






Historical land use dataset of the Carpathian region (1819–1980)

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ABSTRACT

We produced the first spatially explicit, cross-border, digital map of long-term (160 years) land use in the Carpathian Ecoregion, the Hungarian part of the Pannonian plains and the historical region of Moravia in the Czech Republic. We mapped land use in a regular 2 × 2 km point grid. Our dataset comprises of 91,310 points covering 365,240 km² in seven countries (Czechia, Slovakia, Austria, Hungary, Poland, Ukraine and Romania). We digitized three time layers: (1) for the Habsburg period, we used maps of the second Habsburg military survey from years 1819–1873 at the scale 1:28,800 and the Szatmari's maps from years 1855–1858 at scale 1:57,600; (2) The World Wars period was covered by national topographic maps from years 1915–1945 and scales here ranged between 1:20,000–1:100,000; and (3) the Socialist period was mapped from national topographic maps for the years 1950–1983 at scales between 1:25,000–1:50,000. We collected metadata about the years of mapping and map sources. We used a hierarchical legend for our maps, so that the land use classification for the entire region consisted of 9 categories at the most general level and of 22 categories depending on the period and a country.

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1. Introduction

Eastern Europe experienced several major socio-economic transformations during the last two centuries: the demise of the Habsburg Empire, two World Wars, the rise and fall of Socialism, and the eastward expansion of the European Union. As such, the region represents a great ‘natural experiment’ for land use scientists (Alcantara, Kuemmerle, Prishchepov, & Radeloff, 2012; Gutman & Radeloff, 2017; Skokanová, Falčan, & Havlíček, 2016). Large-scale studies from the area are limited by availability of land use data and are commonly based on remote sensing sources which provide land cover and land use information only since the second half of the twentieth century (Feranec, Jaffrain, Soukup, & Hazeu, 2010; Griffiths, Müller, Kuemmerle, & Hostert, 2013; Prishchepov, Müller, Dubinin, Bauermann, & Radeloff, 2013). Despite the availability of long-term large-scale modeled data (Fuchs, Herold, Verburg, & Clevers, 2013), their reliability remains uncertain and depends on the quality of the model

and the input data. However, long-term land use data sources exist for the area of the former Habsburg Empire, where unique sets of military maps from the second half of the eighteenth century and the end of the nineteenth century are available (Timár, Biszak, Székely, & Molnár, 2010). They provide, together with the maps from the World Wars period and topographical maps from the Soviet era, valuable information about long-term land use development (Munteanu et al., 2014; Skokanová et al., 2012). We present those digitized maps as a unique source material for studies long-term land use change in the region.

The aim of the paper is to present and make available information about land use from digitized historical maps of the Carpathian area (here defined as the Carpathian mountains and the Pannonian plain) from three time periods: (1) Habsburg period (maps from 1819–1873), (2) World Wars period (maps from 1923–1945), (3) Socialist period (maps from 1950–1980).

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2. Methods

2.1. Study area

The boundary of the study area follows maps availability, natural boundaries (the Carpathian mountains and Pannonian plain) and boundaries of former and current socio-economic regions. In Poland and Ukraine, the study region is bounded by northern and north-eastern boundary of the Carpathian mountain range. The Romanian part corresponds to historical Transylvania (the eastern part of the Habsburg Empire), and includes the eastern part of the Carpathian mountains. Hungary represents the southern part of our study area. The western part in Austria corresponds to the historical border of the Hungarian Habsburg Empire. In the Czech Republic, the north-eastern part of the study area is bounded by former Moravia Margraviate.

