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Letter to the Editor

Soil charcoal stability over the Holocene—Response to comments by Mikael Ohlson

Mikael Ohlson's effort to refute our finding of Holocene stability of boreal forest soil charcoal is based on three biogeochemical mechanisms: (1) incomplete charcoalification, with partially charred material degrading somewhat faster; (2) biological degradation by soil microorganisms; and (3) abiotic processes like gelifluction or cryoturbation. We thank Mikael Ohlson for underlining these important mechanisms that we did not discuss in our *Short Paper* (de Lafontaine and Asselin, 2011).

Ohlson's comments originate from his observation of a discrepancy between mean charcoal production per fire event during the Holocene and the size of the contemporary soil charcoal pool. He rightfully points to the possible role of secondary combustion during subsequent fires that would turn charcoal into ash. We agree that this might be an important mechanism and that research is needed to decipher its effect on the size of the charcoal pool. Nevertheless, neither this, nor the three other mechanisms referred to by Ohlson, change the fact that we found the same relationship between charcoal mass and number of charcoal particles in several eastern North American boreal forest sites characterized by marked differences in latitude, longitude, altitude, soil type, forest cover, and disturbance regimes. We carefully reviewed the literature cited by Ohlson to support his claim and reached different conclusions.

In their chemical oxidative degradation experiment, Ascough et al. (2011) have shown that charcoal produced at low temperatures (<300°C) was altered faster than charcoal produced at high temperatures (>400°C). The charcoal samples used in their experiment came from various ecosystems (Azores, Brazil, Burkina Faso, Iceland, Ireland, Portugal, Sumatra and United Kingdom) submitted to an array of fire regimes (surface and crown fires of low to high intensity). Our study was restricted to the eastern North American boreal forest, which is characterized by high-intensity crown fires (Johnson, 1992) reaching temperatures between 480 and 810°C (Swift et al., 1993; de Groot et al., 2004). The charcoal assemblages in our study were thus composed of what Ascough et al. (2011: 2362) call "*highly stable* and environmentally recalcitrant" charcoal (italics ours).

According to Baldock and Smernik (2002), charcoal produced at temperatures >300°C is not submitted to significant microbial alteration. Furthermore, Pietikäinen et al. (2000) have shown that soil microorganisms feed on organic compounds adsorbed on charcoal particles, not on charcoal *per se*. Thus, biological activity is unlikely a cause of charcoal degradation in boreal forest soils.

Preston and Schmidt (2006) suggested (but did not test) that gelifluction and cryoturbation processes could cause charcoal degradation. They cited Carcaillet (2001), who also suggested (but did not test) that freeze–thaw cycles could explain the lack of charcoal stratigraphy in alpine soils. He in turn cited Carcaillet and Talon (1996), who suggested (but also did not test) that lower anthracomass at one of their study sites was probably caused by freeze–thaw processes. In short, cryoturbation and gelifluction were assumed, but never verified, as processes of charcoal breakage. Our study clearly showed that 1000-yr-old charcoal sampled at a forest-tundra site under <5 cm organic soil subject to several freeze–thaw cycles in a single year (Asselin and Payette, 2005) had the same relationship between mass and number of particles than charcoal from sites in the southern boreal forest deeply buried in organic soil, and far less affected by freeze–thaw cycles.

While acknowledging the existence of biogeochemical charcoal alteration processes, we nevertheless found that the relationship between charcoal mass and the number of charcoal particles was not significantly different in various biogeographical regions of the eastern North American boreal forest. Moreover, we showed that the relationship is stable with regards to charcoal residence time in soil over the Holocene.

Mikael Ohlson questions our conclusions but fails to provide an alternative explanation for our results. After careful reexamination of the literature he cites to support his claim, we conclude that the biogeochemical mechanisms underlined in his comment are not relevant in boreal forests characterized by a regime of high-intensity crown fires. This is rather good news for palaeoecologists, who should not be worried about missing older fire events from post-burial charcoal fragmentation when reconstructing fire and vegetation histories from soil charcoal data.

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