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ANALYSIS OF HISTORICAL CHANGE USING CADASTRAL MATERIALS IN THE CARPATHIAN FOOTHILLS

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Abstract

Historical cadastral materials can provide the means to study land use changes. In this paper we describe a cadastral-based analysis of land use changes over a150-year period in a village located in the southeastern portion of Poland, known as Galicia, located in the Carpathian foothills. For this analysis, we rely on Austrian-Hungarian cadastral material from the mid-nineteenth and recent cadastral information. We describe the gridded, spatial analysis methods developed for this study. Contrary to expectations, the study discovered a surprising stability in the parcel boundaries during the 150-year period. These specific methods are valuable for studies in areas where Franciscan cadastral materials from the Austrian and Austro-Hungarian Empires were created. Although distinct from land cover-based studies of land cover changes, these techniques and their application are also relevant in other areas of the world where historical cadastral materials can be found.

Keywords: *cadastre, Poland, land use change, Carpathians*

1. UNDERSTANDING HISTORICAL CHANGES

Historical geography understands that the present landscape is the result of processes of the past (Sauer 1941). This fundamental insight has guided historical studies of changes in the built landscape using qualitative methods (Tuan 1976). In numerous studies, historical cadastral data takes on an important role including research of global and regional economic and ecological issues (Kuskova et al. 2008; Erb, Krausmann 2009). Reconstructions of land cover have been used in landscape ecological analysis of land cover changes (Batty and Longley 1986; Bender et al 2005; Clarke et al. 1997; Sloot 2004). However, because of difficulties in obtaining original historical data, assuring its accuracy and processing the large scale maps of the cadastre for analysis at these scales, techniques for studying specific land use changes based on cadastral map data for historical geographic spatial analysis has been limited. Records on historical settlements are not uncommon, however they often steadfastly remain difficult to access subject to a number of accuracy related limitations arising from distortions of the paper, vellum, mylar, or similar material the data is stored on and may only exist in fragmentary form for larger areas. The lack of metadata on archival resources can further impeded the utilization of these resources. Our focus in this paper will lie in describing spatial analysis techniques to understand large scale land use changes through analytical comparisons of cadastral maps collected at different times. We describe a method using raster-based spatial analysis that addresses accuracy and data processing concerns, yet is well suited to the analysis of cadastral materials. In the paper we also consider contextual issues that aid in the interpretation of quantitative analysis results. We conclude with an assessment of accuracy concerns and some comments on the potential of the methods we describe to augment better known landscape change analysis methods.

2. BACKGROUND AND CONTEXTS

Historical geographical techniques for studying land use change use cadastral data to a limited degree. For instance Gregory and Ell (2007) focus mainly on regional and national studies using statistical data with a few small examples of visualization of historical data. In contrast, landscape ecological studies often make use of historical cadastral information as a surrogate of land cover. Bender and collaborators (2005) use land use types from historical cadastral materials as surrogate indicators of vegetation types in an ecological analysis of plot level changes. Domaas (2005) works at a larger scale, relying on older cadastral maps to delineate features resulting from land consolidation and identifying them as key elements of current landscape protection schemes. Fisher-Kowalski and others (2007) draw on historical cadastral materials, among others, to gain regional and national level understanding of socioecological changes. Krausmann's work (2003) again offers an historical ecological study of agriculture, using the cadastre as a key data source for the analysis of environmental change due to the industrial modernization of agriculture. We believe a set of similar methods can be helpful for historical geography as this case study demonstrates.

2.1 Use of cadastral materials in historical analysis of land use change

The basis for land use change analysis, as previous studies amply demonstrate, cadastral materials contain outstanding sources of information about the natural environment and human activities at the time of the preparation and updating or maintenance of cadastral records, especially maps. Categories of land use used in many cadastral maps and records provide unparalleled information about past land use at a very large scale, 1:500 in some cases. The large scale distinguishes cadastral maps from most administrative maps prepared at smaller scales, where significant land use detail may be lost because of scale or due to the generalization of land use categories to fit other administrative purposes. As a critical component of taxation, map sheets were constructed in a scale which enabled the administration to maximize its power by affording detailed representations of local land use (Kain, Baignet 1992). In spite of considerable losses of cadastral materials from archives over the centuries, Central and Eastern Europe still offer exemplary resources to show the utility of using cadastral materials. In many areas, Franciscian cadastral maps, prepared in the Austrian, and after 1867 Austro-Hungarian, Empire, remain a detailed and reliable sources of historical information about the landscape structure of the 19th and early 20th centuries (Skelnicka, Lhota 2002). The Franciscian cadastral maps and registries covered the entire empire (Kain & Baigent 1992), an area of more than 500,000 square kilometers (Krausmann 2003). When available, the historical sources offer possibilities to analyze the changes in landscapes and land use over time (Domaas 2007, Hamre et al 2007).

