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# How reliable is my historical land-use reconstruction? Assessing uncertainties in old cadastral maps

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ABSTRACT

Old maps are a fundamental source for land-use reconstruction frequently used in biodiversity conservation and environmental management. In particular, cadastral maps as one type of old maps, depict both land tenure (discrete category) and land-use (continuous category); thus resulting in uncertainties in determination of individual parcels and their use. These uncertainties pose fundamental questions that are addressed in this paper: (i) to what extent land-use determined the delimitation of parcels?; (ii) how significant did the contrast between two land-use classes have to be to in order to delineate a new boundary? Agroforestry land-use classes were chosen as an example to demonstrate the approaches in the delimitation of parcels among different land-use combinations. We used Franciscan Cadastre, created in the mid-19th century under the Habsburg Monarchy (Central Europe), which depicts up to 10 agroforestry classes, to analyse factors that could influence delimitation of borders between patches (parcels) in old cadastral maps. The study area was located in the rural landscape of N Czechia, where approximately 10% of the agroforestry land area was used. We based our analysis on a detailed database of parcels and their land use type and property information. The novel approach to patch contrast indicator for old map analyses is introduced. The approach is based on statistical testing of the differences between parcel boundaries, separating similar/different owner, similar/different land-use and considering the length of the boundaries. Total number of identified parcels for all districts was 4108. Half of the boundaries length and 60% of boundaries count separated land of different owners. The rest of them separated land of one owner with different owner or with distinct parcels geometry. Our results indicate variable contrast between pairs of neighbouring land use categories. In particular, the contrast between pastures, wood-pastures and forests proved to be very low. Various factors, including land ownership, land-use, as well as landscape patch geometry and configuration were important to delineate a single parcel. We have concluded that these factors have important implications on inaccuracies and uncertainties of land use reconstructions based on old cadastral maps and used as historical baselines for current considerations on land change and environmental management.

## 1. Introduction

### 1.1. Historical land-use

The current effort to understand the roots and address the challenges raised by global environmental change have increasingly strengthened the need for long-term data series and for evolutionary analysis connecting such varied issues as biodiversity, land cover and multifunctional land-use schemes (Antrop, 2005; Szabó, 2010).

Among the sources for historical land-use reconstruction, old map records are considered seminal because of their intrinsic spatial delimitation of land-use in Europe (Cousins, 2001; Hamre et al., 2007; Petit and Lambin, 2002) and the world (Börjeson, 2009; Fujihara and Kikuchi, 2005). The scale of maps used varies from old topographical maps of medium scales in the range of 1:25,000–1:50,000 (Ludwig et al., 2009; Munteanu et al., 2014; Pindozzi et al., 2016) with general information about land-use, to large scales under 1: 5000 in the form of old cadastral maps with delimited plots (Hamre et al., 2007; Johansson et al., 2008). In some studies, sources with different scales and dates of origin were combined (Tomson et al., 2015). Respecting the scale and content depending on purpose of origin, old map sources have enabled research continuity on the loss of particular land-use classes that are of importance for species distribution (habitat loss), management practices (sustainable use) or to quantify the structural changes in landscape (e.g., fragmentation, loss of diversity or unification).

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### 1.2. Cadastral maps

Cadastral maps represent the most accurate source for land-use reconstructions as they display the landscape at the level of land properties intended for tax collection. Although the techniques of cartographic representation of land properties was known in Ancient times and were further developed in private estate maps in the Early Modern Era, they became widely used during the 16th and 17th Centuries. At that time, the purpose of cadastral maps shifted from private land inventories to use by public authorities and governments (Kain and Baigent, 1994). Fundamentally, this shift resulted in the standardization of mapping procedures and symbologies that have been applied to vast administrative units and states. The demands of land administration (Dale and McLaughlin, 2000) and tax collection also challenged the accuracy of land surveys to improve significantly. For these reasons, the Early Modern cadastral maps represent the first detailed spatial representation of land-use that can be used for both the intra- and inter-regional comparative analyses of landscape characteristics. The availability of cadastral maps and their processing in land-use studies, land tenure reconstructions and various landscape-ecological applications range from regions in Italy (Agnoletti, 2007), Germany (Bender et al., 2005), Nordic countries (Cousins, 2001; Hamre et al., 2007), to Central Europe (Bičík et al., 2001; Skaloš et al., 2012), England and the New World (Kain and Baigent, 1994).

