Long-term reconstruction of the fire season in the mixedwood boreal forest of Western Canada

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Abstract: Climate modelling studies have predicted an increase in fire frequency with global warming as well as suggesting a longer fire season occurring later in the year. We used 160 years of fire scars in Pinus banksiana dating from 1831 to 1948 and written fire records from 1927 to 1995 for Prince Albert National Park in the southern boreal forest to look for evidence of changes in the duration and timing of the fire season (defined as the months when large areas burn) that may have accompanied past changes in fire frequency. The Park’s time-since-fire distribution had indicated two such changes: one around 1890 and the other around 1945, both in the direction of decreasing fire frequency. Both fire scars and written fire records indicated that the dominance of the spring fire season (April–June) has remained unchanged over the past 160 years. A small number of scars suggested that the fire season may have extended slightly into the summer (July) prior to 1890 when the fire cycle was much shorter and that the fire season may have shifted to a slightly earlier spring start after 1945 when the fire cycle was much longer.

Key words: fire season, boreal forest, fire frequency.

Introduction

Recent studies on the impacts of increasing atmospheric CO₂ have predicted a possible increasing frequency of forest fires with global warming (e.g., Overpeck et al. 1990; Flannigan and Van Wagner 1991; but see Bergeron and Flannigan 1995; Flannigan et al. 1998). Other studies have also suggested that this predicted increase in fire frequency may be accompanied by an increase in the length of the fire season (Street 1989; Wotton and Flannigan 1993) as well as a shift in the severe fire months to later in the season (Street 1989). However, little empirical evidence exists for the boreal forest that relates changes in fire frequency to changes in the duration and timing of the fire season. We define fire frequency as the inverse of the fire cycle (the time required to burn an area equal in size to the study area (Johnson and Van Wagner 1991; Bergeron 1991; Johnson 1992; Bergeron and Archambault 1993; Weir et al. in press; Larsen 1997). Since no written fire records for the boreal forest go back far enough to span this period of fire-frequency change, other evidence of past fire seasons must be used. One form

of evidence exists in fire scars on trees that were injured but not killed by fire (Gutsell and Johnson 1996). Since trees produce light-coloured, low-density wood early in the growing season (earlywood) and darker coloured denser wood later in the growing season (latewood), we can determine the season when a past fire occurred by examination of the position of the scar within the earlywood and latewood (Dieterich and Swetnam 1984; Basian and Swetnam 1990). The year of the fire can also be determined from the annual rings (Dieterich and Swetnam 1984). Therefore, we can see if there has been a change in the fire season by examining a large sample of fire scars, pre- and post-dating the change in fire frequency, that have been collected over a large area.

Large areas burn in the spring months of April, May, and June in the southern boreal forest of Canada from central Alberta to northwestern Ontario (Alexander et al. 1983; Stocks and Street 1983; Stocks and Flannigan 1987). Therefore, we expect that most fire scars produced under the current spring fire season would be located either within the earlywood or between the latewood and the previous year's latewood (when the trees are dormant). If the higher fire frequency in the 1800s was accompanied by an extension of the fire season into the summer, we would expect to find more latewood scars predating the change in fire frequency.

In this study we present data from both tree fire scars and written fire records to investigate whether documented past changes in fire frequency were accompanied by changes in the fire season.

**Study area and methods**

Our study area was Prince Albert National Park, which encompasses 3461 km² within the mixedwood boreal forest zone (Rowe 1972) in central Saskatchewan. The gently to strongly rolling glacial topography ranges in elevation from 520 to 820 m above mean sea level. The upland forests are dominated by *Pinus banksiana* Lamb., *Picea mariana* (Mill.) BSP, *Picea glauca* (Moench) Voss, *Populus tremuloides* Michx., and *Abies balsamea* (L.) Mill. (Dix and Swan 1971) and the lowland forests by *Picea mariana* and *Larix laricina* (Du Roi) Koch (Jeglum 1972). A full description of the study area is given in Bridge and Johnson (in press).

This study area was selected because we had available a detailed fire frequency study of the Park (Weir et al. in press). Based on a complete, 5 ha resolution time-since-fire map for the Park, the statistical analysis of the fire-frequency distribution showed two statistically significant temporal changes in fire cycle: one around 1890 and another around 1945. Prior to 1890, the Park's fire cycle was 15 years (95% confidence interval of 10–30 years), and after 1890, it changed to 75 years (95% confidence interval of 45–150 years). This change to a longer fire cycle at the end of the last century is consistent with that found by others for the boreal forest as mentioned previously. The Park's fire frequency distribution also indicated a second significant change to a longer fire cycle (>600 years) around 1945.

To investigate the timing of the fire season before and after the 1890 change in fire cycle, we used *Pinus banksiana* trees, since they were the only species in the Park that commonly formed fire scars. Since the start and end dates of earlywood and latewood production depend on both the region and species of tree (Kramer and Kozlowski 1979), we first had to determine the timing of wood production in *P. banksiana* in our study area. This was done by taking increment cores from the bases of the same trees at approximately weekly intervals between April and September 1996. The dates of first appearance of earlywood and latewood were recorded.

