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ORIGINAL ARTICLE

Wildfire risk inferred from tree rings in the Central Laurentians of boreal Quebec, Canada

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Abstract

Recent fire years 2002 and 2005 have been, in the context of the past 40 years, exceptional in Quebec, with area burned totalling over 1.8 million hectares. Without prolonged fire statistics and meteorological records, it remains difficult to place these events in the contexts of climate change and variability. How frequently does this type of year occur? In this study, chronologies of radial increment measurements of *Pinus* spp., considered reliable back to at least 1821, were calibrated to develop an index of past moisture in ground surface fuels in the Baie-Comeau area of the Central Laurentians ecoregion, Quebec (namely the Canadian Drought Code (CDC)). Over 37% of the variance in CDC observations (period 1901–2000) was recovered by the tree-ring estimates. These estimates in turn correlated well ($R^2 = 0.39$) with annual area burned (AAB) by large forest fires (size >200 ha; 1959–1999) in the Central Laurentians ecoregion. The smoothed reconstruction showed the prevalence of periods of drier conditions than average from the 1840s to the 1920s, followed by an episode of moister conditions from the 1930s to the 1960s. The minimum occurrence rate of years of extreme wildfire risk in the Baie-Comeau area was estimated in the 1940s at $0.04\,\mathrm{yr}^{-1}$, while the maximum was estimated in the 1910s at $0.21\,\mathrm{yr}^{-1}$. Occurrence rate at the turn of the 21st century ($0.21\,\mathrm{yr}^{-1}$) was closely similar to that recorded during the 1890–1910s (within the uncertainty bands). These long-term variations matched temporal variations in a previously published time-since-fire distribution. The combined information from these ecological sources of data provides meaningful insights for future management of wildfire risk in the Baie-Comeau area, notably to increasing adaptation capacity in response to climate change.

Keywords: Forest fires; Boreal Canada; Tree-ring reconstruction; Kernel estimation of occurrence rate; Drought; Extreme events

Introduction

Each year, wildfires burn on average 289,000 ha of forests in Quebec, Canada (period 1972–2005; MRNFQ, 2006). In addition to the economic impacts associated with the loss of harvestable trees, costs for fire suppression in this province have averaged nearly $46M (CDN) per year (period 1985–2006; Canadian Interagency Forest Fire Centre, personal communication). Weather has significant influence on the occurrence of these wildfires. These spread rapidly when the fuels are dry and the weather conditions are warm, dry and windy. During 2005 alone, blocking high-pressure systems, several days of high indices of fire weather severity, and more than 38,000 thunderbolts led to the ignition of 141 fires in the north of the province from late May onward (MRNFQ, 2006). These fires burned 345,679 ha of forests. The total amount of burned forest

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during that single year was nearly 817,000 ha, whereas fire suppression costs for the province totalled nearly $107M (Canadian Interagency Forest Fire Centre, pers. comm.). The 2005 fire season in Quebec ranked fourth in importance since 1922, and the largest since that of 1941 (MRNFQ, 2006). The 2002 fire season is also worth mentioning, with 1.42 million hectares of burned forest across the province and $71M in fire suppression costs. These fires were estimated to be responsible for 32% of Quebec's greenhouse gas emissions that year (Lavoué et al., 2007).

Predicting the risk (probability) of extreme fire years in the regional domain and on mid-term timescales (decades) is useful to forest managers as well as climate and carbon modellers. Evaluating the causes of recent extreme fire years, notably in the contexts of climate variability (e.g. oceanic teleconnections) and change (e.g. greenhouse gas forcing), is equally relevant. In the current era of climate change, understanding past and predicting future wildfire risks are scientific challenges that are central to the development of effective policies on forest management aimed at greenhouse gas mitigation, and to increasing adaptation capacity in response to climate change (Le Goff et al., 2005; Bergeron et al., 2006). These objectives, however, remain difficult to achieve. Uncertainties about future wildfire risks can be superimposed on the short time period covered by existing meteorological data and fire statistics, from which a historical range of variability can be determined. Although fire statistics go back to the 1920s, Canadian statistics before 1970 are considered incomplete.

As a way to circumvent these data limitations, significant progress has been made in characterizing past fire activity variability in Canada (and Alaska) from proxy records. These advances include reconstructions from fire scars, stand-establishment records (e.g., Larsen, 1997; Bergeron et al., 2004), charcoal abundance in lake sediments (e.g., Larsen and MacDonald, 1998; Carcaillet et al., 2001; Lynch et al., 2002) and ammonium concentration [NH4+] in ice cores (Yalcin et al., 2006). For instance, insights gained from dendroecological dating of forest stands across boreal Quebec (south of 50°N) suggest that fire activity has been decreasing since European settlement began (Bergeron et al., 2006). While climate variability may have played a key role in inducing such a shift, land use changes and the effectiveness of fire suppression (e.g. Podur and Martell, 2007) over the past decades can be confounding factors. That being said, the fact that diminishing fire activity has also been detected on lake islands, on which fire suppression has never been conducted, provides an argument in support of climate control (Bergeron, 1991). In the absence of long-term meteorological records, within these proxies it remains difficult to dissociate the human influence from the climate one.

Recent achievements in fire science include long-term 'statistical reconstructions' of past wildfire risks from tree rings and tree-ring derived proxy records (e.g., Westerling and Swetnam, 2003; Girardin et al., 2006a). Trees in temperate regions produce annual radial increments, where changes in ring width from one year to the next reflect changes in precipitation and temperature, as well as other factors. Trees can also sense climate variations that promote fire activity, such as the location and magnitude of high pressure systems and seasonal droughts (Girardin and Tardif, 2005). Temporal patterns of annual tree radial increments can be used to infer past changes in moisture content in deep layers of the forest floor and, additionally, to extend wildfire records (area burned and fire occurrence) for periods during which there are no records of fire activity. The interesting aspect of these statistical reconstructions is that they remain relatively unbiased by land use change effects, as their signal is essentially of climatic origin. Although the tree-ring approach appears to be applicable across large areas of the Canadian boreal region (Girardin et al., 2006b; Girardin and Sauchyn, 2008), it has limitations. Heterogeneous landscapes and weather patterns, high amounts of precipitation (>1000 mm per year), and low sample replications of drought-sensitive trees and of old-growth specimens make the regional reconstruction of past changes in wildfire risk a difficult task in the province of Quebec (Girardin et al., 2006b).

This paper presents a new collection of ring-width chronologies from 103 pine trees (*Pinus* spp.) growing in the Baie-Comeau area of eastern boreal Quebec, Canada. The tree-ring samples, which were collected in drought-prone environments, were used to statically reconstruct past changes in wildfire risk (i.e. climate conducive to wildfire) and area burned in the Central Laurentians ecoregion.

Study area

The study area is located in the boreal forest of the Central Laurentians ecoregion of eastern Canada (Fig. 1) and it rises abruptly near the St. Lawrence River. The climate of the ecoregion is classified as being high to mid-boreal, as it is marked by predominantly cool summers and cold winters. The exception is in the Lac-Saint-Jean plains and Saguenay River valley, where summers are warm and moist. Mean annual temperature is approximately 0 °C. Mean summer temperature is 12.5 °C and mean winter temperature is −12.5 °C (Ecological Stratification Working Group, 1996). Total annual precipitation ranges from 800 mm in the north to 1000 mm in the south (Ecological Stratification Working Group, 1996).