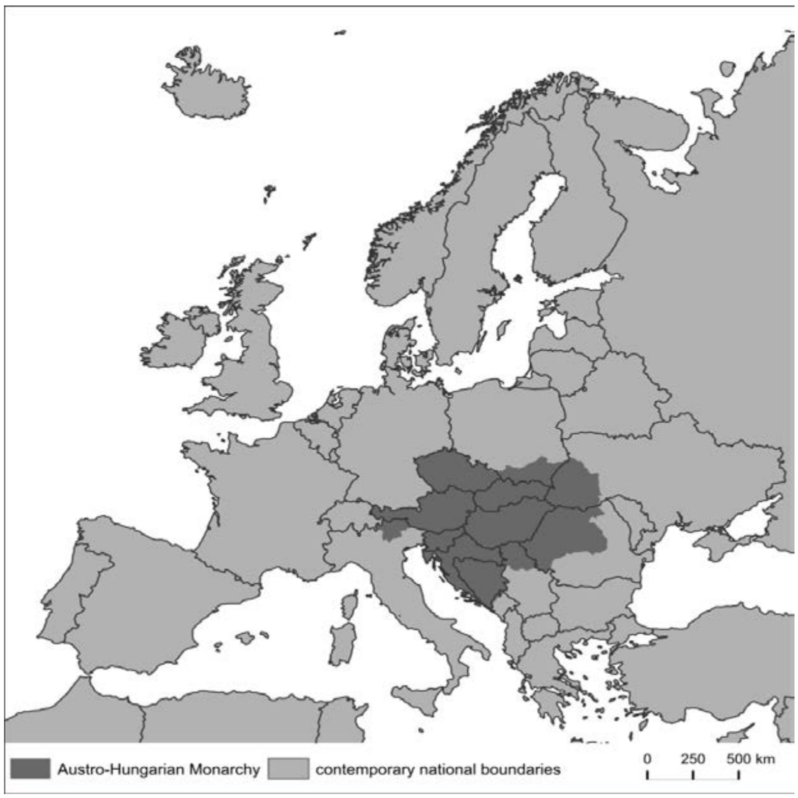

Figure 1. Current political boundaries in Europe and the area of the Austro-Hungarian Empire 1866-1914, which corresponds to the Franciscian cadastre extent

When not destroyed, maps and registries from the 19th and 20th centuries cadastres provide opportunities for historical geographical analysis of land use change in a number of modern European countries including Poland, Czech Republic, Slovakia, Austria, Hungary, Ukraine, Romania, Slovenia, Croatia, and Serbia. Drawing on these resources, published studies include long-term comparisons of land use changes among different countries (Heine et al 2002, Gabrovec, Petek 2003) and studies of changes in relatively small areas on the level of single villages or small towns (Fabijanowski 1957; Krausmann 2003; Skalosˇ, Engstova 2010). The same sources enable analyses for entire countries (e.g. by comparing land registers for tax units) including Austria (Krausmann 2001), Czech Republic (Bicik et al 2001, Jelecek 2002) or Slovenia (Petek, Urbanc 2004). These analyses can be connected to more recent and current administrative data because in many cases the taxation areal units delineated in the Austrian-

Hungarian cadastral maps are similar or comparable to newer sources. In the cases when the tax units have changed over time, new area units have had to be established. An example from the Czech Republic shows that approximately 25% of the cadastral units have changed their areas and the total number of basic territorial units of analysis went from 13,000 to 10,000 (Bicik et al 2001). The use of cadastral maps and registries also offers possibilities to compare detailed socio-economic relationships in the historical landscape to the present landscape. There are important limiting factors to mention that speak to some practical limits for research using the Franciscan cadastral maps. In some cases the only version of cadastral map sheets which survived wars and unrest in the twentieth century is the version containing the parcel boundaries without information about the land use (Boltizar et al 2008). Second, many maps have been destroyed or have been stored in conditions of neglect that the natural process of decay has accelerated and irreparably damaged the paper media. Third, cadastre maps almost always lack the metadata, user of geographic information have become accustomed too. Finally, archived cadastral maps and written registries for very detailed analysis of landscape structure, land use change analyses, or ownership arrangements, e.g., the changes in farm ownership and related agricultural activities, can be difficult to find and access.

