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The effect of protected areas on forest disturbance in the Carpathian Mountains 1985–2010

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Abstract: *Protected areas are a cornerstone for forest protection, but they are not always effective during times of socioeconomic and institutional crises. The Carpathian Mountains in Eastern Europe are an ecologically outstanding region, with widespread seminatural and old-growth forest. Since 1990, Carpathian countries (Czech Republic, Hungary, Poland, Romania, Slovakia, and Ukraine) have experienced economic hardship and institutional changes, including the breakdown of socialism, European Union accession, and a rapid expansion of protected areas. The question is how protected-area effectiveness has varied during these times across the Carpathians given these changes. We analyzed a satellite-based data set of forest disturbance (i.e., forest loss due to harvesting or natural disturbances) from 1985 to 2010 and used matching statistics and a fixed-effects estimator to quantify the effect of protection on forest disturbance. Protected areas in the Czech Republic, Slovakia, and the Ukraine had significantly less deforestation inside protected areas than outside in some periods; the likelihood of disturbance was reduced by 1–5%. The effectiveness of protection increased over time in these countries, whereas the opposite was true in Romania. Older protected areas were most effective in Romania and Hungary, but newer protected areas were more effective in Czech Republic, and Poland. Strict protection (International Union for Conservation of Nature [IUCN] protection category Ia-II) was not more effective than landscape-level protection (IUCN III-VI). We suggest that the strength of institutions, the differences in forest privatization, forest management, prior distribution of protected areas, and when countries joined the European Union may provide explanations for the strikingly heterogeneous effectiveness patterns among countries. Our results highlight how different the effects of protected areas can be at broad scales, indicating that the effectiveness of protected areas is transitory over time and space and suggesting that generalizations about the effectiveness of protected areas can be misleading.*

Keywords: effectiveness, Eastern Europe, EU enlargement, matching statistics, postsocialist transition

Efectos de las Áreas Protegidas sobre la Perturbación de los Bosques en las Montañas de los Cárpatos 1985 – 2010

Resumen: *Las áreas protegidas son una piedra angular para la protección de los bosques, pero no son siempre efectivas durante los momentos de crisis socioeconómica e institucional. Las montañas de los Cárpatos en Europa Oriental son una región sobresaliente ecológicamente, con bosques semi-naturales extensos y bosques de viejo crecimiento. Desde 1990, los países de los Cárpatos (República Checa, Hungría, Polonia, Rumania, Eslovaquia y Ucrania) han experimentado dificultades económicas y cambios institucionales,*

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incluyendo la caída del socialismo, el ascenso de la Unión Europea y una rápida expansión de las áreas protegidas. La pregunta es cómo ha variado la efectividad de las áreas protegidas durante estos momentos a través de los Cárpatos dados estos cambios. Analizamos un conjunto de datos satelitales sobre la perturbación del bosque (es decir, la pérdida de bosque a causa de la cosecha o las perturbaciones naturales) desde 1985 a 2010 y utilizamos estadística correspondiente y un estimador de efectos fijados para cuantificar el efecto de la protección sobre la perturbación del bosque. Las áreas protegidas en la República Checa, Eslovaquia y Ucrania significativamente tuvieron menor deforestación dentro que afuera; la probabilidad de perturbación fue reducida en un 1 – 5 %. La efectividad de la protección incrementó con el tiempo en estos países, mientras que lo contrario fue cierto para Rumania. Las áreas protegidas más viejas fueron más efectivas en Rumania y Hungría, pero las más nuevas fueron más efectivas en la República Checa y Polonia. La protección estricta (categoría Ia-II de la Unión Internacional para la Conservación de la Naturaleza [UICN]) no fue más efectiva que la protección a nivel de paisaje (IUCN III-IV). Sugerimos que la fuerza de las instituciones, las diferencias en la privatización de los bosques, el manejo de los bosques, la perturbación previa de las áreas protegidas y cuando los países se unen a la Unión Europea pueden proporcionar explicaciones para los patrones impresionantemente heterogéneos de efectividad entre los países. Nuestros resultados resaltan cómo pueden ser los diferentes efectos de las áreas protegidas a escalas generales, indicando que la efectividad de las áreas protegidas es transitoria a lo largo del tiempo y el espacio, y sugiriendo que las generalizaciones sobre la efectividad de las áreas protegidas pueden ser engañosas.

Palabras Clave: ampliación de la UE, efectividad, estadística correspondiente, Europa Oriental, transición pos-socialista

Introduction

Worldwide, forested ecosystems provide forest products, open space for recreation, and livelihoods for millions and sequester carbon and harbor biodiversity (Foley et al. 2005; Bonan 2008). However, forests across the globe have been lost rapidly in recent decades (Ellis et al. 2013; Hansen et al. 2013), mainly due to the expansion of agriculture and intensive logging (Laurance et al. 2014; Levers et al. 2014). As a result, intact forest landscapes and older forest, which are higher in biodiversity and carbon than early-successional forests (Gibson et al. 2011), are increasingly scarce, even in regions where net forest cover has increased (Potapov et al. 2008; Brandt et al. 2015). Given the importance of forests to human well-being, understanding what policies can protect forests is essential.

