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Differences in forest disturbance among land ownership types in Poland during and after socialism

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Forest use can increase substantially during periods of societal change, but it is unclear how harvesting rates differ among different landownership types in such times. Our goal here is to quantify the rates and spatial patterns of forest disturbance in private forests, state forests, and a National Park in the Polish Carpathians before and after the collapse of socialism. We analysed a series of classified Landsat TM images (1988–2000) and a landownership map. Our results showed that disturbance peaked in all ownership types in the immediate transition time. However, disturbance rates in private forests were about five times higher than on public lands. The spatial pattern of disturbances was similar across ownership types, but private forests were more fragmented than state and National Park forests. Our study indicates that institutional strength may determine forest use under different ownership types and highlights the multi-scale, nested control of the drivers of land use change.

Keywords: forest ownership patterns; forest disturbance; fragmentation; transition economies; land use and land cover change; land tenure

1. Introduction

Unsustainable forest use threatens the continued provision of important ecosystem services, erodes the basis of local livelihoods, and causes unprecedented biodiversity loss (Lepers *et al*. 2005; Jha and Bawa 2006; Foley *et al*. 2007). Understanding the underlying causes of land use decisions that result in forest change is therefore of growing concern (Angelsen and Kaimowitz 1999; Geist and Lambin 2002). Broad-scale socio-economic, institutional, demographic, or cultural conditions are of paramount importance for land use decisions in forests (Moran and Ostrom 2005; Geist *et al*. 2006), but these factors are modified by local conditions, such as land use history, fine-scale biogeophysical variation, and household density (Dale, Oneill, Pedlowski, and Southworth 1993; Foster, Fluet, and Boose 1999; Liu, Daily, Ehrlich, and Luck 2003).

Different forest ownership types (e.g., private, communal, or public) are an important aspect of local variations that can result in differing forest use. Landownership type affects, for example, deforestation (Dolisca, McDaniel, Teeter, and Jolly 2007; Nagendra, Pareeth, Sharma, Schweik, and Adhikari 2008), forest disturbance (Kittredge, Finley, and Foster 2003), reforestation (Southworth and Tucker 2001; Nagendra 2007), illegal logging (Banana and Gombya-Ssembajjwe 2000), and the spatial pattern of forest lands (Turner, Wear, and

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Flamm 1996; Nagendra *et al*. 2008). However, while the pivotal role of land tenure in amplifying or dampening driving forces of forest change is widely acknowledged, no clear patterns emerge about which landownership type is more successful in safeguarding forest ecosystems from unsustainable use (Tucker and Ostrom 2005).

There is growing evidence that the quality and strength of institutions are major factors contributing to forest use patterns (Deacon 1999; Tucker and Ostrom 2005; Tucker, Randolph, and Castellanos 2007). Within similar landownership types, *de facto* use may differ substantially from *de jure* rules. For example, unsustainable forest use and illegal logging in communal forests may be higher when institutions are weak and law enforcement is lacking (WWF 2007). Comparing forest use indicators among landownership types in areas of institutional change thus has the potential to help us better understand the relationship between landownership and forest use. However, such comparisons have rarely been carried out, mainly because institutional change often occurs gradually making its effects on forest use difficult to discern.

The transition from command-driven to market-oriented economies in Eastern Europe after the collapse of socialism around 1990 is a prime example of institutional change that affected the use of forests. Throughout Eastern Europe and the former Soviet Union, the early transition years were characterized by weak institutions, a low level of control, and an eroding infrastructure for nature protection (Sobolev, Shvarts, Kreindlin, Mokievsky, and Zubakin 1995; Wells and Williams 1998). As a result, increased logging, both legal and illegal, has been reported, including inside protected areas (Nijnik and Van Kooten 2000; Kuemmerle, Hostert, Radeloff, Perzanowski, and Kruhlov 2007; WWF 2007). However, the question remains whether forest use trends in the post-socialist period differed among different types of forest landownership types.

