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Late Holocene influence of societies on the fire regime in southern Québec temperate forests

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ABSTRACT

Climatic change that occurred during the Holocene is often recognized as the main factor for explaining fire dynamics, while the influence of human societies is less apparent. In eastern North America, human influence on fire regime before European settlement has been debated, mainly because of a paucity of sites and paleoecological techniques that can distinguish human influences unequivocally from climate. We applied a multiproxy analysis to a 12 000-year-old paleoecological sequence from a site in the vicinity of known settlement areas that were occupied over more than 7000 years. From this analysis, we were able detect the human influence on the fire regime before and after European colonization. Fire occurrence and fire return intervals (FRI) were based on analysis of sedimentary charcoals at a high temporal and spatial resolution. Fire occurrence was then compared to vegetation that was reconstructed from pollen analysis, from population densities deduced from archeological site dating, from demographic and technological models, and from climate reconstructed using general circulation models and ice-core isotopes. Holocene mean FRI was short (164 ± 134 years) and associated with small charcoal peaks that were likely indicative of surface fires affecting small areas. After 1500 BP, large vegetation changes and human demographic growth that was demonstrated through increased settlement evidence likely caused the observed FRI lengthening (301 ± 201 years), which occurred without significant changes in climate. Permanent settlement by Europeans in the area around 1800 AD was followed by a substantial demographic increase, leading to the establishment of Gatineau, Hull and Ottawa. This trend was accompanied by a shift in the charcoal record toward anthropogenic particles that were reflective of fossil fuel burning and an apparent absence of wood charcoal that would be indicative of complete fire suppression. An anthropogenic fire regime that was characterized by severe and large fires and long fire-return intervals occurred more than 1000 years ago, concomitant with the spread of native agriculture, which intensified with European colonization over the past two centuries.

1. Introduction

Fire is a natural component of most ecosystems worldwide (Bowman et al., 2009) and has had a long-lasting and widespread influence on ecosystem dynamics (Marlon et al., 2016; Power et al., 2008), biodiversity (Blarquez et al., 2010; Colombaroli et al., 2013) and biogeochemical cycles (Carcaillet et al., 2002; Levine, 1990; Mack et al., 2011). Certain ecosystems, such as tropical rainforests or temperate forests, are rarely subjected to fires, except during years that are characterized by extreme climatic conditions (Bernier et al., 2016; Millar and Stephenson, 2015). Many temperate forests in Europe and North America burn relatively rarely due to low ecosystem flammability and fuel spatial arrangements that are unfavorable to fires (Hély et al., 2000; Pausas et al., 2017). These temperate forests now face an increase in climate-driven drought frequency, which is associated with an increase in extreme fire events (Flannigan et al., 2009; Millar and Stephenson, 2015). Severe

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and unusual fire events tend to occur more frequently. These directly threaten temperate forest resilience through increased tree mortality and susceptibility to disturbances that interact with fire, such as insect outbreaks or biological invasions (Fleming et al., 2002; Millar and Stephenson, 2015).

Most temperate ecosystems in Europe and North America have been shaped largely by humans, sometimes over the course of millennia (Vannière et al., 2015). Yet it is unclear whether fires are a natural component of these ecosystems where the increase in large and severe fire events is a result of climate change alone, or they are favored by ecosystem management and other human practices. For example, fire suppression during the 20th century in the western USA has long been recognized as one of the main factors explaining the rise of extreme wildfire events during the 1980s (*e.g.*, Turner and Romme, 1994). Landscape modification through livestock production, agriculture and, later, urbanization has profoundly shaped the long-term fire regime (Marlon et al., 2012). In North America, a large portion of fire outbreaks are of human origin: 85% of fires in the USA account for 44% of burned areas and slightly more than 50% in Canada, which account for only ~20% of burned areas; lightning fires, most notably in northern regions of Canada, represent 80% of burned areas (Balch et al., 2017; Stocks et al., 2002; Wotton et al., 2003).

Human-ignited fires are an important disturbance in temperate forests of eastern Canada, but few studies have analyzed past human contributions to the fire regime in temperate forests (Clark and Royall 1996). Most studies have focused on boreal forests. In the boreal forests of Eastern Canada, the fire regime is generally characterized by short fire-return intervals and long-term dependence upon climatic conditions (Carcaillet et al., 2001; Ali et al. 2009a), especially spring temperatures that are suspected of driving large fire years (Ali et al., 2012). In boreal mixedwood forests, vegetation composition at the landscape scale, particularly the balance between conifers and broadleaved trees, can explain Holocene fire dynamics and has been shown to override the direct influence of climate (Blarquez et al., 2015; Girardin et al., 2013). In temperate forests that are dominated by hardwood species, recent changes in biomass burning have been attributed to humans. During the past two centuries, European settlements were accompanied by an increased use of fire for land clearance and agriculture (Clark and Royall 1996; Clark et al., 1996). However, the dependence of Holocene fire regime dynamics upon climate, vegetation and human activities in Canadian temperate forests is not fully resolved (Clark and Royall 1996; Blarquez et al., 2015).