Protected areas are a key policy to safeguard forests (Joppa et al. 2008). Although the global protected-area network has expanded substantially over the last decades, typically only a small fraction of a biome is formally protected (Butchart et al. 2015). Equally important, many protected areas are not effective (Mascia & Pailler 2011), particularly in areas with weak institutions (Geldmann et al. 2014). The use of protected areas as a conservation tool has been criticized as being inefficient because protected areas are often established in unthreatened areas (Joppa & Pfaff 2009) and metrics of effectiveness may be imperfect (Parrish et al. 2003). The management of protected areas is crucial for their success (Armsworth et al. 2011); thus, understanding where and under what institutional conditions protected areas are effective is a key research priority (Andam et al. 2008; Hill et al. 2015).

The Carpathian Mountains in Eastern Europe offer a fascinating case to investigate the effectiveness of protected areas. This region is of exceptional importance for conservation because it contains Europe's largest remaining temperate seminatural and old-growth forests, numerous endemic and endangered species, and viable populations of wolf (*Canis lupus*), lynx (*Lynx lynx*), bear (*Ursus arctos*), and European bison (*Bison bonasus*) (Turnock 2002; Kuemmerle et al. 2011*b*) and important ecosystem services (Kuemmerle et al. 2011*a*).

From an institutional and socioeconomic perspective, great change occurred in the Carpathians in the 20th and 21st centuries (Kozak et al. 2007*b*; Mickiewicz 2010). After an initial phase of population growth, agricultural expansion, and deforestation, forest cover has rebounded since the early 20th century (Kozak et al. 2007*a*; Munteanu et al. 2014, 2015). After World War II, all Carpathian countries (i.e., Czech Republic, Hungary, Poland, Slovakia, Romania, and Ukraine) became part of the Soviet bloc, and forests were generally exploited heavily and managed, and largely also owned, by the state (Turnock 2002; Sikor et al. 2009). This changed after the breakdown of socialism around 1990, when harvesting decreased, at least initially, and some countries restituted forestland to pre-World-War-II owners (Griffiths et al. 2012). At the same time, the transition from command-and-control to market-oriented economies also entailed institutional reorganization, generally lower levels of control, and economic hardship, resulting in illegal logging (Kuemmerle et al. 2009*a*; Knorn et al. 2012).

After the collapse of socialism, the network of protected areas in the Carpathians expanded rapidly (IUCN & UNEP 2014), in part because joining the European Union (all countries in our study except Ukraine) required an increase in the total area protected (European Commision 2013). What is unclear though is how effective old and newly established protected areas were at reducing loss of forest cover in the Carpathians. Previous research on individual protected areas suggests mixed effectiveness of protected areas in the Carpathians after 1990. Effectiveness is higher in southeastern Poland than in protected areas in the Ukrainian Carpathians and Romania (Kuemmerle et al. 2009*a*; Knorn et al. 2012).

Recent advances in availability and analysis of satellite imagery has resulted in consistent, high-resolution maps of forest disturbance (i.e., loss of the majority of the tree canopy due to harvesting or natural disturbances) across the Carpathians between 1985 and 2010 in 5-year intervals (Griffiths et al. 2014). We analyzed this data set, protected area boundaries, and socioeconomic and biophysical variables by matching protected with control pixels for 1985 and parameterizing fixed-effects regressions to assess whether protected areas across the Carpathian Mountains effectively reduced forest disturbance from 1985 to 2010; whether protected areas established before the breakdown of socialism (i.e., pre-1990) were more effective than those established thereafter (1990–2010); and whether protected areas with higher protection status (International Union for Conservation of Nature [IUCN] Ia, Ib, II) were more effective than less strictly protected areas (IUCN III-VI).

Methods

Study Area

Our 390,000 km^2 study region included the Carpathian Ecoregion and adjacent administrative regions (nomenclature of territorial units for statistics [NUTS] level 3 regions in the EU and oblasts in Ukraine) (Supporting Information). The Carpathian Ecoregion is a temperate mountain ecosystems with mean elevations of 850 m a.s.l. (peaks >2500 m, valleys around 400 m). Forests cover approximately 33% of the study region.

