SHORT COMMUNICATION

NITROGEN ISOTOPIC COMPOSITION AND ELEMENTAL CONCENTRATION OF TREE-RINGS MAY HELP MAP THE EXTENT OF HISTORIC FIRE EVENTS

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ABSTRACT

Elemental and nitrogen isotopic compositions of tree-rings adjacent to a fire-scar in a white birch (*Betula papyrifera*) are compared to those away from the scar in the same tree, and to those of nearby non-scarred yellow birches (*Betula alleghaniensis*) and white birches. The $\delta^{15}N$ value at the fire-scar was 1.5 ‰ lower than non-fire-scarred trees and had elevated Ba, Ca, Mg, Sr, and Mn concentrations relative to elsewhere around the bole and to non-scarred trees. Variations in tree-ring chemistry may be useful in mapping the extent and assessing the magnitude of historic fire events.

Keywords: dendrochemistry, fire-scar, high resolution ICP-MS, laser ablation

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INTRODUCTION

Fire affects forest appearance, ecology, and biogeochemical cycles within the burned watershed (Woodmansee and Wallach 1981, Schlesinger 1991, DeBano *et al*. 1998). Nutrients can be permanently removed by volatilisation and atmospheric transport (Clayton 1976; Raison *et al.* 1985, Schlesinger 1991, Mackensen *et al.* 1996), run-off of nutrient-rich ash, or leaching into groundwater (Raison *et al.* 1985, Schlesinger 1991).

Fire histories are reconstructed using dendrochronology to date existing fire-scars and by determining stand ages (Fritts 1976, Brown and Swetnam 1994). Fire-scar occurrence and change in long-term growth can be used to reconstruct the geographic

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extent of a fire. These analyses require that trees or stumps survive the fire, but many tree species are not fire tolerant and only rarely survive to produce scars. A method whereby fire occurrence can be determined using non-scarred trees would provide a much larger sample population. Nitrogen isotope and elemental compositions of tree-rings may provide such a method. Previous studies have demonstrated that variations in tree-ring δ^{15}N values can be linked to changes in the biogeochemical cycle of nitrogen (Bukata and Kyser 2005). Elemental and isotopic markers in non-fire-scarred trees may record the biogeochemical perturbation and provide useful information about the extent or magnitude of historic fire-events. We compared a fire-scarred tree to three non-fire-scarred trees from a region with an incomplete fire history. While impossible to assert that the non-scarred trees were outside the geographic extent of the fire, if they were within the extent of the fire, it was not intense enough to scar the trees.

METHODS

White birch (*Betula papyrifera*) and yellow birch (*Betula alleghaniensis*) were sampled from the west and east sides of Copper Creek in the Upsalquitch River watershed of northern New Brunswick, Canada (47°30'N 66°21'W). The site has a mixed coniferous and deciduous forest dominated by red spruce (*Picea rubens*), balsam fir (*Abies balsamea*), yellow birch and sugar maple (*Acer saccharum*), with subordinate white pine (*Pinus strobus*) and hemlock (*Tsuga*) underlain by a humo-ferric podzol soil. The yellow birch (E-YB) and one of the white birches (E-WB) from the east side of Copper Creek were ~80 yr old. White birches from the west side were ~60 yr (W-WB) and ~30 yr old (W-WB-FS). A fire-scar on W-WB-FS indicated that it had survived a fire-event in 1979 (Figure 1). From E-WB, four 5 mm diameter increment cores were taken at right angles to one another around the bole. Cross sections were then cut into three radial pieces from each of the other trees.

Tree-rings were visually cross-dated prior to dissection or laser ablation (LA) analysis. Individual growth rings were not visible during LA analysis, so regularly spaced analyses along each transect were performed, and the growth ring years for each analysis were determined afterward. This resulted in some analyses spanning multiple growth rings (Figure 1 and Table 1).

Nitrogen isotopic compositions (δ^{15}N values) and elemental concentrations of micro-samples adjacent to the fire-scar (Figure 1) were compared to analyses elsewhere in the same growth ring and to non-fire-scarred trees.

The δ^{15}N values of individual growth rings were determined by an Elemental Analyser coupled to an Isotope Ratio Mass Spectrometer by Continuous Flow as described in Bukata and Kyser (2005). The δ^{15}N values, which are reported in units of permil (‰) relative to air (δ^{15}N = 0 ‰), were calibrated using certified standards and indicate an uncertainty of <0.3 ‰ (2σ) based on repeated analyses of a laboratory standard.

