Land Use Policy 131 (2023) 106678

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Pockets of persistence of agricultural land use during the socioeconomic shock of forced post-WWII displacements in the Carpathians

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A R T I C L E I N F O

Keywords:
Re-cultivation
Agricultural land abandonment
Spatial determinants
Agricultural accessibility
Logistic regression
Beskid Mountains

A B S T R A C T

Socioeconomic shocks can cause regime shifts in land use, but even during shocks, and when land use change is widespread, some areas persist in their land use. The question is what makes these areas more resistant. Our research goal was to find out what explains where arable farming persisted despite a major socioeconomic shock of forced post-war displacements. Our study area were 291 villages in the Polish Carpathians where abandonment due to the forced displacement of the Ukrainian population after WWII was widespread. We compared pre-war arable land with 1990 CORINE Land Cover data to quantify land-use change throughout the socialist period. We applied logistic regression with economically relevant environmental and access-related variables, and assessed the explanatory power of our models and relative importance of determinants. Forty years after forced displacements, arable farming persisted only in a small portion of what had been farmed in the 1940s (16 %), while the majority of former arable land converted to forests (54 %) or grasslands (22 %). Arable farming persisted mainly in areas with high accessibility that had oak-hornbeam forest as potential natural vegetation, on less steep slopes, and at lower elevations. Our models predicting agricultural abandonment leading to reforestation performed well ($R^2 = 0.57$), but our model of persistent agriculture had low explanatory power ($R^2 = 0.26$) as did models of conversion to grassland ($R^2 = 0.24$). We therefore conclude that agricultural persistence is driven by different factors than agricultural land abandonment. In the long term, after arable farming ceases, areas can either be completely abandoned or convert to less intensive grassland use. These long-term changes have strong effects on biodiversity and ecosystem services, but are not well predicted by environmental and access-related determinants. Our findings can help to develop strategies and policies for areas affected by agricultural land abandonment caused by depopulation, and other socioeconomic shocks, and highlight the need to understand not only why arable land is abandoned, but also what determines its long-term fate.

1. Introduction

Agricultural land abandonment is the cessation or reduction of land management for agriculture, and greatly affects biodiversity and ecosystem services (Alcantara et al., 2012; Prishchepov et al., 2013; Terres et al., 2015). Abandonment often occurs in marginal areas (Gellrich and Zimmermann, 2007; Griffiths et al., 2013; Kolecka et al., 2017) or areas affected by depopulation due to political reasons (Estel et al., 2015; Pazúr et al., 2020; Yin et al., 2019). Mountainous regions often exhibit especially high rates of farmland abandonment because their environmental conditions make them physically isolated (natural barriers), vulnerable to disturbance (natural hazards), and not very productive (Jodha, 1990). Furthermore, limited access to resources and other opportunities prevent inhabitants from participation in "mainstream" activities and hinder adaptation mechanisms (Huang et al., 2020). Thus, it is projected that from 2015 to 2030, almost a quarter of all agricultural land abandonment in Europe will take place in the mountains (Perpiña Castillo et al., 2021).

Agricultural land abandonment was particularly widespread in Eastern Europe in the transition period from state-controlled to open market economy in the 1990s (Benjamin et al., 2007; Kuemmerle et al., 2008) but occurs also in other regions across the globe (Yin et al., 2020) including China (Zhang et al., 2014), Colombia (Sánchez-Cuervo and Aide, 2013), and the USA (Kuhman et al., 2011). However, even in areas

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https://doi.org/10.1016/j.landusepol.2023.106678
Received 23 June 2022; Received in revised form 6 March 2023; Accepted 8 April 2023
Available online 25 April 2023

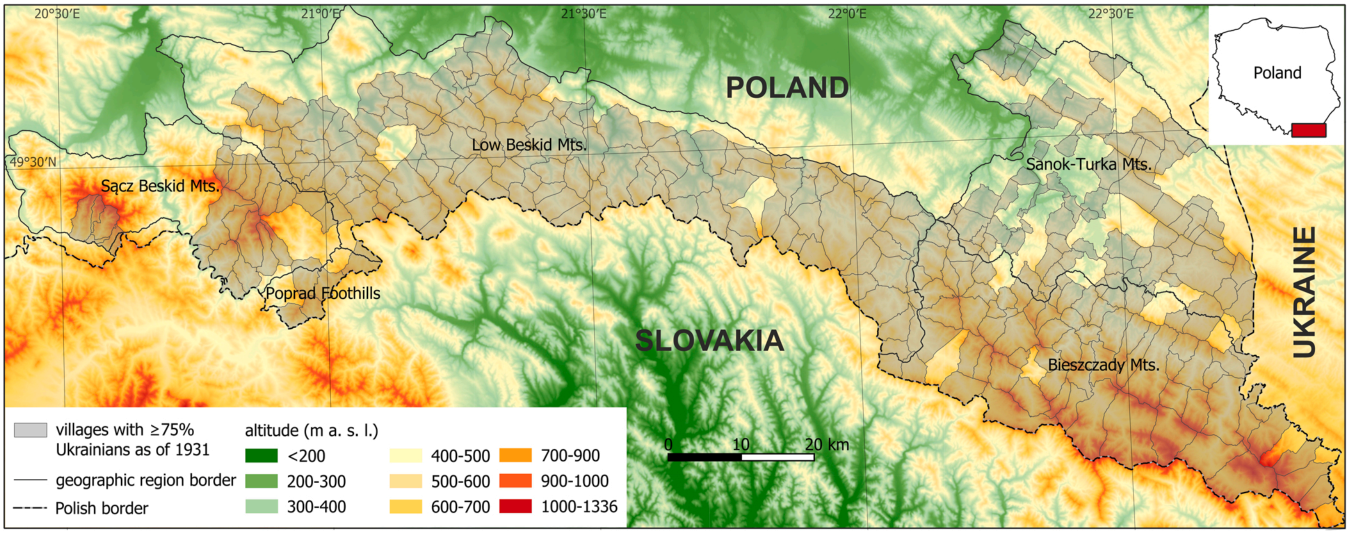

Fig. 1. Study area – the Carpathian villages in Poland, in which the share of later-displaced Ukrainian population was ≥ 75 % before WWII.

where abandonment is widespread, some farmland remains to be cultivated (Baumann et al., 2011; Prishchepov et al., 2013). Furthermore, while some of the abandonment is permanent, re-cultivation of areas once abandoned is also common (Crawford et al., 2022). In the 2000s, re-cultivation occurred in many parts of Central and Eastern Europe (Estel et al., 2015; Pazúr et al., 2020; Smaliychuk et al., 2016), and Central Asia (e.g. in Kazakhstan; Kraemer et al., 2015) as well as in conflict zones after the withdrawal of armed forces, (e.g., in the former Yugoslavia and Northern Caucasus; Witmer and O'Loughlin, 2009; Yin et al., 2019). The question is thus what distinguishes the areas where agricultural land use is persistent, or abandonment is quickly re-cultivated, from those where abandonment is permanent.

There are many studies that seek to identify determinants of abandonment or re-cultivation of arable land (Baumann et al., 2011; Prishchepov et al., 2013; Smaliychuk et al., 2016). These studies have been conducted at a range of spatial scales: local (Dahal et al., 2020), regional (Kolecka et al., 2017), national (Lieskovský et al., 2015), pan-European (Ustaoglu and Collier, 2018) and global (Prishchepov et al., 2021). The general conclusion is that both agricultural land abandonment and re-cultivation are mainly caused by socioeconomic changes (Terres et al., 2015), but their rate, direction, and spatial pattern depend on many site-specific, natural and human factors. The decision to continue or abandon arable farming is largely determined by how profitable agricultural production is (Prishchepov et al., 2013; Terres et al., 2015). For instance, widespread agricultural land abandonment in the former Soviet Union after 1991 was a consequence of abrupt termination of 90 % of the subsidies for the agricultural producers and consumers, which were available in the Soviet agricultural system (Prishchepov et al., 2013). Similarly, financial profit is the highest motivation to continue farming in traditional agricultural landscapes of Slovakia (Lieskovský et al., 2015). Profitability, in turn, is affected by topography (elevation, slope, aspect, and location in the landscape), climate (temperature, precipitation), soil quality (humidity, fertility, erosion potential, etc.), and access to markets (Prishchepov et al., 2013; Pueyo and Beguería, 2007; Sawicka et al., 2012; Szablowska-Midor, 2004).

Similarly, high re-cultivation rates in Eastern Europe in the 2000s was the result of rising global commodity prices and greater profitability of agriculture as well as the enlargement of EU and financial incentives provided under the Common Agricultural Policy (Estel et al., 2015; Griffiths et al., 2013). Many farmers in new EU member states, in order to receive per-hectare subsidies, decided to cultivate even long-abandoned land, even though farming there was often not economically justified and had no prospects for long-term sustainability (Morkunas and Labukas, 2020). Nonetheless, most of the variables determining the spatial pattern of land abandonment also determined re-cultivation, but the direction of the relationships was opposite. The areas where abandonment was most likely were also where re-cultivation was least likely (Pazúr et al., 2020). Many factors were important though, including those related to land productivity (e.g. mean temperature and soil fertility) and those capturing spatial patterns and accessibility (e.g. distance to the nearest forest edge and to the capital city) (Pazúr et al., 2020; Smaliychuk et al., 2016). The higher the travel time, the higher cost of access, which corresponds to decreasing land rent, and a reduction in land use intensity (Geurs and Wee, 2004).