Forest cover varies among countries (Table 1), from 17.2% in Hungary to 43.2% in Slovakia (Griffiths et al. 2014). Forest cover in the Carpathian region changed in the early 20th century (Munteanu et al. 2014). Since World War II, forest area increased and continued to rise after the collapse of socialism, largely due to natural succession on abandoned agricultural fields (Griffiths et al. 2014; Munteanu et al. 2014) and increases in forest plantations outside historic forest ranges (Munteanu et al. 2015). Despite the increase in forest cover, over 20% of the region's forests were subjected to stand-replacing disturbances (i.e., logging or natural disturbances) from 1985 to 2010 (Griffiths et al. 2014). Disturbance trends were similar among countries. The rates of disturbance were highest in the latter years of socialism, were lower in the 1990s, and increased since then. For all countries except Slovakia, disturbance rates were lower inside protected areas than outside protected areas. In some countries, disturbance rates were higher in protected areas established before 1990, whereas the opposite was true in other cases (Table 2).

Protected areas in the Carpathians encompassed over 42,000 km^2 in 2010, approximately 10% of the study area, up from 6.8% in 1990. Slovakia had the highest percentage of protected at 21.2% in 2010. In the Romanian part of our study region, in contrast, 5.3% were protected then. All countries increased their area protected since 1985. In total, we assessed 1,315 protected areas, 718 of which were established before 1990, in the 6 countries. Protected-area delineations, establishment date, and protection status (IUCN I-VI) were obtained from the World Database of Protected Areas (IUCN & UNEP 2014).

Our forest-disturbance maps were previously derived from more than 5000 30-m resolution Landsat TM/ETM+ satellite images compiled into 5-year time steps from 1985 to 2010 (Griffiths et al. 2014). The disturbance map captures stand-replacing disturbances due to natural disturbances (e.g., wind throws, snow breaks, or insect outbreaks, typically followed by salvage logging) or forest harvesting, which represented the vast majority of the disturbances, and has 85% accuracy (Griffiths et al. 2014). We also analyzed a forest-type map by Griffith et al. (2014) to capture deciduous, mixed, and coniferous forests for 1985 and 2010 (Supporting Information). We considered several political, demographic, environmental, and accessibility variables to control for factors other than protected-area status that may affect forest disturbance (Table 3).

Statistical Analyses

To determine the effect of protected status on forest disturbance rates, we combined matching statistics with fixed-effects linear probability models (Wendland et al. 2011; Arriagada et al. 2012). Estimates of protected-area effectiveness can be biased by both observable covariates, which may differ between protected and unprotected areas (Andam et al. 2008), and unobserved variables, which may be correlated with both protection and disturbance (Arriagada et al. 2012). Our combination of matching and fixed-effects models controlled for both sources of potential bias (Ho et al. 2006), although bias may still exist in estimates if unobservable differences co-vary with treatment status over time.

To tackle potential bias due to differences in observable covariates, we used nearest neighbor matching without replacement and a caliper size of a quarter of the standard deviation of the estimated propensity score (0.2) (Guo & Fraser 2010). We matched observations using the following variables: slope, elevation, distance to nearest major road, distance to nearest railroad, distance to nearest town over 50,000 people, distance to nearest river,

Table 1. Summary statistics on forested areas and protected areas* across the Carpathian Mountains from 1985–2010.

	1985	*1990*	*1995*	*2000*	*2005*	*2010*
Czech Republic						
percent forest	34	29	30	32	32	32
percent protected area	13	13	10	15	15	15
number of protected areas in study area	67	108	111	148	156	163
number of protected areas > 50 points	9	11	14	14	14	14
percent protected in large protected areas	96	94	94	93	93	92
percent in strictly protected areas	1	1	3	3	3	3
Hungary						
percent forest	18	17	17	17	17	17
percent protected area	7	8	8	8	8	8
number of protected areas in study area	29	35	35	35	37	37
number of protected areas > 50 points	15	19	19	19	21	21
percent protected in large protected areas	98	98	98	98	98	98
percent in strictly protected areas	44	41	41	41	41	41
Poland						
percent forest	34	31	30	33	33	32
percent protected area	3	6	10	17	17	17
number of protected areas in study area	39	50	68	96	106	108
number of protected areas > 50 points	12	15	28	36	36	36
percent protected in large protected areas	97	97	99	98	98	98
percent in strictly protected areas	44	25	10	8	8	8
Romania						
percent forest	37	35	36	35	35	35
percent protected area	3	4	4	4	8	8
number of protected areas in study area	146	157	202	256	303	304
number of protected areas > 50 points	30	35	44	49	78	79
percent protected in large protected areas	92	94	93	91	95	95
percent in strictly protected areas	53	48	48	48	39	39
Slovakia						
percent forest	45	42	43	44	43	42
percent protected area	16	20	20	22	25	25
number of protected areas in study area	186	220	269	291	302	306
number of protected areas > 50 points	23	32	45	50	54	55
percent protected in large protected areas	94	95	94	94	95	95
percent in strictly protected areas	22	22	25	28	34	32
Ukraine						
percent forest	39	36	36	37	37	37
percent protected area	4	5	7	8	8	8
number of protected areas in study area	258	272	380	411	413	413
number of protected areas > 50 points	28	29	37	44	45	45
percent protected in large protected areas	72	76	74	77	77	77
percent in strictly protected areas	22	31	28	28	28	23

Large protected areas, areas with over 50 sampling points; protected area, all protected areas with International Union for Conservation of Nature (IUCN) categories Ia-VI; strictly protected areas, protected areas with IUCN categories Ia, Ib, and II only.

distance of forested pixels to the closest forest edge, forest type, and the estimated population within 50 km. We used the command PSMATCH2 in STATA to complete the matching and PSTEST to evaluate the balance of the matches (Supporting Information).