2.2. Sources of historical maps

For mapping the Habsburg period, we used the maps of Second Habsburg Military Survey (later Second Military Survey) that covered the largest proportion of the area (Table 1) and Szathmári's map that covered the Southern Romanian Carpathians. The Second Military Survey was ordered by Kaiser Franz I in the year 1806. The survey was based on a coherent triangulation network with the base-point on the tower of the St. Stephan's Cathedral in Vienna (Hofstätter, 1989; Jankó, 2007). The Second Military Survey covers a large continuous area in Central Europe from the Po Plains in northern Italy to Galicia in western Ukraine (Timár et al., 2010). Mapping years varied from 1819 to 1873, however half of the area was mapped in a 12 years period between 1852 and 1864. The accuracy is better than 200 meters in most cases; for the most

populated and important parts of the Empire it is between 25 and 100 meters (Pavelková et al., 2016; Timár et al., 2010).

The Szathmári's maps, named after the lithographer Szathmári Pap Károly, were published in 1864. These color maps were based on the Austrian survey of Walachia carried out between 1855 and 1858. The map set contains 112 sheets at a scale of 1:57,600 (Bartos-Elekes, Timár, Imecs, & Magyar-Sáska, 2013). The legend of the Szathmári's map contains 38 symbols.

The World Wars period was mapped from 10 different map sets (Table 1) spanning the years 1922 to 1944. After the first World War, the Habsburg empire was split and new countries emerged. The regimes and boundaries were changing and the areas were mapped according to new military demands. The most complex situation was in Czechoslovakia. The preliminary (Beneš) maps and Definitive (Křovák) maps were mapped by the Military Geographic Institute in Prague before the Second World War. Both map sets were detailed and up-to-date. Because of the slow speed of mapping, only a small area was covered by the Preliminary (Beneš) maps (Mackovčín & Jurek, 2015). The definitive (Křovák) maps were with the support of aerial photographs in some areas. The spatial error of Křovák maps is less than 1 m (Mackovčín, 2014). The revised Topographic special maps were based on the Third Austrian Military survey that was carried out in Czechia between years 1877 and 1880 and in Slovakia between 1875 and 1883. The geographic names were translated, contours were added and topography was updated using the recent topographic maps and, after 1930, the aerial images (Mackovčín, 2012). However, the actuality of these maps is questionable and we only used the Revised Topographic Special maps in cases that there were no other data sources. The German topographic maps (Sondersausgabe and Karte

Table 1. Map sources and number of the grid points mapped from each map source.

Period	Description	Years of mapping	Scale	Number of points	Reference
Habsburg	Second Habsburg Military Survey	1819–1873	1:28,800	86,764	Timár et al. (2010)
	Szathmári's map	1855–1858	1:57,600	4576	Bartos-Elekes et al. (2013)
World Wars	Preliminari (Beneš) maps	1923–1933	1:20,000	248	Mackovčín and Jurek (2015)
	Revised third Habsburg Military surveys maps by MGI Prague	1923–1945	1:25,000	3263	Mackovčín and Jurek (2015)
	Definitive (Křovák) maps	1931–1938	1:20,000	2649	Mackovčín and Jurek (2015)
	German military maps (Sondersausgabe)	1937–1941	1:25,000	3442	Mackovčín and Jurek (2015)
	German topographic maps (Karte der Slowakei)	1936–1941	1:25,000	3596	Mackovčín and Jurek (2015)
	Revised Topographic Special maps	1938–1941	1:75,000	1080	Mackovčín (2012)
	German topographic maps (Topographische Karte (4 cm-Karte) Messtischblatt	1941–1943	1:25,000	3189	Mackovčín and Jurek (2015)
	Soviet maps	1930	1:50,000	24,323	
	Polish tactical map of Wojskowy Instytut Geograficzny (WIG)	1934–1939	1:100,000	11,226	Krassowski (1974)
	Topographic maps of Hungary	1940–1944	1:50,000	37,015	Timár et al. (2008)
Socialist	Romanian military topographic maps	1978–1983	1:25,000	34,794	Romanian Ministry of Defense, Department of Military Topography (1978–1983)
	Czechoslovak military topographic maps	1950–1959	1:25,000	18,952	
	Polish topographic maps	1974–1983	1:25,000	5583	
	Hungarian military topographic maps	1953–1959	1:25,000	24,299	Cartographic Institute of the Hungarian Ministry of Defense (1953–59)
	Soviet military topographic maps	1950–1962	1:25,000	7040	