2.2 Study area

In this research, we use available historical Franciscan cadastral materials for research into landscape changes since the mid-19th century in the village of Zarszyn, located in the south-east of modern-day Poland (see figure 2). Zarszyn has had and continues to have a strong agricultural economy. The regional climate is suitable for agricultural activity and rich river valley soils remain very productive (Guzik 2002). Although its current population is less than 5000, the village of Zarszyn's history is relatively well-documented back to 1395. Like numerous other villages in the Carpathian foothils, Zarszyn was settled much earlier than villages in the mountains. The village of Zarszyn, however, as historical material relates, was settled almost entirely by Germanic people who later polonized. Although it was founded under Magdeburg Law it had never developed all the allowed functions characteristic for towns. From the 13th century through today it has been a settlement taking up more functions than a village of the region and those functions associated with a town (Ciupka 2003).

This area has also been depopulated several times in recorded history because of hunger, epidemics and destruction occurring after several military conflicts (Przyboś 1995). However, Zarszyn seems to have lied at the eye of the storm. Later, during the period of Austro-Hungarian rules Galicia was peripheral and became a largely neglected and backward region of the Empire (Ciupka 2003). Because of overpopulation and lack of land, fragmentation of parcels widely occurred in the whole Carpathians (Górz, Prochnikowa 1985). After the First World War Galicia was joined to the Republic of Poland. Due to these problems it was one of the most problematic regions of new country. The ethnic structure of Galicia before Second World War was diverse. Besides Polish population in many towns and villages there was large amount of Jewish people (up to 75%), mixed with other nations and ethnics groups like Lemko and Boyko in a regional ethnic melting pot (Przyboś 1995).

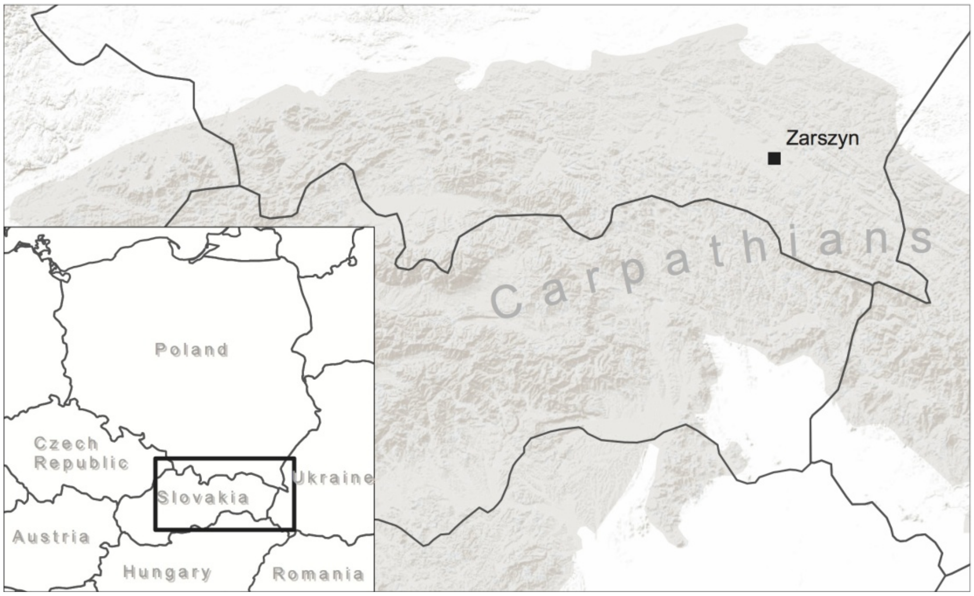

Figure 2. Location of Zarszyn

After the First and Second World Wars, Zarszyn and its surroundings were largely neglected again (Davies 2001). Following the recreation of the non-Communist republic in 1989 changes began to accelerate. Research suggests that currently in Poland, after a period of dominant deforestation many rural areas are experiencing rapid reforestation. This development has been triggered by the complex changes in economy, politics and society (Mather 1992) in which agricultural labor is leaving rural areas for cities and incentives to convert poorer land to forest encourage additional forestation, what happens in Poland as well (Bański 2003, Kozak 2005, Kozak 2010). In spite of the disruptions in the area, for over 500 years the village was never depopulated and the land use and landscape structure developed without major disruptions (Przyboś 1995).

3. SPATIAL ANALYSIS APPROACH AND CONSIDERATIONS

In contrast to studies that reconstruct village land use structure for a specific time, only a limited number of studies so far have focused on the analysis of changes to parcel borders and rural landscape changes (Harvey 2009). In this section we first describe a raster-based spatial analysis methodology for studying landscape changes, especially its relevance for addressing spatial positional accuracy concerns in historical materials.