We used this matching procedure to create three data sets. One data set matched pixels from protected and unprotected areas. The second data set matched pixels from protected areas established before 1990 with protected areas established after 1990, and the third data set matched pixels from strict protected areas with pixels from landscape-level protected areas. We only matched pixels in the first period, 1985, in order to track similar pixels over multiple periods. For example, in the protected versus unprotected data set, if a pixel was unprotected in 1985 but became protected before 2010, it was matched with an unprotected pixel in 1985. We allowed pixels in different countries to be matches so that we could compare the impact of protection within and among countries.

To address a second source of potential bias, namely unobservable static variables (Cameron & Trivedi 2005), we used a fixed-effects panel regression and determined forest disturbance every 5 years from 1985 to 2010 (for equations see Supporting Information). We chose the linear probability model over panel logit or probit

Table 2. Percentage of forest pixels disturbed in each 5-year increment in an entire country (total), unprotected areas, protected areas, protected areas established before 1990, and protected areas established after 1990.

Country	*Period*	*Total*	*Unprotected*	*Protected*	*Before 1990*	*After 1990*
Czech Republic	1985–1990	16.818	17.894	14.286	14.728	10.938
	1990–1995	0.320	0.312	0.339	0.383	0.000
	1995–2000	4.540	5.070	3.297	3.413	2.404
	2000–2005	5.509	5.986	4.384	4.579	2.885
	2005–2010	6.280	7.155	4.235	4.537	1.923
Hungary	1985-1990	7.554	8.658	3.625	3.589	4.000
	1990–1995	0.299	0.382	0.000	0.000	0.000
	1995–2000	3.010	3.488	1.269	1.351	4.000
	2000–2005	3.848	4.382	1.915	1.978	4.167
	2005–2010	2.943	3.310	1.596	1.232	13.636
Poland	1985-1990	9.962	11.977	6.420	5.771	6.756
	1990–1995	1.035	1.183	0.769	0.935	0.684
	1995–2000	2.355	2.514	2.063	2.646	1.769
	2000–2005	3.336	3.977	2.175	1.994	2.268
	2005–2010	4.993	4.745	5.451	5.929	5.212
Romania	1985-1990	5.043	4.796	6.412	2.692	8.583
	1990–1995	0.244	0.244	0.249	0.160	0.300
	1995–2000	4.979	4.982	4.965	3.979	5.526
	2000–2005	2.378	2.295	2.834	1.465	3.613
	2005–2010	3.429	3.343	3.902	2.327	4.801
Slovakia	1985–1990	6.534	7.057	5.817	6.122	4.817
	1990–1995	0.300	0.254	0.364	0.334	0.469
	1995–2000	2.643	2.553	2.766	2.804	2.683
	2000–2005	4.695	3.855	5.882	6.101	5.241
	2005–2010	4.337	4.122	4.643	5.142	3.058
Ukraine	1985–1990	9.047	9.436	7.373	8.942	5.964
	1990–1995	0.373	0.400	0.257	0.374	0.171
	1995–2000	3.362	3.683	1.987	2.186	1.427
	2000–2005	3.919	4.079	3.230	3.659	2.780
	2005–2010	3.271	3.501	2.278	2.988	1.523

specifications due to difficulty of integrating these methods into fixed-effects specifications (Wooldridge 2011). We estimated three separate-fixed effects regressions: one on the protected versus unprotected data set, one on the pre-1990 versus post-1990 data set, and one on the strict versus landscape data set. Models were estimated using the XTREG with the FE option in STATA. If a protected area was created within a panel, it was coded as being present for the full panel. For example, if a pixel is in a protected area that was created in 1993, it would be coded as unprotected in 1985, unprotected in 1990, and protected in 1995, 2000, 2005, and 2010.

Using this two-step technique, we tested the effects of protected areas in general and determined whether the timing of protection (i.e., before or after 1990) and the type of protected area (i.e., IUCN categories Ia-II vs. III-VI) affected forest disturbance for each five-year period in each country. Because the model included interaction terms to tease out the country- and time-specific effects, it was not easy to interpret model coefficients. To address this, we estimated the marginal effects of protection, timing of protected-area establishment, and protected-area type, and calculated standard errors with the delta method (Baum 2010). These marginal effects represented the percentage point change in the likelihood a pixel is disturbed in a given country in a given year and were calculated using the MARGINS command in STATA.

