Quaternary Science Reviews 169 (2017) 378–390

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Broadleaf deciduous forest counterbalanced the direct effect of climate on Holocene fire regime in hemiboreal/boreal region (NE Europe)

Angelica Feurdean [a, b, *], Siim Veski [c], Gabriela Florescu [a, b], Boris Vannière [d], Mirjam Pfeiffer [a], Robert B. O'Hara [a, e], Normunds Stivrins [f, g], Leeli Amon [c], Atko Heinsalu [c], Jüri Vassiljev [c], Thomas Hickler [a, h]

[a] Senckenberg Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage, 25, 60325, Frankfurt am Main, Germany
[b] Department of Geology, Faculty of Biology and Geology, Babeş-Bolyai University, Kogălniceanu, 1, 400084, Cluj-Napoca, Romania
[c] Institute of Geology, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia
[d] Laboratoire Chrono-environnement UMR CNRS 6249, Maison des Sciences de l'Homme et de l'Environnement USR CNRS 3124, Université Bourgogne Franche-Comte, Besançon, France
[e] Department of Mathematical Sciences, NTNU, 7491 Trondheim, Norway
[f] Department of Geosciences and Geography, University of Helsinki, PO Box 64, FI-00014, Helsinki, Finland
[g] Department of Geography, Faculty of Geography and Earth Sciences, University of Latvia, Riga, Jelgavas street 1, LV-1004, Latvia
[h] Department of Physical Geography, Goethe University, Altenhöferallee 1, 60438 Frankfurt am Main, Germany

ARTICLE INFO

Article history:
Received 22 February 2017
Accepted 30 May 2017

Keywords:
Vegetation dynamics
Charcoal morphologies
Surface vs. crown fires
Picea abies
Pinus sylvestis
Fire frequency
Fire severity/area burnt
Baltic

ABSTRACT

Disturbances by fire are essential for the functioning of boreal/hemiboreal forests, but knowledge of long-term fire regime dynamics is limited. We analysed macrocharcoal morphologies and pollen of a sediment record from Lake Lielais Svētiņu (eastern Latvia), and in conjunction with fire traits analysis present the first record of Holocene variability in fire regime, fuel sources and fire types in boreal forests of the Baltic region. We found a phase of moderate to high fire activity during the cool and moist early (mean fire return interval; mFRI of ~280 years; 11,700–7500 cal yr BP) and the late (mFRI of ~190 years; 4500–0 cal yr BP) Holocene and low fire activity (mFRI of ~630 years) during the Holocene Thermal Optimum (7500–4500 cal yr BP). Charcoal morphotypes and the pollen record show the predominance of frequent surface fires, occasionally transitioning to the crown during *Pinus sylvestris-Betula* boreal forests and less frequent surface fires during the dominance of temperate deciduous forests. In contrast to the prevailing opinion that fires in boreal forests are mostly low to moderate severity surface fires, we found evidence for common occurrence of stand-replacing crown fires in *Picea abies* canopy. Our results highlight that charcoal morphotypes analysis allows for distinguishing the fuel types and surface from crown fires, therefore significantly advancing our interpretation of fire regime. Future warmer temperatures and increase in the frequency of dry spells and abundant biomass accumulation can enhance the fire risk on the one hand, but will probably promote the expansion of broadleaf deciduous forests to higher latitudes, on the other hand. By highlighting the capability of broadleaf deciduous forests to act as fire-suppressing landscape elements, our results suggest that fire activity may not increase in the Baltic area under future climate change.

1. Introduction

Ecosystem composition and species ranges are primarily determined by climate, but disturbance by fire is also essential for influencing their structure, diversity and functions (Flannigan et al., 2009). Fire activity has increased over recent decades in many parts of the world and is predicted to intensify with future increases in temperature and frequency of extreme drought years and where biomass accumulation is abundant (Khabarov et al., 2016).