The use of spatial analysis techniques in historical land use change studies involves well known (O'Sullivan and Unwin 2003), yet relatively infrequently used techniques in historical geography. Spatial analysis for historical landscape (or urban form) reconstruction has had a limited role and relies mainly on administrative statistical data from the historical records (Soja 2008). Reflecting this, Gregory and Ell's discussion (2007) of quantitative spatial analysis points to some relevant issues that we need to consider before we discuss our methods in more detail below. In consideration of accuracy concerns with historical cadastral materials regarding the use of vector-based methods (Couclelis 2003; Fisher et al 2006; Hu 2001; Hooke and Perry 1976; Plewe 2002; Tucci et al 2010), we maintain that insightful historical analysis can be based on raster-based quadrat analysis. Retaining a consistent quadrat size for the all years, avoids accuracy issues associated with vector data, accounts for the impact of increasing field size, and more reliably reflect differences in increases of the number of parcels.

However, we are still unable to address one fundamental accuracy concern in this approach, which applies to both vector- and raster-based approaches. Because a cadastral map is published once, changes between publication dates and changes that are temporary may be lost; temporary changes evident during data collection, or later editing of the map may appear permanent. The problem of so-called snap-shot spatial analysis has limitations that we need to take into account (Chrisman 1997). Contextual information about specific events and changes helps inform analysis.

4. METHODOLOGY

4.1 Preparation of the historical cadastral data

For the analysis of landscape change in Zarszyn village, cadastral map sheets and registries were obtained with help of the local county surveyor. The first step of the procedure to prepare the images for digitization was image rectification. Eleven sheets were rectified of the 1852 cadaster for Zarszyn using the georeferencing tool available in ArcGIS 9.3. Because of the unusual projection of the cadastral maps (Cassini Soldner cylindrical projection with local modifications that result in less distortion in the area (Wolski 2001a, Podobnikar 2009), a dense grid of control points based on identical objects was created (Podobnikar 2009). Usually second order polynomial transformation (third order in one case) were used. The average RMS error for all sheets was about 2 meters (it varied from 0,3 to above 3 meters), sufficient for quadrat analysis with 50 meter cells. Students working on the project entered registry data and linked it to the corresponding parcels.

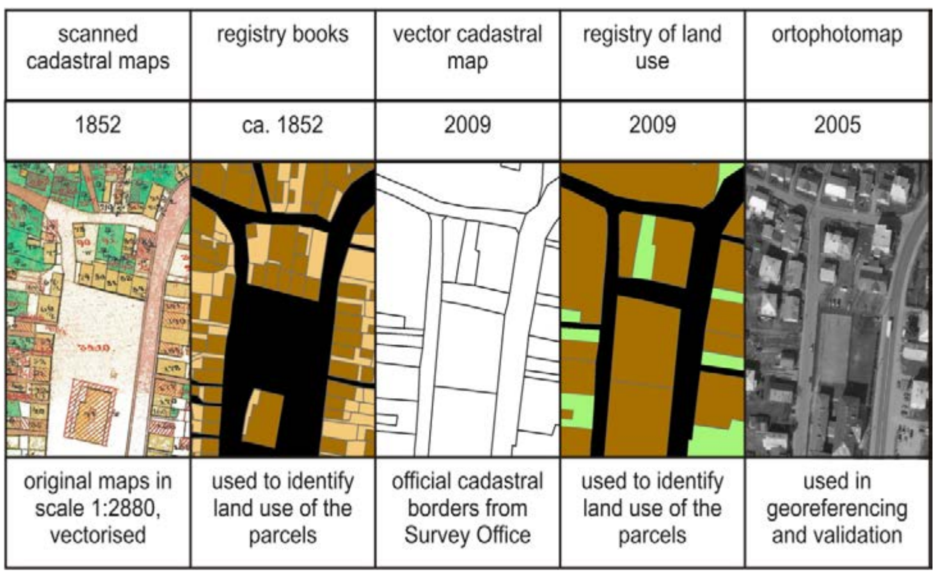

Figure 3. Data used for analysis of land use changes in Zarszyn showing the area of the historical market (presently a school)

4.2 VECTORIZATION

Having rectified those sheets, parcel boundary vectorization was conducted. All of the parcels and added land use classes for each parcel were vectorized. After rectification and vectorization, two sets of vector data (parcels from 1852 and parcels from 2009) were created. For comparison, four types of features from 2005 ortophotomap were vectorized: roads and river network as linesforests as polygon and buildings centers as points. We treated all buildings simply as built-up areas.

