land) were disturbed between 1994 and 2002 and 2075 ha (1.32% of the forest land) were disturbed between 2006 and 2009 (Table 2). However, parts of these disturbances occurred before the official recognition of the protected areas (Maramures in 2004, Rodna and Calimani in 2003). With more than 4800 ha disturbed in 22 years, Maramures had the largest amount of total disturbed area. Moreover, with a disturbance rate of 0.56% between 2006 and 2009 this is the highest of all parks across all time periods. In Rodna, highest disturbance rates

Table 1
Error matrix for the forest disturbance map including area-adjusted user's / producer's accuracies together with mapped and adjusted areas and the 95% confidence intervals.

	Prod. acc	User's acc	Map area (ha)	Adj area (ha)	±95% CI (ha)	±95% CI (%)
Dist. 1987	94.63%	94.00%	30,216	30,015	3049	10.16%
Dist. 1989	96.84%	92.00%	40,309	38,293	3951	10.32%
Dist. 1994	100.00%	96.00%	60,441	58,023	3384	5.83%
Dist. 2002	99.47%	90.00%	375,802	340,036	32,277	9.49%
Dist. 2004	98.48%	90.00%	30,241	27,638	2726	9.86%
Dist. 2006	100.00%	92.00%	21,060	19,375	1632	8.43%
Dist. 2009	100.00%	94.00%	188,849	177,518	12,814	7.22%
Forest	94.77%	95.33%	14,331,822	14,417,346	708,756	4.92%
Non-forest	94.87%	94.67%	13,756,898	13,727,393	708,949	5.16%

Table 2
Disturbances per protected area zone, buffer zone and time period. Numbers correspond to disturbed area (in ha) and yearly rates in relation to forest land (in%).

		1987–1989	1989–1994	1994–2002	2002–2004	2004–2006	2006–2009	sum	forest land (ha)
Maramures Mountains Nature Park	Core zone	16 (0.06%)	21 (0.03%)	198 (0.19%)	4 (0.02%)	26 (0.10%)	87 (0.23%)	352	12,736
	Non-core zone	169 (0.09%)	283 (0.06%)	2057 (0.28%)	133 (0.07%)	209 (0.12%)	1629 (0.60%)	4481	90,253
	Entire park	185 (0.09%)	304 (0.06%)	2254 (0.27%)	138 (0.07%)	235 (0.11%)	1716 (0.56%)	4833	102,989
Rodna Mountains National Park	Core zone	14 (0.04%)	14 (0.02%)	782 (0.61%)	3 (0.01%)	4 (0.01%)	47 (0.10%)	864	16,093
	Non-core zone	13 (0.04%)	24 (0.03%)	463 (0.34%)	13 (0.04%)	7 (0.02%)	187 (0.36%)	707	17,204
	Entire park	27 (0.04%)	38 (0.02%)	1245 (0.47%)	16 (0.02%)	10 (0.02%)	235 (0.24%)	1571	33,296
Calimani National Park	Core zone	10 (0.04%)	1 (0.00%)	230 (0.21%)	1 (0.00%)	0 (0.00%)	38 (0.09%)	280	13,718
	Non-core zone	5 (0.04%)	7 (0.02%)	499 (0.85%)	4 (0.03%)	2 (0.00%)	86 (0.39%)	604	7324
	Entire park	16 (0.04%)	8 (0.01%)	729 (0.43%)	5 (0.01%)	2 (0.00%)	124 (0.20%)	884	21,042
Buffer zone	5-km buffer	382 (0.09%)	583 (0.03%)	2473 (0.28%)	102 (0.04%)	121 (0.04%)	2446 (0.80%)	6107	153,040
	10-km buffer	450 (0.16%)	544 (0.04%)	1950 (0.29%)	130 (0.06%)	184 (0.09%)	1358 (0.46%)	4617	138,330
	15-km buffer	410 (0.09%)	566 (0.04%)	2558 (0.36%)	187 (0.07%)	155 (0.05%)	1402 (0.28%)	5277	151,726
	20-km buffer	306 (0.07%)	458 (0.04%)	2590 (0.26%)	202 (0.05%)	174 (0.03%)	1541 (0.38%)	5270	158,848

occurred between 1994 and 2002 (0.47%), when they were 3-times above its annual average and the highest of the three protected areas during this period. Similar to Rodna, the highest disturbance rates for Calimani were found between 1994 and 2002 (0.43%), and the second highest between 2006 and 2009 (0.20%) (Table 2).

In total, 4.20% of the forest land in Calimani (884 ha) was disturbed between 1987 and 2009, compared to 4.72% (1571 ha) and 4.69% (4833 ha) in Rodna and Maramures, respectively (Table 2). For the time period following the establishment of the three protected areas (2003/2004–2009), disturbance rates were generally lower in the core zones compared to the rest of the park (0.17% [113 ha] for Maramures, 0.06% [51 ha] for Rodna, 0.06% [38 ha] for Calimani).