Our data set contained 102,446 forested pixels and was a random sample with a minimum distance of 0.5 km among samples to control for potential spatial autocorrelation. Of the 102,446 pixels, 12,132 were protected in 1985 and 22,720 were protected by 2010. To ensure that we analyzed only protected areas with a mission to at least partially protect forest, we included only protected areas with at least 50 forested observations in 1985, which eliminated many small protected areas (Table 1). As a robustness check, we applied the model to all protected areas, including small ones, and found qualitatively similar results.

Results

Heterogeneity Across Space and Time

Overall, effects of protected areas on forest disturbance in the Carpathians were heterogeneous over space and time (Fig. 1). For example, in the Czech Republic, the impact of protected areas changed over time. In 1990

Table 3. Description of variables used in the statistical modeling of protected area effectiveness in the Carpathians.

Variable	*Variable description*	*Data source*	*Unit of measure*	*Spatial grain*
Protected area	protected areas delineation	EEA 2013; IUCN & UNEP 2014	m	vector
	IUCN level of protection	EEA 2013; IUCN & UNEP 2014	6 levels	vector
	year area was declared protected	EEA 2013; IUCN & UNEP 2014	years	vector
Forest cover	forest cover 1985, 1990, 1995, 2000, 2005, 2010	Griffiths et al. 2014	yes or no	30 m
	forest types 1985, 2010	Griffiths et al. 2014	coniferous, mixed, deciduous	30 m
	distance to forest edge in 1985, 1990, 1995, 2000, 2005, 2010	Griffiths et al. 2014	m	30 m
Geo-political	administrative boundaries (NUTS0 and NUTS3[a])	ESRI 2008	km	vector
Sociodemographic	population count 1990, 1995, 2000, 2005, 2010 in a 10-km and 50-km radius around sample point	CIESIN et al. 2005	no. of people	~5 km
	percent privately owned forest		percent	NUTS3*
Environmental				
	elevation	Farr et al. 2007	m	90 m
	slope	Farr et al. 2007	m	90 m
Accessibility				
	distance to nearest settlement	EEA 2013	m	vector
	distance to nearest road	CIESIN & ITOS 2013	m	vector
	distance to nearest railroad	ESRI 2008	m	vector
	distance to nearest main river	Vogt et al. 2007	m	vector

**Nomenclature of territorial units for statistics.*

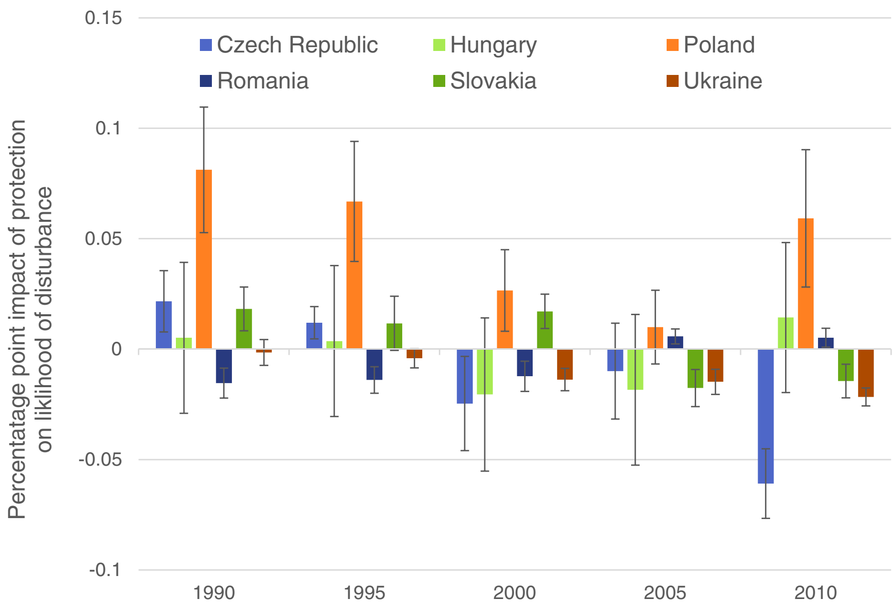

Figure 1. The marginal effects by country and year of forest protection on the likelihood a forest pixel will be disturbed (vertical lines, SE calculated using the delta method).

and 1995, protection did not have a statistical effect on the likelihood of disturbance, whereas in 2000, 2005, and 2010, protection decreased the likelihood of disturbance. Similarly, the effect of protected areas was to decrease forest disturbance, and the size of this effect increased over time. Protection in Ukraine decreased the likelihood of disturbance throughout our study period and in the time periods 1995–2000, 2000- 2005, and 2005–2010; this difference was statistically significant (Fig. 2).