Rapid socioeconomic changes, and especially so-called socioeconomic shocks, such as armed conflicts and major political shifts, often trigger land abandonment (Baumann and Kuemmerle, 2016). Wars in particular can have strong effects, if they are accompanied by forced displacements, which can be a trigger causing abrupt change of the social-ecological system in the terminology of systems theory (Ramankutty and Coomes, 2016; Walker et al., 2006). When that happens, agricultural abandonment can be very rapid and widespread (Baumann et al., 2011; Baumann and Kuemmerle, 2016; Eklund et al., 2017). Whether or not that abandonment is reversible depends on the strength of self-reinforcing processes that may maintain the new land use regime and resist a shift back to the old regime, e.g. low profitability of agricultural production, and rural outmigration to urban centers. Low reversibility means that the land-use regime transitions to another stable state (Müller et al., 2014). In general though, after a shock, re-cultivation tends to be more gradual as areas are re-populated by returning refugees or new settlers (Soja, 2008). Furthermore, even during severe socioeconomic shocks, abandonment may not affect all arable land raising the question whether agriculture persist either because it never ceased, or because re-cultivation occurred rapidly.

Declines in rural population density does not always result in full agricultural abandonment. Sometimes, the result is a reduction of the intensity of agricultural land use, for example when arable land is being replaced by semi-natural grasslands, hay meadows, or pastures. Even though such reductions in land use intensity prevent natural succession to forests, a change from arable land to grasslands still has major consequences to biodiversity and ecosystem service provision (Bengtsson et al., 2019; Habel et al., 2013). Agricultural abandonment is therefore not binary in nature (Dramstad et al., 2021), it is often largely fleeting (Crawford et al., 2022) and patterns depend on changes in landholding status and land rights over time (Holl et al., 2022). Thus, abandonment can be terminal, incomplete, hidden or reoccurring (Prishchepov et al., 2021). Nonetheless, although land abandonment is the most important proximate driver of landscape change in Europe (Plieninger et al.,

Table 1
Geographic determinants that we calculated for our models. The control variable indicating the level of depopulation is also included.

No.	Determinant	Variable	Variable type	Source data
1	Agricultural accessibility	Access cost [log10] (Jabs and Affek, 2019)	Scale	DEM, VMap Level2, BDOT10k
2	Access to markets	Distance to markets (towns) in km	Scale	www.stat.gov.pl, VMap Level2
3	Slope	Slope in degrees	Scale	DTED Level2
4	Location in the landscape	*Topographic Position Index* - TPI (Tagil and Jenness, 2008)	Scale	DTED Level2
5	Elevation	Elevation in meters a.s.l.	Scale	DTED Level2
6	Insolation	*Heat Load Index* – HLI (McCune and Keon, 2002)	Scale	DTED Level2
7	Soil moisture	*Compound Topographic Index* – CTI (Gessler et al., 1995)	Scale	DTED Level2
8	Potential natural vegetation	5 forest classes: riparian, fertile oak-hornbeam, fertile beech-fir, poor deciduous, other	Nominal	(Matuszkiewicz, 2008)
9	Soil quality	Soil agricultural suitability	Rank	(Skiba and Drewnik, 2003)
10	Population change	Total vs partial depopulation (1931–1950)	Nominal	(Soja, 2008)

2016), little attention has been paid so far to model the distinction between full agricultural abandonment and conversion to less intensive grassland use.

Therefore, our main goal was to quantify the determinants for both persistent arable land and post-arable grassland, and to compare each of these agricultural land uses with full agricultural abandonment resulting in a conversion into forest. We defined persistent arable land as places that were a) continuously farmed, or b) abandoned and then re-cultivated. Our specific objectives were to:

1. Determine the use of former arable land in the Polish Carpathians 40 years after displacements.
2. Determine the ability of geographic determinants to explain land use change on post-displacement arable land, including persistence of arable farming versus full agricultural abandonment (reforestation) and change to less intensive agricultural use (conversion to semi-natural grasslands).

2. Methods

2.1. Study area

Our study area was the eastern part of the Polish Carpathians, which consists of four mountain and one foothill geographic regions all belonging to the Beskid Mountains (Fig. 1; Solon, 2018). The underlying geology is Carpathian Flysch, and soils are mostly Eutric and Dystric Cambisols (Skiba and Drewnik, 2003). The study area has temperate climate with strong altitudinal zonation, with oak-hornbeam forests dominating naturally up to 550 m a.s.l. (foothill zone), beech and fir forests up to 1050–1150 m a.s.l. (lower montane zone), and above that spruce forests or grassland communities (sub-alpine zone) (Szafer and Zarzycki, 1972; UNEP, 2007).

Before World War II, our study area was mainly inhabited by Ukrainians, especially two Carpatho-Ruthenian ethnic groups: Lemkos and Boykos (Soja, 2008). In the 1940s, almost all of them were forcibly displaced, an estimated 620,000 people (Eberhardt, 2011). From 1944 to 1946, Carpathian Rusyns were re-settled entirely in the territory of Soviet Ukraine as part of a population exchange agreement that

Table 2
Land cover in 1990 (CLC 1990) on pre-war arable land in post-displacement Carpathian villages.

CORINE Land Cover 1990	CLC code	ha	%
Discontinuous urban fabric	112	442.53	0.41
Industrial or commercial units	121	28.39	0.03
Mineral extraction sites	131	11.70	0.01
Construction sites	133	51.59	0.05
Sport and leisure facilities	142	0.24	0.00
Non-irrigated arable land	211	17,844.24	16.39
Pastures	231	20,734.17	19.04
Complex cultivation	242	5318.04	4.88
Land principally occupied by agriculture…	243	2658.59	2.44
Broad-leaved forest	311	14,646.43	13.45
Coniferous forest	312	15,611.53	14.34
Mixed forest	313	27,998.78	25.71
Natural grasslands	321	2903.84	2.67
Transitional woodland-shrub	324	240.12	0.22
Watercourses	511	32.61	0.03
Water bodies	512	360.37	0.33
TOTAL		108,883.19	100.00 %

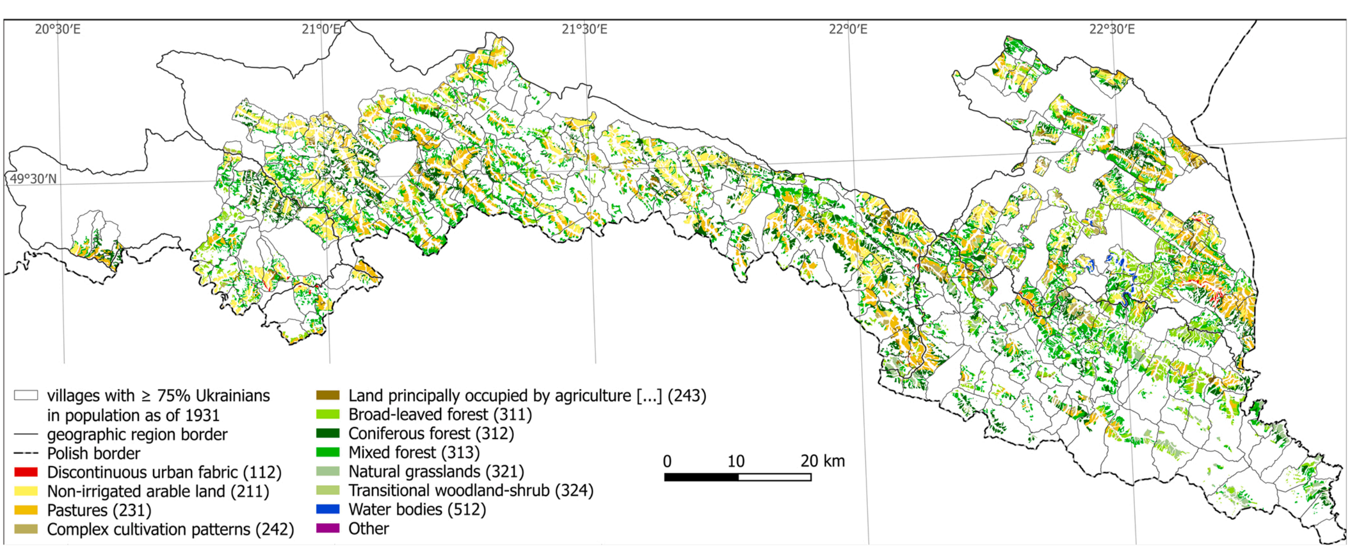

Fig. 2. Land cover in the 1990 (CLC 1990) on pre-WWII arable land in post-displacement Carpathian villages.

Table 3
Unstandardized coefficients of the ten best models (ordered based on BIC) explaining the spatial pattern of 1. persistence of arable land 2. conversion to forest, 3. conversion to grassland, and 4. conversion to forest vs conversion to grassland; "–" means the term not included in the model.

