fire

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Perspective

Sparking New Opportunities for Charcoal-Based Fire History Reconstructions

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Paleofire research is the study of past fire regimes using a suite of proxies (frequency, area burned, severity, intensity, etc.). Charcoal preserved in sedimentary archives constitutes one of the most ubiquitous measures of past fire regimes along with fire-scarred tree rings, chemical markers of fire, and black carbon residue [1,2]. The quantity of charcoal accumulating in sediments over time reflects changes in biomass burned and captures the range of its variability across multiple time scales (e.g., decadal to millennial [3]). The Global Paleofire Working Group Phase 2 ($GPWG_2$; http://pastglobalchanges.org/ini/wg/gpwg2/intro) is a team of scientists interested in reconstructing past fire regimes in diverse environments. This paper provides a brief introduction to the evolution of charcoal-based paleofire science as a discipline and presents the outcome of the recent workshop organized by the $GPWG_2$ in Montreal (October 2017), focusing on applications of paleofire knowledge to the management of a range of ecosystem challenges.

The palynologist Iversen [4] was the first to study charcoal-based fire signals, on pollen slides, as a proxy for environmental change. But it was decades later, in the late 1960s and the 1970s, with the pioneering work of Waddington [5], Simmons [6], and Mehringer et al. [7], that Iversen's approach became adopted by others. Charcoal-based paleofire research really emerged as a discipline during the 1990s, with an increasing number of publications (~20 paper year^{-1}, Figure 1b), with the publication of seminal papers [3,8–11], as well as an incremental growth in the diversity of journals where charcoal-based paleofire research was being published (Figure 1b). Since 2005, however, charcoal-based paleofire science accelerated as a discipline, demonstrated by a sharp rise in the number of publications, indicating that the target audience of paleofire studies was expanding in scope (Figure 1b).

Interestingly, since 1990, there has been a trend toward increasing multi-disciplinary applications of charcoal-based paleofire sciences (Figure 1a). Indeed, the long-term perspective afforded by paleofire research is appealing to a range of socio-environmental research, as it enables the study of the dynamic interplay among fire, vegetation, land-use, land-cover, and climate changes across multiple spatial and temporal scales that are mostly inaccessible with other types of proxy data [12]. A paleofire perspective provides a unique understanding of ecosystem functioning, because ecological processes, like large infrequent fires (i.e., a discrete disturbance event), require a multi-centennial time scale to be fully appreciated.

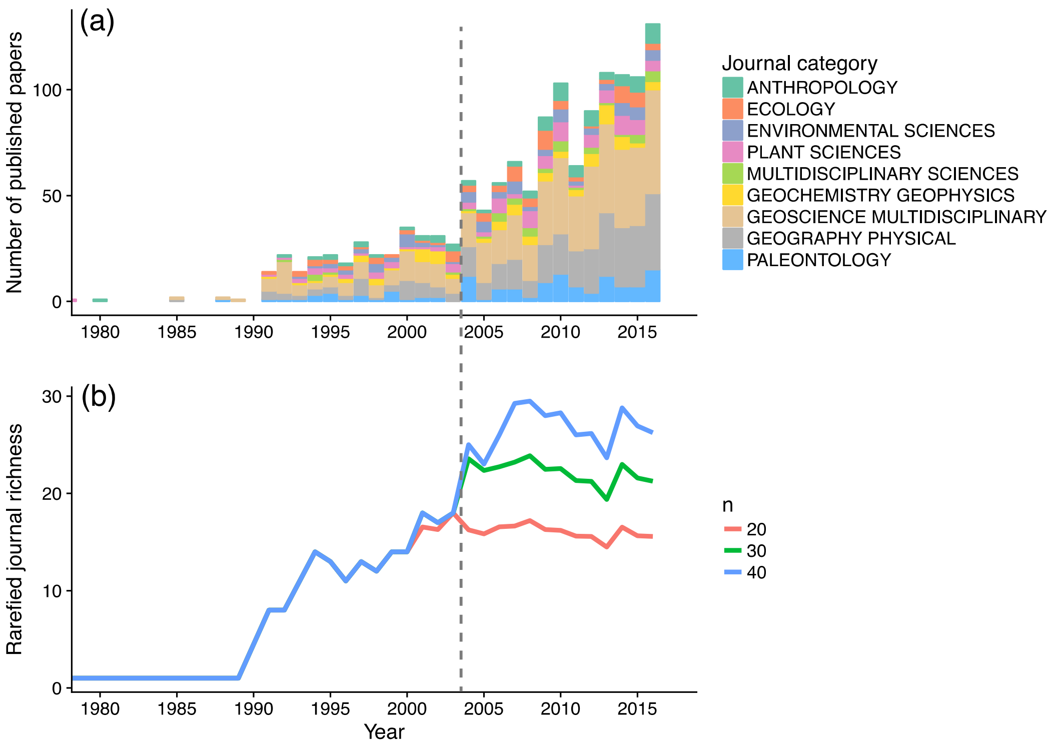

Figure 1. Meta-analysis of published scientific articles (n = 960) containing the terms "paleo *" and "charcoal" from the Thompson ISI Web database between 1980 and 2016. (**a**) Number of published articles by year and corresponding ISI web journal categories. (**b**) Diversity of the journals publishing articles with the keywords "paleo *" and "charcoal" assessed using rarefied journal richness (Birks & Line, 1992) [13]. For each year under analysis, the rarefied journal richness was computed with constant annual publication sums of 20, 30, and 40 articles; i.e., journal diversity was standardized in order to take into account publication volume growth during the studied period.