However, a different pattern emerged in the other three countries. In Hungary, the effects of protected areas were not significantly different from zero in any period (Fig. 1). In Romania, protected areas decreased disturbance relative to unprotected areas in 1985–1990

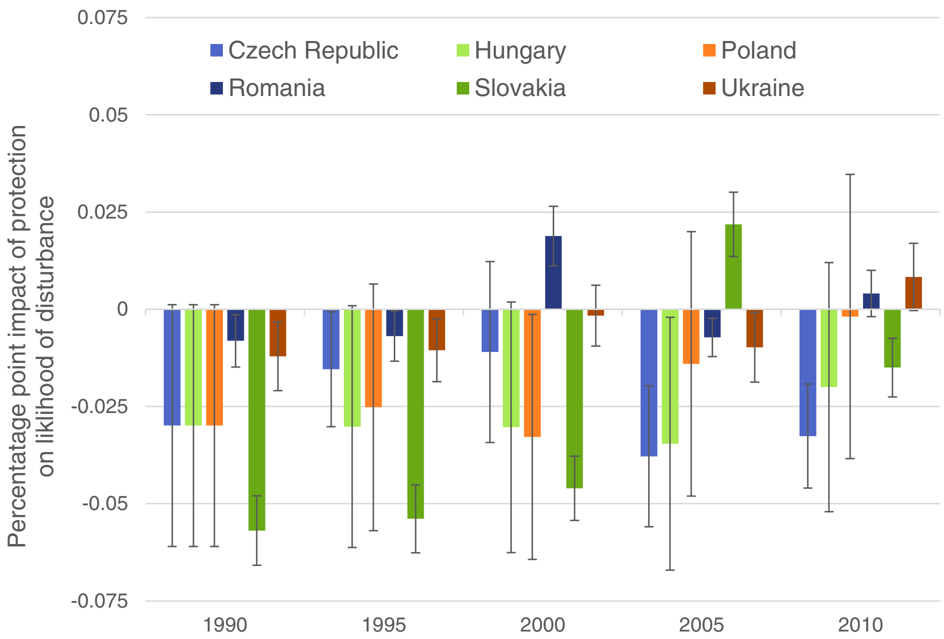

Figure 2. The marginal effects by country and year of International Union for Conservation of Nature (IUCN) categories Ia-II status relative to IUCN categories III-VI on likelihood a parcel will be disturbed (vertical lines, SE calculated using the delta method).

and 1990–1995, but after 2000 there was no statistically significant impact of protected areas. The likelihood of disturbance inside relative to outside protected areas also increased markedly after 2000. Finally, in Poland the effect of protection was to increase forest disturbance; effects were statistically significant in 1985–1990, 1990–1995, and 2005–2010 (Fig. 1).

Age of Protected Areas

Whether a protected area was established before 1990 was sometimes an important indicator of its impact on forest disturbance rates, but as with protection overall, the effects of the timing of protected-area establishment were heterogeneous (Table 4). In the Czech Republic, Poland, and Slovakia, protected areas established before 1990 were significantly less effective in some periods than protected areas established after 1990. In Hungary and Romania, the opposite was true. Protected areas that were established there before 1990 were more effective in curbing forest disturbance, at least in some periods, than protected areas established after 1990 (Table 4). In Ukraine, the impact of the time of protected-area establishment was not statistically significant (Table 4).

Protection Status

The effects of protected-area status, as given by the IUCN category, on forest disturbance were also heterogeneous, but strict protection did not have a stronger impact on curbing forest loss than landscape protection, and the latter sometimes even led to lower levels of forest loss than strict protection (Fig. 2). The impact of strict protection also changed over time. In Poland and Slovakia, strict protection increased forest disturbance relative to landscape protection in most time periods. For Ukraine, Czech Republic, Hungary, and Romania, protected-area category did not significantly affect forest disturbance rates inside protected areas at any time (Fig. 2).

Discussion

Whether or not protected areas remain effective in terms of curbing forest disturbance during times of socioeconomic and institutional overhaul is not well understood. We investigated the effects of protected areas on curbing forest disturbance across the Carpathians from 1985 to 2010. The impact of protection on prevention of forest disturbance was overall fairly small, and protected-area effectiveness differed greatly among countries and periods. Our results are thus in line with regional and global studies showing that protected-area impact varies across space and time (Joppa & Pfaff 2011; Haruna et al. 2014). Most notably, we found that protected-area effectiveness varied greatly in areas with similar socioeconomic and institutional shocks (i.e., collapse of the Soviet Union, expansion of the EU).

The timing of protected area establishment had little bearing on the effectiveness of protection, but in countries with a relatively slow transitions to or no market economies, old protected areas were more effective than new protected areas. We also found that, similar to tropical areas (Nelson & Chomitz 2011; Pfaff et al. 2014), strictly protected areas were not necessarily more effective at preventing forest loss. In sum, our results are consistent with the existing literature that shows the heterogeneity of protection effectiveness across time, space

Table 4. Marginal impact* of a protected area being established before 1990 relative to being established after 1990.