To examine the relationship between forest change and forest ownership in the context of major institutional change, we studied Europe's largest temperate forest ecosystem, the Carpathians. We selected the Eastern Polish Carpathians, because this region is heavily forested and characterized by different forest ownership types (i.e., state forest, private forest, and forests inside protected areas). Contrary to many other Eastern European countries, private forests existed in Poland throughout the socialist period, forest tenure did not change substantially after 1989, and the transition occurred relatively rapidly (Kissling-Naf and Bisang 2001; Augustyn 2004). Moreover, digital information on forest ownership is available, making the region particularly well suited for comparing forest disturbance among landownership types in a rapidly changing socio-economic and institutional environment. In a previous study, we quantified forest disturbance before and after the fall of the Iron Curtain in this region (Kuemmerle *et al*. 2007). Building upon these results, we investigated the following questions:

(1) Did forest disturbance and forest fragmentation differ among a National Park, Private Forests, and state-owned forest during socialism?
(2) Were there differences in forest disturbance and forest fragmentation after the breakdown of socialism among the three forest ownership types?

2. Study region

Our study region (Figure 1) encompassed 3300 km^2. Study area boundaries were based on administrative units and the extent of one Landsat scene (path 186, row 26). Altitudes vary from 240 to over 1300 m above sea level. Climate is moderately cool and humid

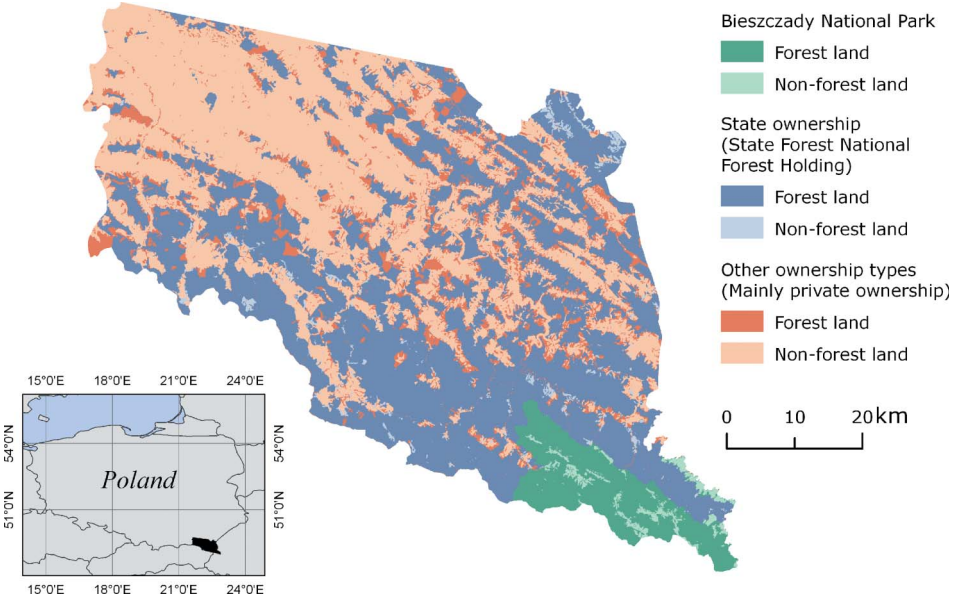

Figure 1. Forest cover and forest landownership types in the Bieszczady Mountains in the Polish Carpathians. Available in colour online.

(Obrebska-Starklowa, Hess, Olecki, Trepinska, and Kowanetz 1995; Augustyn 2004), with annual mean precipitation of about 1000–1200 mm and annual average temperatures between 5 and 6°C, except for the highest mountain ranges. There are three altitudinal zones of potential natural vegetation in the study region: the foothill zone (<500–600 m) with broad-leaved species such as oak (*Quercus robur*; *Quercus petraea*), lime (*Tilia cordata*), and hornbeam (*Carpinus betulus*); the montane zone (500–600 to 1000–1200 m) dominated by European beech (*Fagus sylvatica*) and mixed with silver fir (*Abies alba*), Norway spruce (*Picea abies*), sycamore (*Acer pseudoplatanus*), and white alder (*Alnus incana*); and the zone of predominantly anthropogenic mountain meadows (połoniny) (>1000–1200 m) (Balon *et al*. 1995; Denisiuk and Stoyko 2000; Perzanowski and Szwagrzyk 2001).