During the last decade, a significant increase in the number of charcoal-based paleofire publications (Figure 1a) has substantially improved our understanding of (1) key drivers for different fire-climate conditions [14], (2) anthropogenic fire regime alteration [15], and (3) new perspectives on long-term fire ecology paradigms [16]. Moreover, charcoal-based paleofire science has evolved recently toward improved information about other fire-regime parameters, including the possibility to explore area burned [17], fire severity metrics [18], and fuel types [19].

Today, charcoal-based paleofire science has reached a critical point in its evolution; in order to increase the relevance and application of this body of knowledge, notably by stakeholders and non-fire-science specialists, there is an increasing need to expand the access and utility of paleofire data. New avenues for research have been identified for data-model fusion [20], and for disseminating research to ecosystem managers, practitioners, and policy-makers regarding fire management [21] and fire risk mitigation [22]. Indeed, the information derived from paleofire studies can be used by landscape managers aiming to preserve and sustain biodiversity under threat by accelerating rates of climate change [23]. Furthermore, the lack of knowledge on current ecosystems resilience and their natural variability, including the role of anthropogenic legacies, often leads to a misunderstanding of realistic targets and an appropriate choice of baseline conditions [24]. Thus, the time scale covered by paleo-data represent an opportunity to provide insights about the long-term ecological functioning of ecosystems [25]. However, while there is an increasing number of trans-disciplinary conceptual papers emphasizing the interest of long-term data for ecosystem management and biodiversity conservation [26], there are actually very few studies that have done so in practice [27].

The recent workshop of the $GPWG_2$ in Montreal was specifically dedicated to "the application of paleofire knowledge to current and future ecosystem management" and identified several potential paths forward. Prior to this workshop, each participant was asked to reach out to ecosystem manager(s), environmental policy maker(s), and/or conservation practitioner(s), with a short survey about their interest in scientific data, in particular paleofire information, in relation to their work. While most survey participants were potentially interested in this information, few were aware of the existence of such data and were uncertain about their applicability. Furthermore, discipline-specific vocabulary or jargon, as well as differential access to data and tools, seem to limit the reception of the discipline and therefore its practical application.

Discussions at the workshop therefore focused on developing common language and tools to facilitate discussion and improve understanding. For the charcoal-based paleofire community, this can be done by developing calibration studies [28], where raw charcoal data can be more easily interpreted as fire information. Moreover, some geographical regions lack fire history information, particularly grass-dominated ecosystems from boreal, temperate, and tropical regions, and it is still not possible to quantitatively reconstruct fire-regime variables in most ecosystems [28]. Filling these gaps thus represents a challenge for the charcoal-based paleofire community, but clearly a parallel investment in improving communication with local stakeholders working in these ecosystems is an essential task for the future.

There is also a need for more open, freely available, and understandable data. The Global Charcoal Database (GCD; www.paleofire.org) developed by the $GPWG_2$ aims to compile paleofire records available worldwide and to document fire history. Since its inception over a decade ago, the GCD has evolved as long-term data storage and a web-interfaced research tool, widely used by the paleo-community. However, raw charcoal data, as those stored in the GCD, are hardly usable outside of this community. These data need to be translated into fire metrics that can be used by ecosystem managers, environmental policy makers, and conservation practitioners.

Developing decision-support tools is the first challenge but may not, however, be enough to ensure their use if the utility of long-term data is not considered outside of the scientific community. Management strategies and practices deserve more than a closing paragraph in a scientific paper. To make paleofire data more useful for ecosystem managers, practitioners, and policy makers, we need to improve visualization tools of our data and explicitly identify their limitations. Therefore, future research programs have to be co-created with the stakeholders who will find these data useful. Improving discussions among scientists, environmental agencies, governmental institutions, NGOs, and private companies is imperative. New applications of charcoal-based fire history reconstructions are already emerging. For instance, Cyr et al. [29] have successfully used paleofire data to re-orientate timber management target in the boreal forests of Québec. Other case studies in Québec and Europe documented new insights into the degree of human-shaped landscape with fire [15,30], providing unique information that would help set conservation strategies. The $GPWG_2$ represents an emerging group of engaged scientists that aim to strengthen the linkages among conservation practitioners, ecosystem managers, and a range of environmental stakeholders.

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