5. Discussion

Rapid socio-economic changes due to the transition from socialism towards a market-economy triggered forest disturbances and illegal resource use even inside protected areas. Our results help to address the question of how forest cover in the Romanian Carpathians has changed after the collapse of socialism, and how this, in turn, may have affected the ability of Romania's protected areas to safeguard biodiversity. Our remote sensing analysis indicated widespread forest cover changes between 1987 and 2009, especially since 2006. Disturbances inside protected area boundaries were even higher than those in their surrounding. While our remote sensing based approach cannot distinguish between natural and anthropogenic disturbances, our results, field visits and interviews suggest that natural disturbances alone do not explain the increasing trend in forest loss. We suggest that the ongoing forest restitution process and associated harvesting were a major underlying cause for the accelerated disturbance rates observed (Griffiths et al., *in press*).

Massive socio-economic transformations accompanied by substantial economic hardship, and the restitution process translating into logging thus present considerable challenges for nature conservation. The observed disturbance rates show that the effectiveness of the three protected areas is challenged, and forest disturbance is both compromising habitat integrity within protected areas and may be fragmenting their surrounding landscapes. Since forest loss close to protected areas can affect ecosystem functions and processes, hamper species dispersal, or induce edge effects (Cameron, 2006; DeFries et al., 2010), protected area management and conservation planning should consider that parks are embedded in larger landscapes which are important for conservation. While Romania now has an extensive network of parks that appear "protected on paper", continued monitoring of these parks is necessary to ensure their effectiveness. As shown in our analysis, satellite image interpretation can contribute substantially to this task.

Natural stand-replacing disturbance events occur in the Romanian Carpathians and include insect infestation, avalanches and wind-throw, with the latter being the most important (Schelhaas et al., 2003; Toader and Dumitru, 2005). Forest fires are not widespread and cause negligible disturbances (0.15% of the Romanian forest area in 1965–1998) and are always confined to small patches (Anfodillo et al., 2008; Rozyłowicz et al., 2011). Nevertheless, natural disturbances are unlikely to explain the forest cover change trends we observed. Whereas some large-scale natural disturbances occurred in our study region, wind disturbances often affect regions much smaller than our minimum mapping unit (Rozyłowicz et al., 2011). Moreover, natural disturbances cannot explain the strong increase in forest disturbances we observed after 2006. Indeed, wind-throw events occur across the Carpathians, but with varying frequency (Lavnyy and Lässig, 2007) and for Romania with a declining frequency and intensity since 1975 (Popa, 2008).

Wind-throw events or insect outbreaks are most frequent in artificial spruce plantations (Keeton and Crow, 2009; Kuemmerle et al., 2009; Macovei, 2009), that often comprise non-native genetic spruce variations, and thus are related to forest management history (Schelhaas et al., 2003). Moreover, intensive exploitation in the past simplified forest structure and composition at stand and landscape scales, resulting in fragmentation and high contrast forest edges that increase vulnerability to wind-throw (Macovei, 2009; Toader and Dumitru, 2005). Many forest cover changes classified as natural disturbances may therefore actually be anthropogenic in origin. Likewise, this evidence suggests that wind-throw events should be at least equal in areas outside of reserves which have more substantial forest management histories.

Corruption and lack of transparency is also a major problem, leading to cases where sanitary or salvage logging has been misused to harvest healthy forest stands (Brandlmaier and Hirschberger, 2005). Informal, interviewees have even pointed out to us during field work that corridors in forests were deliberately placed to inflict wind-throw and thereafter allow for salvage logging. In sum, although we cannot separate natural disturbances and logging based on satellite data alone, true natural disturbances are rare in the Carpathians and natural disturbances neither explain the increase in disturbance rates since 1989, nor the differences in disturbance rates inside and outside protected areas.

Instead, we suggest that the major institutional and socio-economic changes relate to the high rates of disturbance during post-socialism compared to disturbance rates observed during the last years of socialism. We caution that a causal connection cannot be established, as spatially-explicit ownership data on forest ownership is currently not available. However, our results, extensive field-visits, expert interviews and other studies from other areas in Romania (Griffiths et al., *in press*) all unanimously suggest that the disturbance trends we observed are indeed due to the changes in forest legislation (Irimie and Essmann, 2009; Mantescu and Vasile, 2009).