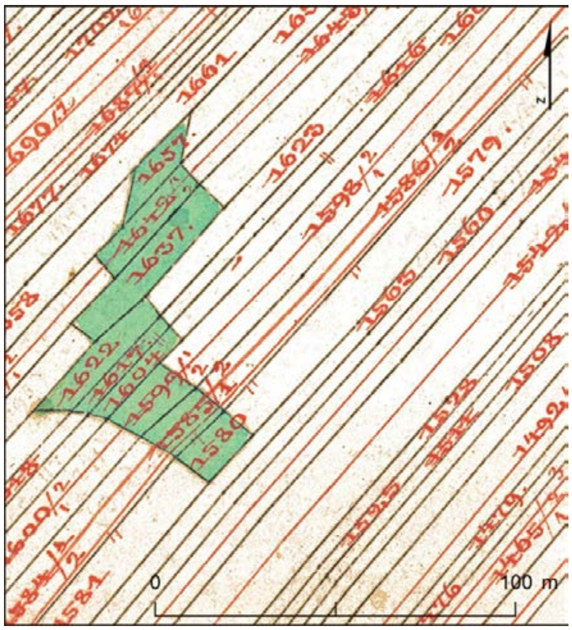

Figure 4. Very narrow ‘strip’ parcels created through traditional inheritance practices

Even with the quadrat analysis approach, concerns with low positional accuracy are particularly relevant in the case of Zarszyn. The village has many narrow parcels, including 'strips' of land arising though traditional inheritance procedures, that can be only 2-3 meters wide, yet are many meters long (see Figure 5) The raster based quadrat analysis technique holds the greatest potential to statistically assess and compare changes.

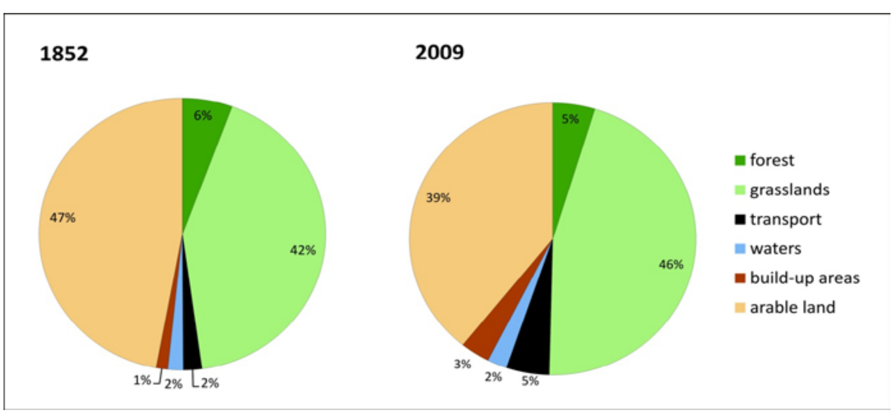

Figure 5. Example of drawn-in changes on original cadastral map (black lines - original, red lines - later changes)

5. SPATIAL ANALYSIS

In this section we present details of the spatial analysis and the three analyses. The following section covers how contextual information based on the historical record was used in interpreting these results. To compare the parcels density as a basis for the analysis of land use change between the two snap shots we utilized four methods, focusing on two quantitative grid-based methods.

First, for the analysis of parcel fragmentation, preparation of the data and analysis involves several necessary steps. We used a grid with equal sides 50 meters in length (n = 3991) and overlaid the grid on each vector cadastral data set. We then measure the length of the parcel boundaries in each grid cell for both data sets. Then an index to indicate the degree of parcel fragmentation was calculated.

$$F = (L_1 - L_2) / (L_1 + L_2)$$

Formula 1: Parcel fragmentation index calculation (L_1 refers to the length of the boundaries from the 1852 cadastre, L_2 refers to the length of the boundaries from the 2009 cadastral data; F is calculated for each raster cell)

Values of the index of parcel fragmentation range between -1 and 1, where -1 indicates a high degree of fragmentation of parcel boundaries and 1 refers to a high degree of consolidation in the raster cell. The value 0 indicates no changes. To avoid dividing by 0 (having 0 in denominator), such cases were labeled with "no changes" value. Such construction of the formula (similar to the NDVI, NDSI and many other remote sensing indices) guarantees normalization of the results, helping in further analyses. This intermediary map was generalized further using a majority filter. This filter distinguishes regions of boundary changes. The resulting map shows five types of boundary change in Zarszyn between cadastral maps from 1852 and cadastral data from 2009. For each region, the mean value of land use change were calculated (see Table 1 and Figure 5 for a map).