der Slowakei) were produced from 1936. They were based on the third Austrian Military Survey maps or on the Revised Topographic Special maps that were transferred to 1:25,000 scale. The Topographische Karte (4 cm-Karte) Messtischblatt, produced in 1941–1943, are based on field mapping and therefore are highly reliable. Information about the land use in the 1930s in Poland and Ukraine was derived from the Polish tactical map of Wojskowy Instytut Geograficzny (WIG 1:100,000). At the time of their creation, the maps were considered an excellent example of the modern cartographic design and valuable source of information including land use (Krassowski, 1974).

In the beginning of the Second World War, the Kingdom of Hungary started to create a map of its territory including the temporarily regained Slovak Highland, Carpathian Ruthenia, Northern Transylvania and Southern Land (Timár, Molnár, Székely, Biszak, & Jankó, 2008). Because of the high demand for a new map in times of war, the 1:50,000 scale map sheets were hastily created between 1940 and 1944. The content and quality of the map sheets are quite heterogeneous depending on the available base-maps (Jankó, 1992). Most of them (286 sheets) are a photographic enlargement of the revised or partly corrected 1:75,000 scale maps. Sixty-five sheets were created from the rescaled and renewed (with photogrammetric support) 1:25,000 scale Third Military Survey maps. Thirty-two sheets are revised versions of earlier 1:50,000 scale maps. The remaining 20 sheets derive from newly surveyed 1:25,000 scale maps.

The maps for the Socialist period were produced following the common methodology for the Central and East European socialist countries. All the maps were in the same scale, and use similar map symbols. The maps are based on aerial images and provide the information with high spatial accuracy. The maps were produced for each country in different periods. Although

for Poland the maps were produced for civil purposes, unlike the other countries, the land use information on that map was comparable to military maps.

2.3. Digitizing

We mapped the land use according to 2 km regular square grid, that matches the requirements of the INSPIRE (Infrastructure for Spatial Information in the European Community) Directive (<http://inspire.ec.europa.eu>) and LUCAS (Land Use and Cover Area frame Survey) grid (Jacques & Gallego, 2005). Our dataset comprises of 91,310 points covering 365,240 km².

To harmonize the thematic resolution of the historical maps, we used a hierarchical legend (Table 2). All points were attributed a land use category of the first level (1) and, whenever it was possible, the land use was defined according to subcategories described by levels 2 to 4. This strategy enabled us to analyze all digitized points at the most general level, but also to locally analyze the land use information at a more detailed level. The legend classes could be also harmonized with the current land use derived from satellite images (Feurdean et al., 2016; Munteanu et al., 2017). We mapped the land cover in exact point location (regardless of the surrounding area). This needs to be considered for further use and interpretations.

Due to low-quality map sheets from the Second Military Survey (3456 points) and Soviet maps (83 points) mainly in the mountainous regions of Romania, we could not clearly distinguish grassland and arable land categories. In order to avoid classifying these surfaces as unidentified, we used code number 9 ‘Agriculture or Grassland and Shrub’ to keep this land use information in the database, allowing for use of different methods to account for uncertainty.

Table 2. Levels of land use classification: hierarchical map legend.

