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Research Paper

Effects of post-WWII forced displacements on long-term landscape dynamics in the Polish Carpathians

Andrzej N. Affek[a,b,*], Jacek Wolski[a], Maria Zachwatowicz[c], Krzysztof Ostafin[d], Volker C. Radeloff[b]

[a] *Institute of Geography and Spatial Organization, Polish Academy of Sciences, Twarda 51/55, 00-818 Warsaw, Poland*
[b] *SILVIS Lab, Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, 1630 Linden Drive, Madison, WI 53706, USA*
[c] *Faculty of Geography and Regional Studies, University of Warsaw, Krakowskie Przedmieście 30, 00-927 Warsaw, Poland*
[d] *Institute of Geography and Spatial Management, Jagiellonian University, Gronostajowa 7, 30-387 Cracow, Poland*

HIGHLIGHTS

- Post-WWII forced displacement caused major forest increase in Polish Carpathians.
- 115k of 181k (63%) of forest increase until 1970 due to displacement.
- Land-use regime switched from agricultural to forest-dominated stable state.
- Displacement caused more forest increase than post-socialist abandonment.
- Displacement areas now one of the largest wilderness areas in Central Europe.

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ABSTRACT

Armed conflicts and major political changes can result in the forced displacement of thousands of people and may have substantial effects on the environment. However, it is difficult to predict and mitigate long-term consequences of such displacements, especially when they trigger abrupt land-use changes that result in a regime shift of the land-use system. Our main goal was to determine the effects of post-WWII forced displacements on long-term landscape dynamics in the Polish Carpathians. After World War II, 630,000 Ukrainians were forcibly displaced from southeastern Poland, leading to permanent depopulation of mountain borderlands. We conducted a village-level analysis of forest area change across the Polish Carpathians (1685 villages/cadastral communities), and a detailed analyses of landscape change and land-cover trajectories in two highly depopulated test sites. Our source data were pre-war (1850s–1860s and 1930s) and post-war (1970s and 2010s) census data and topographic maps. We found a substantial forest area increase after displacements, far outpacing the widely reported forest increase due to the collapse of socialism in early 1990s, and a striking landscape simplification. Astonishingly, almost two thirds of the post-war (1930s–1970s) forest area increase in the entire Polish Carpathians (115,000 ha out of 181,000 ha) was due to the forced displacements. The land-use regimes shifted from being agriculturally-dominated to being forest-dominated, and approached a stable alternative state. As a result, a once densely populated rural region has become one of the largest 'wilderness' areas in Central Europe, with vast areas void of human settlements and resurgent wildlife populations. This highlights that forced displacements, which are common during and after armed conflicts, can have substantial and long-lasting effects on land use.

* Corresponding author at: Institute of Geography and Spatial Organization, Polish Academy of Sciences, Twarda 51/55, 00-818 Warsaw, Poland.
E-mail addresses: a.affek@twarda.pan.pl (A.N. Affek), j.wolski@twarda.pan.pl (J. Wolski), m.zachwatowicz@uw.edu.pl (M. Zachwatowicz), krzysztof.ostafin@uj.edu.pl (K. Ostafin), radeloff@wisc.edu (V.C. Radeloff).

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1. Introduction

About 41.3 million people worldwide were displaced as of 2019 due to conflicts and violence, with 10.8 million new displacements in 2018 only (IDMC, 2019). Displacement substantially affects the well-being and socio-cultural identity of people and their relation with land (Piskorski, 2011). Furthermore, displacements can alter land use patterns (Woube, 2005). There is strong evidence that environmental changes can cause human migrations (see e.g., Abel, Brottrager, Crespo Cuaresma, & Muttarak, 2019). Conversely, the permanent displacement of large populations can also have strong effects on the environment (Ghimire, 1994; Kim, 1997; Ssekandi, Mburu, Wasonga, Macopiyo, & Charles, 2017), both in the area where people settled, that is, the target region, and in the area they left (Gorsevski, Kasischke, Dempewolf, Loboda, & Grossmann, 2012).

Typically, displacements reduce pressures on the land left behind (e.g., Baumann, Radeloff, Avedian, & Kuemmerle, 2015; Witmer, 2008; Yin et al., 2019), but increase pressure in the area where people move. For example, displacement can cause deforestation for agricultural and settlement purposes (Ghimire, 1994; Hugo, 1996). The most common land-use effects in the place of origin are agricultural land abandonment (Baumann et al., 2015; Witmer, 2008; Yin et al., 2019), bush and forest regrowth (Landholm, Pradhan, & Kropp, 2019), and sometimes the complete cessation of any kind of human activity (Kim, 1997). There are cases though of land use intensification following displacements, particularly when armed groups use agriculture as an income source (Eklund, Degerald, Brandt, Prishchepov, & Pilesjö, 2017; Landholm et al., 2019) or civilians expand agriculture due to food insecurity (Alix-Garcia, Bartlett, & Saah, 2013). The exact post-displacement land-cover trajectories depend on both the magnitude of displacement and on subsequent population movements, both of which are determined by political and economic conditions (Baumann et al., 2015; Witmer, 2008; Yin et al., 2019). However, most of the studies that examine the effects of armed conflicts on land use do not explicitly address the effects of displacements but rather the overall effects of the conflicts, and most are focused on immediate effects. Less is known about displacements' long-lasting consequences, especially their environmental legacies and if the resulting land-use changes are reversible or not.

Displacements can be considered through the lens of systems theory as a trigger causing an abrupt change of the social-ecological system (Ramankutty & Coomes, 2016; Walker et al., 2006). Such an abrupt change may be reversible or not, depending on the strength of the self-reinforcing processes. If the abrupt change is irreversible, it results in a shift of the land-use regime and the establishment of an alternative stable state (Müller et al., 2014). However, achieving fully stable states in case of complex social-ecological systems is rare due to intrinsic stochasticity and the multimodal, open character of these systems (Ramankutty & Coomes, 2016; Walker et al., 2006). Irrespective of how stable the alternative states are, there is a need to understand both the potential risks and the consequences of regime shifts (Biggs, Peterson, & Rocha, 2018). Insight into system dynamics before and after forced displacements could help identify whether such displacement can trigger abrupt changes and shifts toward alternative stable states. More broadly, it could help recognize how vulnerable systems are to external triggers and link land-use regime shifts with land cover changes (Ramankutty & Coomes, 2016). Historical land-use regime shifts related to displacement may thus complement the existing Regime Shifts Database (Biggs et al., 2018) with abrupt systemic changes that are not yet represented there, thereby increasing the strength of meta-analyses of current and future land-use regime shifts.

Studying the effects of post-war displacements, and capturing past human-environment interactions, may shed new light on the possible land-use effects of present day forced displacement, and on the effects of other causes of migrations such as poverty, natural disasters, desertification, and climate change (MacDonald et al., 2000; Ssekandi et al., 2017). A powerful example of such a legacy is World War II because of its great magnitude, strong effects on land system, and widespread post-war displacements (Machlis & Hanson, 2008).