* Corresponding author. Senckenberg Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage, 25, 60325, Frankfurt am Main, Germany.
E-mail addresses: angelica.feurdean@gmail.com, angelica.feurdean@senckenbgerg.de (A. Feurdean), siim.veski@ttu.ee (S. Veski), gabriella.florescu@yahoo.com (G. Florescu), boris.vanniere@univ-fcomte.fr (B. Vannière), Mirjam.pfeiffer@senckenberg.de (M. Pfeiffer), bohara@senckenberg.de (R.B. O'Hara), normunds.stivrins@helsinki.fi (N. Stivrins), leeli.amon-veskimeister@ttu.ee (L. Amon), atko.heinsalu@ttu.ee (A. Heinsalu), jyri.vassiljev@ttu.ee (J. Vassiljev), Thomas.Hickler@senckenberg.de (T. Hickler).

http://dx.doi.org/10.1016/j.quascirev.2017.05.024
0277-3791/

However, fire behaviour is complex and regulated by the interplay between climate, fuel amount and composition, ignition regimes, and landscape variables (van der Werf et al., 2006; Whitlock et al., 2010; Krawchuk and Moritz, 2011). The relative importance of these factors varies across a range of spatial and temporal scales and is often modulated by site-specific factors, i.e., topography, vegetation structure, local soil properties and fuel moisture (Pitkänen et al., 2003; Gavin et al., 2006; Girardin et al., 2013).

In Europe, boreal forests are among the most fire-sensitive ecosystems (Wallenius 2011; Khabarov et al., 2016). Several characteristics make boreal forests particularly prone to increases in fire activity. Firstly, boreal forests are composed of trees with high contents of flammable volatile compounds, low hanging branches, and flammable surface fuels (mosses, lichens). These litter and canopy properties promote fire occurrence (Mutch, 1970). However, where broadleaf deciduous trees with high leaf moisture and lower content of flammable compounds mix with needleleaf boreal species, fire risk is often reduced and the severity of occurring fires tends to be lower. Most fires in contemporary Eurasian boreal forests are low to moderate intensity surface fires (Granström, 1996; Grooth et al., 2013; Archibald et al., 2013). This observation contrasts with long-term fire regime reconstructions, which reveal that stand-replacing crown fires used to be common in the past (Pitkänen et al., 2003).

Past changes in fire activity at centennial to millennial scales are usually inferred from sedimentary charcoal records in lakes or peat-bogs using both micro- and macrocharcoal. However, charcoal-based fire reconstructions often lacked spatial (location, burnt area, surface or crown type of fire) characteristics linked to a specific fire regime. There are several key recommendations in using charcoal records for a comprehensive understanding of fire regime dynamics (Marlon et al., 2016). These include but are not limited to: i) the use of high-resolution, macroscopic records with restricted transport distance from the fire source; ii) contiguous sampling strategy along the sediment column; iii) distinction of charcoal morphotypes, at least to separate wood-derived from grass-derived charcoal in order to disentangle changes in fuel and fire type; and iv) charcoal calibration studies on the relationship between charcoal and fire metrics. Great progress has been made with respect to the implementation of macrocharcoal analysis and application of continuous sampling strategies in detection of fire metrics (Brown and Giesecke, 2014; Clear et al., 2013; Vannière et al., 2016; Feurdean et al., 2017). However, the analysis of charcoal morphotypes has rarely been conducted, and where applied, has usually been restricted to the two main categories, herbaceous vs. wood-derived charcoal (Daniau et al., 2013; Maezumi et al., 2015). Only a few case studies from North America provide additional separation of charcoal morphotypes (Scott et al., 2000; Enache and Cumming, 2006; Jensen et al., 2007; Courtney-Mustaphi and Pisaric, 2014).