No	(Intercept)	Soil moisture [CTI]	Distance to markets	Elevation	Population change	Potential natural vegetation	Soil quality	Insolation [HLI]	Agricultural access cost	Slope	Location in the landscape [TPI]	$AdjR^2Nag.$	df	BIC
1. Persistent arable land vs Conversion to all other land use (N = 4600)														
1	-6.46	–	0.041	–	+	+	–	–	1.57	0.060	-0.005	0.258	9	3489
2	-5.70	–	0.040	–	+	+	–	–	1.39	0.060	–	0.255	8	3490
3	-5.31	–	0.041	–	+	+	–	-1.73	1.56	0.062	-0.004	0.258	10	3496
4	-4.20	–	0.041	–	+	+	–	-2.33	1.39	0.063	–	0.255	9	3496
5	-6.60	–	0.039	0.0004	+	+	–	–	1.56	0.059	-0.005	0.258	10	3497
6	-6.38	–	0.041	–	+	+	-0.02	–	1.57	0.060	-0.005	0.258	10	3497
7	-6.56	0.01	0.041	–	+	+	–	–	1.57	0.061	-0.004	0.258	10	3497
8	-6.05	0.03	0.040	–	+	+	–	–	1.40	0.064	–	0.255	9	3497
9	-5.58	–	0.040	–	+	+	-0.03	–	1.40	0.061	–	0.255	9	3498
10	-5.65	–	0.041	-0.0002	+	+	–	–	1.40	0.061	–	0.255	9	3498
2. Persistent arable land vs Conversion to forest (N = 3224)														
1	-21.18	–	0.029	–	+	+	–	–	4.87	0.114	-0.011	0.571	9	2086
2	-20.77	–	0.027	–	+	+	-0.11	–	4.91	0.114	-0.011	0.571	10	2092
3	-19.56	–	0.030	–	+	+	–	-2.38	4.85	0.116	-0.011	0.571	10	2092
4	-21.03	–	0.031	-0.0005	+	+	–	–	4.88	0.114	-0.011	0.571	10	2094
5	-21.37	0.02	0.029	–	+	+	–	–	4.87	0.116	-0.011	0.571	10	2094
6	-20.63	–	–	–	+	+	–	–	4.90	0.113	-0.012	0.566	8	2094
7	-20.12	–	–	–	+	+	-0.15	–	4.95	0.113	-0.011	0.567	9	2097
8	-19.04	–	0.028	–	+	+	-0.11	-2.54	4.89	0.116	-0.011	0.572	11	2098
9	-20.96	0.02	0.027	–	+	+	-0.11	–	4.90	0.116	-0.011	0.571	11	2099
10	-20.69	–	0.029	-0.0003	+	+	-0.11	–	4.92	0.115	-0.011	0.571	11	2100
3. Persistent arable land vs Conversion to grassland (N = 1791)														
1	-6.19	–	0.047	0.0029	+	–	–	–	0.86	–	-0.009	0.244	6	2138
2	-5.66	–	0.045	0.0031	+	–	-0.14	–	0.89	–	-0.009	0.246	7	2142
3	-6.19	–	0.046	0.0030	+	–	–	–	0.87	-0.008	-0.009	0.244	7	2145
4	-6.38	0.02	0.047	0.0030	+	–	–	–	0.87	–	-0.009	0.244	7	2145
5	-5.83	–	0.047	0.0029	+	–	–	-0.56	0.86	–	-0.009	0.244	7	2145
6	-5.36	–	0.060	–	+	–	–	–	0.97	–	-0.007	0.233	5	2148
7	-5.65	–	0.045	0.0032	+	–	-0.14	–	0.91	-0.009	-0.009	0.246	8	2148
8	-5.83	0.02	0.045	0.0031	+	–	-0.14	–	0.90	–	-0.009	0.246	8	2149
9	-5.07	–	0.045	0.0031	+	–	-0.14	-0.90	0.89	–	-0.009	0.246	8	2149
10	-4.29	–	0.049	0.0021	+	–	–	–	0.50	–	–	0.231	5	2152
4. Conversion to forest vs Conversion to grassland (N = 3459)														
1	-11.31	–	-0.025	–	–	–	–	-5.72	3.63	0.123	–	0.405	5	3068
2	-12.60	–	-0.027	–	–	–	–	-5.06	3.84	0.122	-0.004	0.407	6	3068
3	-11.16	–	-0.020	-0.0014	–	–	–	-5.77	3.74	0.126	–	0.407	6	3070
4	-16.03	–	-0.028	–	–	–	–	–	3.89	0.116	-0.005	0.404	5	3071
5	-15.00	–	-0.025	–	–	–	–	–	3.64	0.117	–	0.401	4	3073
6	-12.25	–	-0.023	-0.0010	–	–	–	-5.22	3.89	0.124	-0.003	0.408	7	3074
7	-10.92	–	-0.026	–	–	–	-0.09	-5.86	3.66	0.123	–	0.406	6	3074
8	-11.72	0.04	-0.025	–	–	–	–	-5.71	3.64	0.127	–	0.405	6	3075
9	-12.22	–	-0.028	–	–	–	-0.08	-5.20	3.87	0.122	-0.004	0.408	7	3075
10	-12.75	–	-0.025	–	+	–	–	-5.07	3.87	0.122	-0.004	0.408	7	3076

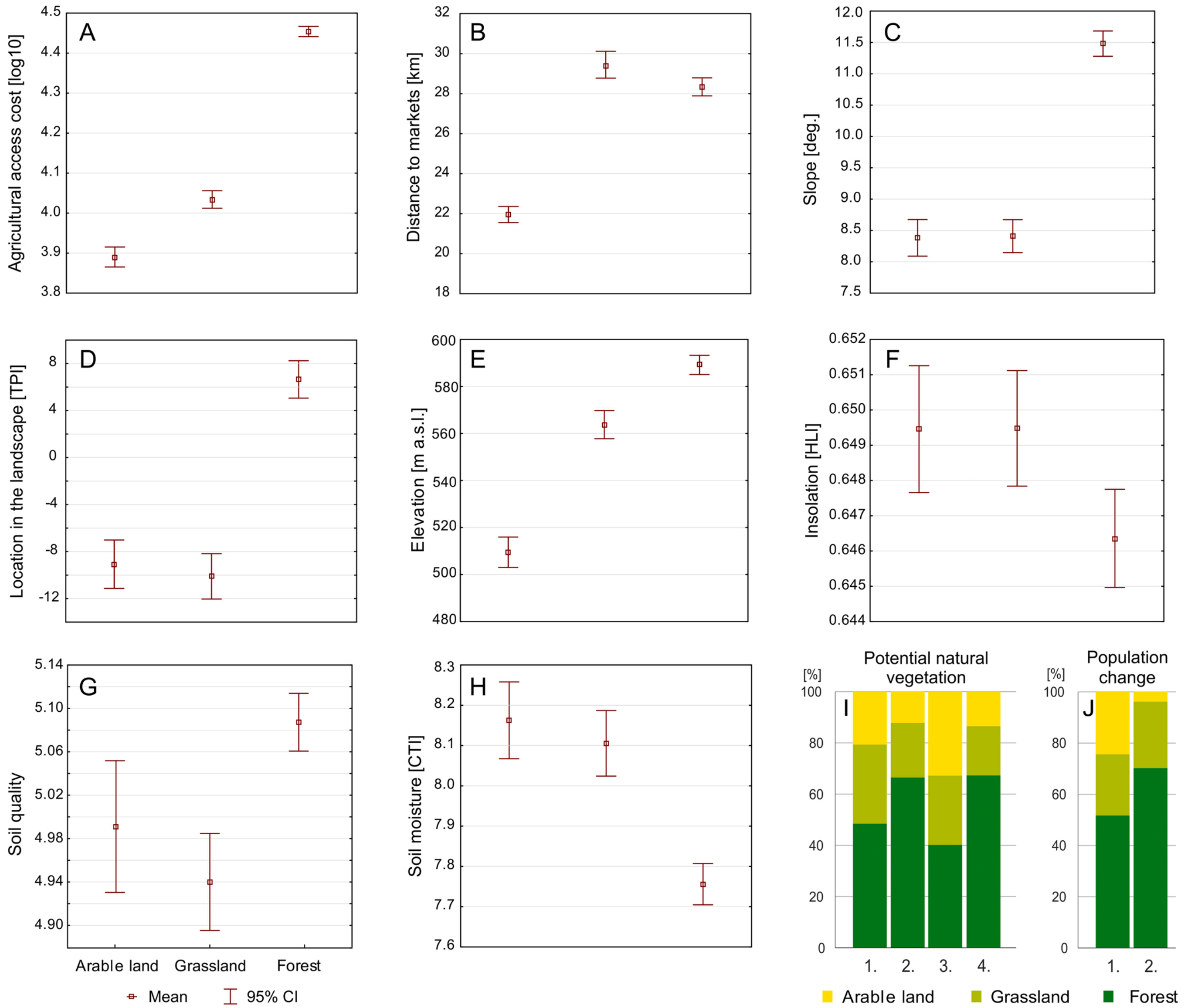

Fig. 3. Characteristics of pre-displacement arable land broken by the three main land-cover types in 1990 (arable land, grassland and forest). Legend for (I): 1. Riparian forest 2. Fertile beech-fir forest, 3. Fertile oak-hornbeam forest, 4. Poor deciduous forest; and for (J): 1. Partial depopulation, 2. Total depopulation.

accompanied with the establishment of a new Polish-Soviet border (Czerniakiewicz and Czerniakiewicz, 2005). Then, in 1947, a second displacement action was announced (the so-called Operation Vistula). The remaining 140,000 Ukrainians who survived the previous deportations and still lived in the Polish Carpathian villages were forcibly relocated and scattered in various places within the post-war borders of Poland. The official aim of this action was to remove material support and assistance to the guerrilla activities of Ukrainian Insurgent Army (Motyka, 2011), but there was also the goal to create an ethnically homogeneous nation-state (Snyder, 1999).