In Central and Eastern Europe millions of people were forcibly displaced after World War II (Rieber, 2000). These displacements were mostly caused by post-war border and political shifts, policies aimed to create ethnically homogenous nation-states, and – in the case of German communities – by the notion of their collective responsibility for Nazi war crimes (Eberhardt, 2011; Rieber, 2000). In many European regions, particularly in the rural and marginalized mountainous borderlands, forced displacements resulted in permanent depopulation, which greatly changed land use (Affek, Zachwatowicz, & Solon, 2020; Bičík & Štěpánek, 1994). The main change was forest expansion, both through natural succession and active planting (e.g., Kozak, Estreguil, & Troll, 2007; Wolski, 2007). However, forest area increases related to politically driven forced displacements overlapped spatially and temporally with the broader process of forest transition, i.e., the economically-driven reversal from decreasing to expanding forest areas (Mather, 1992), which in the Carpathian region began in the Interwar period (Kozak et al., 2007; Kozak, 2010; Munteanu et al., 2014). Furthermore, the long-term effects of post-WWII displacements are potentially confounded by widespread forest area increases due to land abandonment after the collapse of socialism in the early 1990s (Griffiths, Müller, Kuemmerle, & Hostert, 2013; Kuemmerle et al., 2008). Therefore, it is difficult to distinguish the effects of conflict-related forced displacements from other factors influencing land use (Baumann & Kuemmerle, 2016; Baumann et al., 2015), and necessary to assess not only the magnitude of reforestation, but also to identify potential changes in pathways and the speed of reforestation, in order to differentiate abrupt land-use changes from gradual changes (Ratajczak et al., 2018).

The main goal of our study was to determine the effects of forced displacement on land cover. Specifically, we examined the widespread post-WWII forced and permanent displacement of the Ukrainian population that had inhabited the Carpathians within the post-war Polish borders. Our main research questions were: what were the short- and long-term effects of displacements on (1) forest area, and (2) landscape composition. To answer these questions we formulated the following specific objectives:

1a. To determine village-level forest area change in the Polish Carpathians over two 40-year periods (1930s-1970s and 1970s-2010s);
1b. To quantify the independent effect of displacements on forest area change and determine the share and area of new forests caused by the displacements;
2. To determine landscape changes and trajectories of land-cover change in depopulated, post-Ukrainian villages.

2. Methods

2.1. Study area

Our study area was the Carpathians within the current borders of Poland, which we further limited for modeling purposes (i.e., to ensure data availability and consistency) to the borders of the former Austrian province of Galicia, and to whole villages according to their pre-WWII extent (in total 1685 villages covering 17,000 km^2, which corresponds to 85% of the Polish Carpathians) (Fig. 1). Displacements were concentrated in the south-eastern third of the study area, so that the north-western part of the Polish Carpathians, where no displacement took place, served as a control (Fig. 2A). The topography in the eastern part ranges from 240 to 1346 m above sea level, and in the western from 210 to 2499 m a.s.l. The potential natural vegetation is temperate forest, with spruce dominating above 1150 m a.s.l. (only in the western part), beech (*Fagus sylvatica*) and fir (*Abies alba*) from 600 to 1275 m a.s.l., and oak (*Quercus robur*) and hornbeam (*Carpinus betulus*) dominating in the lower parts. Only 0.6% of the study area is above timberline (Matuszkiewicz, 2008).

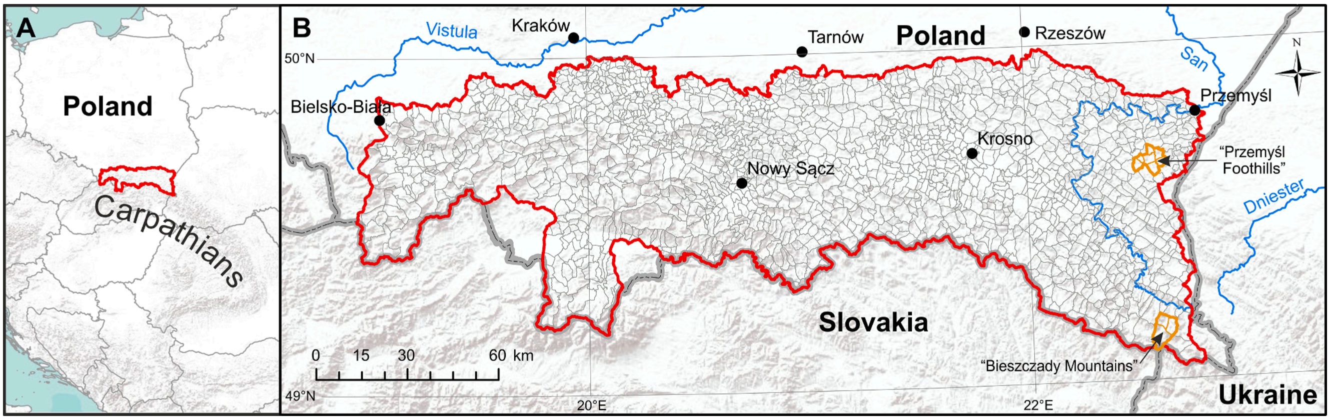

Fig. 1. A – location of the study area in Europe, B – study area with pre-war administrative village-level division (1685 villages) used for modeling (grey borders) and test sites representing post-displacement Carpathian foothills ("Przemyśl Foothills") and middle mountains ("Bieszczady Mountains") (orange borders). Background layer: ArcGIS Basemap (World Hillshade). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