Second, for the analysis of land use changes, we compare land use records used in the Franciscan survey with the contemporary cadastral land use records. The thematic consistency of land use categories is a crucial step in any kind of long-term land use change analysis involving comparisons (Lambin, Petit 2001, 2002). The differences in the thematic classes were homogenized by simplifying all the land uses into six comparable categories of land use, which are: Forest, Grasslands, Transport Infrastructure, Water, Built-up Areas and Arable Lands. Both data sets were converted to raster format, where land use change analysis, on the basis of map algebra methods were prepared.

Third and finally, we compared changes in the land use to the changes in boundary density. The land use maps were acquired as stated above and the boundary density maps, respectively for 1852 and 2009 were calculated using line density tool (ArcGIS 10). Density methods may be applied to linear as well as point forms (de Smith et al 2011). The length of the boundary segments were calculated for 100m the circle radius (search radius). The defined radius value is suitable for the village, where minimal parcel width may achieve values smaller than 10 meters. The relation between boundary density and land use classes were calculated separately for 1852 and 2009, what means that results depend on both boundary changes as well as the changes in area of respective land use classes. The average value of boundary density for land use categories were calculated for surface-related land uses (excluding roads and water in Zarszyn case) and separate into distinct regions by predominant type of boundary change, see Table 1.

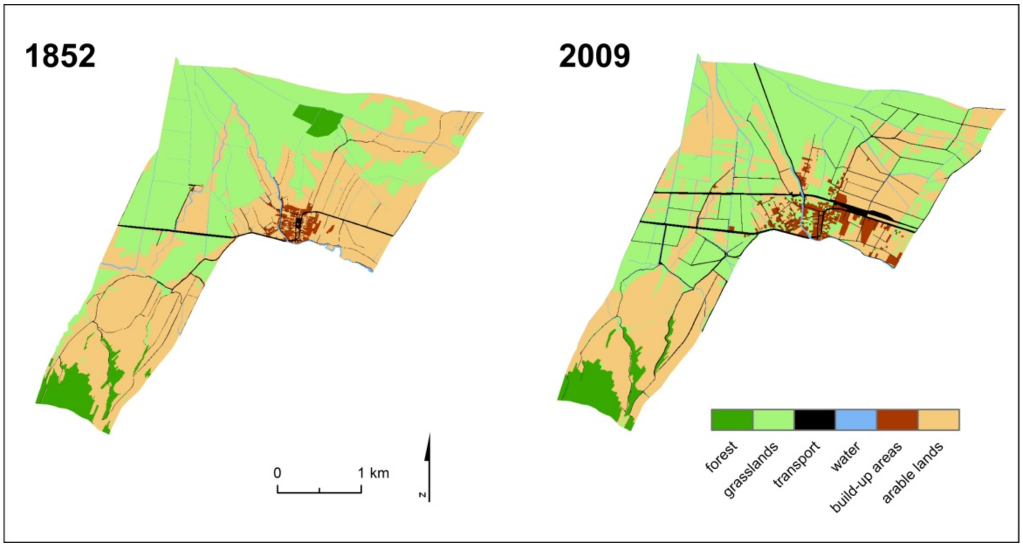

Figure 6. Parcel fragmentation and consolidation map

6. RESULTS

6.1 Changes in parcel boundaries (fragmentation and consolidation)

The spatial analysis of boundary length changes indicates that most areas experienced slight or no changes during the period 1852-2009 (see figure 6). Boundary changes were negligible in the northwestern part of Zarszyn. Despite the destruction during both the First and Second World Wars, including the removal of the Jewish population, the center of the village experienced only slight boundary changes as well. Consolidation occurred in over 27% of the village area. The parts of the village where consolidation was the most important process are located in the southern and eastern parts of the village in the areas used as arable land both in 1852 as well as in 2009. Similar consolidation processes, however with less intensity, occurred in the north-eastern part of Zarszyn, both on the arable lands used as such in 1852 and nowadays, as well as on the grasslands converted into arable lands.

We identified the fragmentation of some parcels in only around 16% of the village area. The main areas of parcel fragmentation are located along the transportation corridors (road and rail) as well as in outlying parts of the village, e.g., in the eastern part.

6.2 Land use changes

We identified land use changes in 32% of the area of Zarszyn between the 1852 and 2009 “snapshots”. Most of the changes, observed on the eastern and western part of the village, took place in agricultural lands through noted conversions of grassland into arable lands and vice versa (together 20% of the village area). Arable land were the most dominant land use in 1852 in Zarszyn (47%) (see figures 7&8), but during the period studied the area decreased (to 39%). The share of the grasslands by contrast, increased (from 42% to 46%) being the main form of land use in Zarszyn in 2009. The area of forest has slightly decreased in Zarszyn (from 6% to 5%). The changes appeared mostly in the northern part of the village, typically assigned for agriculture (the forest complex were converted into grasslands). The locations of these changes correspond to areas to post World War II parcel boundary consolidations.