Tree-ring metal concentrations (Ba, Ca, Mg, Sr, Mn, Zn, Fe, Cu, Pb, and Cd) were determined by Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) calibrated with solution analysis of acid digested wood samples as described in Kyser *et al.* (2003). Tree-rings were analysed using a New Wave Research 213 nm Nd/YAG laser operated in raster or line mode at 20 Hz with a beam width of 300 μm coupled to a Thermo ELEMENT Magnetic Sector ICP-MS. A pre-analysis scan by the laser prepared a fresh surface, free of potential surface contamination from sample preparation. Based on replicate analyses, a relative error of less than 10 % was determined for each element. Full details of the analytical technique are given in Bukata and Kyser (2008).

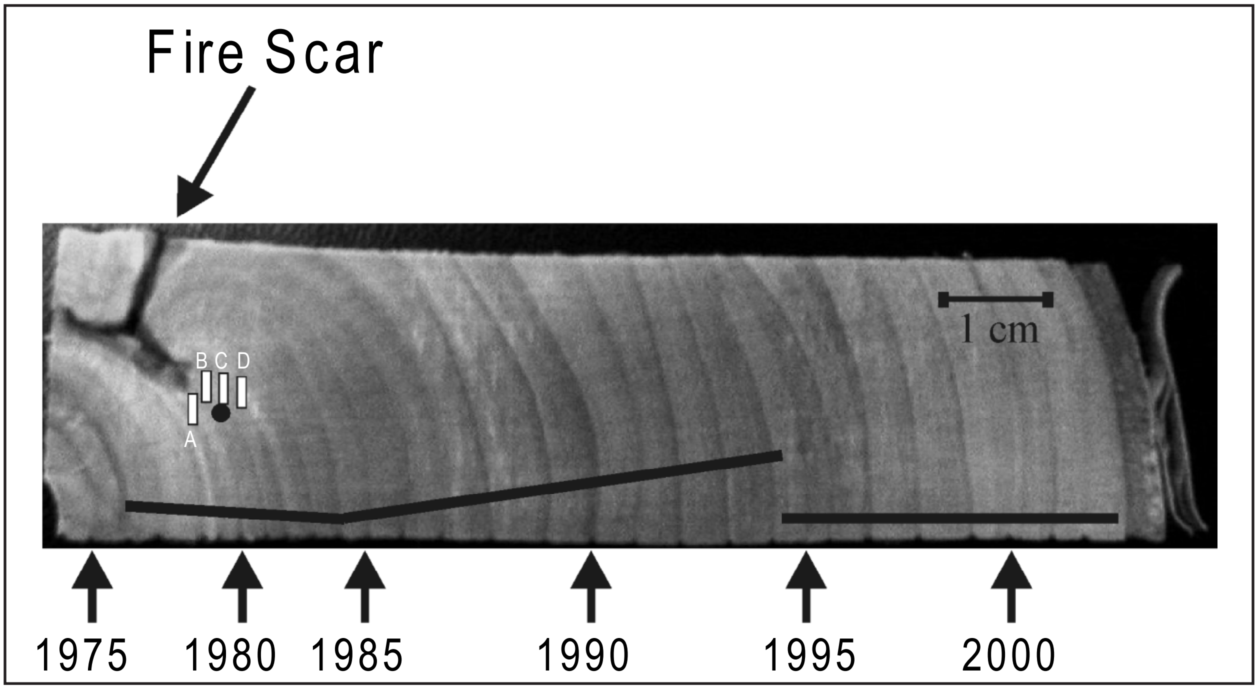

Figure 1. Photograph of W-WB-FS including the scar in the 1979 growth ring. Laser micro-sampling locations proximal to the fire-scar (boxes labelled A, B, C and D) as well as a transect (line) are indicated. Filled black circle indicates micro-sample location for nitrogen isotope analysis.

Table 1. Tree-ring elemental concentrations (μg/g) in at the sub-sampled locations in W-WB-FS (Figure 1).

	Sub-sample locations on Figure 1 (ring years)			
Element	**A (1977-80)**	**B (1980-81)**	**C (1981)**	**D (1981-82)**
Ba	129.5	205.9	27.8	20.0
Ca	6765.9	5401.3	308.6	258.3
Mg	1278.6	1093.8	140.3	75.0
Sr	16.9	16.8	2.4	1.8
Mn	1212.9	1324.0	66.1	62.8
Zn	43.7	67.6	27.9	28.9
Fe	4.5	8.2	9.0	7.5
Cu	1.3	1.7	1.6	1.3
Pb	0.4	0.6	0.4	0.3
Cd	0.6	1.4	0.2	0.2

RESULTS

The δ^{15}N values of the fire-scarred tree were similar to, or lower than, the non-fire-scarred trees prior to the fire-event of 1979 (Figure 2). A sub-sample in the 1980 growth ring near the fire-scar in the fire-scarred radius (filled black circle on Figure 1) was significantly lower than the non-fire-scarred trees (Figure 2). The δ^{15}N values of tree-rings in the fire-scarred tree were significantly lower than non-fire-scarred tree average every year after except the first year ($p < 0.01$; one-sample z-test).