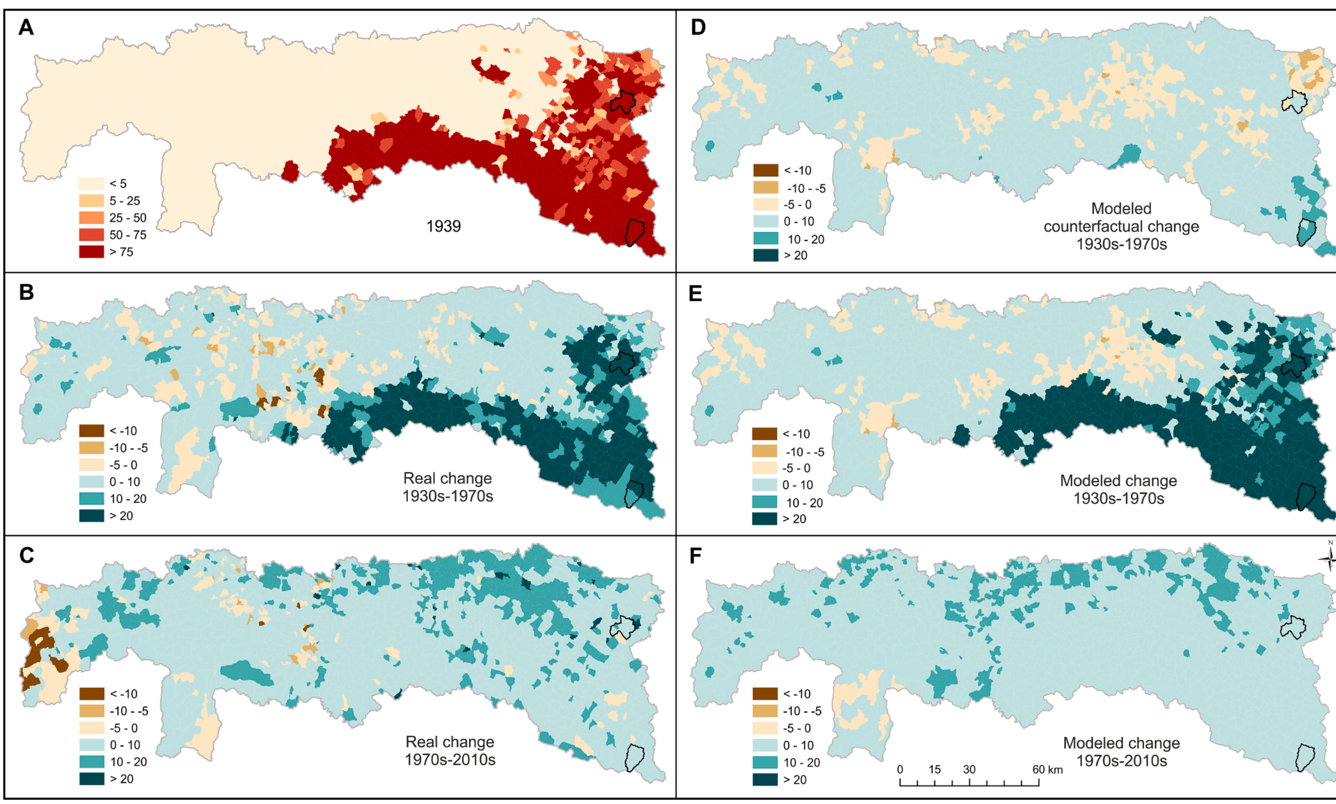

Fig. 2. A – % of Ukrainian population in 1939 (displaced in 1940s); B – real forest area change in 1930s-1970s; C – real forest area change in 1970s-2010s; D – modeled counterfactual forest area change for 1930s-1970s (as if there had been no displacements); C – modeled forest area change for 1930s-1970s; F – modeled forest area change for 1970s-2010s. All data at the village level (N = 1685). Forest area changes in % of village area.

Before World War II, the south-eastern part of today's Polish Carpathians was a Polish-Ukrainian ethnic borderland. Especially at the turn of the 19th and 20th century, there was massive outmigration to the USA and South America (Pollack, 2010), despite of which, the population density in our study area continued to rise though due to the very high birth rate until the late 1930s (ranging from $< 30/km^2$ at higher elevations to $> 120/km^2$ in the foothills) (Soja, 2008). After the development of railways at the end of the 19th century, the extensive Carpathian forests started to be heavily exploited, but due to complex topography, limited access, and logging being selective and largely focused on the most valuable trees, overall forest area remained relatively stable up to WWII (Affek et al., 2020; Kozak, 2010; Munteanu et al., 2014; Wolski, 2007). Concomitantly, a gradual shift away from pastoralism, which was widespread both in the form of transhumance in the upper parts and silvopastoralism in the lower parts, and toward crop-based agriculture began, which resulted in the gradual abandonment of high-elevation pastures (Kubijowicz, 1926). However, many local rural communities were culturally conservative and did not adopt new technologies and cultural patterns coming from the Western world (Wolski, 2016).

In the 1940s the Polish Carpathians and their foothills experienced one of the greatest forced displacements in the modern history of Europe. First, from 1944 to 1946 a total of 480,000 Ukrainians were displaced from the provinces of Rzeszów, Kraków, and Lublin to the

Ukrainian Soviet Socialist Republic (Eberhardt, 2011). This was part of a larger population exchange between the post-war Poland and the Soviet Union, aimed at ethnic consolidation after the delineation of the new border along the Curzon Line (Eberhardt, 2011). The second wave of displacements took place in 1947 (the so-called Operation Vistula), when the remaining 140,000 Ukrainians including Poles from mixed families, were displaced within the Polish post-war territory. The action was carried out by the Soviet-installed Polish communist authorities with the aim of removing material support and assistance to the Ukrainian Insurgent Army (UPA) and bring an end to its guerilla activities (Motyka, 2011). However, the dispersion of Ukrainians throughout the entire area of the "Recovered Territories" of northern and western Poland, and later efforts to polonize them suggest that the creation of an ethnically homogeneous nation-state was an additional goal (Snyder, 1999). The implementation and acceptance of such ethnic policy in broader society was fostered by strong Polish-Ukrainian antagonism, which developed already in the interwar period (Wolski, 2016), and peaked after the Ukrainian Insurgent Army massacres of Poles in Volhynia and Eastern Galicia in 1943 (Motyka, 2011; Snyder, 1999). As a sidenote, the displaced Carpatho-Ruthenian ethnic groups belonging to the East Slavs, that is Lemkos and Boykos peoples, are often regarded as a subgroup of Ukrainian people. They were either Eastern Orthodox or Greek-Catholic, while Poles were Roman-Catholic, thus religion was the main determinant of national identity in the ethnic borderland up to World War II, ahead of language and culture (Eberhardt, 2011). Acknowledging the ethnic diversity of the East Slavs living in the Carpathian region, we retained the terminology used in the demographic sources (Eberhardt, 2011; Kubìjovič, 1983) and call the entire displaced population 'Ukrainians'.

As a result of displacements, 126 Carpathian villages were completely depopulated, and in an additional 250 villages only a few Polish families remained (Appendix A, Fig. A.1). Due to the policy of no-return, destruction of settlements and often adverse natural conditions these villages have for the most part not been resettled (Pudło, 1992), and especially in remote mountain areas the depopulation was permanent.

In addition of our analyses of the entire Polish Carpathians, we selected two test sites where before WWII>90% of population were Ukrainians to analyze the detailed changes in landscape composition and the trajectories of land-cover change after displacement. One test site ("Przemyśl Foothills") represents the Carpathian foothills, and the other ("Bieszczady Mountains") the Carpathian middle mountains. "Przemyśl Foothills" covers 6096 ha and comprises 7 pre-war villages, while "Bieszczady Mountains" covers 6170 ha and comprises 3 pre-war villages. Population dropped from 4830 and 1590 people (79 and 26/km^2) in 1939 to 58 and 77 (0.9 and 0.4/km^2) people in 2011, in "Przemyśl Foothills" and "Bieszczady Mountains" respectively (Kubìjovič, 1983; https://stat.gov.pl). We selected those 10 villages, because they are representative of post-displacement villages in the foothills and middle mountains, where the depopulation resulting from displacements was permanent.