Specifically, the Franciscan (or Stable) Cadastre is frequently used for historical land-use reconstruction in the former Austrian Empire. This cartographic and written source was produced between 1817 and the 1880s (Feucht, 2008; Timár and Biszak, 2010). Current use of this source includes long-term change of land-use (Beranová et al., 2017; Bičík et al., 2001; Kanianska et al., 2014; Lipský, 1995; Raška et al., 2016), development of tenure fragmentation influencing land change (Affek, 2015; Sklenička et al., 2017), shifts in landscape functions (Skaloš et al., 2014) and the impact of history on current vegetation structure (Vojta and Drhovská, 2012). The Franciscan Cadastre was also used to study spatially explicit continuity of forest and non-forest woody vegetation in contrast to open habitats (Forejt et al., 2017; Skaloš et al., 2015). The Franciscan Cadastre was proposed to be used practically as a basis for restoration projects, erosion control measures and establishment of ecological networks based on habitat continuity (Brůna and Křováková, 2005).

### 1.3. Limitations of old maps: State of the art

Generally, the main advantages of old maps usage are based on the robustness of spatial quantitative information and the visual form of the information, making them easy to analyse. On the other hand, there are a few constraints (Yang et al., 2014) when using the old map sources:

(i) Regional and temporal limitation of the data, i.e., some sources cover only certain states/historical lands of current countries, and maps represent a single-state visual representation of otherwise dynamic tenure systems (cf. Raška et al., 2014).
(ii) Intentional distortion of information – mapping for military and other purposes often resulted in intentional distortion, for strategic reasons, of certain elements or objects in the mapped region.
(iii) Issues concerning the necessity of geometric transformation of an old map (Čada and Vichrová, 2009), which were created in various geographic and projection systems.
(iv) Differences in the understanding of mapping criteria and mapping instructions by individual mapping agents (land-surveyors).

According to Leyk et al. (2005), uncertainties in researching historical land-use based on old map sources can be divided into three major groups. First, there is the uncertainty inherent in the historical data in the methods of production of the original cartographic work and methods of survey, as shown by examples of building delimitation inaccuracies found on old plans (Tucci and Giordano, 2011). Second, there is the processing uncertainty connected with the method of acquisition of digital data from the original source (e.g., the difference between manual and automatic digitization). Third, there is the possible uncertainty in the application of the gathered data based on different semantics. Kaim et al. (2014) presents an example of different semantics denoting discrepancy of land-use classification in maps from 1840s to 1860s. Concerning historical land-use, one must also be aware of shifts in meaning of terms addressing land-use, as was shown by an example of the use of the words ‘forest’ and ’wald’ (Vera, 2000).

### 1.4. Research aims

In this paper, we further develop Verás notice on uncertainty of land-use assignment (Vera, 2000) and newly define and provide empirical evidence for another kind of uncertainty resulting from criteria used to delimit different land-use classes found in old maps. Our starting point is that cadastral maps have clearly drawn boundaries, but a question arises about the factors that were used to determine the polygons represented on the maps. In particular, the question is whether the determination of boundaries was based on contrasts between neighbouring land-uses, or rather on contrast between neighbouring ownerships. The rationale for this assumption lies in understanding that the cadastral maps depict both tenure and land-use, but while tenure is a discrete category, land-use could, in fact, represent a continuum. For tax collection purposes, any plot must have been assigned to only one land-use class. This, in turn, must have been based on criteria which have not yet been studied in detail.

This situation could lead to fundamental misinterpretations concerning reconstruction of land-use changes and landscape metrics, as well as the relationship between tenure and land-use schemes. Therefore, in this study, we addressed the following questions: (i) to what extent land-use controlled the delimitation of parcels on old cadastral maps?; (ii) how significant did the contrast between two land-use classes have to be to in order to delineate a new boundary?; and (iii) what are the implications of the above issues concerning reliability of data derived from old cadastral maps for landscape-ecological applications?

These questions could be especially important in the case of agroforestry land-uses, that are often depicted on old cadastral maps (Agnoletti, 2007; Forejt et al., 2017; Krčmářová and Jeleček, 2017). For this reason, we use the agroforestry classes as a case for detailed analyses in this paper as one example of the Austrian Franciscan Cadastre (Fig. 1). The study area illustrating the questions posed has been chosen to represent an historical rural landscape with high diversity of land-use classes and with current attempts to re-establish the former multifunctional land-use based on the historical accounts.

Following the introductory section, the paper continues with brief rationale for the case study, and introduction of the cadastral maps and statistical analytical techniques used in the study. In the results, we first address the reconstructed land-use structure and then analyse the importance of agroforestry in historical landscapes. Because cadastre is always based on delimitation of parcels/patches, not only land-use structure but also land-use diversity, land ownership and geometry of the parcels is included in the analysis. Finally, we analysed the influence of land ownership, land-use and the geometry of the parcels for delimitation of the parcels. In the discussion we note the uncertainties resulting from the use of old cadastral maps for landscape-ecological research and consider the limits of our approach, while calling for further studies based on other old cadastral maps in different environmental and legal settings.