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12,000-Years of fire regime drivers in the lowlands of Transylvania (Central-Eastern Europe): a data-model approach

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ABSTRACT

The usefulness of sedimentary charcoal records to document centennial to millennial scale trends in aspects of fire regimes (frequency, severity) is widely acknowledged, yet the long-term variability in these regimes is poorly understood. Here, we use a high-resolution, multi-proxy analysis of a lacustrine sequence located in the lowlands of Transylvania (NW Romania), alongside global climate simulations in order to disentangle the drivers of fire regimes in this dry climatic region of Central-Eastern Europe. Periods of greater fire activity and frequency occurred between 10,700 and 7100 cal yr BP (mean Fire Interval = mFI 112 yr), and between 3300 and 700 cal yr BP (mFI 150 yr), whereas intervals of lower fire activity were recorded between 12,000 and 10,700 cal yr BP (mFI 217 yr), 7100 and 3300 cal yr BP (mFI 317 yr), and over last 700 years (no fire events detected). We found good correlations between simulated early summer (June, July) soil moisture content and near-surface air temperature with fire activity, particularly for the early to mid Holocene. A climate–fire relationship is further supported by local hydrological changes, i.e., lake level and runoff fluctuations. Fuel limitation, as a result of arid and strongly seasonal climatic conditions, led to low fire activity before 10,700 cal yr BP. However, fires were most frequent during climatically drier phases for the remaining, fuel-sufficient, part of the Holocene. Our results also suggest that the occurrence of more frequent fires in the early Holocene has kept woodlands open, promoted grassland abundance and sustained a more flammable ecosystem (mFI < 150 years) whereas the decline in fire risk under cooler and wetter climate conditions (mFI = 317 years) favoured woodland development. From 3300 cal yr BP, human impacts clearly were partly responsible for changes in fire activity, first increasing fire frequency and severity in periods with fire-favourable climatic conditions (halving the mFI from 300 years to about 150 years), then effectively suppressing fires over the last several centuries. Given the projected future temperature increase and moisture decline and the biomass accumulation due to the agricultural land abandonment in the region, natural fire frequency would be expected to return to <150 years.

1. Introduction

Current and future changes in spatial patterns in temperature and precipitation are projected to greatly influence the distribution and variability in fire regimes in Europe (EEA Report, 2012). However, fire regimes are complex and regulated by several factors ranging from climate, fuel (load, connectivity, and flammability) and ignition regimes (natural or anthropogenic) to landscape variables (van der Werf et al., 2006; Krawchuk et al., 2009; Whitlock et al., 2010; Spessa et al., 2010; Thonicke et al., 2010; Krawchuk and Moritz, 2011; Daniau et al., 2012; Molinari et al., 2013). These parameters are not entirely independent of each other; climate acts as a top-down driver (conditions need to be dry enough to enable ignition and to sustain burning) and vegetation cover as a bottom

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up driver (i.e., fuel must be sufficiently abundant and dry to sustain combustion), while humans can change fire ignition rates, fuel types and land cover. Disentangling the relative contribution of each of these drivers of fire regimes is therefore difficult and in many parts of the world this is complicated by long-standing anthropogenic impacts (Willis and Birks, 2006; Rius et al., 2012). The sedimentary charcoal records can provide information on centennial to millennial changes in fire regimes, notably fire frequency and to some extent fire severity, and, when associated with other proxies (of climate, vegetation and human impact), can be used to determine the drivers of long-term changes in these regimes and thereby enhance our understanding of their interaction (Vannière et al., 2008; Marlon et al., 2013).

Although the influence of anthropogenic burning on ecosystems and atmospheric gas composition is widely recognised, when and how strongly humans have altered the natural fire frequency and severity in different regions is still poorly understood (Vannière et al., 2010). This is because most of the available charcoal records do not have a high enough temporal resolution to adequately reconstruct fire frequency; tend to be limited to only a few geographical areas; their data sets are inadequate to allow environmental drivers to be disentangled from human impact or proxies for human impact are not adequately considered (Black et al., 2008; Colombaroli et al., 2008; Carcaillet et al., 2009; Kaltenrieder et al., 2010; Ali et al., 2012; Gałka et al., 2013).

The first synthesis of sedimentary charcoal records from the Carpathian region covering the last 15,000 years revealed a strongly divergent pattern in biomass burning between the lowlands and uplands during the Holocene (Feurdean et al., 2012). This is not surprising since the Carpathian region is characterised by strong variations in climate, topography and human impact; the key factors in the distribution of its biogeographical provinces and elevational vegetation zones. There is, however, currently no quantification of the changes in fire frequency (total number of fires within a time window), and magnitude (fire intensity or area burnt) in this region or more widely in Central-Eastern Europe. Extending fire research into a wider range of geographical regions and ecosystems with different human impact can be used as a substitute for measuring of how different vegetation types react to changes in fire activity throughout time and is therefore of relevance in predicting their sensitivity to future climate and land use change.