2.2. Effects of displacement on forest area across the Polish Carpathians

To estimate the effect of the forced displacements on forest area, we conducted a village-level analysis across the Polish Carpathians (in total 1685 villages/cadastral communities, "*Katastralgemeinden*" in German). For this, we reconstructed the mid-19th century high-resolution village-level administrative borders of the former province of Galicia (part of Austro-Hungarian Empire) for the Carpathians within the current Polish borders. Our map sources were the Administrativ Karte von den Königreichen Galizien und Lodomerien of Kummersberg at a scale of ca. 1:115,000, published in 1855, current data from National Register of Boundaries, and the second military survey of the Habsburg Empire 1:28,800 of 1860s. We calculated village-level forest area in the Carpathians in the 1930s and 1970s based on topographic maps (Bednarczyk, Kaim, & Ostafin, 2016; Ostafin et al., 2017). Forest area in the 2010s was derived from the national Database of Topographic Objects 1:10,000 (BDOT10k). By combining the data from the three time points, we obtained two maps of village-level forest area change (in percentages of village area) for the 1930s-1970s and the 1970s-2010s. For each village, we also obtained past land use and ownership information from the 1868 census (Skorowidz, 1868), and ethnic structure from the 1939 census (Kubìjovič, 1983). Topography-related variables were derived from the Digital Terrain Elevation Data for Poland (DTED Level 2 with 30-m resolution).

In order to quantify the extent to which land-cover changes were caused by the displacement of the Ukrainian population, we parameterized regression models of village-level forest area change from the 1930s to the 1970s, and from 1970s to 2010s. In these models, the share of the population that was Ukrainian in 1939 served as a proxy measure of displacement intensity, because the entire Ukrainian population was displaced and forcibly re-settled elsewhere (Fig. 2A). We also included other potential predictors related to environmental and socioeconomic conditions, such as initial land use and ownership pattern, population density, accessibility (distance to markets), soils and topography (Table 1). We preselected those variables that in univariate models were at least weakly correlated (Spearman rho < -0.15 or > 0.15) with forest area change (Appendix B, Tables B.1 and B5). We identified seven villages as strong outliers (out of 1685), six of which were in the control group, and removed them because they would have been sources of potential bias. As a robustness check, we parameterized models with all data points, and their results were similar (results not shown). To quantify the relationship between each of our candidate predictors and forest area change, we fitted a series of linear models containing all possible combinations of our covariates, using the 'dredge()' function in R package "MuMIn". We examined the scatterplots to see if there were non-linear relationships, but found none that were obviously so, and when we tested the squared terms of variables (e.g., we observed steeper forest area increase in villages with $> 90\%$ Ukrainians), they explained less variance than when they entered the model without the squared term (results not shown). To identify the best model, we ranked them all according to their Bayesian Information Criterion (BIC), which penalizes over-parameterized models. We assessed the total explanatory power of models by calculating their adjusted R^2, and checked for multicollinearity by calculating the Variance Inflation Factor (VIF). Hair, Black, Babin, and Anderson (2010) suggest that a VIF of 10 represents a high degree of collinearity and recommend lower VIF thresholds. We therefore employed a conservative VIF of 4 in our models, which was also a natural break among our variables.

To assess the relative importance of the predictors included in the best model, we applied hierarchical partitioning analysis to calculate the independent, joint, and total contributions of each predictor to overall explained variance (Chevan & Sutherland, 1991). We used the 'hier.part()' function to apply hierarchical partitioning in R package "hier.part". We also assessed potential biases arising from spatial autocorrelation by calculating and mapping Moran's I of the model residuals (see Appendix C).

To assess the overall change in forest area due to the displacements, we applied our regression model to calculate the counterfactual increase in forest area that would be expected if a village had no Ukrainians, and subtracted that from the prediction based on the actual ethnic composition, using the following formula:

$$OFAC = \sum_{i=1}^{N} A_i (FAC - FACr)/100 \quad (1)$$

where $OFAC$ – overall forest area change only due to displacements (in ha), N – number of villages, A_i – area (in ha) of ith village, FAC – modeled forest area change (in % of village area), $FACr$ – modeled counterfactual forest area change (in % of village area) if there had been no displacements. We calculated and mapped FAC and FACr for each village, converted the values from percentages of village area to hectares, and

Table 1
Source data of variables considered in our modeling.

	Variables	Source type	Source	Model for 1930s-1970s	Model for 1970s-2010s
1	Forest area change 1930s-1970s [% of village area]	maps	(Bednarczyk et al., 2016; Ostafin et al., 2017)	R	P
2	Forest area change 1970s-2010s [% of village area]	spatial data	(BDOT10k; Ostafin et al., 2017)	–	R
3	Forest area in 1860s [% of village area]	census	(Skorowidz, 1868)	P	P
4	Forest area in 1930s [% of village area] “F”	map	(Bednarczyk et al., 2016)	P	P
5	Forest area in 1970s [% of village area]	map	(Ostafin et al., 2017)	P	P
6	Ukrainian population in 1939 [% of village population] “U”	census	(Kubìjovič, 1983)	P	P
7	Population density in 1857 [persons/km^2]	census	(Skorowidz, 1868)	P	P
8	Elevation [mean for a village]	DEM	DTEDlevel2	P	P
9	Slope [mean for a village] “S”	DEM	DTEDlevel2	P	P
10	Distance to town with population above 20,000 [km] “D”	map, census	various sources	P	P
11	Soil agricultural suitability [mean for a village]	map	(Skiba & Drewnik, 2003)	P	P
12	Land owned by landlords in 1860s [% of village area]	census	(Skorowidz, 1868)	P	P
13	Landlord forests in 1860s [% of village area]	census	(Skorowidz, 1868)	P	P
14	Landlord arable fields in 1860s [% of village area]	census	(Skorowidz, 1868)	P	P
15	Landlord pastures in 1860s [% of village area]	census	(Skorowidz, 1868)	P	P
16	Landlord gardens in 1860s [% of village area]	census	(Skorowidz, 1868)	P	P
17	Peasantry forests in 1860s [% of village area]	census	(Skorowidz, 1868)	P	P
18	Peasantry arable fields in 1860s [% of village area]	census	(Skorowidz, 1868)	P	P
19	Peasantry pastures in 1860s [% of village area] “P”	census	(Skorowidz, 1868)	P	P
20	Peasantry gardens in 1860s [% of village area]	census	(Skorowidz, 1868)	P	P

R – response variable; P – predictor variable

subtracted the latter from the former, which provided us with an estimate of the portion of the forest area increase in the Polish Carpathians due to the displacements (OFAC). To account for uncertainty of modeling, we calculated the 95% confidence interval (CI) of the estimated overall forest area change. We calculated our CI by summing up the intervals for predictions of the mean response of each village's predicted difference in forest change (FAC-FACr). Lastly, to directly compare the effect of displacement on forest area change between the two periods, we selected a subset of relevant variables, that is variables that were important in at least one period, and modeled again both time periods, this time with the same set of variables.