Level 1	Level 2	Level 3	Level 4
1. Urban/ Built-up			
2. Agriculture	21. Seasonal agriculture 22. Perennial agriculture	221.Orchards 222.Vineyards	
3. Grassland and shrubs	31. Meadows and pastures	311. Meadows 312. Pastures	3111. Wet Meadow 3112. Dry Meadows 3121. Wet Pastures 3122. Dry Pastures
	32. Wooded pastures and shrubs		
4. Forest	33. Dwarf pine 41. Deciduous forest 42. Mixed forest 43. Evergreen forest		
5. Wetlands	51. Reed 52. Peat bogs & mires		
6. Water	61. Standing waters 62. Water courses		
7. Bare land	71. Natural rock 72. Quarries	711. Solid rocks 712. Sand	
8. Unidentified/No data			
9. Agriculture or grassland and shrub			

To minimize the error caused by spatial inaccuracies of the maps, we adopted a backdating approach (Bednarczyk, Kaim, & Ostafin, 2016; Feranec, Hazeu, Christensen, & Jaffrain, 2007). Time layers were not digitized separately but the positions of the points in older maps were verified and corrected according to the recent most accurate maps. The backdating approach was applied in Slovakia, Poland and Czechia. In Hungary, Romania, Ukraine and Austria the backdating has not been adopted.

The uncertainty of the mapping was assessed in the test area of Polish Carpathians (Supplement 1) using uncertainty labels and trajectory analysis. During the digitizing and interpretation, an additional label indicating high uncertainty was assigned to each point if it was located on the border between two land use categories. For trajectory mapping, we assessed likelihood of the land use change at each point based on expert knowledge.

3. Results

The main trends in land use change between the years 1820 and 1980 in the Carpathian region were urban and built-up area sprawl, increase of open agricultural land, and wetlands reduction. The urban and built-up area increased rapidly from 1264 points (each point representing $\sim 4 \text{ km}^2$; 1.5%) in Habsburg time to 2735 points (3.3%) in the World Wars period. During the Socialist period, the total urban area slightly increased to 2812 points (3.4%), but decreased in Romania and Ukraine. The urban expansion was most intensive in the historical cities Budapest (from 9 points to 71 points) and Krakow (from 1 point to 14 points) and the industrial region of Ostrava (from 0 points to 14 points).

The agricultural area increased from 32,796 points (39.2%) at the Habsburg period to 35,575 points (42.5%) during World Wars period, and 37,147 (44.4%) in the Socialist period. Agriculture expanded mostly in lowlands, but in Ukraine and Poland also at higher altitudes. Decrease of agricultural land after the WWII was recorded in Poland, Slovakia and Czechia.

The total area of grasslands and shrubs decreased during the Habsburg time period from 19,298 (23%) to 17,613 points (21%) and then slightly decreased to 16,100 points (19.2%), but there were substantial changes in grassland area in all countries. The area of wetlands dramatically decreased from 1029 (1.2%) to 235 points (0.3%), especially in Hungary. Forest area in Carpathian region decreased during the first two study periods from 28,234 points (33.7%) to 26,440 points (31.6%) and then was relatively stable in socialist period (26,576 points, 31.7%). Substantial increase over study period was recorded in Poland but decreases occurred in Ukraine. Forest transition occurred during the World Wars period in Hungary and Romania.

As a proxy for evaluation of mapping uncertainty, we used the trajectory analysis that summarizes pixels showing unreal or improbable land use changes (see Supplement 1). For the whole area, the most uncertain are classes, which are rare in the dataset (Bare land, Water and Wetlands). Only about 1.45% of points were classified as ‘errors’ or ‘others’ in the trajectory analysis for the entire study area. As much as 88.55% of the points (Land use change or no-change) can be considered to have high accuracy. About 10% of points have the medium degree of change reliability.