Next, our sample of fire scars came from complete disks removed from the bases of 174 fire-scarred *Pinus banksiana* trees that were distributed throughout the Park. The disks were originally collected as part of the data used to construct the time-since-fire map for the Park (Weir et al. in press) but were used in that study only to date the fires. On the basis of the time-since-fire map, we concluded that the scars represented 174 different fires, even those that were dated to the same year. The disks were sanded and the year of the fire and position of the scars within the annual ring were determined under a microscope (ll. Dieterich and Swetnam 1984; Basian and Swetnam 1990). Fire-scar dates caused by post-1927 fires were corroborated with the Park's written fire records.

Each of the 174 fire scars were classified as dormant, earlywood, or latewood scars as described earlier. Dormant-season scars are those positioned between the latewood of one annual ring and the earlywood of the next ring. We plotted the number of scars in each category by decade and also compared the percentage of scars in each of these categories for the periods before and after 1890.

To study the fire season before and after the second change in fire cycle around 1945, we used the Park's written fire records of 331 fires that occurred from 1927 to 1995. The data were partitioned into a pre-1945 and post-1945 period. Using the dates on which the fires started, we compared the monthly distribution of area burned between these two periods.

A comparison of the seasonal distribution of fires (both pre- and post-1890 and pre- and post-1945), we used a contingency $\chi^2$ analysis.

**Results and discussion**

The tree cores that were collected repeatedly from the same trees during the 1996 growing season indicated that earlywood production in *Pinus banksiana* began May 25–30 and latewood production began July 15–20. This suggests that the Park's fire season scars would be produced by fires occurring before May; earlywood scars, by fires occurring May and June; and latewood scars, by fires occurring July to September. These dates should not be affected by moderate changes in the phenology of earlywood and latewood production as might occur if climate change influenced cambial phenology. The written fire records indicate that fires rarely burn longer than 3 weeks, and there are no fires in these records that started in the spring and were still burning in summer.

The earliest fire recorded in the scars was in 1831, while the most recent scar was dated 1948. All but 4 (2.3%) of the 174 scars were either dormant or earlywood scars (Fig. 1). Although dormant scars may have been produced by fall or winter fires, we assumed that they were attributable to spring (April–June) fires because of the insignificant area burned by fall or winter fires (see below). Snow usually occurs here by mid-October. Thus, over the entire period spanned by the fire scars (1831–1948), 97.7% of the scars represented spring fires, indicating the dominance of spring as the fire season.

A comparison of the pre-1890 and post-1890 seasonal distribution of fires based on the fire scar data indicates a significant difference between these two distributions ($\chi^2 = 10.57$; $\chi^0.052 = 5.99$). The major difference is in the proportion of latewood scars: 10.7% of the pre-1890 scars are in the latewood, while 33.7% of the post-1890 scars (Fig. 2). This suggests that the spring fire season may have extended into the summer during the shorter fire cycle of the late 1800s. However, we qualify this conclusion by noting that it is based on a small number (28) of scars representing
fires from the pre-1890 period compared with the much larger number (146) of scars from the post-1890 period. The Park's written fire records for 1927–1995 (Fig. 3) show that 97% of the area burned was attributable to fires that occurred in April–June. However, note that fires occurred in all months of the year with large numbers of fires still occurring in July–October (see also Stocks and Street 1983). Therefore, the fire season (when most of the area burned occurs) appears not to be determined by ignitions (lightning or human caused) but primarily by weather conditions that contribute to the spread of fires (Street and Stocks 1983; Nash and Johnson 1996). Figure 4, which gives the distribution of percent area burned by month for the periods before and after 1945, again shows the dominance of the spring months (April–June) in both periods. However, the χ² analysis found that the pre-1945 and post-1945 monthly distributions of area burned were significantly different.
There was no area burned before May prior to 1945, while the majority of area burned after 1945 occurred in April, suggesting a change in the start of the fire season. Also, the area burned prior to 1945 was concentrated in the month of June (91%), while after 1945 the area burned was distributed more evenly between the three spring months. Again, we qualify this trend by noting that the post-1945 data represent only 20,946 ha (14.5%) of the total 144,051 ha burned in the period covered by these fire records.

**Conclusions**

Evidence from both fire scars on trees and written fire records from Prince Albert National Park in the southern boreal forest indicates that the spring fire season (April–June) has remained remarkably stable over the past 160 years despite two documented increases in fire cycle, the first around 1890 and the second around 1945. The fire-scar data suggest a slight extension of the fire season into the summer prior to 1890, while the written fire record data suggest a slightly earlier start to the fire season in the spring after 1945. However, these trends are based on small sample sizes and do not provide strong evidence at this time to indicate that a major shift in the timing of the fire season occurred in conjunction with the changes in fire frequency. Thus, even if there had been some change in the growing season over time (i.e., if our estimated dates for the beginning of earlywood and latewood production were off by several weeks for some periods in the past), it would not change the conclusion that, over the period covered by this study, the fire season has remained a predominantly spring fire season. Most of the fire scars (pre- and post-1890) are located in the dormant or earlywood portion of annual rings (not in the latewood), and most of the area burned as noted in the fire records has occurred April–June (both pre- and post-1945).

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**References**

