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The origin of grasslands in the temperate forest zone of east-central Europe: long-term legacy of climate and human impact

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ABSTRACT

The post-glacial fate of central European grasslands has stimulated palaeoecological debates for a century. Some argued for the continuous survival of open land, while others claimed that closed forest had developed during the Middle Holocene. The reasons behind stability or changes in the proportion of open land are also unclear. We aim to reconstruct regional vegetation openness and test the effects of climate and human impact on vegetation change throughout the Holocene. We present a newly dated pollen record from north-western fringes of the Pannonian Plain, east-central Europe, and reconstruct Holocene regional vegetation development by the REVEALS model for 27 pollen-equivalent taxa. Estimated vegetation is correlated in the same area with a human activity model based on all available archaeological information and a macrophysical climate model. The palaeovegetation record indicates the continuous presence of open land throughout the Holocene. Grasslands and open woodlands were probably maintained by local arid climatic conditions during the early Holocene delaying the spread of deciduous (oak) forests. Significantly detectable human-made landscape transformation started only after 2000 BC. Our analyses suggest that Neolithic people spread into a landscape that was already open. Humans probably contributed to the spread of oak, and influenced the dynamics of hazel and hornbeam.

1. Introduction

Early Holocene climate changes triggered major ecosystem changes resulting in the spread of trees in northern latitudes. In central Europe, temperate deciduous trees are believed to have eventually formed forests (although the structure of these forests has been long subject to a heated scientific debate e.g., Vera, 2000; Birks, 2005; Mitchell, 2005). Along with this natural process, people started to intensively shape the landscape as agricultural practises expanded in the Neolithic.

In the lowlands of east-central Europe open vegetation currently represents an abundant habitat type harbouring many grassland plant taxa (Chytrý, 2010). The fate of these taxa in the Late Quaternary has puzzled scientists for many decades. The crucial question is how grassland taxa survived in the developing forests of the early Holocene (Gradmann, 1933; Ložek, 1971, 2011; Vera, 2000; Magyari et al., 2010; Hejcman et al., 2013). There appears to be evidence that in some regions wooded steppe persisted until (and therefore predates) the adoption of sedentary lifestyle and agriculture in the Neolithic. For example in the heart of the Pannonian Plain such open spaces created an important baseline for the expansion of Neolithic farming communities (Járai-Komlódi, 1968; Havinga, 1972; Magyari et al., 2010), whose vegetation management was difficult to detect by classical palaeoecological methods (Willis and Bennett, 1994; Magyari et al., 2012). However, in other regions such continuity of open habitats is less known and more debatable. In the north-western outcrops of the Pannonian Plain, where steppe communities occur at present, the results of several pollen records allowed for the possibility of the existence of species-rich steppes from the Last Glacial interstadial 1 (GI-1; 14 ka) until the Neolithic

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(7.5 ka BP; Svobodová, 1989, 1997), but other authors argued for the continuous afforestation of the region in the same period (Rybníčková and Rybníček, 1972).

To gain solid knowledge on the origins of grasslands and to disentangle the factors driving long-term changes or stability, one needs information on past vegetation, climate and human activities. However, each information type presents its own methodological challenges and interpreting the results in an interdisciplinary framework adds further complexity to the analysis. Data on past vegetation is usually derived from pollen. However, it is rather problematic to realistically reconstruct the proportion of open land based solely on pollen percentages (Sugita, 2007a; Gaillard et al., 2010; Kuneš et al., 2011). Quantitative vegetation reconstruction based on the understanding of pollen production and dispersal can remedy this problem. Recent model calibrations allow researchers to obtain robust reconstructions of past land cover, especially as regards the ratio of forest and open land (Hellman et al., 2008; Mazier et al., 2012; Abraham et al., 2014).

Climatic conditions and various types of activities by human populations are considered to be important factors shaping vegetation and maintaining open land (Mercuri et al., 2011; Connor et al., 2013; Feurdean et al., 2015). Climate models were shown to be important for the evaluation of past vegetation patterns (Gaillard et al., 2010; Pielke et al., 2011), however, for local studies climate patterns based on Global or Regional Climate Models (Strandberg et al., 2014) do not provide the desired site-specific spatial resolution. As an alternative, several studies used site-specific, locally calibrated climate models (Bryson, 2005), which provided 100-year time resolution (Higgins and MacFadden, 2009; Riehl et al., 2009). As far as human activities are concerned, different models of population densities for particular time periods emerged with the help of archaeological and historical data (Pongratz et al., 2008; Kaplan et al., 2009; Gaillard et al., 2010; Shennan et al., 2013). Nevertheless, such models concerned continental to global scales and are much too coarse to be meaningfully applied on a regional scale. There are ongoing efforts to reconstruct prehistoric regional population dynamics with the help of ^{14}C dating (e.g., Hinz et al., 2012; Shennan et al., 2013; Lechterbeck et al., 2014; Whitehouse et al., 2014). Unfortunately, there are several problematic issues connected to these procedures indicating that the results can be biased by several factors, such as sampling strategies including site density (Mercuri, 2014), period preferences or changes in mobility and subsistence strategies (Contreras and Meadows, 2014; Crombé and Robinson, 2014). To derive more exact information on regional, archaeologically reflected human activities in a long-term perspective, a model based on a detailed and complete archaeological survey is essential.