Results from individual records, as well as syntheses of data in the Global Charcoal Database (GCD) from northeastern Europe show elevated biomass burning during the early and late Holocene and a minimum during the mid Holocene (Carcaillet et al., 2002; Power et al., 2008; Marlon et al., 2013; Brown and Giesecke, 2014; Clear et al., 2014; Molinari et al., 2013). Paradoxically, there were fewer fires during the warm and dry climatic conditions of the mid Holocene (8000–4000 cal yr BP) and more fire associated with the cooler and moister climate of the early and late Holocene (11700–8000 cal yr BP and 4000–present). One explanation for this contradiction may be found in the role of fire-related functional traits of the dominant plant species, i.e., traits that determine fire resistance and post-fire regeneration capability. Indeed, a recent inter-continental comparison of North American and Eurasian boreal fires using remote sensing data has shown that species-specific traits can lead to significant differences in fire regimes across continents (Rogers et al., 2015). This highlights the importance of considering species-level traits linked to fire in order to better understand differences in fire regime dynamics in similar biomes.

Here, we determine how long-term interactions between climate, vegetation and humans affected fire regime dynamics in the boreal and hemiboreal forests. As a case study we used Lake Lielais Svētiņu, today located in the hemiboreal forest of Latvia, but which in the past was positioned within the boreal zone. We conducted pollen analysis and for the first time in this region, analyses of macrocharcoal and charcoal morphotypes to: i) assess how functional properties of dominant species determining fire resistance and regeneration capability affect fire regime; and ii) demonstrate how charcoal morphotypes can provide valuable information on fuel sources and fire type, i.e., surface vs. crown fires. We hypothesize that i) under similar growing-season water deficits, fires were more common in coniferous than in broadleaf deciduous forest; and ii) vegetation traits can offset direct connections between fire and climate and therefore may help to explain observed discrepancies in fire-climate trends. We show that our findings are essential to assess expected future changes in fire-vegetation feedbacks, specifically with respect to the role of broadleaf deciduous forests to reduce fire occurrence under future climate change.

2. Materials and methods

2.1. Study area

Lake Lielais Svētiņu (56°45′N, 27°08′E; 96.2 m a.sl; size 18.8 ha; water depth 4 m) is located in the Lubāns lowland, eastern Latvia (see Veski et al., 2012, Fig. 1). The bedrock consists of Devonian dolomite covered by Quaternary deposits. The Lake Lielais Svētiņu catchment (~12 km^2) is predominantly forested (primarily *Betula, Picea abies,* and *Pinus sylvestris* with scattered stands of *Ulmus, Tilia, Alnus* and *Quercus*) and partly covered by agricultural fields (Stivrins et al., 2014). The climate in the area is a combination of continental (Eurasia) and maritime (Atlantic Ocean) influences, with a mean annual temperature of +5.2 °C, a mean July temperature of +16.9 °C, and a mean December temperature of - 4.1 °C (Stivrins et al., 2014).

2.2. Sampling, chronology and sediment analysis

The retrieval of a 1135 cm sediment sequence was performed from ice cover in March 2009 and 2013, using a combination of Russian type corer (1 m length, 10 cm diameter) and a Willner gravity corer for the soft surface sediment (~22 cm; see Veski et al., 2012; Stivrins et al., 2014 for details concerning coring and lithology). Twenty-three radiocarbon measurements were performed at the Poznan Radiocarbon Laboratory (Poland), Institute of Geology at Tallinn University of Technology (Estonia) and Isotoptech Znt. Laboratory, Debrecen (Hungary). Loss on ignition (LOI) analysis was used to estimate organic matter (550 °C) and to track sediment erosion and secondary charcoal deposition into the lake (for methodology see Veski et al., 2012; Stivrins et al., 2014). The sediment core used in the current study (core 2013) was correlated with the core from 2009 based on the changes in lithology and organic matter content (Fig. A1), and the age-depth model was built using the OxCal 4.2.4 (Bronk Ramsey and Lee, 2013) and the IntCal13 (Reimer et al., 2013) and NHPine16 (Hogg et al., 2016) (Fig. A1).