2.3. *Effects on the landscape in two test sites*

To show the spatially-explicit landscape effects of forced displacements we mapped land cover in detail in our two selected test sites (“Przemyśl Foothills” and “Bieszczady Mountains”), where vast majority of inhabitants were forcibly displaced (Affek et al., 2020; Wolski, 2007). We compared the most detailed pre-war land-cover map (the Austrian 1:2880 cadastral map developed in the mid-19th century) with post-war 1:10,000 topographic map from the 1970s, and with BDOT10k for the 2010s. We assumed the 1970s and 2010s were appropriate time points to capture immediate and long-term landscape effects of displacements in the 1940s respectively. The pre-war map of 1930s that we used to model forest area has a resolution that is too low (1:100,000) and land cover classes that are too simplified to combine them with the detailed post-war land-cover maps. That is why we compared the detailed post-war land cover maps for our 10 selected villages with similarly detailed maps for the mid-19th century instead. In prior in-depth studies, we found that landscape pattern between the mid-19th century and WWII was relatively stable in both test sites (<5% net change) (Affek et al., 2020; Wolski, 2007), thus we assumed the older cadastral maps, which are widely used in historical landscape research (Dolejš & Forejt, 2019), reflect the pre-war state adequately. Furthermore, no other high-resolution data sources (such as aerial photographs) were available for that period. The map sources and how we analyzed them are described in detail in Appendix D.

Resulting from our land-cover analyses were three high resolution land-cover maps (1850s, 1970s, and 2010s) for “Przemyśl Foothills” and “Bieszczady Mountains” which were consistent in the level of detail and land-cover classes. We mapped six classes for each of the three dates: built-up area, orchard, arable field, grassland, transitional woodland-shrub, and forest. Via land-cover transition matrices, we calculated the trajectories of change from the 1850s to the 1970s, and then to the 2010s. We performed the spatial analyses of the vector data layers in ArcMap 10.2.2 (ESRI ArcGIS Advanced).

3. Results

3.1. *Effects of forced displacement on forest area*

Between the 1930s and the 1970s, forest area increased from 617,600 to 798,700 ha (i.e., by 181,100 ha, 29.3% growth, 9.1 percentage points increase) across the Polish Carpathians, and from 534,700 ha to 702,900 ha (168,200 ha, 31.4%, 9.9 percentage points) in the 1685 villages, which we included in our modeling. Our village-level analysis showed substantial spatial variation in forest area change though, with much larger forest area increases (>20 percentage points per village) in the south-eastern part of the study area (Fig. 2C). The pattern was strongly correlated to the distribution of pre-war Ukrainians (Pearson's $r = 0.802$, $p < 0.0001$), (Table 2).

To determine the independent effect of displacements on forest area change in the 1930s–1970s we applied our highest-ranked model, which included 5 covariates: Ukrainian population in 1939, slope, peasantry pastures in 1860s, forest area in 1930s, and distance to towns with > 20,000 citizens (Appendix B, Table B.4). The selected model explained 70% of the observed variance (adjusted $R^2 = 0.70$) with a standard error of the estimate of 7.25 percentage points and a maximum VIF of 2.9. Hierarchical partitioning of the explained variance showed that the Ukrainian population in 1939, i.e., our proxy for forced displacement, was responsible for 75% of all independent effects (53% of the total variance), far ahead of the second most important factor, which was distance to markets (Fig. 3, Appendix B, Table B.4). Villages that had a

Table 2
Village-level forest area change (1930s-1970s, and 1970s-2010s) in percentage points in villages of different ethnic structure.

		1930s-1970s				1970s-2010s			
Share of Ukrainian population	N of villages	Min	Max	Mean	SD	Min	Max	Mean	SD
<5%	1,180	−21.21	23.47	2.46	3.97	−13.04	28.23	7.54	4.92
5–90%	238	−0.94	63.26	17.36	12.84	−1.81	25.10	7.21	4.70
>90%	260	−3.24	67.39	30.48	13.76	−3.28	36.36	5.58	4.36

All differences significant at $p < 0.001$

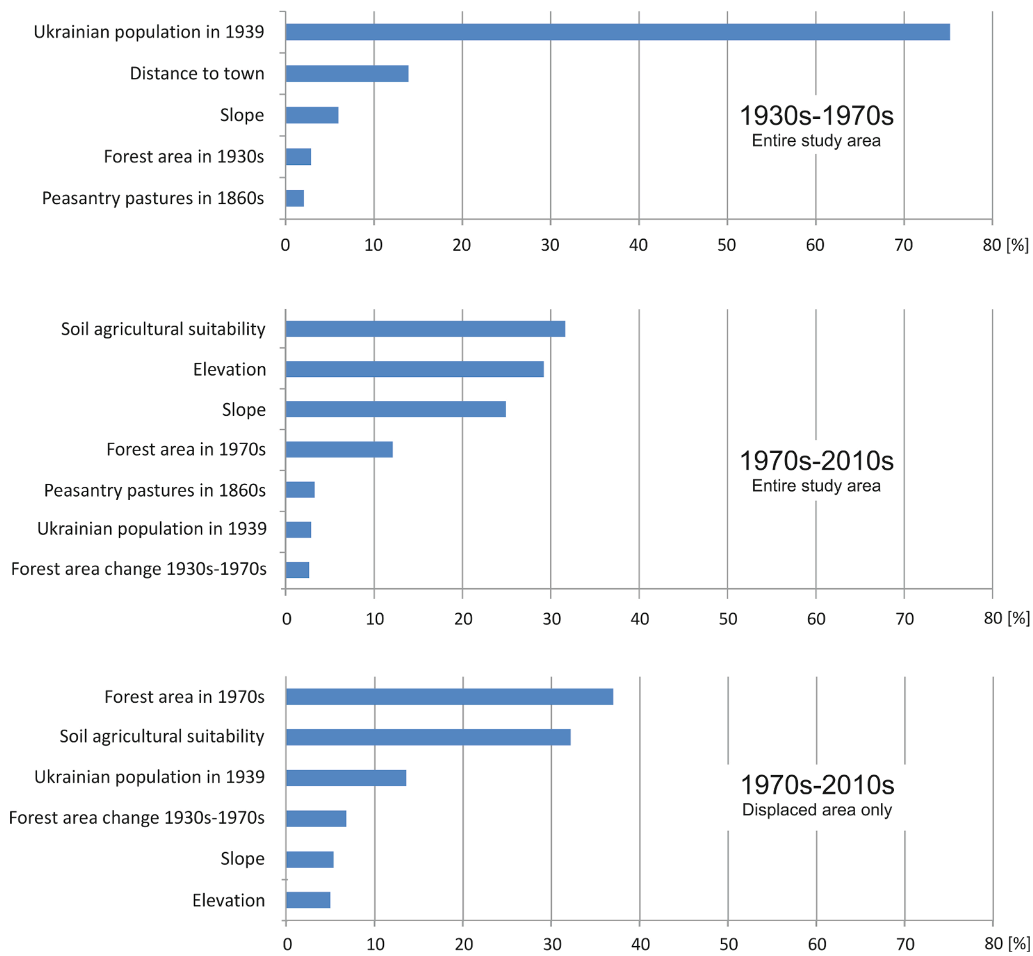

Fig. 3. Hierarchical partitioning results showing the independent effects of each variable in the models of forest area change in 1930s-1970s (top) and 1970s-2010s (middle). In the bottom panel, only villages with Ukrainian population in 1939 > 0% were considered.

higher share of Ukrainians prior to WWII, and those located further away from towns, with steeper slopes, and higher share of initial forest area and peasantry pastures had the highest post-war increases in forest area.