Forests in the region are highly productive (up to 6 m^3/ha annual increments in standing volume, Nijnik and Van Kooten 2000) and forestry has been economically important for centuries (Turnock 2002; Augustyn 2004). Since the nineteenth century, forest cover steadily increased after several centuries of heavy exploitation and conversion of forests to farmland (Kozak, Estreguil, and Troll 2007). Harvesting rates were relatively high in many areas in the Carpathians during socialism, but considerable forest regrowth also occurred in some areas that were depopulated during the 1940s following border changes between the Soviet Union and Poland and several forced resettlements (Snyder 1999; Augustyn 2004). Today, the region is among Europe's most densely forested areas. Forest management profoundly affected most forests in the Bieszczady Mountains, yet some of Europe's last remaining primeval forests are also found here, mostly within the boundaries of the 29,000 ha Bieszczady National Park (Figure 1), founded in 1973 and enlarged several times until 1999 (Denisiuk and Stoyko 2000).

3. Data and methods

3.1. Data sets used

We obtained a digital map of land under the management of the State Forests National Forest Holding (*Państwowe Gospodarstwo Leśne Lasy Państwowe*) from the Regional Directorate of the State Forests in Krosno. Forests were defined in this map to include forest stands, clear-cuts, areas where forest regrowth occurs (e.g., via forest planting on former farmland), and some permanent openings (e.g., mountain meadows). The vector map, originally compiled from 1990s forest management maps produced at a scale of $<$1:10,000, was fully updated in 2007 through extensive field surveys. The borders of the Bieszczady National Park were made available by the Geography Department of the Ivan-Franko University (Lviv, Ukraine).

A forest disturbance map was available from a previous study (Kuemmerle *et al*. 2007). This map was derived from Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images from 1988 to 2000 using a two-stage strategy. First, we separated forest and non-forest from the images from the late 1980s. Forests that had been disturbed right before image acquisition were classified as non-forest in this map. To include such areas in our analyses, we identified all non-forest patches within forest areas and used 1970s Landsat Multi-Spectral Scanner (MSS) images to check whether such patches represented forest disturbances or permanent openings. Our analyses thus focused on areas that were either forested in 1988 or had been cleared just before 1988. Some reforestation on abandoned or set-aside farmland occurred in the study region (Kuemmerle *et al*. 2008). However, we excluded these areas from our analyses, because land tenure of reforestation areas was often unclear, and because we were mainly interested in assessing forest disturbance differences among ownership regimes, and reforested areas were too young to be harvested. To identify forest disturbance, we used the forest disturbance index (Healey, Cohen, Yang, and Krankina 2005) and a multitemporal classification (i.e., composite analysis, Coppin and Bauer 1996). We analysed all forest areas and identified the classes ‘unchanged forest’, ‘disturbances before 1988’, ‘disturbances in 1988–1994’, and ‘disturbances in 1994–2000’. A detailed description of the image analyses is provided in the work of Kuemmerle *et al*. (2007).

3.2. Comparing post-socialist forest disturbance among landownership types

We labelled all forests identified in the satellite image analyses (i.e., permanent forest and disturbances) according to their ownership class. Forests within the State Forests National Forest Holding were labelled as ‘State Forests’ and forests within the boundaries of the protected areas were labelled as ‘Bieszczady National Park’. The land tenure outside the National Park and the State Forests varied (private, public, cooperative, etc.), particularly concerning farmland. However, the majority of forests were privately owned and managed ($>$75% in the Podkarpackie Province, GUS 2008), both before and after the system change. We therefore labelled forests outside the National Park and the State Forests as ‘Private Forest’ (Figure 1).