4. Discussion and conclusion

Our dataset represents the first detailed, visually digitized, cross-boundary data on long-term land use in the Carpathian region. Most modeled global historical land cover/land use datasets have lower spatial resolutions from 5 arc minutes to 0.5 degrees (Hurtt et al., 2011; Kaplan et al. 2011; Kaplan, Krumhardt, & Zimmermann, 2009; Klein Goldewijk et al. 2011; Klein Goldewijk, Beusen, & Janssen, 2010; Pongratz, Reick, Raddatz, & Claussen, 2008) and less detailed thematic resolution focused on one to five Main Map classes. Other large-scale historical land cover datasets of the study area are derived from satellite images using automatic classification (Griffiths et al., 2013, 2014) or Corine Land Cover methodology (Feranec et al., 2000), and do not go beyond the 1970s. The latest available European long-term land cover maps were generated by HILDA-v2.0 (Historic Land Dynamics Assessment) (Fuchs et al., 2013; Fuchs, Herold, Verburg, Clevers, & Eberle, 2015). The maps are available in 10 years’ time interval and in 1 km^2 grid but only for five land cover classes. The accuracy of the reconstruction is best for the forest class (overall accuracy 91% in Carpathian area) because forest mask from 1900 and volume stock maps were used to upgrade the land cover reconstruction results (Fuchs, Verburg, Clevers, & Herold, 2015).

A comparison of different map sets in land change research is subject to three domains of uncertainty: production-oriented, transformation-oriented and application oriented (Leyk, Boesch, & Weibel, 2005). The production-oriented uncertainty is inherent in the maps used for land cover/land use interpretation. In our case, the variety of cartographic materials resulted in the wide range of land use classes definitions. The Habsburg time period is covered by 95% of the Second Military Survey maps and 5% by the Szathmari’s maps. The image of the land use is homogenous, although the time span is relatively wide. The most diverse in terms of map coverage is the World Wars period. Although the time span is relatively short, the problem differences of used maps map pose interpretation problems (Table 1) In some cases, e.g. in Poland, a completely new high-quality mapping initiatives resulted in a

very precise image of the 1930s land use (Kaim et al., 2014). In other cases, the maps were based on the previous editions of other topographic sources. There are also differences in scale (1:20,000–1:100,000), however, the studies of the same dataset in the Polish Carpathians showed that the impact of the scale in such comparisons is relatively small (Kaim et al., 2014). For the socialist period, the same kind of 1950s Soviet military maps were available for the Czech Republic, Slovakia, Hungary and Ukraine. For Poland and Romania civil topographic maps were used. The time span of the coverage is compact (30 years maximum) and the scale of the maps is the same (1:25,000).

Another aspect of the production-oriented uncertainty is related to the geometric foundations of the map production process which causes the position inaccuracies of maps. This problem is mostly related to the oldest maps used in the study. Although the Second Military Survey maps were created using uniform geodetic horizontal control (Čada & Vichrová, 2009), the differences among editions are visible. On the newest editions of the Second Military Survey maps (available for Poland, Romania and Ukraine), the Root Mean Square Error error usually did not exceed 30 m, while in part of the Czech Republic, Hungary and Slovakia it was only slightly more, usually not exceeding 50 m. The highest values, up to 100 m or very rarely even more, were found on the oldest editions of the maps, located partly in Hungary and partly in Slovakia. The error could be even higher in mountain areas. The average error of the Second Military Survey maps of Tyrol and Salzburg area (outside of our study region) was 100 m and maximum error reached 500 m in the upper Salzach valley (Timár, 2009). In the east of Czechia, the positional error for the Second Military maps is 25–100 m (Pavelková et al., 2016). According to Skokanová et al. (2012) the error is 11–30 m for Second Military maps and for the military topographic maps 10–15 m. The positional accuracy of the World Wars period maps depends on the mapset: for Krovak maps it was 1 m, for Beneš maps 1.5–4 m (Mackovčín, 2014). To minimize the impact of positional inaccuracies, we decided to use the backdating approach to better define the exact position of the point over time (Bednarczyk et al., 2016; Feranec et al., 2007). However, Kaim et al. (2016) show that using backdating for point position cannot exclude all the positional inaccuracies among the maps e.g. due to differences in scale. In some cases, it is still difficult and subjective to locate the point on 1:100 000 map based on the point location on 1:25 000 map. In this paper, backdating procedure was employed over the territory of the Czech Republic, Poland, Slovakia and Ukraine only. The backdating procedure was not employed in Hungary, Romania and Austria, therefore here the analyses focused on land use trajectories are uncertain.