The unstandardized full regression equation used to calculate the modeled forest area change was:

$$FAC = -3.434 + 0.255\ U + 0.224\ D + 0.721\ S - 0.181F + 0.119P, \quad (2)$$

where *FAC* – modeled forest area change 1930s–1970s, *U* – Ukrainian population in 1939, *D* – distance to town, *S* – slope, F – forest area in 1930s, *P* – peasantry pastures in 1860s (see also Table 1). The map of modeled forest area change for 1930s–1970s closely resembles the actual forest area change (Fig. 2C and E), while the map of counterfactual forest area change indicates that some areas (less elevated and closer to towns) would have had a decrease in forest area, instead of an increase, if it had not been for the displacements (Fig. 2B and E). When we applied Eq. (1) to calculate the forest area increase due to the forced displacements (OFAC), we obtained an estimate of 114,700 ha (±4670 ha with 95% confidence). In other words 63% of the overall forest area increase (114,700 out of 181,000 ha) between 1930s and 1970s in the entire Polish Carpathians was due to the forced displacement. Furthermore, in villages inhabited by ≥ 90% Ukrainian population in 1939 (260 villages), the displacement caused 73,100 ha of the 88,400 ha of total forest area increase (83%).

In the 1970s–2010s, the forest area in the Polish Carpathians continued to expand, but generally at a slower pace (Fig. 2D). Interestingly, the largest increases occurred then in the densely populated foothills, where no post-war forced displacements took place, while areas where earlier displacements were common had only moderate forest area increase. Indeed, we found a weak but significant negative correlation between forest area change in the 1970s-2010s and pre-war share of Ukrainian population ($r = -0.137$, $p < 0.0001$). The map of modeled forest area change for that period shows the above-mentioned regularities even more clearly (Fig. 2F). However, our explanatory variables only weekly predicted forest area change (adjusted $R^2 = 0.28$). The independent effect of displacement constituted only 3% of all independent effects, and was far behind the independent effect for soil agricultural suitability (30%), elevation (26%), slope (24%) and forest area in 1970s (11%). The best model for that period included two interaction effects (Ukrainian population × elevation, and Ukrainian population × slope), which we did not include when we assessed the independent effects of predictors. In villages with a higher share of Ukrainians in 1939 (>90%) forest area increase was negatively correlated with slope, but that correlation was positive for villages with a lower share of Ukrainians (<5%). However, when we parametrized the model only for the post-displacement villages (N = 523), the overall model performance increased (adjusted $R^2 = 0.32$), as did the independent effect of ethnicity (14%) and initial forest area (37%). Interestingly, the forest area increase in 1970s–2010s was significantly negatively correlated with elevation, slope, share of Ukrainians and the initial forest area, and positively with soil agricultural suitability (see Appendix B, Tables B.5 to B.8 for details). The comparison of the two periods based on the models with the identical subset of seven variables showed that the independent effect of displacement was 63 times larger for the 1930s–1970s than for the 1970s–2010s (0.508 versus 0.008), which is equivalent of 72.5% and 3.5% of all independent effects in each model, respectively (see Appendix B, Table B.9). The relationship between the displacement and forest area change was positive in the first period, and negative in the second period.

3.2. Effects on the landscape

In “Przemyśl Foothills” and “Bieszczady Mountains”, where we conducted our detailed land-cover change analyses, each village had ≥ 90% Ukrainian population prior to WWII, and land cover changed dramatically after the post-WWII displacements (Fig. 4). The direction of change was similar in both areas (reforestation), but the magnitude was much larger in the foothills, where some of the reforestation occurred already before displacements. As a result, while the land cover was substantially different between the “Przemyśl Foothills” and “Bieszczady Mountains” in the pre-war period, they were already quite similar in the 1970s, and almost identical in the 2010s (Fig. 4). From the 1850s to the 1930s, forest area was essentially stable and changed only from 56% in the 1850s to 55% in 1930s in the “Bieszczady Mountains” and from 33% in the 1850s to 37% in 1930s in the “Przemyśl Foothills”. By the 1970s, the forest area had increased substantially, to 75% and 77% respectively, and continued to grow thereafter, reaching 84% in the 2010s in both areas. Built-up areas and arable fields disappeared almost completely after WWII. This was particularly striking in the foothills, where it resulted in the shift of the dominant land cover from arable fields to forest.

The land-cover trajectories from the 1850s to the 2010s were similar in both areas, with permanent forest being the most common sequence, followed by post-war transitions from open farmland (either grassland or arable land) to forest (Table 3). Whereas forests and grassland were