The displacement of ethnic Ukrainians was by and large permanent. Only in some villages and after many years was there gradual repopulation, and even there population levels never fully recovered (Soja, 2008). From 1956 to 1958, occasionally permissions for refugees to return were issued, but only very low percentage of former inhabitants could obtain them. Furthermore, the new Polish settlers who came to displaced villages were mostly lowland farmers not used to mountain conditions. Lastly, in accordance with the principles of the centrally planned economy, various forms of collective farming were established on nationalized land in the 1950s and ‘60s, and many of them had low profitability throughout the socialist period (Wolski, 2016). However, until the transition to open markets in the early 1990s, the socioeconomic conditions in the region were relatively stable.

We focused in our analysis on arable land that lost its pre-war owners, which is why we limited the research area to 291 mountainous villages in the Carpathians that had before WWII a share of later-displaced Ukrainian population of ≥ 75 %. Also, selecting a borderland area with varied terrain allowed us to capture large variability in the re-use pattern (i.e., not only complete re-cultivation, as was the case in the lowlands), as well as wide ranges of values of geographic determinants, including accessibility and topography (Fig. 1).

2.2. Data

To reconstruct the pre-war village boundaries, we analysed the 1:115,000 Austrian map of Kummersberg: *Administrativ-Karte von den Königreichen Galizien und Lodomerien* published in 1855 (Mapster, 2014), the second military survey of the Habsburg Empire 1:28,800 of 1860s (Arcanum, 2020), and current data from the National Register of Boundaries (GUGiK, 2020). Based on the 1939 Ukrainian ethnic census

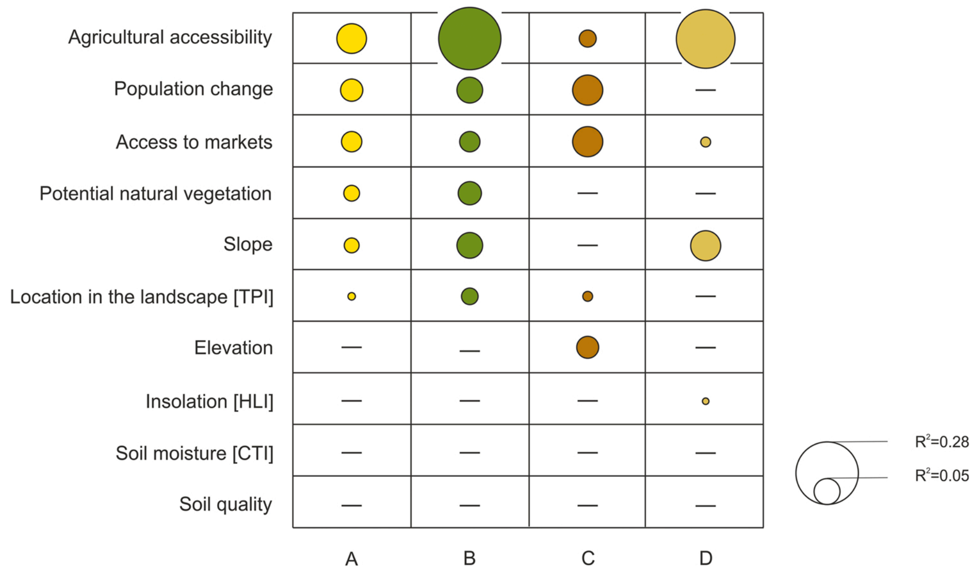

Fig. 4. Importance of each determinant explaining land use change on pre-war arable land after displacements (A: arable land → arable land vs arable land → all other land use; B: arable land → arable land vs arable land → forest; C: arable land → arable land vs arable land → grassland, D: arable land → forest vs arable land → grassland). Circle areas correspond to the partial pseudo-R^2 (Nagelkerke, 1991).

Table 4
Explanatory power (adjusted R^2 Nagelkerke) of the four best models run for the total study area and separately for each geographic region.

Region	Persistent arable land vs Conversion to all other land use	Persistent arable land vs Conversion to forest	Persistent arable land vs Conversion to grassland	Conversion to forest vs Conversion to grassland
Sanok-Turka	0.247	0.577	0.362	0.420
Bieszczady	-*	-*	-*	0.329
Lower Beskid	0.206	0.539	0.116	0.478
Sącz Beskid**	0.327	0.590	0.283	0.183
TOTAL study area	0.258	0.571	0.244	0.405

* Not enough persistent arable land plots to run the model.
** Together with Poprad Foothills.

Table A1
Ranking of soils from the Map of Carpathian soils (Skiba and Drewnik, 2003) in terms of agricultural suitability.

Rank	WRB (2015)
1	Chernozems
2	Fluvisols
3	Calcaric Leptic Cambisols
4	Calcaric Cambisols
5	Eutric Cambisols, Gleyic Cambisols, Stagnic Cambisols
6	Dystric Cambisols
7	Albic Luvisols, Stagnic Luvisols
8	Histosols, Dystric/Eutric Stagnosols, Histic Gleysols
9	Albic Podzols
10	Calcaric Hyperskeletic Leptosols, Calcaric/Dolomitic Folic Leptosols
11	Dystric Eutric Leptosols, Dystric Folic Leptosols
12	Lithic Leptosols, Regosols, Dystric/Eutric Leptosols

Table B1
Aggregating categories of Potential Natural Vegetation.

Aggregated class	Potential natural vegetation original class (Matuszkiewicz, 2008)
Riparian	*2. Salici-Populetum, 4. Ficario-Ulmetum, 6. Alnetum incanae, 7. Carici remotae-Fraxinetum*
Fertile oak-hornbeam	*19. Tilio-Carpinetum* fertile
Fertile beech-fir	*33. and 35. Dentario glandulosae-Fagetum* montane*, 34. Dentario glandulosae-Fagetum* submontane*, 40. Galio-Abietenion*
Poor deciduous	*18. Tilio-Carpinetum* poor*, 38. Luzulo luzuloidis-Fagetum, 46. Luzulo luzuloidis-Quercetum*
Other	*57. Abieti-Piceetum, Galio-Piceetum*

Table C1
Resistance values for the distance unit (10 m) adopted in the cost distance analysis.

Land cover	Resistance value	Slope value in degrees	Resistance value
paved roads	1	< 1	1
pastures, arable lands	20	1–5	2
shrubs	30	5–10	5
forest	50	10–15	15
watercourses with a width < 3 m	60	15–20	25
watercourses with a width 3–5 m	80	20–25	40
watercourses with a width > 5 m	100	25–30	60
big rivers (width > 50 m)	9999	30–40	100
water bodies	9999	> 40	9999

Adopted after Jabs and Affek (2019).

(Kubijovic, 1983), we selected villages with a pre-war Ukrainian population ≥ 75 %.

To delineate pre-war arable land, we analysed the 1:100,000 Tactical Map (TM) of the Polish Military Geographic Institute from 1936 to 38 (www.mapywig.org). This is the finest-scale map from the interwar period with full coverage (Affek, 2016). We georeferenced the scanned map sheets of both series (TM and Kummersberg) using affine and spline rubbersheeting transformation, respectively (Affek, 2013). To determine land-cover at the end of the socialist period, we selected the 1:100,000 1990 CORINE Land Cover database (CLC 1990) (Copernicus Program, 2020). Unfortunately, there are no data sources depicting

Table D1
Descriptive statistics of pre-displacement arable land broken down by main land cover type in 1990.

Land cover 1990	Determinant	N	Min	Max	Mean	Std. Error	SD
Arable land	Soil moisture [CTI]	779	5.81	16.63	8.16	0.05	1.36
	Insolation [HLI]	779	0.58	0.72	0.65	0.00	0.026
	Location in the landscape [TPI]	782	-84.99	91.15	-9.08	1.05	29.37
	Slope [°]	782	0.29	28.06	8.38	0.15	4.16
	Elevation [m]	782	287	767	509.49	3.29	91.91
	Agricultural access cost [lg10]	782	2.14	4.67	3.89	0.01	0.36
	Soil quality [1–11]	782	2	7	4.99	0.03	0.87
	Distance to markets [km]	782	5.04	47.58	21.94	0.25	6.97
Grassland	Soil moisture [CTI]	1029	5.77	16.40	8.10	0.04	1.33
	Insolation [HLI]	1029	0.57	0.75	0.65	0.00	0.03
	Location in the landscape [TPI]	1032	-106.69	107.35	-10.12	0.98	31.60
	Slope [°]	1034	0.00	28.57	8.42	0.13	4.30
	Elevation [m]	1034	285	945	563.50	3.05	98.03
	Agricultural access cost [lg10]	1034	2.57	5.14	4.03	0.01	0.36
	Soil quality [1–11]	1034	2	8	4.94	0.02	0.73
	Distance to markets [km]	1034	7.00	72.46	29.69	0.40	12.76
Forest	Soil moisture [CTI]	2507	5.45	15.96	7.76	0.03	1.31
	Insolation [HLI]	2507	0.54	0.75	0.65	0.00	0.04
	Location in the landscape [TPI]	2511	-120.90	163.08	6.63	0.81	40.58
	Slope [°]	2528	0.00	33.99	11.49	0.10	5.16
	Elevation [m]	2529	293	1004	589.38	2.08	104.55
	Agricultural access cost [lg10]	2529	1.91	5.27	4.46	0.01	0.33
	Soil quality [1–11]	2529	2	11	5.09	0.01	0.68
	Distance to markets [km]	2529	4.94	74.14	28.57	0.23	11.63

Table D2
Frequency and adjusted residuals of different land cover in 1990 on the pre-displacement arable land with different potential natural vegetation.

