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Climate and biomass control on fire activity during the late-glacial/early-Holocene transition in temperate ecosystems of the upper Rhone valley (France)

Élise Doyen *, Boris Vannière, Damien Rius, Carole Bégeot, Laurent Millet

Laboratoire Chrono-environnement, UMR 6249 CNRS, Université de Franche-Comté, Besançon, France

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ABSTRACT

The main objective of this study is to document paleofire activity during the late-glacial/early-Holocene transition in temperate ecosystems. For this purpose, we cored lakes Paladru and Moras (Rhone valley, France) and quantified sedimentary charcoal accumulation rate and fire frequency. To assess the role of climate and vegetation in paleofire activity, charcoal data were compared to vegetation dynamics based on pollen analyses and to climate reconstructions. The first increase in paleofire activity occurred at the beginning of the Bølling/Allerød Interstadial period (14,500 cal yr BP), synchronous with temperature and fire-prone vegetation increases. During the Younger Dryas, paleofire activity first decreased (12,600–12,200 cal yr BP) and then abruptly increased (12,200–11,600 cal yr BP). This change corresponds to a known climate partitioning that occurred during the Younger Dryas and implies that a sufficient quantity of biomass was available during the second period. At the beginning of the Holocene, fire activity remained high. This is in agreement with the increases in temperature and vegetation density. The change in forest composition since ca. 11,200 cal yr BP partly explains the decrease in paleofire activity, whereas warm climate conditions seem suitable for fire ignition and propagation.

Introduction

Fire is an important driver of environmental processes that affect global ecosystem patterns through changes in vegetation cover, climate and the carbon cycle (Cofer et al., 1997; Bowman et al., 2009). Climate variations control fire regime through vegetation and soil moistures, biomass composition and structure, and fire-conductive weather patterns (Pausas, 2004). At the same time, fire induces feedback control on climate changes through greenhouse and aerosol emissions, albedo surface changes and the restriction of forest cover expansion (Daniau et al., 2012). Thus, it is crucial to anticipate the future effects of climate change on fire regimes in the current period of climate warming (Schneider et al., 2007).

Fire activity depends on interactions between climate, vegetation and human activities (Whitlock et al., 2010). The use of fire for land clearing in Western Europe has occurred as a consequence of the agricultural expansion during the Neolithic period (e.g., Colombaroli et al., 2008; Doyen et al., 2013a) while the significant human influence on biomass burning seemed to start ca. 4000 cal yr BP (Vannière et al., 2008; Rius et al., 2011; Doyen et al., 2013b). Therefore, since the development of farming activities (i.e., 7000 years ago), it has been difficult to disentangle the respective influence of climate and vegetation changes on fire activity independent of human impacts (Vannière et al., 2011).

The period between the late-glacial ice recession and the early Holocene was marked by rapid and strong climate changes, while the influence of hunter-gatherers on the environment was negligible and/or restricted to small areas (Brown, 1997; Kalis et al., 2003). Thus, this time period can be used to assess the interactions between climate, vegetation and fire activity without the possible confounding influence of human activities. Undisturbed sediments that accumulated in lacustrine systems since the glacial retreat are appropriate archives to study the late-glacial/early-Holocene transition (e.g., Magny et al., 2006a). Most of the published studies specifically dedicated to paleofire reconstructions during the late-glacial/early-Holocene transition have been carried out in North America (e.g., Higuera et al., 2009; Marlon et al., 2009). In Europe, available studies have focused on the Mediterranean basin (Tinner et al., 2005; Magny et al., 2006a; Kaltenrieder et al., 2010; Vescovi et al., 2010; Connor et al., 2012; Leys et al., 2013), and some records document the history of fires in temperate areas during these periods (Clark et al., 1989; Feurdean et al., 2012; Rius et al., in press).

The objectives of the present study are: (*i*) to reconstruct the fire history of Lake Paladru and Lake Moras, two sites located in the upper Rhône valley (eastern France) and (*ii*) to assess the biomass burning response to high-amplitude climate and vegetation changes during the late-glacial/early-Holocene transition. The relationship between fire

* Corresponding author.
E-mail address: el.doyen@laposte.net (É. Doyen).

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activity and vegetation dynamic was studied using pollen analyses (in percentages and concentrations) from these two lacustrine records. The relationship between fire regime and climatic changes was studied by comparing results from charcoal analysis with regional climate dynamics provided by a vegetation-independent proxy (i.e., chironomid-inferred summer air temperatures reconstructed from the neighboring Jura mountains; Heiri and Millet, 2005).

Material and methods

Environmental settings

Lake Paladru (45°27′18″N, 5°32′06″E, 492 m a.s.l.) and Lake Moras (45°40′55″N, 05°16′06″E, 304 m a.s.l.) are located 32 km apart in the French Alpine foreland, in the upper Rhône valley (Fig. 1a). The area is characterized by a sub-continental climate: the mean annual precipitation rate is 1060 mm/yr; mean July and January temperatures are 19.9°C and 2.2°C, respectively.

The study sites are two moraine-dammed lakes formed during the last glacial maximum. Lake Paladru has an area of 392 ha, a catchment area of 5200 ha and a maximum depth of 36 m (Fig. 1b). The watershed (maximum elevation: 780 m a.s.l.) is composed of molasse and is covered in several places by moraine deposits. Two small streams feed the lake. Lake Moras is smaller, with an area of 20 ha, a catchment of 400 ha and a maximum depth of 12.5 m (Fig. 1c). Water drains into the lake from a small watershed (maximum elevation: 420 m a.s.l.) that is composed of Jurassic calcareous substratum (184 ha) and is covered in several places by moraine deposits (167 ha). The water is supplied to the lake by underground springs; discharge is into a small stream at the southern extremity of the lake.