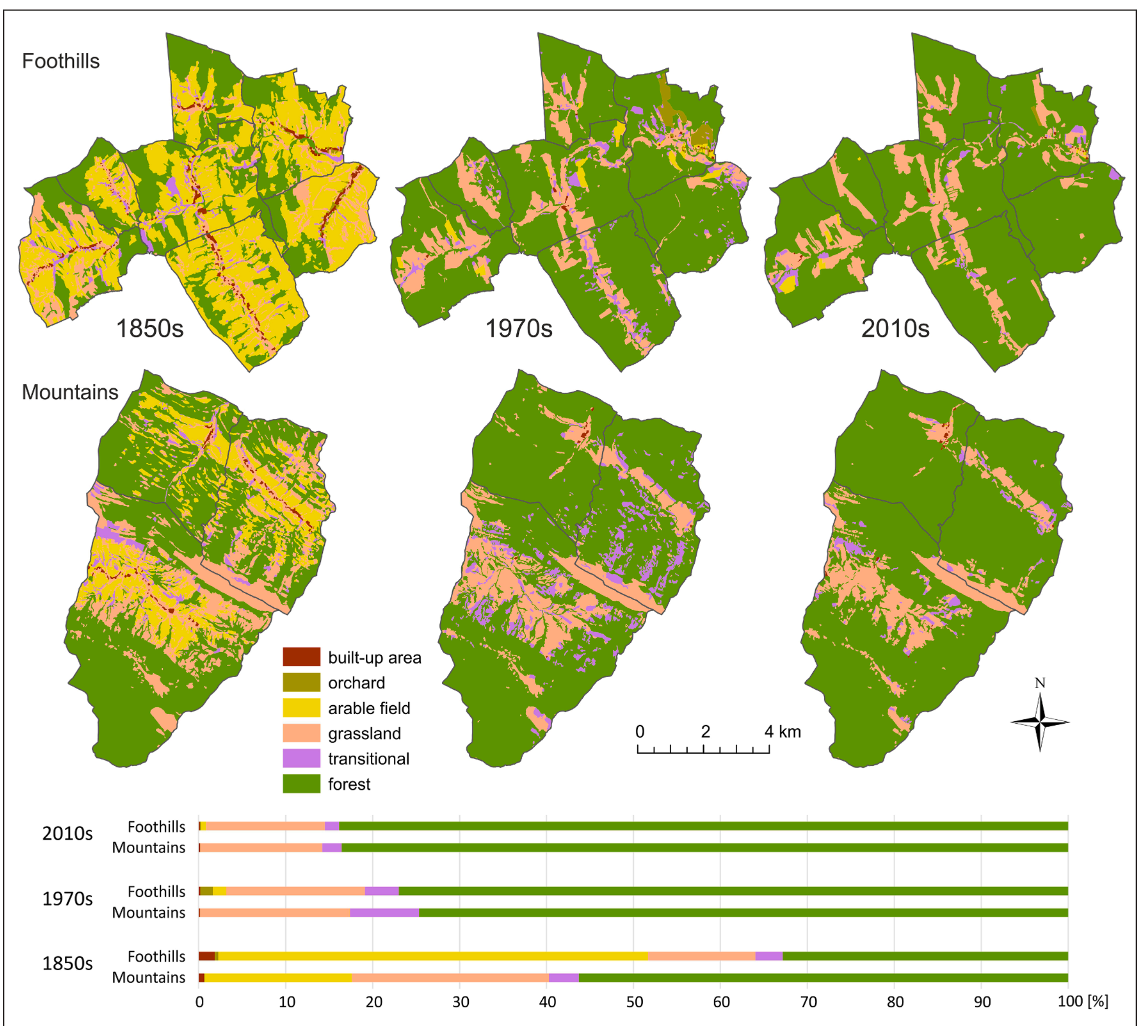

Fig. 4. Landscape pattern and composition in 3 decades in two test sites representing Carpathian foothills and middle mountains with population displacement in 1940s.

Table 3
Land-cover trajectories (1850s → 1970s → 2010s) for the two test sites ("Przemyśl Foothills" and "Bieszczady Mountains").

"Przemyśl Foothills"		"Bieszczady Mountains"	
% of the test site*	Trajectory	% of the test site*	Trajectory
31.94	permanent forest	56.19	permanent forest
31.86	arable field → forest → forest	8.65	grassland → forest → forest
8.64	grassland → forest → forest	6.66	arable field → forest → forest
7.46	arable field → grassland → grassland	5.99	permanent grassland
3.09	arable field → grassland → forest	5.90	arable field → grassland → grassland
2.31	trans → forest → forest	3.43	grassland → trans → forest
1.89	arable field → trans → forest	2.60	trans → forest → forest
1.31	permanent grassland	1.73	arable field → trans → forest
11.51	other	1.60	grassland → grassland → forest
		1.26	arable field → grassland → forest
		5.98	other

* Only trajectories above 1% of the test site area are shown.

the main land-cover types in the mountains before displacements, and the foothills used to be dominated by farmland, both areas were largely void of arable land and built-up areas by the 2010s, and completely covered by forest, bushes, and grassland. As a result of displacements, markedly different pre-war landscapes of Carpathian middle mountains and foothills became very similar by the end of our study period.

4. Discussion

We found that forced displacements in the Polish Carpathians after WWII explained 63% of all the forest area increase from the 1930s to the 1970s, highlighting that displacements can trigger widespread and permanent land use changes. In general, the trend of forest area increase and agricultural land abandonment since WWII is common throughout the Carpathians and many mountain regions of the world (Lasanta et al., 2017; MacDonald et al., 2000). These processes are usually consequences of a multitude of factors, which often operate at broad scales and are interrelated, including long-ranged demographic changes, technological advances, socio-economic and institutional reforms launching new rules of land management, or external trends in land use patterns (see also Baumann et al., 2015). However, the magnitude of changes that took place in the eastern part of Polish Carpathians and high correspondence with the distribution of displaced Ukrainian population clearly indicate that the displacement factor was the main cause for agricultural abandonment and subsequent increases in forest area. Similar landscape changes occurred after WWII in other post-displacement borderland regions of Poland (Latocha, 2012) and other European countries [e.g., in Czechia (Bičík & Štěpánek, 1994) and Slovenia (Hladnik, 2005)], and in other continents where armed conflicts force people to leave their land (Baumann & Kuemmerle, 2016).

Forced displacements are widespread, and may have strong effects on land cover (Hugo, 1996; Woube, 2005), but it is not clear how long those effects persist. We found that the post-WWII forest area change in the Polish Carpathians that resulted from the forced displacements, persisted for 70 years, and were much more important than other factors such as access to markets, topography, and pre-war land use and ownership patterns. Indeed, we estimated that almost two-thirds of post-war forest area increase was due to the forced displacements (see also Kozak, 2010; Kozak et al., 2007; Munteanu et al., 2014).

Forest area increase continued after the 1970s, and especially the collapse of socialism in early 1990s, which lead to agricultural abandonment, also fostered forest area increases (Kolecka et al., 2017; Kozak, 2010; Kuemmerle et al., 2008). In our study area, the only exception to this general trend was a substantial forest area decrease in the Silesian Beskids (Western Carpathians) due to massive bark beetle outbreak in the 2000s (Grodzki, 2007), and that decrease is likely temporary. However, much to our surprise, the post-socialist forest area increase was considerably smaller than the increase after WWII. Furthermore, the post-socialist forest area increase was lower in post-displacement areas compared to the rest of the Polish Carpathians. The relative importance of the different factors explaining forest area change 1970s-2010s in the displaced areas and the direction of relationships indicated that the legacy of the displacement continued, but the effect was much weaker and opposite to that from the previous period. In 1970s-2010s, increases in forest area in displaced areas were more common in villages at lower elevations, and with better soils and less steep slopes, which is not the common pattern of forest expansion. We suggest that this unusual pattern of afforestation is due to a saturation effect (Schneeberger, Bürgi, & Kienast, 2007), in that forest area increased so much in the displacement areas after WWII that only small plots were still available for the new forests to grow. The negative correlation (Spearman's rho $= -0.398$, $p < 0.0001$) between initial, 1970s, forest area and 1970s-2010s forest area increase further supports this interpretation.

The major driving forces and patterns of change in the post-1990 period are common for the entire Carpathians, because all Carpathian countries were under socialist governance between 1945 and 1991 and all countries except Ukraine are now members of the EU (see e.g., Griffiths et al., 2013; Munteanu et al., 2014). Across the Carpathians, forest area increases was rapid after the 1990 because that is when agricultural land was abandoned (Griffiths et al., 2013; Kuemmerle et al., 2008; Munteanu et al., 2014). However, the parts of Poland where forced displacement took place followed different path. Here, the magnitude and pace of land use change in the post-war period was much higher than in the post-socialist era, and they were already abandoned and underwent afforestation and succession 40 years earlier (Affek et al., 2020; Wolski, 2007).

