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Forest fires within a temperate landscape: A decadal and millennial perspective from a sandstone region in Central Europe

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ABSTRACT

In Europe, fire is considered an integral part of forest dynamics only in the Mediterranean and in Fenno-Scandinavia. In Central Europe, the ecological role of fire is largely neglected and deemed unimportant. To fill this knowledge gap, we studied ancient and recent fires in temperate coniferous forests of a sandstone landscape. We used palaeoecological and contemporary forestry data to reveal wildfire events in the present-day landscape and in the distant past. Using linear regression and the ENFA method, we identified the factors influencing fire occurrences in the landscape on two time scales. Analyses of soil charcoal concentrations correspond with contemporary forestry data. The main driving factors affecting the incidence of fires were topographic features, namely the heat load index and presence of rocks. Additional important factors were forest composition features, especially the abundance of *Pinus sylvestris*. Even though the landscape is populated and attractive to tourists, present-day anthropogenic factors, surprisingly, have only marginal effects. Fires have been occurring in similar fire-prone habitats at least since the Subatlantic period, regardless of whether they were caused by humans or lightning. Our results therefore show that fire affects long-term forest vegetation development also in temperate forests of Central Europe. This has far reaching consequences for forest management because, contrary to prevailing beliefs, fire must be considered a natural driver of forest vegetation patterns even in this temperate region.

1. Introduction

Wildfires are an important disturbance factor influencing forest ecosystems. They have a strong impact on both biotic and abiotic conditions. Fire eliminates sensitive species in favour of species that are able to survive or easily regenerate in burned places (Agee, 1998; Lloret et al., 2005). They alter the local light and thermal regime as well as physical, chemical and biological qualities of the soil (Certini, 2005). The occurrence of wildfires depends on complex interactions among the climate, topographic characteristics, vegetation structure and composition and the presence of natural or anthropogenic ignition triggers. Forest fires are more frequent during dry climatic periods, on convex relief forms and on south facing slopes (Angelstam, 1998). The frequency of wildfires decreases with increasing humidity, for example, towards the poles, higher elevations and a regions with a more oceanic climate (Angelstam, 1998; Skre et al., 1998). The most common natural cause of wildfires is lightning (Tinner et al., 1999; Goldammer and Page, 2000; Niklasson and Granström, 2000). Generally, a gradual increase in biomass burning during the Holocene has been detected on the continental scale in Europe (Carcaillet et al., 2002; Power et al., 2007). It has been proposed that climate warming following deglaciation is responsible for this trend (Marlon et al., 2012). However, recent studies from the Alps (Stahli et al., 2006), Pyrenees (Rius et al., 2011) and the Pannonian Basin (Feurdean et al., 2013) have shown substantial regional variation indicating a predominant role of anthropogenic drivers acting during the mid- and late Holocene (Molinari et al., 2013).

Wildfires in Europe are associated mainly with the Mediterranean region and the Boreal forest zone. In these areas, fire is considered to bethe main forest vegetation disturbance factor (Engelmark, 1993; Skre et al., 1998; Pausas and Vallejo, 1999), and its ecological role and history are well studied there (Niklasson et al., 2010). In northern Eurasia, fires are often associated with forests of Scots pine (*Pinus sylvestris*). This coniferous tree species often occurs in drier conditions and produces resiny,

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easily inflammable litter. At the same time, Scots pine possesses several physiological and morphological adaptations to fire, for example, thick bark, a deep root system and an ability to quickly regenerate after fire in places with mineral soil (Agee, 1998). Regular fires can maintain pine stands also in places where other tree species would otherwise prevail due to site conditions (Engelmark, 1987; Angelstam, 1998; Gromtsev, 2002). Natural fire disturbances are thought to be of such importance that emulating them has been considered a legitimate forest management practice (Bergeron et al., 2002; Kuuluvainen, 2002).

The situation in Central Europe, where the most prevalent natural forests are composed of temperate broadleaf species, is entirely different. The ecological role of fire has traditionally been neglected (Clark and Merkt, 1989; Ellenberg, 1996), and forest fires are regarded as purely adverse results of human activity. But even in temperate Central Europe, fire can play an important ecological role, at least in some forest types, where it shapes their stand structure, dynamics and species composition (Tinner et al., 2005; Niklasson et al., 2010). A comparable situation exists in North America where the perception of the importance of fire in temperate deciduous forests is increasing, but still remains to be disputable. On the other hand, no one doubts, for example, the fire-driven dynamics of the Pine Barrens, a temperate pine forests on sandy soils in north eastern USA (Abrams, 1992; Hoss et al., 2008). In Central Europe, there is evidence that wildfires normally occur in natural Scots pine-dominated forests in sandstone areas, which are considered a geographically disjunct analogy to boreal coniferous forests of northern Europe (Novak et al., 2012). There is also evidence that wildfires occurred throughout the Holocene period (i.e. the last 10,000 years). Charred plant material has been found in sedimentary peat bog records (Pokorný and Kuneš, 2005; Abraham, 2006) and in sand sediments under rocks (Sádlo and Herben, 2007). However, the spatial and temporal dynamics of forest fires, and the environmental factors responsible for their occurrence over millennia had so far not been studied in the area.