Concentrations of Ba, Ca, Mg, Sr, and Mn were significantly elevated ($p < 10^{-5}$: one-sample z-test) adjacent to the fire-scar relative to elsewhere around the bole or in any non-

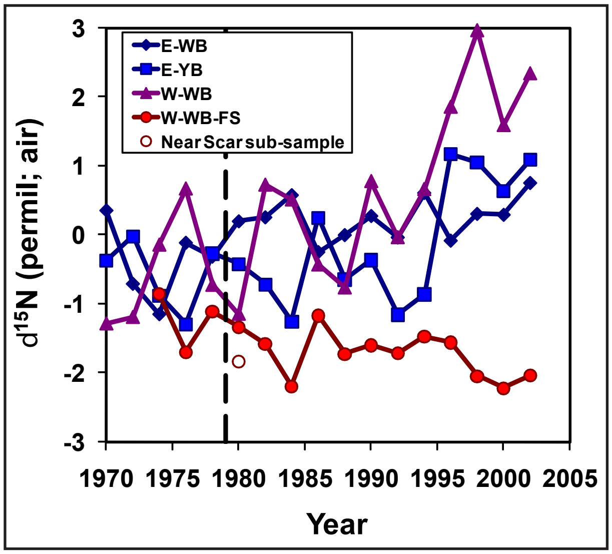

Figure 2. δ15N values of even numbered annual rings in all the trees analysed in this investigation. p < 0.01 (one-sample z-test) between the fire-scarred tree (W-WB-FS) and the average of the non-scarred trees was measured for 1982 to the end of the record and in thE 1980 sub-sample. Dashed line indicates the fire-event. Error associated with each measurement is 0.3 ‰.

scarred tree. Concentrations of Zn, Pb, and Cd were significantly elevated ($p < 0.0025$) adjacent to the fire-scar relative to both before and after the fire event. Concentrations of Fe and Cu were not significantly elevated adjacent to the fire-scar relative to elsewhere around the bole, the non-scarred trees, or before and after the fire-event (Figure 3 and Table 1).

DISCUSSION

Högberg (1997) suggested that after a high intensity fire, vegetation $\delta^{15}N$ values may be elevated due to loss of litter and soil organic matter followed by increased microbial activity in the soil. Microbially produced nitrate would have lower $\delta^{15}N$ values and be leached from the soil, leaving remaining bioavailable nitrogen in the soil with elevated $\delta^{15}N$ values. Such a shift has been seen following a severe fire (Grogan *et al*. 2000). We observed the opposite response wherein the fire-scarred tree recorded lower $\delta^{15}N$ values than the non-fire-scarred trees following the fire (Figure 2), most likely due to the occurrence of a lower intensity fire. In a low-intensity fire, fewer trees would be damaged and less soil organic matter and litter would be lost. Nitrate loss and microbial activity in the soil, while increased, would be much less so than from a high intensity fire. Litter generally has a $\delta^{15}N$ value lower than soil nitrogen (Nadelhoffer and Fry 1994), so that as post fire-event litter decomposes, it will form a larger component of the bioavailable nitrogen pool than new litter did prior to the fire. Lower $\delta^{15}N$ values of bioavailable nitrogen after a low-intensity fire-event would result.

Adjacent to the fire-scar, the 1980 growth ring of W-WB-FS (Figure 1) has a lower $\delta^{15}N$ value than the grouped 1980 sample from around the bole in the same tree (Figure 2). This is consistent with tree-ring $\delta^{15}N$ values recording spatially localised perturbations to the soil nitrogen cycle (Bukata and Kyser 2005). The nitrogen isotope shift was initially localised to the fire-scarred side of the tree. The occurrence of a sustained fire-related shift in $\delta^{15}N$ values around the bole suggests that tree-ring $\delta^{15}N$ values can potentially be used to map the extent of historic fire-events in trees without fire-scars.