Aboriginal use of fire prior to European colonization is not fully understood and has been frequently debated (Campbell and McAndrews, 1995; Clark, 1995; Clark and Royall, 1995; Dey and Guyette, 2000; Guyette et al., 2006; Parshall and Foster, 2002). On one hand, low population densities do seem to have precluded any influence on the fire regime and associated ecosystem modifications (Campbell and Campbell, 1994). On the other hand, the use of fire in land clearance for firewood supplies or hunting, and slash-and-burn agriculture was widespread before European colonization in the northeastern United States, where even low-density aboriginal populations were suspected of burning large areas of the landscape through escaped fires (Pyne 1997). Indeed, lightning fires are rare in Eastern North American temperate forests and southern Canada in particular (Stocks et al., 2002), but wildfires did occur during the Holocene (*e.g.,* Power et al., 2013; Blarquez et al., 2015).

Ecosystems became inhabited by humans as soon as they became biologically viable (Pedersen et al., 2016), which would have occurred after ca. 12 500 years BP in southern Canada. During this period, mega-herbivores and vegetation started to recolonize deglaciated land (Gill et al., 2009), a period after which human influence upon the long-term fire regime cannot be ruled out. The magnitude of human influence on the fire regime is difficult to measure because archeological archives tend to distort our vision of processes occurring at the landscape scale; indeed, numerous taphonomic biases are rarely taken into account (which are related to charcoal production, and conservation or representativeness in archeological assemblages; see Théry-Parisot et al., 2010; Carcaillet, 2017). Fire data from natural archives, such as lake or peat bog sediments, are also difficult to relate to human practices, which is partly due to the difficulty of reconstructing past population densities and a lack of methods for correlating sedimentary archives with human history. Moreover, sedimentary archives are often located far from known archeological sites and cultural centers (Bowman et al., 2011; Clark and Royall, 1995).

In this study, we used a multiproxy approach to understand the interaction between fire and humans. We studied a natural paleoecological site that was located within the vicinity of an area that was occupied for at least 7000 years, and which had experienced a gradual increase in human density and land-use that lead to the modern city complex of Hull-Gatineau-Ottawa (Laliberté, 2000, 2002). From that natural archive, we analyzed fire occurrence from a high-resolution charcoal record and vegetation from pollen analysis. Holocene fire intervals were compared to human population densities that were inferred from the analysis of a large dataset of archeological radiocarbon dating in the area (Chaput and Gajewski, 2016), and demographic and technological models (Klein Goldewijk et al., 2010). Fire dynamics for the past 200 years were compared with the known post-settlement history of the region to estimate the influence of early European farming and later industry on the fire regime.

We hypothesize that humans influenced the Holocene fire regime and that this influence was modulated by population density. We hypothesize that humans did light fires well before European colonization and that human landscape modifications influenced the long-term fire regime (eventually beyond its range of natural variability, *sensu* Willis and Birks, 2006). Ultimately, high population densities should eliminate fire from the ecosystem, primarily through fuel management and secondarily through fire exclusion. Consistent with Pyne (1997), we hypothesized that European colonization took place within open to semi-open landscapes and forests that were partly cleared by aboriginal fires. The post-settlement increase in fire use and later suppression would thus be the continuation of a preexisting history of human fire use in southeastern Canada.

2. Material and methods

2.1. Site description

The Folly peat bog is situated in Gatineau Park near the cities of Hull and Gatineau, Quebec, which are north of the Ottawa River and the urban area of Ottawa, Ontario (Fig. 1). Folly peat bog (45.4552°N, −75.7813°W) is situated near the park entrance at an elevation of 133 m asl. The peatland area is 14 ha within a small watershed of about 28 ha in area. Although it is commonly referred to as a bog, the main part of the peatland is a nutrient-rich, forested peat swamp surrounding a small treeless bog that is located near its center. The bog portion of the peatland was cored in September 2014 with a Russian corer and a box corer for the uppermost part of the core (*i.e.*, sphagnum peat). Fibrous peat sediments dominate from 0 to 250 cm depth. From 220 to 250 cm, the sediments gradually change from peat to gyttja and, from 250 to 850 cm, shift to gyttja that is indicative of lake sediments. Below 850 cm, clay sediments that originated from marine transgression of the Champlain Sea (13 000–10 500 years BP) are found (Fig. 2). The