Changes in the temporal distribution of fire events on the millennial scale are usually inferred from the sedimentary charcoal record in lakes or peat-bogs (Rius et al., 2011). This approach can reveal the frequency of fires in ancient times; however, the spatial distribution of ancient fires remains uncertain. On the contrary, spatially explicit fire histories can be derived from fire scar chronologies, which usually span only the last several centuries, however (Niklasson et al., 2010). In any case, well preserved traces of fire in the tree-ring record are rather infrequent and fragmentary in Central Europe due to the rarity of old scared trees caused by intensive forestry. Another possible reason is the prevalence of low-severity fires, which usually do not leave scars on mature pine trees (Piha et al., 2013).

The goal of this study was to determine the role of environmental factors affecting the frequency and distribution of forest fires on two temporal scales. We traced the occurrence of wildfires over the last three decades and in the last millennium combining two complementary approaches – the study of historical forest management records and assessment of charcoal content in the topmost layer of forest soil. Comparing fire patterns on two different time scales, but using similar environmental correlates, strengthens the inferences about processes controlling the distribution of forest fires in the landscape. Specifically, we aimed to reveal:

1. Whether the region under study has a continuous long-term fire history.
2. Whether the spatial distribution of wildfires is driven by the same environmental factors over decades as over millennia.
3. Whether the spatial distribution of wildfires in the landscape is driven more by anthropogenic or natural factors.

We also discuss the implications of our findings for forest management practice in protected natural areas of Central Europe.

2. Materials and methods

2.1. Study area

We worked in the Bohemian Switzerland National Park (BSNP), situated in the NW region of the Czech Republic (Fig. 1). It is part of a larger landscape territory – the Elbe Sandstones, which also include the Saxon Switzerland National Park in Germany. The BSNP was established in 2000 and covers an area of 79 km^2. Elevations vary from 116 to 619 m a.s.l. The bedrock is composed of quartzose sandstone rocks of Cretaceous origin with occasional outcrops of Tertiary volcanic bodies. The terrain is very rugged, with cliffs, pillars, rock walls, arches, gorges, canyons and several conic volcanic hills. The depth of some gorges exceeds 200 m. Such landscape heterogeneity results in great variation in habitat conditions within a relatively small area, for example, frequent alternation of moist shady gorges with steep slopes and dry insolated rock tops (Fig. 1).

The main part of the BSNP is covered by forest. The natural vegetation is an acidophilous beech and mixed spruce-fir-beech forest (*Luzulo-Fagetum*). Other forest communities occur in special habitats – Norway spruce (*Piceaabies*) stands in narrow gorges with climatic inversion, acidic Scots pine and oak–pine forests (*Dicrano-Pinetum*; *Vacciniovitis-idaeae-Quercetum*) on sandstone rock tops, and herb-rich beech forest (*Melico-Fagetum*) on several volcanic hills (Mikuláš et al., 2007).

The contemporary forest is dominated mainly by spruce and pine plantations; natural vegetation remains mainly in inaccessible terrain (rock tops, gorges, hill slopes, etc.). The approximate present BSNP forest composition is: 71% Norway spruce (*Piceaabies*); 16% Scots pine (*P. sylvestris*); 6% European beech (*Fagus sylvatica*); 3% European larch (*Larix decidua*), which is not native in this region; 2% invasive White pine (*Pinus strobus*) and 1% silver birch (*Betula pendula*). The abundance of other occurring species, for example, sessile oak (*Quercus petraea*), European ash (*Fraxinus excelsior*) and black alder (*Alnus glutinosa*), etc., is less than 1%.

The earliest traces of human presence in the region date to the Mesolithic age (9500–5500 BC), when hunters and gatherers settled rock shelters (Svoboda, 2003). There is weak evidence that humans occupied the area during the Neolith and Bronze Age. Since that time, there is no evidence of any important human presence up until the early Middle Ages (Jenč and Peša, 2003).

Compared to the rest of the Czech Republic, forest fires are markedly more frequent in this area (Jankovská, 2006). References

Fig. 1. Common topography of the BSNP landscape (Pravčický důl valley).