Comment

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Lakes cannot burn and buried charcoals cannot fly: Reconciling lake- versus soil-based reconstructions of past forest dynamics

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Abstract

Fundamental understanding of paleoecological proxies is necessary when attempting to compare, complement, or contrast two or more methods, and lack thereof may lead to erroneous conclusions. This comment addresses three such misunderstandings found in a recently published paper by Paillard et al. regarding soil macrofossil charcoal analysis (SMCA) and its relationship to lacustrine sediment analysis. The aim is to correct some misinformation associated with the following three assertions: *(1) Broadleaved tree species produce fewer charcoal fragments than coniferous species.* Although coniferous stands are more fire-prone, experimental burning shows that species with denser wood, that is, broadleaves, produce greater amounts of charcoal under similar fire conditions. *(2) Preservation of charcoal particles is poor at the referenced study site.* Once buried in the mineral soil compartment, charcoal particles remain quite stable. As such, SMCA has revealed Late Pleistocene marginal stands of broadleaved species. *(3) Underestimating the importance of range-edge dynamics on the results of SMCA reconstructions*. SMCA offers a stand-scale historical reconstruction that has proven well-suited to study peripheral stands and to reflect the heterogeneity of a landscape mosaic. By attempting to reconcile the SMCA (in situ) and lake sediments (ex situ) narratives, Paillard et al. missed one key aspect of comparing complementary proxies: they show different aspects of the past.

Keywords

boreal-temperate ecotone, lacustrine sediment analysis, marginal populations, paleoecological proxies, soil macrofossil charcoal analysis, sugar maple

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When attempting a reconstruction of past forest ecosystems, researchers must clarify the various criteria behind their choice of paleoecological archive (i.e. proxy). Fundamental knowledge of applicable methodologies is a key pre-requisite for proxy selection. Incomplete understanding can lead to erroneous ecological conclusions. Such questions were raised in a recent paper by Paillard et al. (2023), where the appropriateness of the use of a forest soil anthracological proxy (i.e. soil macrofossil charcoal analysis, SMCA) for the reconstruction of past marginal population dynamics within the boreal-temperate ecotone (BTE) was put in doubt. Three points were raised by Paillard et al. (2023) relating to the relevance of SMCA (i.e. pedoanthracology in their terms) to detect marginal populations of temperate species: (1) the putatively low charcoal production of sugar maple as a broadleaved, temperate, and non-fire adapted species, (2) the poor preservation of charcoal older than a thousand years, at least at the Rémigny site studied by Pilon and Payette (2015), and (3) the peculiarities of range-margin dynamics and the possibility of local establishments and extinctions. The use of these arguments to attempt to undermine SMCA suggests that there is a misunderstanding of the way in which lacustrine sediment analyses, the main source of data for the study, and forest soil anthracology differ in application. This comment aims to address the factual errors and possible misinterpretations put forward by Paillard et al. (2023) and to provide a broader context to the relationship and complementarity between the two proxies.

Charcoal production and the effects of vegetation on fire regimes

The type of tree species in the landscape has a marked effect on its fire regime. Temperate species such as sugar maple (*Acer saccharum*) create a disconnect between the soil and canopy, thus limiting the severity of fire (Drever et al., 2006). Further, the air

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under a broadleaved canopy is usually more humid, thus less conductive to the spread of fire (Drever et al., 2006). Finally, the wood of broadleaved trees is fundamentally less flammable, due to the absence of resins and its higher water content (Hély et al., 2000). These points might account for a reduced fire activity in broadleaved-dominated stands (although differences in seasonal moisture availability mean that deciduous stands in spring may be as flammable or even more so than coniferous stands (Hély et al., 2000)) but are not related to the intrinsic propensity of a given species to produce charcoal particles with the eventual occurrence of a fire within the BTE. Anatomical characteristics should instead be examined to provide further information. While this area of ecological knowledge is still relatively sparse, Fréjaville et al. (2013) attempted a calibration of the charcoal production of various tree species and showed that bark thickness and wood density were the main drivers for the process. Although the authors did not investigate North American species, they report that broadleaved species characteristics (thinner bark and denser wood) mean they generate more charcoal compared to conifers. They also suggest that the variables driving the production of charcoal change with individual tree size and age, implying that various species can ultimately produce an equivalent amount of charcoal if the stand includes individuals of different sizes. Hence, although it is not possible to provide a robust estimate of charcoal production by sugar maple at the moment, suffice to say that the fire-suppressing predisposition of its stands does not necessarily mean that the species should leave fewer charcoal particles in the soil after a fire, as was suggested by Paillard et al. (2023).