Table 1. Regions of boundary changes in Zarszyn (see figure 6 for a map)

Region no.	Degree of parcel boundary fragmentation	Area of the village in 2009	Dominant land use types in 1852 and 2009
1	fragmentation	15,89%	grassland
2	fragmentataion > consolidation	1,24%	arable land
3	slight or no change	38,15%	grassland and forest
4	consolidation > fragmentation	17,32%	arable land
5	consolidation	27,4%	arable land

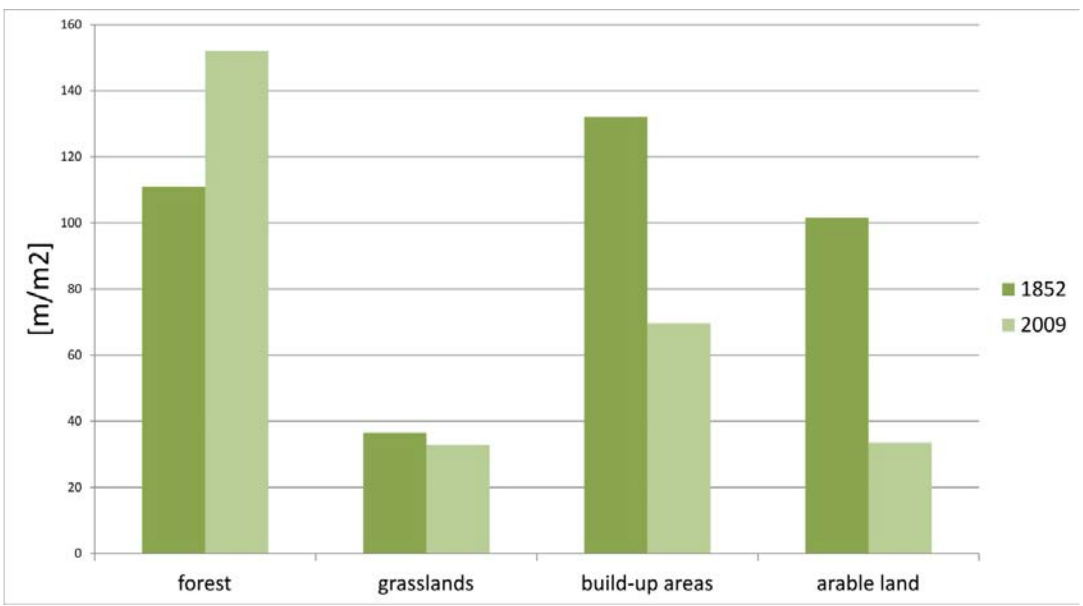

Figure 7. Land use proportions in 1852 and 2009

In the central part of the village, changes were connected mostly to the development of the transport infrastructure and built-up areas. Appearance of the railway line was the main factor. The share of the transport infrastructure increased from 2% to 5%, while the proportion of buildup areas increased from 1% in 1852 to 3% in 2009. New settlements appeared only in the village center. The water surface area has slightly increased from 1.7% to 2.2% in the same period.