In this study we combine three models to reconstruct Holocene vegetation dynamics in a spatially defined area. Firstly, we use the pollen record from the extinct Lake Vracov, situated in the north-western part of the Pannonian Plain, to create a REVEALS vegetation model of the area. Secondly, we review all existing excavation reports to gather information on the location, dating and identified activities of the archaeological sites and finds of the same area to produce reliable estimates of human occupancy through a Monte Carlo simulation-based model. Thirdly, we use a macrophysical climate model for the area as an independent data source of past climate. We address the following questions: i) What was the extent of open land since the beginning of the Holocene and did grassland vegetation persist until anthropogenic deforestation? ii) How did vegetation respond to climate changes in the area? iii) Can we track specific patterns in human–vegetation interactions?

2. Material and methods

2.1. Site description

The extinct Lake Vracov, nowadays transformed into a fishpond, is located on the Bzenecký brook in the floodplains of the Morava river in the north-western part of the Pannonian Plain (Fig. 1) in the Czech Republic. The area is formed by Upper Quaternary deposits of blown sands and loess with chernozem underlain by Neogene and Pliocene brackish and freshwater sediments. The high content of calcium and magnesium in these deposits created higher salinity in the water of the lake. To be able to compare vegetation, climate and human occupancy, an area of 25 km around the lake was selected (Fig. 1). This study area comprises the Outer Western Carpathians and vales along the Morava river. Lowlands along the Morava river lie between 150 and 275 m a.s.l. and are framed by 30 m high terraces covered by eolic loess. Vast areas of eolic sands with dunes of 13 m height occur on the right side of the Morava river between Vracov and Hodonín (Havlíček and Zeman, 1986). The northern part of the area is bordered by the hills of Ždánice Forest and Chřiby, while the south-eastern edge is formed by the White Carpathians (Czudek, 1972).

2.2. Present-day vegetation

The lowlands of the Morava river host riverine forests, meadows, mires and sand steppes. The riverine forests are influenced by the Carpathian mesophyticum and consist of *Ulmenion* with *Fraxinus* species (Chytrý, 2013). In drier places at upper elevations *Carpinus betulus* and *Acer campestre* are frequent. Alder carrs with dominant *Alnus glutinosa* are not very common. Acidophilous oak or hornbeam-oak forests occur on sandy soils and were partly changed to semi-natural pine forests. On smaller patches, willow carrs with *Salix cinerea*, *S. aurita* and *Betula pubescens* developed. Sand steppes are represented by *Corynephorus canescens*, *Filago arvensis*, *F. minima*, *Plantago psyllium*, *Spergula pentandra*, *Veronica dillenii*, *Linaria genistifolia*, *Thymus serpyllum* and *Armeria elongata* (Chytrý, 2010). The vegetation of the hills (Chřiby and Ždánice forest) belongs to the supracolline or montane belts with beech or oak-hornbeam forests. In the south and south-west, forest vegetation mixes with the xerothermic flora of the Pannonian thermophyticum.

The largest part of the landscape consists of agricultural land (European Environmental Agency, 2013). According to potential natural vegetation maps (Bohn et al., 2000), the study area lies within the range of the occurrence of Pannonian lowland mixed pedunculate oak forests (Fig. 1). The vegetation of these forests co-occurs with dry grasslands (*Festuca rupicola*) and scrubs (*Prunus fruticosa*, *P. tenella*) as well as with sand steppes (Chytrý, 2010). Links of this unit with other semi-open and open vegetation further to the east are illustrated in Fig. 1.

2.3. Palaeovegetation data and model

The pollen record originated from sediments of the extinct Lake Vracov, which had been created by a dam formed by Lateglacial fluvial and eolian processes (Havlíček et al., 1995). The initial mineral sedimentation changed to organogenic accumulation of algal gyttja at the beginning of the Holocene. Open water lake surface existed until the Middle Holocene when partial terrestrialization started as documented by layers of mosses and sedge-moss communities (Rybníčková and Rybníček, 1972, 1983; Svobodová, 1997). The lake basin was drained one hundred years ago. Sediments were sampled from the bottom of the drained lake by Kamil Rybníček in 1967. Altogether ca. 80 profiles were taken for