Coring and geophysical logging

In each lake, overlapping cores were taken at the deepest part of the basin (Fig. 1b–c) using a stationary piston corer (UWITEC system) operated from a surface platform. Magnetic susceptibility and gamma density were measured at 5-mm intervals with a Multi Sensor Core Logger (Geotek). Sediment color variations were checked using high-resolution pictures. These three parameters were used to correlate the sedimentary levels of the core sections to create a master core without gaps for each lake. All further analyses were performed on these master cores (550–370 cm section for Lake Paladru) and (555–470 cm section for Lake Moras).

Pollen analyses

Samples (2 cm^3) from Lake Paladru were taken at 8-cm intervals between 550 and 425 cm core section and at 16-cm intervals between 425 and 370 cm of the sediment core section, while Lake Moras was sampled at 5-cm intervals along the 555 to 470 cm section. Samples were prepared for pollen analysis using the standard procedure described by Faegri and Iversen (1989). *Lycopodium clavatum* tablets were added to each subsample to calculate pollen concentration in Lake Moras (Stockmaar, 1971), while the volumetric method was used to calculate pollen concentration in Lake Paladru. Pollen was identified and counted at 500× magnification. A mean of 1060 (±550) pollen grains from terrestrial plants (Total Land Pollen, hereafter referred to as TLP) were counted in each subsample using transmitted light. Pollen identification was based on identification keys (Beug, 2004), photography books (Reille, 1992, 1998) and a reference collection of modern pollen types. Pollen counts were expressed as percentages of TLP, excluding pteridophytes, aquatics and indeterminable grains from the total pollen sum and as concentrations (number pollen grains/cm^3). In the discussion part, TLP concentration and AP/TLP ratio were used as proxy for biomass/fuel load and woody cover, respectively.

Sediment analyses

Geochemical core logging was undertaken using an ITRAX XRF core scanner (CEREGE laboratory, Aix-en-Provence, France) to track the occurrence of allochtonous mineral inputs. The relative abundances of calcium (Ca), titanium (Ti) and potassium (K) were measured using a Chromium tube with a count-time of 15 s and a sampling step of 5 mm set at 30 kV.

Charcoal analyses

Fire history was reconstructed from macro- and microscopic charcoal particles accumulated in lake sediments.

The size of a charcoal particle partly determines its ability to be transported (Clark, 1988). Micro-charcoal analysis (particles between 10 and 200 μm) is generally considered to reflect regional fire activity (within a radius of ca. 20–50 km around the lake; Tinner et al., 1998); whereas macro-charcoal analysis (particles larger than 200 μm) mainly traduce local fire history (within a radius approximately between 1 and 2 km around the lake; Higuera et al., 2007).

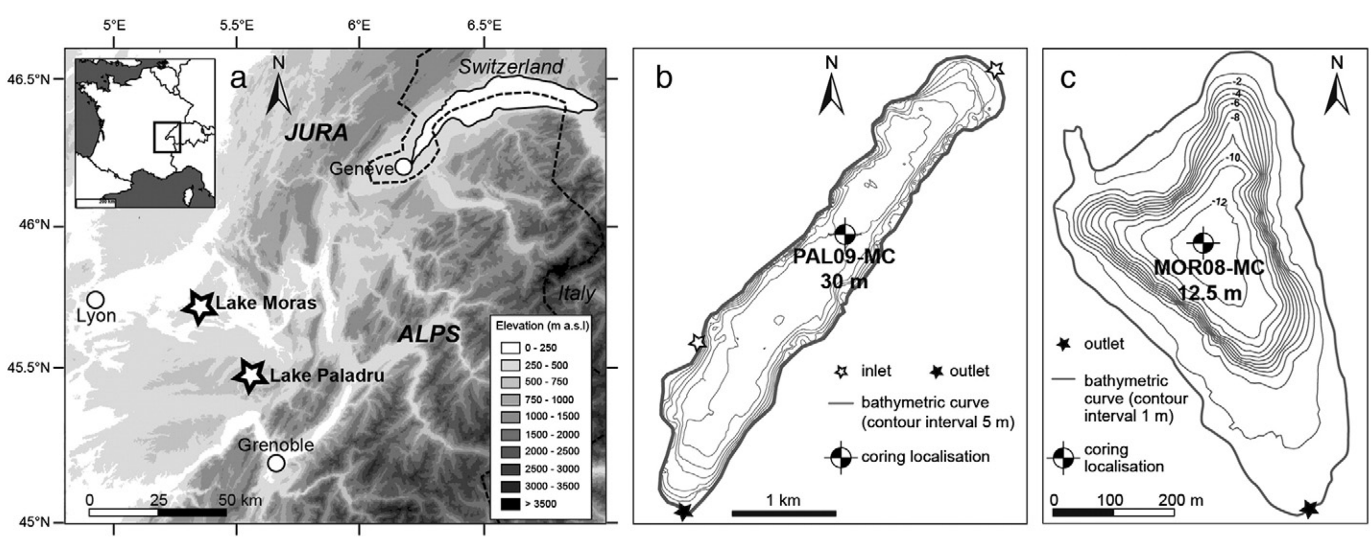

Figure 1. a) Location of Lake Moras and Lake Paladru, b) bathymetric map of Lake Paladru and location of the core samples, c) bathymetric map of Lake Moras and location of the core samples.