To compare post-socialist forest changes among landownership types in the study area, we summarized the area and proportion of total forest as well as the area of unchanged forests and disturbed forests in the three time periods before 1988, 1988–1994, and 1994–2000 for each landownership class. This allowed us to calculate mean annual disturbance rates for each time period. Disturbance rates for the period before 1988 were calculated assuming that only disturbances that occurred up to 6 years were detectable from the Landsat TM image (i.e., older disturbances were not detectable because of forest regeneration, see Kuemmerle *et al*. 2007).

To quantify whether the spatial pattern of forest cover and forest disturbances differed among forest landownership types, we applied landscape metrics at the class level (O'Neill *et al*. 1988; Turner and Gardner 1991). We calculated the number of patches, patch density, mean patch size, and the standard deviation of patch size for unchanged forest and the disturbance classes for each landownership type separately (McGarigal 1994). Patch density was derived as the number of patches per square kilometer of all land per ownership type. To assess the level of spatial aggregation of unchanged and disturbed forests for each ownership type, we also derived the aggregation index (AI). This index assumes that pixels in a class with the highest level of aggregation (AI = 100) share the maximum number of possible edges (i.e., a single compact patch). A class is completely disaggregated if its pixels share no edges (AI = 0) (McGarigal 1994).

4. Results

Forest disturbance rates in the study area were overall relatively moderate, but differed strongly among landownership types and time periods. During the last years of socialism, annual forest disturbance rates inside protected areas and State Forests were relatively similar (0.07%). Yet, disturbance rates were higher by a factor of five in privately owned forests (Figure 2). This situation did not change considerably in the early transition years (period 1988–1994). Annual disturbance rates in the National Park remained stable, but increased slightly in State Forests and in privately owned forests (Figure 2). In the second half of the 1990s (1994–2000), however, annual forest disturbance rates in private forests dropped considerably and approached the level of disturbance in State Forests and the National Park (Figure 2). All three landownership types showed a similar overall pattern

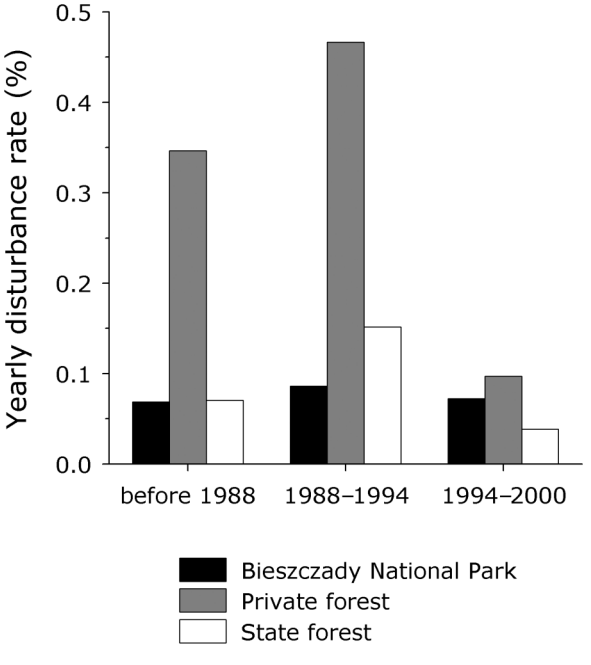

Figure 2. Forest disturbance rates per forest landownership type and for the time periods before 1988, 1988–1994, and 1994–2000 (forest disturbance rates before 1988 were calculated using a 6-year interval for better comparison).

Table 1. Differences in the spatial pattern of the four classes mapped from the multitemporal satellite images ('unchanged forest', 'forest disturbances before 1988', 'forest disturbances in 1988–1994', and 'forest disturbances in 1994–2000') among the three forest ownership types analysed (forest within the Bieszczady National Park, privately owned forests, and state-owned forests).