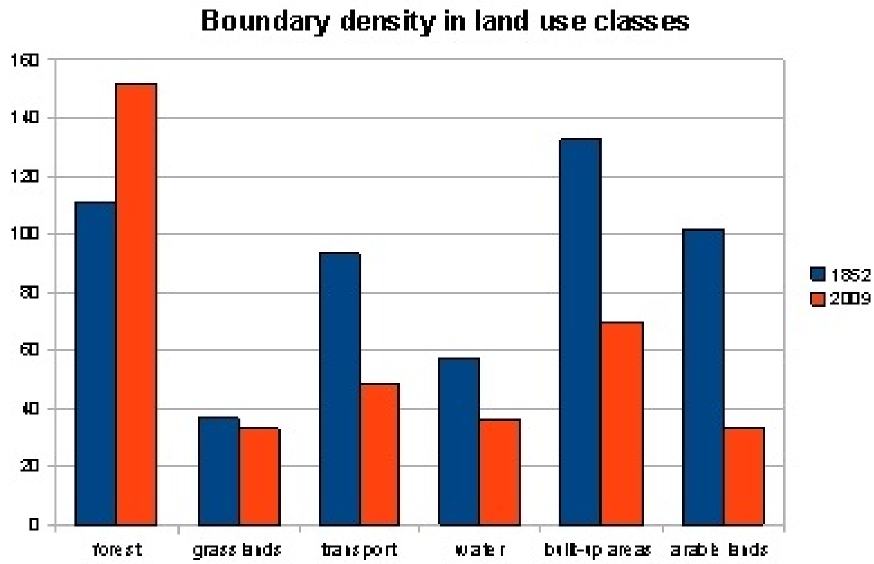

Figure 8. Land use in Zarszyn 1852 and 2009

6.3 Relation between parcel boundaries changes and land use

We found interesting insights into differential land use changes through the spatial analysis of parcel boundary and land use changes.

Table 2. Land use changes by type of parcel boundary fragmentation

	Region area [ha]	**Land use change (percentage by area)**
Fragmentation	150	44
Fragmentation greater than consolidation	6	56
Slight or no changes	346	31
Consolidation greater than fragmentation	173	38
Consolidation	270	20

The analysis results show that average boundary density value increased only in the forests and decreased in all other land use categories in Zarszyn between 1852 and 2009. However, there are interesting differences among other land use types. Boundary density decreased mostly in the arable lands and built-up areas. While the decrease of the parcel boundary density of the grasslands was slight, in areas where boundary fragmentation dominated, changes of the land use was much widespread. In areas where parcel consolidation dominated, the rate of the land use change was much lower (see Table 2).

7. CONCLUSIONS

In this paper we present spatial analytical methods and results for the analysis of changes using cadastral materials. The results of study point to a surprising level of stability in Zarszyn compared other villages of the region in terms of parcel boundaries and in regards to land use (Janicki 2004; Wolski 2001b; Woś 2005). The noted increase to parcel sizes, however, offers few surprises, as it reflect general tendencies in Central and Eastern Europe since Second World War to create larger parcels and areas for farming (Davies 2001) even in Poland where collectivization had less impact than in other countries of the region (Hagedorn 2004). This is a surprising result considering the disruptions of the 1940s that greatly altered many nearby villages. Another surprise is the decrease of forest in the village contrary to other areas in the Polish Carpathians (Dec et al. 2009; Kozak 2010, Woś 2005).

With this research in the village of Zarszyn, the analysis plainly reveal considerable stability in the continued dominance of agriculture. In Zarszyn 89% of the village was used as agricultural land in 1852 compared to 85% in 2009. This leads to some questions for future research in the context of the declining importance of agriculture in the Carpathians (Kurek 1996). Will surrounding villages and villages generally in the Carpathian's also exhibit this degree of stability? Our hypothesis is that favorable environmental conditions, as well as local traditions support the position of the agriculture, as in the case of Zarszyn (Guzik 2002) in other areas as well. Unfortunately, most cadastre records were destroyed or are unavailable in the region limiting ways to assess the overall stability in the region.

Parcel consolidation refers mostly to changes in ownership of arable land. It might be connected to the fact that a professionalization of the agriculture needs more land - the narrow parcels, typical for Zarszyn in 1852 are no longer useful and efficient. Nevertheless land use has changed in those areas only to the limited degree (20% change in the length of the boundaries in these areas). Most of the areas that experienced parcel fragmentation are located along transport corridors related to the development of built-up areas (Antrop 2004).

While the spatial analysis we describe here is very useful, it has limits. Historical cadastral data offers a potential source of detailed information about land uses in the past in the case of a lack of data and to supplement other data sources. As Gregory and Ell (2007) point out, "historical geography is rarely data-rich...". Cadastral data offers a valuable source of data, but this data too faces constraints. Missing data, incomplete records, ambiguity in notations, and even errors occur. The periodicity of the data, distortions in source materials, and changes in categories can impair analysis. A historical geographic approach to research that merges spatial-analytical techniques using past and recent cadastral data with interpreted historiographic information can still provide, as demonstrated here, intriguing insights. The approach and spatial analysis techniques can be used whenever historical cadastral and related materials are available, for instance in urban areas that have seen considerable growth. As we point out, access to local and regional historians and historical geographers can be crucial in evaluating cadastre materials and addressing some of the limits.

We conclude that an important contribution of this work is the development of spatial analytical approaches that can utilize low positional accuracy source materials for studying land use change. Although the methods for studying land use change we present are optimized for Austro-Hungarian cadastral materials, the methods can be used in other urban and rural areas with available historical cadastral materials. The techniques we present in this article can be of value throughout Europe and even around the world in areas with access to historical cadastre materials to help better understand geographical processes of change.

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