New owners appear to harvest much of their forests to gain short-term profits. Moreover, new forest owners often lack of capacity and knowledge for sustainable forest management and nature conservation principals and legislation. New forest owners additionally often doubt the permanence of their newly gained property rights and there is a lack of knowledge on sustainable harvesting principles (UNDP, 2004). Additionally, cases of illegal logging in restituted forests brought to court often remain unpunished or are left with inadequate consequences (pers. comm., local scientists)¹. In consequence, widespread logging and over-harvesting was evidenced after the first restitution law in 1991 (Nichiforel and Schanz, 2011). Most of the restituted forest were immediately cleared by new owners (Mantescu and Vasile, 2009). Similar trends occurred in the subsequent restitution phases following the respective laws in 2000 and 2005 (Ioras et al., 2009), amplified by weakened institutions and increasing economic hardship. The effectiveness of the three protected areas we studied is in question. Since Maramures is one of the poorest regions of Romania and more than 24,000 ha (16% of the park area) has been restituted, habitat fragmentation and degradation due to clear-cutting and unsustainable forest management is a major threat (UNDP, 2004). Accordingly, our results show that frequent disturbances throughout Maramures, including old-growth forest (e.g., Fig. 3b, circle 1), took place since the collapse of socialism, even partly exceeding those outside the protected areas (Table 2; Fig. 3). After 1989, the entire Maramures Mountains became a target of timber companies and timber harvesting is now the mainstay of the local economy (Munteanu et al., 2008).

¹ Full names are not provided to protect interviewees and informants.