Here, we present a high-resolution 12,000 year palaeoecological record from Lake Stiucii in the lowlands of the Transylvanian Plain (NW Romania) which explores for the first time the variability in fire frequency and severity over the Holocene in Central-Eastern Europe. Specifically, we aim to: i) disentangle the drivers of long-term changes (climate, vegetation, humans) in fire regimes and understand their interaction; ii) determine which climate variables are the best predictor of the long-term changes in fire regimes, and iii) assess how fire regimes changed with different types of agro-pastoral activities. We have used a sediment macro-charcoal record to reconstruct trends in biomass burning and fire frequency at a local scale, and a pollen record and charred remains to determine variability in fuel load and composition. Climate conditions based on global simulations were used alongside local and regional climate reconstructions from proxy data to explore the influence of climate on the fire activity. Pollen indicators of anthropogenic impact at Lake Stiucii, alongside local archaeological and historical data, as well as modeled population density and cultivated area estimates (Klein Goldewijk et al., 2011) were used to evaluate the human impact on fire activity.

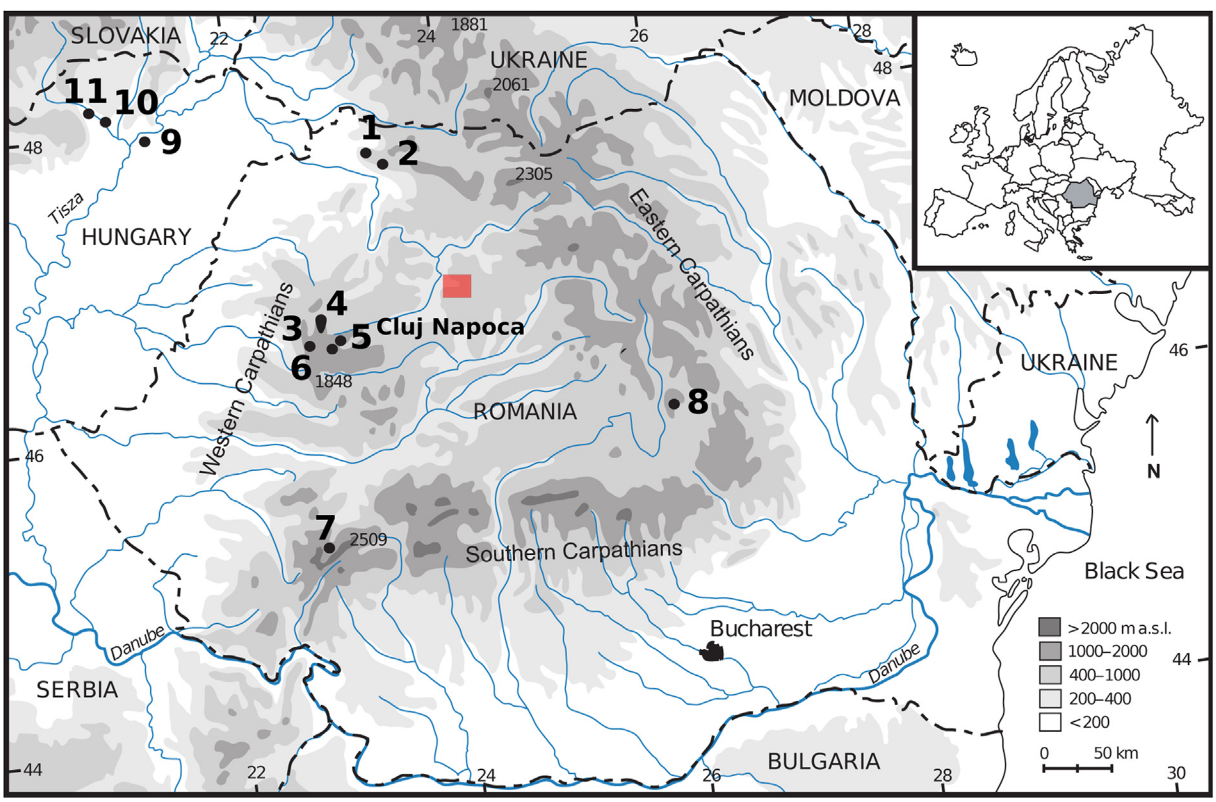

Fig. 1. Location of Lake Stiucii (square) in the lowland of Transylvania, NW Romania and in Europe. The location of other sites used in the synthesis paper of Feurdean et al. (2012) is highlighted: 1) Preluca Tiganului, 2) Steregoiu; 3) Padis Sondori, 4) Molhasul Mare, 5) Doda Pilii, 6) Calineasa, 7) Taul dintre Brazi, 8) Saint Ana, 9) Sarló-hát, 10) Nagymohos and 11) Kis Mohos.