	Forest ownership type	Number of patches	Patch density	Mean patch size (ha)	Standard deviation of patch size	Aggregation index
Unchanged forest	National Park	188	0.21	132.52	1782.81	97.69
	Private	8213	1.01	5.66	28.98	80.00
	State	1043	0.14	178.50	3547.13	97.02
Disturbance before 1988	National Park	106	0.12	1.03	2.71	61.88
	Private	643	0.08	0.44	0.91	47.83
	State	795	0.11	0.57	0.98	50.97
Disturbance 1988–1994	National Park	151	0.17	0.87	2.42	57.02
	Private	2417	0.30	0.59	0.67	47.34
	State	2619	0.36	0.69	1.24	50.67
Disturbance 1994–2000	National Park	163	0.18	0.64	1.01	52.46
	Private	2210	0.27	0.43	0.60	43.82
	State	2114	0.29	0.46	0.56	44.08

when comparing disturbance rates over time (i.e., an increase in disturbance rates in the early 1990s followed by decreasing disturbance rates in the late 1990s).

Forestlands were not distributed equally among landownership types in the study region. While 96% (183,700 ha) of all land managed by the state was forested, forest cover was 86% (25,000 ha) inside Bieszczady National Park, and only 20% (42,800 ha) on privately owned land. Private forests accounted for only 17% of the total forestland found in the study area (10 and 73% of forests were inside the National Park and State Forests, respectively).

We also found marked differences in the spatial pattern of unchanged and disturbed forests among landownership types (Table 1). Most notably, the mean patch size of unchanged forest was much smaller for private forests (5.66 ha) compared with State Forests and the Bieszczady National Park (178.50 and 132.52 ha, respectively). Although the area covered by private forests was much smaller than in the other two landownership types, forest patches in this ownership type were much more numerous than forest patches inside the State Forests and the National Park, and patch density was much higher (Table 1). The mean size of disturbances was similar between private forests and State Forests at all time periods (between 0.46 and 0.69 ha), but higher in Bieszczady National Park (up to 1 ha). There were also many more disturbed patches in private forests and State Forests after the system change compared to before 1988. Unchanged forest patches were clustered in State Forests and in the National Park (AI $>$ 97), but dispersed in private forests (AI = 80). Disturbances occurred relatively disaggregated, and the level of aggregation did not differ substantially among landownership types and time periods (Table 1).

5. Discussion

Prior research had shown that rates of land cover change, and especially forest harvesting, can increase substantially during politically unstable times, when a society shifts from one type of

government to another, and major changes in socio-economic conditions occur (Peterson and Aunap 1998; Achard *et al*. 2006; Kuemmerle *et al*. 2007). Here, we show that increases in forest harvesting differed markedly among landownership types, and that privately held forests exhibited much higher disturbance rates than State Forests and a National Park in our study area. While this general trend may not be surprising, the magnitude of the difference was certainly surprising to us. It is important to remember, though, that Polish society went through profound societal changes in the early 1990s. Governmental control of economic activities was drastically reduced, and newly gained access to Western markets increased private consumption and the need for cash. As a result, the actual ownership of forests did not change, but management activities in these forests certainly did.

Concurrently, the legal framework for forest management changed. In 1991, the new forest legal act (Forest Act, *Ustawa o lasach*) was passed, and it became effective in 1992. This legal act largely removed the control of State Foresters over private forests, especially in respect to the amount of timber harvested. In the years following 1991, this legal change resulted in unsustainable clear-cutting in private forests across Poland. Interestingly, the legal framework changed again in the mid-1990s, possibly in response to excessive clear-cutting in private forests. In 1994, a new regulation was added to the general legal codification system that punished harvesting timber in private forests without valid permission or in the absence of a valid management plan. And in 1997, it became obligatory to obtain a timber certification in private forests prior to harvesting.