In addition to the increases in forest area, we found major declines in landscape diversity after displacements. The pre-war small fields, meadows and pastures were either afforested and taken over by State Forests, underwent natural forest succession, or were converted to large-scale agricultural monocultures managed by agricultural cooperatives or State Farms. The majority of buildings were burned or demolished and the cultural continuity and centuries-old landscape characteristics were largely lost (Affek et al., 2020; Kozak et al., 2007; Soja, 2008). Nonetheless, some traces of past cultural landscape are still visible in the microtopography (e.g., hollow ways, agricultural terraces, and stone mounds) and vegetation (e.g., post-grazing beeches, old fruit trees) (Affek, 2016; Wolski, 2007). After the transition from the centrally-planned to a market-driven economy in the 1990s, most of the collective farms collapsed and their agricultural land was either privatized or afforested and added to the State Forests (Affek et al., 2020; Kuemmerle et al., 2008). However, even the creation of strong individual property rights was not sufficient to maintain agriculture, because limiting availability of agricultural inputs combined with limited access to markets prevented landowners from reaping the gains of specialization and increasing agricultural productivity (Rozelle & Swinnen, 2004).

Agricultural land abandonment is a common immediate effect of forced displacements during wars. For example, it occurred also in Bosnia and Herzegovina (Witmer, 2008) and the Caucasus region (Baumann et al., 2015; Yin et al., 2019). Our results highlight how long-lasting forest area increase can be, because we analyzed land cover changes up to 70 years after the displacement. Most prior analysis of the effects of wars on land use examined on a decade or so afterwards (e.g., Witmer, 2008; Yin et al., 2019), except of some studies of post-WWII displacements in Poland and Czechia, which also reported long-lasting effects (e.g., Bičík & Štěpánek, 1994; Latocha, 2012).

A common problem, limiting the scope of land change assessments in conflict zones, is the restricted access to the areas of interest. Therefore, models of land change in conflict zones in Eastern Africa (Gorsevski et al., 2012) and Caucasus (Baumann et al., 2015; Yin et al., 2019) were based on satellite images and did not include local demographic data, which means that they did not account for displacement explicitly. Our approach made use of spatio-temporal land cover patterns derived from historical and contemporary maps combined with a detailed village-level demographic census. Accounting for land use and land ownership legacies reaching back to the feudal system, while controlling for other potential drivers (e.g., topography) enabled us to extract ethnicity as the factor for displacement and quantify, for the first time, forest area change arising from post-war displacements, thereby substantiating prior circumstantial evidence that displacements were the main cause for the widespread forest cover increase in the Polish Carpathians (Affek et al., 2020; Kozak et al., 2007).

The landscape change after Carpathian displacements can by interpreted in the theoretical framework proposed by Ramankutty and Coomes (2016) as an abrupt change of a middle-scale land-use regime observable at the regional level. The agriculturally-dominated pre-displacement land-use regime, which had only minor forest area fluctuations related to legal, economic and ownership changes, was maintained by reinforcing forces including (1) sociocultural conservatism, (2) very high birth rate balancing rural outmigration, (3) poor transport infrastructure and (4) mountainous borderland location. Preconditions (early-warning signals) that the pre-war land-use regime was potentially susceptible to a future shift include tensions between neighboring ethnic groups stemming from the emergence of nationalist movements and ideologies in the 1920s and 1930s, World War II and its resulting border changes, and the introduction of the new communist political system in Poland.

We found that the land-cover changes due to the forced displacement were irreversible. This means that the displacement represents a shock event (Baumann et al., 2015) or a catastrophic driver (Kozak et al., 2007). Displacement belongs to the type-3 triggers of land-use regime shifts (rapid demographic change) (Ramankutty & Coomes, 2016). The distinguishing feature of ethnic displacements is the disappearance of a culturally entrenched mode of land use in addition to demographic change. We found that over time a new, forest-dominated land-use regime was established, with forest cover complemented by a substantial share of fallow land and a small number of collective animal farms. Several self-reinforcing processes prevented a return to the old regime, including the destruction of pre-war settlements, ownership and agricultural reforms (i.e., nationalization and collectivization of farmland), laws preventing the return of the displaced people, borderland location combined with a long-held belief in the temporary nature of post-war order, harsh living conditions in the mountains, poor infrastructure, low profitability of agricultural production and a centrally planned economy. That is why only about 6000 (3%) of the displaced families returned (Pudło, 1992), and a state campaign of settling Poles from other regions during the late 1950s and 1960s had very limited success (Wolski, 2016). We argue that what limited the resilience of the pre-war land-use regime to the displacements were both the characteristics of the pre-war land system and the strength of the post-displacement reinforcing processes. That is why land abandonment did not revert and instead became permanent, even where environmental conditions were favorable, and despite economic incentives for agriculture (Pudło, 1992). Irreversible shifts in land cover due to forced displacement may be likely elsewhere too, especially if unregulated boundaries, uncertain land tenure, landmines, and legal restrictions prevent displaced people from returning or new settlers to replace them (Baumann et al., 2015; Witmer, 2008; Yin et al., 2019).

Permanent shifts of the land system may trigger rewilding (Baumann et al., 2015; Kim, 1997). In the Carpathians, the land-use change following displacements entailed large-scale natural succession and forest regeneration processes. Once densely populated rural region became one of the largest wilderness areas in Central Europe, with vast areas free from human settlements, and with resurgent wildlife. It is currently the area with the lowest light pollution in Poland (Ścieżor, Kubala, & Kaszowski, 2012) and the largest mountain population of purebred European bison in the world (Perzanowski & Olech, 2014).

Shock events such as displacements have the potential to shift the land systems into an alternative stable state (Müller et al., 2014). The forest saturation effect observed in the post-displacement areas from the 1970s to the 2010s suggests that the land system began to approach a new stable state 30 years after the perturbation occurred. Nonetheless, we share the view of Ramankutty and Coomes (2016) and Walker et al. (2006) that land systems are unlikely to be fully stable and in the case of post-displacement Carpathian areas the path towards stable state ended with the end of socialist period and the emergence of new drivers.

5. Conclusions

We found that permanent and widespread land-cover changes took place over both 30 and 70 years after forced displacement following WWII. A new land-use regime was established, effectively maintained by a diverse set of self-reinforcing processes, which means that displacements triggered a land-use regime shift, from agriculturally-dominated to forest-dominated. The observed forest saturation effect in the post-displacement areas, when the collapse of socialism in the early 1990s triggered widespread abandonment elsewhere, indicate that land-system approached a new stable state and the new forces were further strengthening the post-war land-use regime. Our result show that policies related to displacements, especially prohibitions to return to the area, played a key role in shaping the post-displacement landscape. Our findings have important socioeconomic and environmental implications because they highlight the strong land use legacies of the post-WWII displacements on Carpathian landscapes for seventy years, which may be relevant elsewhere when predicting the landscape consequences of forced displacements.

CRediT authorship contribution statement

Andrzej N. Affek: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. **Jacek Wolski:** Investigation, Resources, Writing - original draft, Writing - review & editing. **Maria Zachwatowicz:** Writing - original draft, Writing - review & editing. **Krzysztof Ostafin:** Resources, Writing - review & editing. **Volker C. Radeloff:** Conceptualization, Funding acquisition, Methodology, Resources, Supervision, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2021.104164.

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