			Potential natural vegetation			
			Riparian forest	Fertile beech-fir forest	Fertile oak-hornbeam forest	Poor deciduous forest
Land cover 1990	Arable land	Count	121	323	323	14
		Adjusted Residual	1.7	-12.5	13.6	-1.3
	Grassland	Count	181	561	266	20
		Adjusted Residual	4.3	-4.9	2.6	-1.1
	Forest	Count	284	1749	396	70
		Adjusted Residual	-5.0	14.0	-12.9	1.9

Table D3
Frequency and adjusted residuals of different land cover in 1990 on the pre-displacement arable land with different levels of depopulation (1931–1950).

			Depopulation	
			Total	Partial
Land cover 1990	Arable land	Count	52	677
		Adjusted Residual	-14.0	16.8
	Grassland	Count	304	548
		Adjusted Residual	2.2	-5.3
	Forest	Count	807	1382
		Adjusted Residual	9.0	-8.5

agricultural land use immediately after the forced displacement (i.e., in the late 1940s or early '50s) that could help distinguish between continuous agricultural land use and re-cultivation.

2.3. Spatial determinants

To determine the extent to which geographic determinants explain persistence of arable farming after forced displacements, we collected data on various environmental and access-related characteristics (Prishchepov et al., 2013; Pueyo and Beguería, 2007; Sawicka et al., 2012; Szablowska-Midor, 2004). These included basic topographic features (elevation, slope), and relief-related variables indicating soil moisture, insolation and general location in the landscape (valley, slope or ridge) (Table 1). Specifically, we assessed soil moisture by the *Compound Topographic Index* (CTI) (Gessler et al., 1995), insolation by the *Heat Load Index* (HLI) (McCune and Keon, 2002), and location in the landscape by the *Topographic Position Index* (TPI) (Tagil and Jenness, 2008), which is also related to erosion and soil thickness (Florinsky et al., 2002). We calculated TPI within 1500 m of each pixel (Affek, 2016). Elevation, slope, TPI, CTI and HLI were all derived from the 30-m Digital Terrain Elevation Model (DTED Level2), developed for NATO by the Military Centre of Geodesy and Remote Sensing in 2001. To calculate CTI and HLI, we used Geomorphometry and Gradient Metrics Toolbox (Evans, 2020), and for TPI the Land Facet Corridor Designer (Jenness et al., 2011), an open-source extensions for ESRI ArcGIS 10.

We also included measures of soil quality for agricultural production. We derived these from the map of Polish Carpathian soils (Skiba and Drewnik, 2003) and ranked soil types from 1 (best suitability) to 12 (worst) (see Appendix A). Furthermore, we included potential natural vegetation (PNV), which is an aggregate measure of the overall soil- and climate-dependent potential of a given area (Hengl et al., 2018). We took potential natural vegetation types from the map of Poland in the scale 1:300,000 (Matuszkiewicz, 2008). We aggregated potential natural vegetation into five forest classes: riparian, fertile oak-hornbeam, fertile beech-fir, and poor deciduous (in total 98.9 % of all sample plots) and an *other* class, which we excluded from further analysis (see Appendix B).

To assess the accessibility of land for agriculture we used an integrated measure called *agricultural accessibility* (access cost based on the distance to the nearest farmstead, road quality and slope; Jabs and Affek, 2019) (see Appendix C for details). We also included another access-related variable – access to the markets – because it is often a significant determinant explaining land use changes when agriculture is not for subsistence only (Baumann et al., 2011; Müller et al., 2009). We calculated access to markets as the Euclidean distance to the nearest

Table D4
Parameter estimates and effects of the selected models with persistent arable land as reference category.

	Variable/ parameter	B	Std. Error	WaldChi-Square	df	Sig.
All other land use	Agricultural access cost	1.57	0.121	168.74	1	< 0.001
	Location in the landscape [TPI]	-0.01	0.001	9.70	1	0.002
	Slope	0.06	0.010	36.86	1	< 0.001
	Distance to markets	0.04	0.005	59.87	1	< 0.001
	Population change			49.77	1	< 0.001
	Total depopulation	-1.14	0.162	49.77	1	< 0.001
	Partial depopulation	0[a]	.	.	0	.
	Potential natural vegetation			42.33	3	< 0.001
	Riparian forest	-0.09	0.133	0.41	1	0.522
	Fertile beech-fir forest	-0.46	0.328	1.97	1	0.160
	Fertile oak-hornbeam forest	-0.62	0.099	38.86	1	< 0.001
	Other deciduous forest	0[a]	.	.	0	.
Grassland	Agricultural access cost	0.86	0.181	22.70	1	< 0.001
	Elevation	0.00	0.001	16.99	1	< 0.001
	Location in the landscape [TPI]	-0.01	0.002	20.53	1	< 0.001
	Distance to markets	0.05	0.007	42.97	1	< 0.001
	Population change			58.91	1	< 0.001
	Total depopulation	-1.31	0.170	58.91	1	< 0.001
	Partial depopulation	0[a]	.	.	0	.
Forest	Agricultural access cost	4.87	0.237	424.45	1	< 0.001
	Location in the landscape [TPI]	-0.01	0.002	32.82	1	< 0.001
	Slope	0.11	0.013	80.87	1	< 0.001
	Distance to markets	0.03	0.007	15.49	1	< 0.001
	Population change			25.71	1	< 0.001
	Total depopulation	-0.99	0.196	25.71	1	< 0.001
	Partial depopulation	0[a]	.	.	0	.
	Potential natural vegetation			54.93	3	< 0.001
	Riparian forest	-0.23	0.174	1.67	1	0.196
	Fertile beech-fir forest	-0.11	0.406	0.08	1	0.784
	Fertile oak-hornbeam forest	-0.95	0.130	53.70	1	< 0.001
	Other deciduous forest	0[a]	.	.	0	.

a - set to zero because this parameter is redundant.

town with a population > 20,000, because proximity to such urban centers ensures direct access to markets, and the storage and trade infrastructure.

We focused on geographic (environmental and access-related) determinants potentially affecting the profitability of farming and did not include socioeconomic and political determinants such as the individual characteristics of farmers or farm companies, external incentives, state and regional policies etc. We did so because we wanted to keep the model more universal, so the detected regularities be transferrable to other regions, but also because there is little fine-scale reliable socio-economic and political data available for the post-war era. We also controlled for the real change in population after displacements, because some villages became totally depopulated, while others only partly. We used the village-level data, which depicts population change between 1931 and 1950 (total vs partial depopulation) (Soja, 2008). For the 10 % of villages, for which no data for 1950 was available, we compared the 1931 census with the 1988 census instead (Soja, 2008). To justify the use of the 1988 census instead of data from 1950 we compared population density at the district level on the basis of the 1950 national census of the Rzeszów voivodship and the 1988 Statistical Yearbooks of the Krośnieńskie and Nowosądeckie voivodships (GUS, 1954; Górka, 1989; Węgrzyn, 1990). The results for the relevant districts (Gorlice, Jasło, Krosno and Sanok) showed only minor differences (3.4–14.3 persons/km^2, depending on the district) from 1950 to 1988, on average less than 10 %.

2.4. Modelling

To quantify the relative importance of geographic determinants and their overall power to predict land use change of arable land after the displacement, we parameterized logistic regression models. We divided arable land of the 1930s into 40-m pixels, and retained all pixels with $\geq$ 50 % arable land (678,990 pixels). To limit spatial autocorrelation and to avoid pseudo-replication for large fields, we applied systematic sampling, with 480-m distance among plots, which resulted in 4725 sample plots. According to statistical yearbooks from 1939 and 1990, respectively, 99.5 % and 99.7 % of farms in the region were $<$ 15 ha in size (GUS, 1939; GUS, 1990), so there was no more than one sample plot per farm (480×480 m = 23 ha). Furthermore, inspired by Müller and Munroe (2008), we cross-validated parameter estimates and goodness of fit measures obtained for the full sample (with 480-m sampling distance) with those obtained for four independent subsamples, each with 960-m sampling distance to assess the robustness of the results.

In the next step, we used *raster statistics for polygons* function in ArcGIS to calculate the mean values of topography-related quantitative determinants for each sample plot, and extract information about soil agricultural suitability and potential natural vegetation. Then, we parameterized the general model: persistent arable land vs transition into all other land use. Arable land that did not persist largely converted to two types of land use in 1990: grassland (CLC codes 231 and 321) or forest (CLC codes 311, 312, 313), and so we also fit three, more specific models: persistent arable land vs transition into grassland, persistent arable land vs transition into forest, and transition into grassland vs transition into forest. We ran our models both for the entire study area, and for each geographic region separately.

We carried out statistical analyses in R Studio (R version 3.6.3) and IBM SPSS Statistics 26. Before modelling, we checked all variables for normality and outliers. We log-transformed agricultural accessibility to approximate a normal distribution. We fit a series of logistic regression models containing all possible combinations of our variables, using the 'dredge()' function in R package "MuMIn" (Bartoń, 2019), and ranked models by the Bayesian Information Criterion (BIC), which penalizes over-parameterization. We also calculated two additional evaluation criteria (Akaike's Information Criterion – AIC, and Information Complexity criterion – ICOMP) to ensure that our model rankings were robust. The overall model performance (goodness of fit) was expressed by pseudo-R^2 coefficient of determination (Nagelkerke, 1991) that corrects the upper bound of the Cox and Snell index (Cox and Snell, 1989). We checked for multi-collinearity by applying the generalized variance-inflation factor GVIF (Fox and Monette, 1992), using the conservative cut-off value of ≤ 4 (Craney and Surles, 2002).