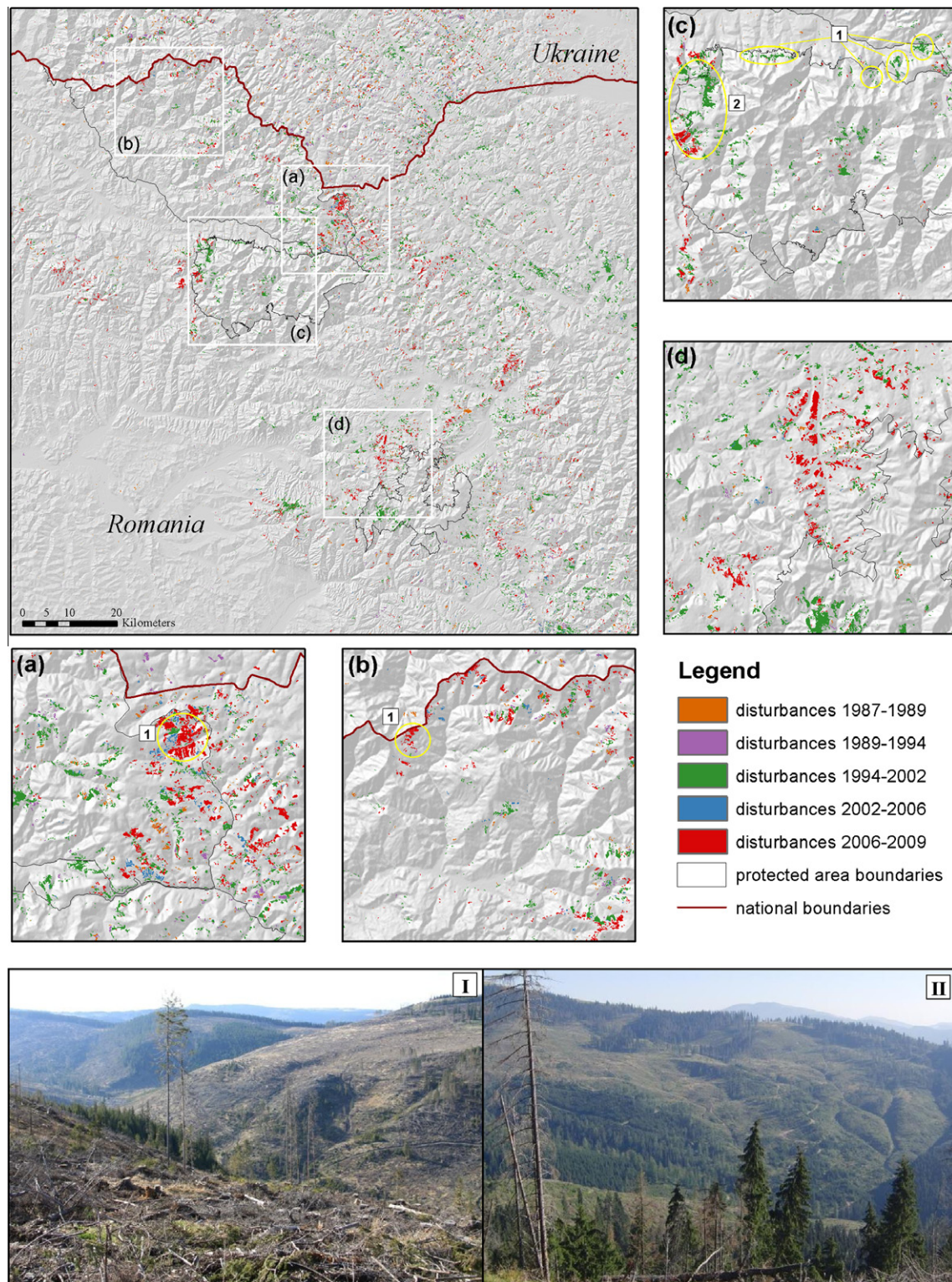


Fig. 3. Forest disturbances rates within and around the protected areas. Circles highlight disturbance events described in the text. (a) eastern part of Maramures, (b) northern part of Maramures, (c) western part of Rodna, and (d) western part of Calimani. Photographs of (I) forest loss in the Tibau basin in Maramures Mountains Nature Park, and (II) a wind-throw area in the western part of Rodna Mountains National Park (Photos: M. Mindtrecu; J. Knorn).

One prominent example of logging exceeding the maximum allowed patch size of 3 ha is found in the upper Tibau Basin (Fig. 3a, circle 1; Fig. 3, photograph I), where a forest area of up to 500 ha was cleared between 2006 and 2009. This substantially increases flood vulnerability in the area, taking into account that extensive logging both outside and inside Maramures already contributed

to severe flood events in the past (Munteanu et al., 2008; UNDP, 2004). The lower protection status of the Maramures Nature Park may further explain the highest disturbance rates of all three protected areas inside and outside the core zone (Table 2). Considering that each of the rangers is responsible for patrolling on average almost 12,400 ha (Ioja et al., 2010) (while a forester

is usually in charge of only 1000 ha), enforcing legislation remains challenging.

Forests inside Rodna are now owned by more than 20 entities. This fragmentation of ownership and management creates an extremely difficult situation for the park administration. It is encouraging, though, that the main proportion of forest disturbances in Rodna occurred before 2002 (Fig. 3). According to the park administration, parts of these disturbances are due to illegal logging (Fig. 3c, circles 1). This was the case, for example, in the Pietrosu Mare scientific reserve between 1995 and 2004. Due to an increased exposure, the remaining forest suffered additionally from wind-throw impacts and bark-beetle infestation (pers. comm. with park administration). Beside these logging events, our results clearly depict impacts of wind-throws in the western part of Rodna (Fig. 3c, circle 2; Fig. 3, photograph II).

Rodna presents a particularly striking example for the lack of appropriate buffer zones. The two scientific reserves Pietrosu Mare and Piatra Rea do not have a buffer area on the northern side of the park. Reasons for this originate in the history of the establishment of parks in Romania. Due to economic pressure and without knowledge of modern conservation planning principles, it was generally agreed that small protected areas are best for biodiversity conservation (Sorani et al., 2000). One reason for high disturbance rates in the surroundings of the parks may thus originate from the absence of suitable buffer areas.

In Calimani, we found the least amount of forest disturbances and rates of all protected areas (Table 2). However, recent forest disturbances increased substantially around the Calimani, likely contributing to an increased isolation of the park. Parts of the scattered disturbance patches in the western part of the protected area are the result of wind-throws between 1994 and 2002 (pers. comm. with park administration) (Fig. 3d).

Our study showed widespread forest cover changes in Romania since the breakdown of socialism, mainly due to excessive logging triggered by the recent forest restitution. Forest disturbances were even widespread within protected areas and old-growth forests, sometimes exceeding disturbance rates in the surrounding landscape. The root causes of increasing logging rates in the post-socialist period are economic hardships and a generally low awareness of the role of natural resources and biodiversity, particularly concerning non-market ecosystem services (e.g., flood protection) (UNDP, 2004; Young et al., 2007). In addition, institutional decay, corruption, and an under-funded nature protection program further hamper the implementation of nature conservation legislation. The high amount of forest disturbances we found thus adds to recent voices of concern regarding nature protection in Romania (UNEP, 2007). The Carpathians, and especially Romania, harbor unique high-conservation value forests that redevelop only very slowly (Ioras et al., 2009; Wirth et al., 2009). Halting the ongoing loss of these forests requires capacity building and reinforcing Romania's nature protection infrastructure. In the short run, continued monitoring of forest losses and protected area effectiveness are needed, and satellite image analyses offers valuable tools for doing so.

Acknowledgements

We gratefully acknowledge support by the Alexander von Humboldt Foundation, the European Union (Integrated Project VOLANTE FP7-ENV-2010-265104) and the NASA Land Use and Land Cover Change Program of the National Aeronautics and Space Administration (grant number NNX09AK88G). A. Sieber, E. Stanciu, M. Turcic, V.N. Nicolescu, Dr. I. Blada, and the park administrations provided valuable input that greatly improved this manuscript. We thank A. Janz and S. van der Linden for implementing the imageSVM software (www.hu-geomatix.de). We also thank

V. Butsic, three anonymous reviewers and the editor for constructive criticism and helpful comments.

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