	Czech Republic (pre-1990 n = 6240, post-1990 n = 780)				*Hungary (pre-1990 n = 1980, post-1990 n = 780)*			
Year	*impact*	*SE*	*Z*	*p>|z|*	*impact*	*SE*	*Z*	*p>|z|*
1995	0.016	0.008	2.000	0.045	−0.002	0.001	−1.940	0.052
2000	0.022	0.011	1.950	0.051	−0.004	0.010	−0.440	0.660
2005	0.019	0.012	1.660	0.097	−0.002	0.016	−0.160	0.873
2010	0.044	0.006	7.030	0.000	−0.038	0.020	−1.940	0.053
	Poland (pre-1990 *n* = 12,738, post-1990 *n* = 5,892)				Romania (pre-1990 *n* = 21,504, post-1990 *n* = 11,868)			
	impact	SE	*Z*	*p>|z|*	impact	SE	*Z*	*p>|z|*
1995	0.008	0.018	0.420	0.675	−0.001	0.003	−0.400	0.688
2000	0.022	0.011	1.950	0.051	−0.018	0.009	−1.900	0.058
2005	0.035	0.023	1.530	0.125	−0.033	0.008	−4.100	0.000
2010	−0.022	0.038	−0.570	0.565	−0.040	0.008	−4.820	0.000
	Slovakia (pre-1990 *n* = 8,580, post-1990 *n* = 18,564)				Ukraine (pre-1990 *n* = 4,998, post-1990 *n* = 4,836)			
	impact	SE	*Z*	*p>|z|*	impact	SE	*Z*	*p>|z|*
1995	0.010	0.010	1.060	0.289	0.001	0.004	0.380	0.706
2000	0.009	0.011	0.860	0.388	0.004	0.010	0.380	0.701
2005	0.035	0.010	3.360	0.001	−0.001	0.010	−0.070	0.947
2010	0.045	0.010	4.520	0.000	0.013	0.011	1.250	0.212

**Interpreted as the percent change in probability of forest harvest.*

(Joppa & Pfaff 2011; Pfaff et al. 2015), and protection levels (Nelson & Chomitz 2011; Pfaff et al. 2014). In addition to these factors, we found that the protected-area effectiveness was heterogeneous during times of socioeconomic and institutional overhaul. Collectively, our results thus caution against generalizing from individual cases and suggest that national forces (i.e., policies) and local conditions (e.g., attitudes, sociocultural setting) may be important drivers of protected-area effectiveness.

Heterogeneity Across Space and Time

We suggest the strength of institutions, the differences in forest privatization, forest management, and the timing of accession to the EU may provide explanations for the highly heterogeneous effectiveness patterns among countries. From a statistical point of view, we were not able to include such variables in our analysis because consistent subnational data do not exist for the Carpathians a whole. Yet, we connect broad-scale information to our results conceptually to present a more complete picture.

Following the collapse of socialism, levels of forest disturbance in the Carpathians were high (Griffiths et al. 2014), and our results show that effectiveness of forest protection was overall relatively low at this time. Funding for nature conservation declined in many Carpathian countries in the 1990s (Turnock 2002), as did levels of control (e.g., ranger patrols) and law enforcement. At the same time, economic hardship was substantial, leading to an increase in illegal logging (both for fuelwood and for export), sometimes inside protected areas (Kuemmerle et al. 2009*b*; Knorn et al. 2012). Finally, official harvests outside strictly protected areas plummeted after 1990, mostly due to diminishing timber markets and lack of machinery and fuel (Nijnik & Oskam 2004; Kuemmerle et al. 2009), which likely reduced the difference between protected and unprotected forests in terms of disturbance. To a large extend, forest loss in the whole region was low in the 1990s, so it may not be a surprise that the impact of protected areas was not great during this time.

A second set of factors that may explain the heterogeneous effectiveness of protected areas is the diversity of forest ownership regimes. In some countries, such as Romania and Hungary, forests were managed by the state during socialism but formally owned privately, and these countries underwent large-scale forest restitution after 1990 (Programme Carpathian 2008). In contrast, forests in Poland and Ukraine were owned by the state during socialism and thereafter. Our results suggest that forest restitution led to an increasing likelihood of disturbance inside protected areas, whereas stable ownership patterns resulted in fewer changes in protected-areas effectiveness over time (see Poland and Ukraine in Fig. 1). Romania restituted half of its forests after 2000, including inside protected areas (Abrudan 2012), where we found decreasing protected-area effectiveness (Fig. 1), likely due to some harvesting of restituted forests regardless of their protection status (Griffiths et al. 2012; Knorn et al. 2012). This was not a general pattern, however, which suggests that domestic factors, especially the level of law enforcement and corruption, may also be important causes for the divergence of protected-area effectiveness in countries with similar forest ownership and privatization strategies (Kuemmerle et al. 2009*b*).