To assess relative importance of determinants (contribution to the determination of response variable) we performed dominance analysis (Budescu, 1993) as implemented in the R package 'dominance analysis' (Navarrete and Soares, 2020). The obtained hierarchy of importance

Table D5
Characteristics of pre-displacement arable land. Average values and standard deviations for sample plots in each geographic region and in total.

	Bieszczady Mts.		Lower Beskid Mts.		Sanok-Turka Mts.		Sącz Beskid Mts.*		TOTAL study area	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Elevation [m]	630.57	100.08	540.60	83.88	515.29	91.57	675.54	107.24	563.11	105.83
Location in the landscape [TPI]	-9.69	38.92	-1.99	36.76	2.72	33.38	0.83	47.11	-1.97	37.59
Soil moisture [CTI]	7.71	1.19	8.13	1.41	7.91	1.48	7.69	1.35	7.95	1.40
Insolation [HLI]	0.64	0.03	0.65	0.03	0.65	0.03	0.65	0.04	0.65	0.03
Slope [°]	11.09	5.23	8.99	4.31	10.06	5.19	13.35	5.69	10.06	5.04
Agricultural access cost [lg10]	4.40	0.42	4.15	0.43	4.22	0.50	4.16	0.50	4.22	0.47
Soil quality [1–11]	4.89	0.85	4.97	0.68	5.14	0.87	5.22	0.59	5.02	0.77
Distance to markets [km]	41.26	12.30	21.89	6.25	27.08	10.65	26.90	6.06	27.50	11.48

*Together with Poprad Foothills.

Table D6
Land cover in 1990 on former arable land. Adjusted standardized residuals (Adj.Res.) indicate if the percent of a given CORINE land cover class in a given region is significantly larger/smaller than would be in proportional distribution. Values higher than 1.96 and lower than − 1.96 indicate significance with $p \leq 0.05$.

CORINE Land Cover 1990	CLC code	Geographic region							
		Sanok-Turka Mountains		Bieszczady Mountains		Low Beskid Mountains		Sącz Beskid Mountains*	
		% within region	Adj. Res.	% within region	Adj. Res.	% within region	Adj. Res.	% within region	Adj. Res.
Discontinuous urban fabric	112	1.10	4.30	0.00	-2.20	0.10	-3.10	1.00	1.80
Industrial or commercial units	121	0.10	1.60	0.00	-0.50	0.00	-0.90	0.00	-0.30
Mineral extraction sites	131	0.00	-0.60	0.00	-0.50	0.00	-0.90	0.20	3.20
Construction sites	133	0.00	-1.20	0.00	-1.00	0.20	2.20	0.00	-0.60
Non-irrigated arable land	211	16.30	-0.30	0.50	-14.60	22.00	9.10	24.90	4.80
Pastures	231	20.00	0.80	11.50	-6.60	23.10	6.20	13.80	-2.90
Complex cultivation patterns	242	6.90	4.40	5.20	0.80	3.60	-3.10	2.20	-2.50
Land principally occupied by agriculture…	243	2.50	1.10	1.70	-0.90	2.00	-0.50	2.40	0.40
Broad-leaved forest	311	15.80	3.00	25.20	11.80	7.10	-11.40	11.10	-1.40
Coniferous forest	312	9.50	-5.30	13.20	-0.60	16.70	5.00	14.50	0.40
Mixed forest	313	25.40	-0.90	30.10	2.90	24.80	-2.20	28.80	1.20
Natural grasslands	321	0.80	-4.90	11.50	18.60	0.30	-9.20	1.00	-2.20
Transitional woodland-shrub	324	0.20	-0.20	0.80	3.40	0.10	-2.00	0.00	-1.10
Watercourses	511	0.00	-0.90	0.20	2.90	0.00	-1.30	0.00	-0.40
Water bodies	512	1.30	6.80	0.00	-2.00	0.00	-3.70	0.00	-1.30

*Together with Poprad Foothills.

Table D7
Frequency and adjusted standardized residuals (Adj.Res.) indicating if the percent of arable land, grassland or forest in 1990 in a given geographic region is significantly larger/smaller than it would be in proportional distribution. Values higher than 1.96 and lower than − 1.96 indicate significance with $p \leq 0.05$.

			Subregion			
			Sanok-Turka Mountains	Bieszczady Mountains	Low Beskid Mountains	Sącz Beskid Mountains*
Land cover 1990	Arable land	Count	208	5	466	103
		Adjusted Residual	0.6	-14.7	8.6	4.6
	Grassland	Count	265	212	496	61
		Adjusted Residual	-0.1	0.9	1.6	-3.9
	Forest	Count	646	631	1027	225
		Adjusted Residual	-0.4	10.7	-8.1	-0.2

* Together with Poprad Foothills.

reflects the average contribution of each determinant in the model expressed by the partial Nagelkerke pseudo-R^2, recommended by Azen and Traxel (2009) for dominance analysis in logistic regression models.

In the final step we applied one-way ANOVA and post hoc Tamhane pairwise tests (used when the variances are not equal; Tamhane, 1977) to test for the significance of differences between mean values of the continuous geographic determinants obtained for different land uses. For categorical determinants, we used the adjusted standardized residuals (Adj.Res. – the difference between the observed counts and expected counts divided by an estimate of the standard error; Agresti, 2002) to indicate if the area of a given land-cover class in a given depopulation class/potential natural vegetation type/geographic region was significantly larger or smaller than in a proportional distribution.

3. Results

3.1. Directions of post-displacement farmland transformations

Land use of the post-displacement Carpathian villages changed substantially after WWII (Fig. 2). In the late 1930s, 32.2 % of the area of villages that we analysed was arable land, but by 1990, the end of the socialist period, that dropped to only 7.2 %. Most of the arable land converted by 1990 to forests (53.5 %) or grassland (semi-natural and pastures, 21.7 %) (Table 2). Only 16.4 % persisted as arable land, either because fields were never abandoned, or re-cultivated. These three main conversions occupied 91.6 % of the study area. However, we acknowledge that within the two heterogonous CLC classes (242 and 243), there was probably also some arable land, and so in 1990 a little bit more land

Table D8
Explanatory power (adjusted R^2 Nagelkerke) of the models parameterized separately for each geographic region. Determinants listed in order of importance.

Region	Persistent arable land vs Conversion to all other land use		Persistent arable land vs Conversion to forest		Persistent arable land vs Conversion to grassland		Conversion to forest vs Conversion to grassland	
	Variables	R^2	Variables	R^2	Variables	R^2	Variables	R^2
Sanok-Turka	Agricultural accessibility, Elevation, Slope, Location in the landscape, Potential natural vegetation	0.25	Agricultural accessibility, Slope, Potential natural vegetation, Location in the landscape, Elevation	0.58	Elevation, Location in the landscape, Potential natural vegetation, Agricultural accessibility	0.39	Agricultural accessibility, Slope, Distance to markets	0.42
Bieszczady	-	-	-	-	-	-	Agricultural accessibility, Slope Insolation Elevation	0.34
Lower Beskid	Agricultural accessibility, Population change, Potential natural vegetation, Location in the landscape, Slope, Elevation, Insolation	0.21	Agricultural accessibility, Potential natural vegetation, Slope, Location in the landscape, Insolation	0.54	Population change, Location in the landscape, Elevation, Slope, Agricultural accessibility	0.12	Agricultural accessibility, Slope, Potential natural vegetation, Population change, Location in the landscape, Distance to markets	0.50
Sącz Beskid	Slope, Agricultural accessibility, Elevation	0.35	Agricultural accessibility, Slope, Soil quality	0.60	Slope, Elevation, Agricultural accessibility	0.39	Agricultural accessibility, Soil quality, Elevation	0.23

Table E1
Cross-validation results (comparison of parameter estimates and goodness of fit) for the full sample (with 480 m sampling distance) and the four subsamples, each with 960 m sampling distance.

Sample	1_960 m	2_960 m	3_960 m	4_960 m	460 m
N	1189	1156	1150	1105	4600
	Unstandardized coefficients (B)				
Constant/Intercept	-7.471	-6.123	-7.017	-5.768	-6.462
Distance to markets	0.034	0.051	0.037	0.041	0.041
Population change (binary)	1.274	1.274	1.246	0.807	1.140
Potential natural vegetation (cat)	-	-	-	-	-
Agricultural access cost	1.849	1.360	1.742	1.472	1.567
Slope	0.054	0.068	0.067	0.056	0.060
Location in the landscape [TPI]	-0.006	-0.004	-0.007	-0.003	-0.005
	Significance of coefficients (p)				
Distance to markets	0.001	< 0.001	0.001	< 0.001	< 0.001
Population change (binary)	< 0.001	< 0.001	< 0.001	0.008	< 0.001
Potential natural vegetation (cat)	0.169	< 0.001	0.015	0.014	< 0.001
Agricultural access cost	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Slope	0.004	0.001	0.002	0.006	< 0.001
Location in the landscape [TPI]	0.056	0.190	0.019	0.381	0.002
	Model goodness of fit				
$AdjR^2Nag.$	0.256	0.279	0.271	0.239	0.258

Table E2
Bayesian information criterion (BIC) model rankings compared with rankings based on other information criteria (Akaike Information Criterion – AIC and Information complexity criterion – ICOMP) and the goodness of fit measure (Adjusted Nagelkerke R^2) of the ten best models ranked by BIC. For all information criteria, lower values are better.