Another surprise in our results was the relatively high disturbance rate in private forests prior to 1988. No major changes in the forest legal code or timber prices occurred during this period. However, we speculate that there may have been already a weakening of governmental institutions during these final years of the Socialist rule in Poland. And our analysis of forest fragmentation showed surprisingly large differences in the forest patch size between privately and publicly owned forests, and a marked increase in the number of disturbance patches during the transition time. Forest fragmentation has major ecological implications (Andren 1994; Wade, Riitters, Wickham, and Jones 2003; Jha *et al*. 2005; see also Kuemmerle *et al*. 2007), and changes in landscape patterns may have amplified the environmental impact of the observed disturbance rates.

When interpreting our results, it is important to remember, though, that our satellite image-based change detection could only detect clear-cuts and not selective logging. The State Forests conduct a substantial proportion of their harvests as selective cuts. The disturbance rates we detected cannot be equated with the total forest area harvested or the total volume removed. Similarly, it is important to note that while large-scale natural disturbances are very rare, they do occur occasionally and not all detected forest disturbances are necessarily because of harvesting. The higher mean patch size and standard deviation of patch size of disturbances in Bieszczady National Park is likely the result of a few insect infestations. Mean patch size of disturbances on private and State Forests were remarkably similar between the two ownership types and peaked for both during the transition time.

While Polish State Forests are overall very well managed, we also note that forest harvesting in State Forests during the transition time from 1988 to 1994 may not always have been conducted by state foresters themselves. Timber thefts and illegal logging have been reported elsewhere in the Carpathians (Nijnik and Van Kooten 2000; Bouriaud 2005), and may have occurred in our study area as well. And the lack of governmental oversight in regards to forest harvesting on private forests may have made it possible for some private forest owners to claim that timber was removed on their own land, while harvesting it on public land. We cannot assess the extent to which this may have happened, but note that

differences in forest harvesting rates among landownership types may have been even stronger if timber thefts from public land did not occur.

Other studies that examined the effects of land tenure on forest disturbance rates have found diverging results. In some studies, private ownership protected forests better from overuse (Banana and Gombya-Ssembajjwe 2000; Nagendra 2007; Sikor and Thanh 2007) and this confirms economic theory (Tucker 1999). However, others found similar evidence as we did, i.e., public ownership protected forests better from overuse and illegal timber harvesting (Gibson and Becker 2001; WWF 2003; Bouriaud 2005). Ultimately, land tenure may not be the key issue, and no ownership regime is clearly better in protecting forest from unsustainable use (Tucker and Ostrom 2005).

Our results suggest that the strength of institutions and the *de facto* rules of forest use are at least as important as the tenure regime itself in determining forest disturbance rates (Tucker and Ostrom 2005; Tucker *et al*. 2007). And economic and societal change that weakens institutions causes elevated forest disturbances on all ownership types. Previous studies had already reported that changes in property rights can trigger unsustainable use (Deacon 1999; Mena *et al*. 2006) and this appears to have occurred in other parts of Eastern Europe too (Turnock 2002; Strimbu, Hickey, and Strimbu 2005). But while forest ownership remained stable in our study region, our results show that forest disturbance rates nevertheless increased substantially during the early transition period when institutions were weak, and forest management policies were unclear and inadequately enforced (Bouriaud 2005). This suggests that governance is more important than may have previously been appreciated.

Generally speaking, the spatio-temporal patterns of forest harvesting that we observed provided strong evidence for hierarchical and multi-scale controls affecting land cover change. At the broad scale (e.g., national scale), political structures, legal frameworks, and general socio-economic conditions exerted a strong influence over land cover change as indicated by the spike in forest harvesting rates on all land ownership types in the period from 1988 to 1994. However, at the local scale, these general conditions were mediated by land ownership, as evidenced by the strong differences in harvesting rates between private and public ownerships. The relative importance of broad-scale and local conditions on forest harvesting rates appeared to be similar, because differences in harvesting rates among time periods were in the same order than differences in harvesting rates among ownership types. Future studies aiming to understand land cover change thus may benefit from a multi-scale approach and a focus on times of social, economical, and political change.

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