Differences in forest management among countries, as well as legacies from past land use, are a third group of factors that may explain the heterogeneous outcomes we found. Selective harvesting is common in some countries, especially in deciduous forests (e.g., Romania and Poland), whereas clearcutting is more common in others (e.g., Ukraine, Slovakia, Czech Republic). Moreover, spruce plantations from the first half of the 20th century are widespread across the Carpathians (Munteanu et al. 2015) and prone to windthrows and insect infestation, after which salvage logging typically occurs both within and outside protected areas (Griffiths et al. 2012). Together these factors may explain some of the trends we found, for example in Poland, where the effectiveness of protection decreased (Fig. 1) during a time of widespread dieback of spruce monocultures due to pollution, including inside protected areas (Main-Knorn et al. 2009). Similarly, in Slovakia, a massive windthrow occurred in the Tatra Mountains in 2004, most of it inside the Tatra National Park (Falt'an et al. 2009), and it was reflected in our results as a decrease in effectiveness in this period (Fig. 1).

A fourth group of factors explaining heterogeneous effectiveness is the different timing of countries' accession to the European Union. The Czech Republic, Poland, Slovakia, and Hungary joined in 2004, Romania in 2007, and Ukraine not at all. As part of the accession policies, countries were required to increase their extent of protected area to meet EU targets (Jones-Walters & Čivić 2013), and they initiated this process several years prior to accession. Moreover, integration into EU markets fueled the adoption of sustainable forest management schemes and forest certification (Ioras et al. 2009). The timing of EU accession roughly coincides with protected areas becoming more effective in Slovakia and Czech Republic, cautiously suggesting that the EU policies may have been beneficial for forest conservation. However, in Romania, which joined later, we saw the opposite trend, possibly in relation to forest owners harvesting prior to tightening regulation (Knorn et al. 2012), and although one would expect increasing protected-area effectiveness after 2007, this period was not well captured by our data.

Age of Protected Areas

As with protection in general, the differences in effectiveness between newly established and older protected areas varied among countries. In Romania and Hungary, protected areas established before the collapse of socialism were more effective than those established thereafter, maybe because no forests in such pre-1990 protected areas were restituted in Romania (Ioras & Abrudan 2006). In contrast, in Poland, the Czech Republic, and Slovakia, newer protected areas were more effective (Fig. 2). The finding that new protected areas can be even more effective than older protected areas is encouraging in the light of the recent expansion of protected-area networks in the Carpathians after the EU accession of most countries, especially given that for many countries this process was far from being finalized in 2010, the last year of our assessment. However, in these countries newer protected areas were sometimes placed in areas that were more remote than older protected areas. Ultimately, our Carpathian-wide results remain surprising given that older protected areas should be institutionally and publically more accepted, which is why we expected lower levels of illegal logging, as has been found elsewhere in Eastern Europe (Wendland et al. 2011; Sieber et al. 2013).

Protection Status

Heterogeneity in effectiveness may also occur in terms of protection status (Nelson & Chomitz 2011; Carranza et al. 2014; Geldmann et al. 2014; Pfaff et al. 2014), for instance when multiple-use protected areas efficiently reduce natural disturbances such as forest fires (Nelson & Chomitz 2011). Our findings reveal that in the Carpathians strictly protected areas (IUCN Ia-II) were not more effective in curbing forest loss than less-protected areas (IUCN III-VI). This result was contrary to our expectation. One potential explanation may be natural disturbances (such as windthrows and dieback due to pollution), which affected forested areas irrespective of protection status. Most notably, the 2004 windthrow event in Tatra National Park may provide an explanation for the large differences between protection status in Slovakia in 2005 (Falt'an et al. 2009). The fact that these less strictly protected areas were equally efficient in protecting forests as strictly protected areas provides starting points for conservation policies that focus on maintaining and forging links between people and nature, thereby promising to be more effective in the long run than reactive conservation actions (Linnell et al. 2015).

Globally, what determines the effectiveness of protected areas in safeguarding forests remains unclear. We found that there can be high heterogeneity in effectiveness outcomes at a regional scale, potentially due to diverging economic pathways, different levels of control and illegal logging, different forest ownership regimes, and different land-use legacies affecting forest disturbance inside protected areas. While our study thus furthers understanding of the conditions under which protected areas succeed or fail, we emphasize the importance of location and community-specific conditions. Ultimately though, it is encouraging that protected-area managers across the Carpathians have found ways to actively protect forests, even during times of socioeconomic and institutional shocks and despite considerable challenges for conservation during the post-Soviet era.

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Supporting Information

Fixed-effects model specifications (Appendix S1), additional modeling results (Appendix S2), and a map of the study area (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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