	Model No	BIC	AIC	ICOMP	$AdjR^2$
1. Persistent arable land vs Conversion to all other land use (N = 4600)	**1**	**3489**	**3431**	3458	0.26
	2	3490	3438	**3457**	0.25
	3	3496	3432	3474	0.26
	4	3496	3438	3471	0.26
	5	3497	3432	3469	0.26
	6	3497	3433	3461	0.26
	7	3497	3433	3462	0.26
	8	3497	3439	3461	0.26
	9	3498	3440	3460	0.25
	10	3498	3440	3468	0.25
2. Persistent arable land vs Conversion to forest (N = 3224)	**1**	**2086**	**2031**	2063	0.57
	2	2092	2031	2063	0.57
	3	2092	2032	2074	0.57
	4	2094	2033	2074	0.57
	5	2094	2033	2067	0.57
	6	2094	2045	2058	0.57
	7	2097	2042	**2056**	0.57
	8	2098	2031	2075	0.57
	9	2099	2033	2067	0.57
	10	2100	2033	2075	0.57
3. Persistent arable land vs Conversion to grassland (N = 1791)	**1**	**2138**	2105	2144	0.24
	2	2142	**2103**	**2143**	0.25
	3	2145	2107	2149	0.24
	4	2145	2107	2148	0.24
	5	2145	2107	2155	0.24
	6	2148	2120	2149	0.23
	7	2148	2105	2147	0.25
	8	2149	2105	2147	0.25
	9	2149	2105	2155	0.25
	10	2152	2124	2154	0.23
4. Conversion to forest vs Conversion to grassland (N = 3459)	**1**	**3068**	3037	**3069**	0.40
	2	3068	**3031**	3074	0.41
	3	3070	3033	3077	0.41
	4	3071	3040	3076	0.40
	5	3073	3049	3076	0.40
	6	3074	3031	3084	0.41
	7	3074	3037	3071	0.41
	8	3075	3038	3073	0.41
	9	3075	3032	3076	0.41
	10	3075	3032	3075	0.41

was cultivated. However, those two CLC classes occupied only 7.3 % of the total area, to the amount of uncertainty introduced by these classes was small. Furthermore, almost 400 ha of former arable land was under water due to river engineering and construction of water reservoirs. Among the different geographic regions in our study area, agriculture persisted to a varying degree, being highest in the Sącz Beskid (24.9 %), and lowest in the Bieszczady Mountains (0.5 %) (for the detailed comparison between the geographic regions, see Appendix D).

3.2. Determinants of land-cover change on former arable land

The best model explaining where arable farming persisted included six out of our ten variables: agricultural accessibility, distance to markets, depopulation, slope, location in the landscape (TPI), and potential natural vegetation (Table 3). However, the overall performance of our best model was quite poor, with $R^2 = 0.26$. Arable farming persisted most often in more accessible locations, in close distance to markets, on flat slopes and in the valleys, where fertile oak-hornbeam forests are the potential natural vegetation, and in only partially depopulated villages (Fig. 3). The dominance analysis showed a fairly equal importance of the determinants, with those related to access being most important (Fig. 4).

Comparison of modeling results for different samples and sampling distances (460 and 960 m) showed that the general model was robust (parameter estimates and goodness of fit measures were relatively stable, see Appendix E, Table E1), and that spatial autocorrelation had already been sufficiently reduced with the 460-m sampling distance. We based our selection of the best models on the BIC. That models also ranked high based on the other two criteria (AIC and ICOMP) (Appendix E, Table E2). Although some other models comprising more parameters sometimes ranked higher in terms of AIC or ICOMP, their goodness of fit was no better than the top models selected based on BIC (Table E2).

The best model explaining full abandonment (conversion into forests) included the same six variables, but in slightly different order of importance: agricultural accessibility, distance to markets, depopulation, slope, location in the landscape (TPI), and potential natural vegetation. Furthermore, the overall performance of this model was quite good, with $R^2 = 0.57$. Conversion into forest took place most often on the least accessible former arable land, on steep slopes and mountain ridges, and far from settlements and markets. Furthermore, areas that converted to forests were concentrated where beech-fir forests are the potential natural vegetation. The dominance analysis showed that agricultural accessibility was by far the most important geographic determinant discriminating persistence of arable farming versus conversion to forest.

The best model explaining conversion into grassland included five of the ten variables: agricultural accessibility, distance to markets, depopulation, location in the landscape, and elevation. However, its overall performance was quite poor, with $R^2 = 0.24$. Post-arable grasslands were located on higher elevated and less accessible locations, further away from markets, and more often reported in fully depopulated villages. However, these locations were still significantly more accessible and at lower elevations than post-agricultural forests (Fig. 3). Slope, location in the landscape, insolation, soil moisture and quality were environmental parameters that did not differentiate the persistent arable land from those that converted into grassland in displacement areas. The dominance analysis showed that distance to markets and the level of depopulation were the two most important determinants.

The best model explaining conversion to grassland vs conversion to forest included only four variables: agricultural accessibility, slope, distance to markets and insolation, with the former two being by far the most important. The overall model performance was average, with $R^2 = 0.41$. Post-arable grasslands were located on less steep slopes, closer to markets, and in more insolated and better accessible locations.

We obtained varying levels of model performance when running the models for individual geographic regions (Table 4). The models for full abandonment differed not very much in explanatory power across regions (R^2 from 0.54 to 0.59), but the models explaining conversion to grassland did (R^2 from 0.18 to 0.48). The mean R^2 for the regional models was very close to the explanatory power of the models performed for the entire study area. For the different models for each geographic region, we obtained quite diverse sets of significant determinants (Appendix D, Table D6). Interestingly though, agricultural accessibility was included in all 13 regional models, and in 9 models (70 %) it was the most important determinant. In contrast, access to markets, was a significant determinant in all four models for the full study area, but at the regional level it was significant in only in 2 out of 13 models (15 %). Furthermore, the rate of population change remained significant only in one region – the Lower Beskid.

4. Discussion

4.1. Limited agriculture persistence in post-displacement areas

The Carpathian agricultural landscape underwent a substantial transformation following population displacement after WWII. Only a small fraction of former arable land (16 %) remained in cultivation by 1990, either because it was never abandoned, or because it was re-cultivated. Most of the pre-displacement arable land was fully abandoned and turned into forest, which resulted in the rewilding of vast areas of former villages (Affek et al., 2021). However, the shift to less intensive agricultural use (i.e., to grasslands used as pastures or for hay-cutting) was also common, meaning that new owners either found livestock production to be more profitable, or wanted to prevent woody growth and thereby keep their options for a later return to arable farming open. The landscape change in the Carpathians after displacements can by thus interpreted as an abrupt change of land-use regime for which rapid demographic change acted as a trigger (Ramankutty and Coomes, 2016). The limited persistence of agricultural land use was largely due to permanent depopulation (Soja, 2008). Even though displaced residents were allowed to return in the 1950s, only a few decided to do so. One reason for this is because the settlements of the Ukrainian population left after displacements were immediately burned and destroyed (Wolski, 2016). Borderland location, poor infrastructure, generally unfavourable farming conditions (Musiał et al., 2010) and low agricultural accessibility (Jabs and Affek, 2019) were additional post-war self-reinforcing forces that prevented a return to the old land-use regime (Affek et al., 2021).

Permanent abandonment is generally rare (Crawford et al., 2022), but common in areas affected by displacements or conflicts (Sánchez-Cuervo and Aide, 2013; Witmer and O'Loughlin, 2009; Yin et al., 2019). However, the degree of agriculture persistence in the Polish Carpathians was very low even compared to other post-displacement areas, and despite economic incentives for agriculture (Affek et al., 2021). For example, in Poland's "Recovered Territories", from which the German population fled after World War II, the re-population was very fast and there was almost no reforestation (Koral, 2001). The reason for this was that former German farms were often left in good condition, arable land was fairly accessible and located on flat terrain with fertile soils (Koral, 2001). In general, in post-war Central and Eastern Europe the fertile arable land in the lowlands were almost all rapidly re-cultivated shortly after the displacements, but in mountainous areas, far from population centres, the majority of arable land was permanently abandoned (Eberhardt, 2011; Soja, 2008; Zelinka et al., 2021).

While uncommon, our results showed that some arable land did persist after the displacements. Some of this arable land was continuously farmed, but other was re-cultivated quickly after WWII, according to historical records and memories of local people. For example, the statistical records for 1950 and 1957 showed that the area of individual farms increased from 24.4 % to 25.4 % in the six districts that were in half displacement areas (PWRN, 1958, 1959, GUS, 1954). Moreover, already in 1957, 16,294 ha of arable land was managed by state-owned farms. Because the state-owned farms were established on nationalized land at least few years after abandonment (Wolski, 2016), all state arable land must have been re-cultivated. In general though, re-cultivation appears to be much more common after economically-driven agricultural land abandonment. For example, after the collapse of the Soviet Union the share of farmland in north-central Kazakhstan decreased from 54 % to 30 %. After that, only 25 % of abandoned farmlands were re-cultivated there (Kraemer et al., 2015), while in western Ukraine, a half of abandoned farmlands was re-cultivated and half remained unused (Smaliychuk et al., 2016). The question remains, what determines which arable land persists.