Charcoal preservation and the effects of landscape heterogeneity

The soil macrofossil charcoal record from the Rémigny site covers the last *ca*. 7200 years (Pilon and Payette, 2015). It shows a sudden increase in charcoal abundance during the last millenium compared to the period between 7200 and 1000 calibrated years before present (cal BP). Paillard et al. (2023) erroneously interpreted this result as indicative of lower fire activity before 1000 cal BP, a scenario that differs from their own fire reconstructions based on the accumulation rate of microcharcoal in lake sediments (i.e. CHAR peaks). To reconcile the narratives, Paillard et al. (2023) suggested that the low soil charcoal macrofossil abundance is indicative of degradation and disappearance of the older charcoal particles produced before 1000 cal BP. However, it has been shown that soil macrofossil charcoal particles are recalcitrant to degradation over several millennia and remain quite stable once buried and stabilized in the mineral soil compartment (de Lafontaine et al., 2011; de Lafontaine and Asselin, 2011). Indeed, SMCA has already been used to detect cryptic glacial microrefugia of broadleaved temperate species within a periglacial desert as far back as >45,000 cal BP (de Lafontaine et al., 2014). At Remigny, the drop in charcoal abundance older than 1000 cal BP is maintained at a low, but steady, level for the remainder of the record (Pilon and Payette, 2015). Using accumulation curves of the average number of fires detected as a function of the number of radiocarbon-dated charcoal, Pilon and Payette (2015) showed that their fire reconstruction was likely complete, with a maximum of 21 observed fire events matching a maximum of 21 estimated fire events. According to Pilon and Payette (2015) a higher fire frequency prevailed at Rémigny during the last 3500 years and present day compared to the period between 7200 and 3500 cal BP. We agree with this view and refute the interpretation of soil macrofossil data in Paillard et al. (2023). First, when interpreted correctly, the fire history inferred by Pilon and Payette (2015) at Rémigny strikingly matches the reconstruction made by Paillard et al. (2023) at nearby Lac Chasseur (i.e. more fires since *ca*. 4000–3500 years ago). Second, the highly sensitive spatial resolution of SMCA (i.e. stand scale, in situ) reconstructions might provide a different picture compared to a more regional (i.e. ex situ) average described by lake sediment (CHAR analysis) reconstructions (Gazol and Ibáñez, 2010), whereby charred particles can travel up to 30 km (Oris et al., 2014). Differences between SMCA and CHAR analysis (which is likely not the case here) would rather reflect the fact that SMCA provides direct in situ evidence, whereas palynology and CHAR analysis of lake sediments provide a broader regional context. Thus, it should not be expected that a given forest stand's fire/composition history matches exactly with a broader regional (ex situ) inference based on an amalgamation of multiple stands and perhaps watersheds.

Charcoal usefulness and the effects of range-edge dynamics

Paillard et al. (2023) recognized that the absence of sugar maple before 720 cal BP in the soil charcoal record might indicate recent establishment of the species at the Rémigny site, as initially suggested by Pilon and Payette (2015). This inference is also consistent with the genetic imprint suggesting a founder event at the Rémigny site (Graignic et al., 2018). Instead, Paillard et al. (2023) found an earlier maple arrival at Lac Chasseur between 5500 and 4500 cal BP, which they seemingly consider contradictory with results from Rémigny, 800 m away. A late arrival at Rémigny could reflect range-edge dynamics, such as local population fluctuations, which, they concede, would not be indicative of a complete regional absence of the species, including around their sampled lake (Lac Chasseur) before 720 cal BP. In this, at least, we agree. In situ deposition and burial of burned woody material after a fire makes for a spatially sensitive proxy for the reconstruction of past forest ecosystems at the stand-scale. A study by Ohlson and Tryterud (2000) suggests that the spatial resolution of macrocharcoal particles >2 mm can be measured in tens of meters, rather than hundreds of meters to kilometers. Hence, SMCA appears as the ideal proxy to assess the microenvironmental differences between neighboring, albeit contrasting, stands within a heterogeneous landscape (Pessenda et al., 2005). As such, SMCA was often selected for inferring ecological histories of small and isolated marginal populations located at the limit of a species range (de Lafontaine et al., 2014; de Lafontaine and Payette, 2011, 2012; Jules et al., 2018; Dumont et al., 2023; Minchev et al., in prep.; Mondou Laperrière et al., submitted; Payette et al., 2015, 2017, 2018a, 2018b). Furthermore, it has been seen as complementary to lake sediment proxies because the strengths of one approach might compensate for the weaknesses of another (Gavin et al., 2014). This is largely why we disagree with the arguments made by Paillard et al. (2023) regarding the use of SMCA in this context. Scale matters: the stand-scale SMCA reconstruction made by Pilon and Payette (2015) at Rémigny, some 800 m from the local- to regional-scale reconstruction made by Paillard et al. (2023) at Lac Chasseur, need not yield similar results regarding maple establishment date and wildfire history. Yet, they might both be correct, simply reflecting different spatial scales. Instead of debating which methodology is superior, we recommend that each proxy be used to its fullest extent so that a more complete understanding of past forest dynamics at a range of spatial scales can be obtained.

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