Transformation-oriented uncertainty is caused by pre-processing operations done on the maps in GIS. In this case, all the maps were either available in the georeferenced form or were subject to georeferencing based on the control points identified on the current cartographic sources. The land use was interpreted manually, which might have resulted in human-induced errors, but excluded any misclassification problems present in automatic procedures (Leyk et al., 2005). For some points in Romanian mountains was not possible to distinguish between arable land and grassland. Here the land use was assigned to class ‘Agriculture or Grassland and shrub’. The backward editing could be used to assign the land use to class ‘Agriculture’ or ‘Grassland and shrubs’ if there is a need.

Application-oriented uncertainty is related to the comparison of different cartographic sources to each other. Comparison of the land use based on diverse cartographic sources may be highly influenced by the differences in land use definitions. The differences in definitions are mainly the result of the map purposes. The Second Military Survey maps were based on the stable cadastral mapping but their overall purpose was military. Similarly, most of the World Wars period maps and Socialist topographic maps for the Czech Republic, Hungary, Slovakia and Ukraine were prepared for military purposes. Only the maps representing the socialist times for Poland and Romania were civil topographic maps. It does not mean that in each case the land use definitions were exactly the same but it substantially limits the potential differences in semantics. For example, in all cases the forest class was understood as a land use, not land cover, which is an important advantage when comparing of maps with satellite data where land use – land cover differences might be higher than among maps. The potential land use diversity was also partly minimized by the using of hierarchical land use catalogue. We could distinguish seven main classes with high certainty. The more detailed levels are less certain (especially in case of meadows and pastures) and do not cover the whole study area.

This dataset is relevant both to scientists and practitioners working in the Carpathians. Data were used for example for assessing the effect of land use legacies on contemporary forest disturbance (Munteanu et al., 2015) and agricultural land abandonment (Munteanu et al., 2017), for testing of different historical data acquisition approaches (Kaim et al., 2016) or for evaluation of land cover changes at regional scale (Konkoly-Gyuró & Balázs, 2016). Data could be used for basic land cover changes analyses in specific regions or countries, analyses focused on specific land use class or processes (for example urbanization, wetland loss), additional calibration of long-term land cover or climatic models, driving forces analyze and many other historical land cover analyses.

5. Data

The historical land cover data are presented as supplementary material in the shapefile format (Carpathian_LandCover.shp) and are projected in Lambert Azimuthal Equal Area projection (ETR-S_1989_LAEA). The shapefile contains following fields:

POINT_X – X coordinates

POINT_Y – Y coordinates

NUTS0_name – the name of country

IIMM_LC – land use in the Habsburg period (see legend in Table 2)

IIMM_year – the year of mapping in the Habsburg period. In cases where the year was unknown and the information about the mapping period was available, the mean year of the period was reported

IIMM_source – the source of the historical maps from the Habsburg period (see Table 1)

WW_LC – land use in the World Wars period (see legend in Table 2)

WW_year – the year of mapping in the World Wars period. In cases where the year was unknown and the information about the mapping period was available, the mean year of the period was reported

WW_source – the source of the historical maps from the World Wars period (see Table 1)

topo_LC – land use in the Socialist period (see legend in Table 2)

topo_year – the year of mapping in the Socialist period. In cases where the year was unknown and the information about the mapping period was available, the mean year of the period was reported

topo_source – the source of the historical maps from the Socialist period (see Table 1)

backdating – areas, where backdating was adopted (0 – no backdating, 1 – backdating).

Software

For the georeferencing and digitizing of historical maps, we used ESRI ArcGIS products (ArcMap 9.x – 10.x). Some historical maps were pre-processed and available via web map services. Historical maps of Slovakia were available at geportal of Slovak Environmental Agency (<http://geportal.gov.sk/>); the maps for Czechia at geportal of Czech Environmental Information Agency (<https://geportal.gov.cz/>).

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