4.2. Determinants of agriculture persistence in post-displacement areas

Of the geographic determinants considered, persistence of post-displacement arable land was driven mainly by agricultural accessibility, access to markets, potential natural vegetation type, and slope. Higher costs and longer travel times to less accessible arable land make agriculture less profitable there and therefore it is abandoned in the first place (Lieskovský et al., 2017). Access to markets and related sales opportunities is another access-related determinant that proved important for agriculture persistence because it affects profitability of agriculture, in particular when agriculture is not for subsistence only. Easy access to markets allows farmers to save time and cost when transporting crops, and also provides social functions for rural population (Prishchepov et al., 2013). Persistent agriculture was also determined by agricultural productivity, which is lower on steep slopes due to erosion, and at higher elevation due to frosts and less favourable climate (Kumar et al., 2020; Nastis et al., 2012). The potential natural vegetation reflects the suitability of a given area for vegetation growth, which reflects agricultural productivity (Kumar et al., 2020). Areas where oak-hornbeam forest can develop are among the most suitable for agriculture in Central Europe, and this is where agriculture started already during in the Middle Ages (Rüther and Walentowski, 2008). Accordingly, we found that arable land was the most persistent where oak-hornbeam forests are the potential natural vegetation. The important modifying factor was the level of population change after displacements, with total depopulation linked closer with agricultural abandonment, and partial depopulation with persistent agriculture.

The determinants limiting agriculture persistence and abandonment in the Carpathian post-displacement areas were similar to those that affect economically-driven agricultural land abandonment in marginal lands, including mountainous areas. Most of the areas subject to economically-driven agricultural land abandonment are situated far from population centres, and often in mountainous regions, where the natural environment further limits agriculture (Kuemmerle et al., 2008; MacDonald et al., 2000; Terres et al., 2015). Land abandonment can also be caused by availability of more fertile and easier-to-cultivate land elsewhere, economic development, opening up new markets and the emergence of new non-agricultural sources of income (Conti and Fagarazzi, 2004). In the Polish Carpathians among the determinants of economic agricultural abandonment during the post-socialist transition, slope had the highest explanatory power, followed by accessibility and topography (Kolecka et al., 2017). Similarly, in Slovakia, agricultural abandonment in 1990–2000 was much more likely on lower quality soils, in less accessible areas and in the vicinity of non-farmed land, while in 2000–2006 – on steeper slopes and closer to shrubs (Pazúr et al., 2014). In the European Russia, the productivity of the land, as measured by average grain yields, had the greatest effect on agricultural land abandonment, which was also common in isolated farmlands close to forest and far from markets (Prishchepov et al., 2013). In China, abandonment rates were higher on steep slopes, poor quality soils and far from villages (Zhang et al., 2014). Accordingly, there is a similarity between the variables affecting abandonment and persistence of agriculture, in that the productivity and profitability of agricultural production are important for both. On the other hand, in our research, the model for persistent agriculture had much lower explanatory power than the model for full agricultural abandonment resulting in forest regrowth. That suggests that there are other determinants than the universal geographic ones that we included in our models that affect agriculture persistence, such as socio-economic factors that differ among farmers.

The main novel contribution of our research is the comparison of determinants of conversion of arable land into grassland (i.e., less intensive agricultural use) versus the conversion into forest (i.e., full abandonment, and end of agricultural practices). In our results, transition into grassland was partly explained by access to markets and elevation, while conversion into forest primarily by agricultural accessibility. In turn, the most important determinants of whether arable land converted into grassland or overgrown with forest were agricultural accessibility and slope. Interestingly, post-agricultural grasslands were located on average further away from markets than post-agricultural forests. That may be because post-agricultural grasslands were concentrated in desolated and completely depopulated villages where state-owned farms engaged in grazing (Turnock, 2002). These state-owned farms were established according to the plan created by the central government, on a relatively accessible and agriculturally suitable areas but regardless of the local market (Grala, 2020).

Our results showed major differences between the determinants and explanatory powers for the models conducted for the entire study area and for individual geographic regions. Interestingly, in the model for the entire study area, access to markets was one of the most important determinant, while for the different regions this was in most cases no longer significant. We therefore think that the differences in the average market access between geographic regions (up to 20 km, see Appendix D, Table D5) largely determine the differences in agricultural persistence among the regions. Explanatory power for the models explaining full agricultural abandonment and conversion to grassland varied considerably depending on the region, but for full abandonment (reforestation) it was uniformly high in each regional model (between 0.52 and 0.59). Conversion to grassland was generally poorly explained by our geographic determinants, and the Lower Beskid was the region where the model performed the worst (R^2 =0.12). This region is characterized by very minor elevation differences and slopes, and also by the least diverse climate and vegetation, which meant that topography-related variables were inherently of limited value here. Other specific determinants, not included in the models, may be particularly important in the Lower Beskid, because this is the region where numerous, large, state-owned animal farms the establishment after the war (Turnock, 2002). However, despite the substantial diversity across regions, accessibility- and productivity-related determinants remained crucial in explaining land use change on post-displacement arable land in each region.

5. Conclusions

We found that arable farming persisted in the Polish Carpathians only in small pockets, and most of the arable land was abandoned after the socioeconomic shock of forced displacements in the aftermath of WWII. Forty years after forced displacements, former arable land had mostly converted to either forests or grasslands. Persistence of agricultural land use, which includes both continuous farming and rapid recultivation, was mostly driven by agricultural accessibility, access to markets, potential natural vegetation, and topography, but their overall explanatory power was quite low. Full abandonment was explained by similar set of determinants, and those determinants explained abandonment better than either persistence of arable farming and conversion to grassland. We therefore conclude that agriculture persistence is not simply the opposite process of agricultural land abandonment. Post-displacement change in agricultural practices into less intensive uses, all of which strongly affect biodiversity and ecosystem services, is more difficult to predict with the considered environmental and access-related determinants. As such, our general results should be transferable to other regions experiencing forced displacements and limited repopulation. More broadly, our findings can be used to develop strategies and policies in response to displacement in areas affected by depopulation-related agricultural land abandonment.

Declaration of Interest statement

The Authors declare no conflict of interest.

Data Availability

Data will be made available on request.

Acknowledgements

This work was supported by the Polish National Agency for Academic Exchange, Poland [Grant No. PPN/BEK/2018/1/00501], and NASA's Land Cover and Land Use Change Program, USA. We thank S. Skiba for sharing the soil map of the Polish Carpathians, M. Degórski for the help in ranking Carpathian soils, and L. Farwell for statistical advice.

Appendix A

Table A1

Appendix B

Table B1

Appendix C

Calculation of agricultural accessibility

To estimate agricultural accessibility (current as of 1990), we used the cost-distance tool available in ArcGIS software, which calculates the least accumulative cost distance for each cell to the nearest source (least cost path) (ESRI, 2018). Cost distance tool creates output raster, where each cell is described by accumulative cost of reaching from the nearest source cell.

To create source raster, from which we calculate accessibility, we used KUMN layer with residential buildings from the Database of Topographic Objects (BDOT10k). We established resistance value corresponding to the relative travel costs incurred by a farmer who drives a tractor/horse cart from an arable field to the nearest farm building. To generate the cost raster, we used data on roads, watercourses, land cover and slope. For this purpose, we took roads and watercourses from the VMap Level2 spatial database with an accuracy corresponding to a scale of 1: 50,000, land cover from CLC 1990 with an accuracy corresponding to a scale of 1: 10,000. We calculated slope with the use of DTED Level 2. The assigned resistance values for each spatial unit (raster cell 10 m) are shown in Table C1. On the layer with resistance values for land cover, we overlaid the resistance layer with paths and roads and then summed them up with the slope values. Digital layers of roads and residential buildings were available based on 1:25,000 topographic map from the 1980s (http://mapy.geoportal.gov.pl/wss/service/img/guest/TOPO/MapServer/WMSServer).

Appendix D

Additional tabular results, including the comparison of geographic regions

Table D1–D4

The comparison at the regional level showed that the Bieszczady Mountains stood out from other geographic regions with an exceptionally small area of persistent agriculture and a much higher percentage of post-agricultural forests, in particular broad-leaved forests (Table D5). Moreover, the analysis of adjusted residuals revealed that in the Bieszczady Mountains there was considerably more grassland on former arable land classified as natural in CLC 1990 (Adj.Res.=18.6) compared to proportional distribution, while post-arable pastures – substantially less (Adj.Res.=−6.6). In turn, Sanok-Turka Mountains differ from other regions because of higher than proportional share of complex cultivation patterns within the pre-war arable land (Adj.Res.=4.4), smaller share of post-agricultural coniferous forests (Adj.Res.=−5.3), and substantial share of water bodies on top of former arable land (e.g. the Solina Reservoir). Similar patterns were obtained when only three major land-cover classes were distinguished (Table D6). In this division, significantly lower than proportional share of arable land was observed in the Bieszczady Mountains (Adj.Res.=−14.7), while significantly higher in the Low and Sącz Beskids (Adj.Res.= 8.6 and 4.6, respectively).

Differences in agriculture persistence between the regions reflect differences in agricultural accessibility (Jabs and Affek, 2019). The lower the accessibility, the less arable land persited (be it continuous farming or rapid re-cultivation). According to Musiał et al. (2010), Low Beskid Mountains and the Sanok-Turka Mountains are characterized by relatively good overall agro-climatic conditions, while Bieszczady Mountains and Sącz Beskid Mountains belong to areas with much worse conditions. The Bieszczady Mountains, where the reforestation was on the largest scale, was characterised not only by the most unfavourable farming conditions, but also by the lowest population density and access to markets (Musiał et al., 2010; Wolski, 2016). These characteristics, along with different economic development planned by the central government for each region, partly explain regional differences in the persistence of row-crop agriculture (Tables D5–D8).

Appendix E

Model robustness assessment and impact of spatial autocorrelation on the general model (persistent arable land vs transition into all other land use)

Tables E1 and E2

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