Elemental markers of forest fires must exhibit enhanced or diminished uptake after the fire-event and must display little radial mobility between tree-rings. Many of the elements that have elevated concentrations at the fire-scar (Ba, Ca, Mg, Sr, and Mn; Figure 3 and Table 1), especially Ca and Mg, have been shown to have enhanced environmental mobility as a result of fire (Smith 1970, Raison *et al.* 1985, Guyette *et al.* 2002). Here, concentrations of these elements are elevated adjacent to the scar but not away from the scar (Figure 3 and Table 1). These elements were either concentrated at the scar in response to the wound, deposited on the outside of the tree in ash and diffused into the wound, or were

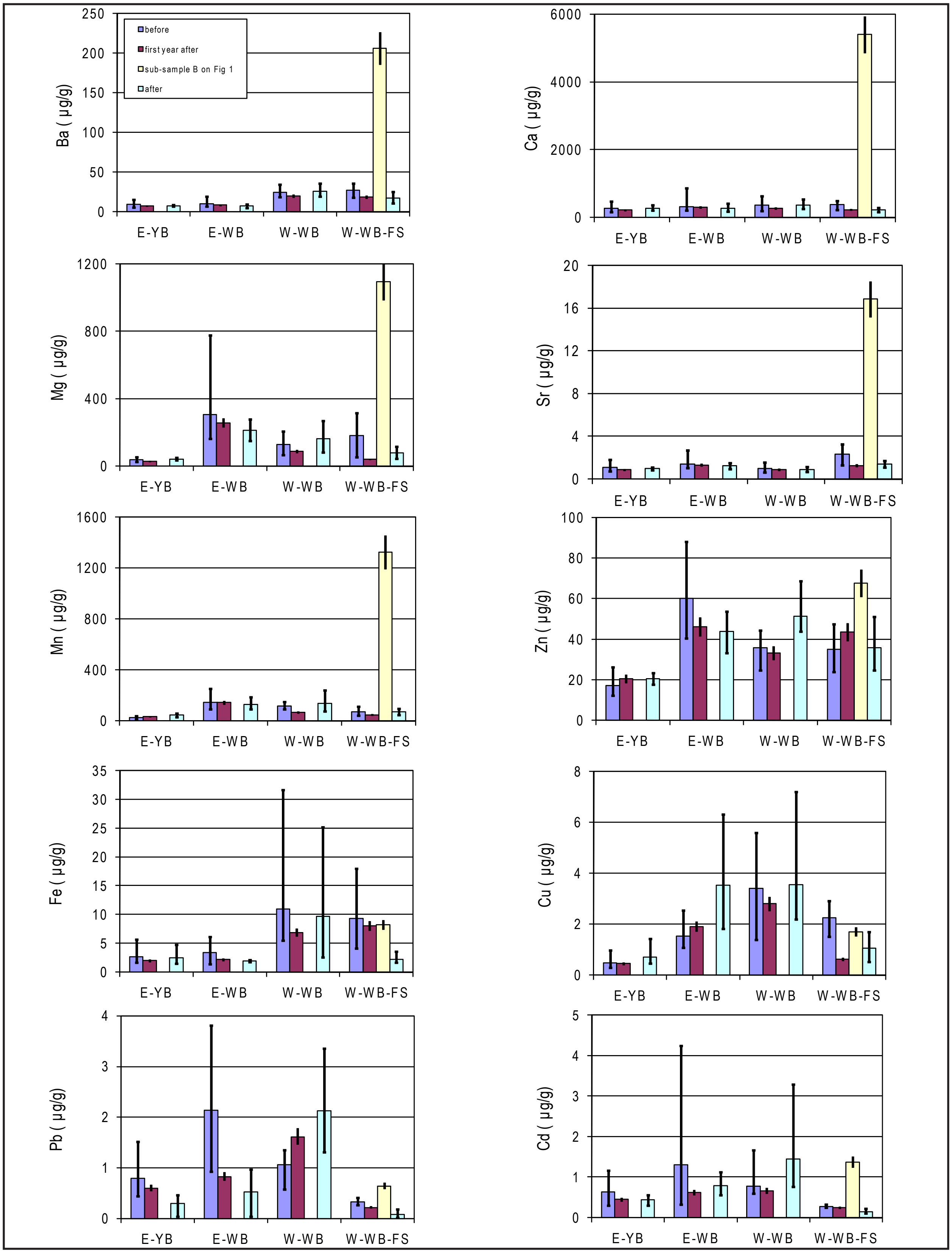

Figure 3. Metal concentration measured in tree-rings before, first year after, at the fire scar in W-WB-FS, and after the fire event. Error bars (bracketed) on the before and after concentrations represents the full range of measured values and those on the individual concentrations in the first year after and at the scar (non-bracketed line) indicates analytical error on the measurement.

deposited on the outside of the tree and incorporated into the bole as the tree healed around the scar. Fire intensity likely affects both the amount of and mobility of elements in the soil. In the 1979 fire event, a significant increase in concentrations was only observed at the scar and not around the bole. As a result, elemental concentrations alone may not be suitable for establishing the geographic range of forest fires in non-scarred trees.

Variations in soil pH may account for differences in overall elemental concentrations in tree-rings but unless the soil pH changed during the life of the tree, soil pH would not affect the temporal trend observed. There are possible species effects that may impact the amount of elemental uptake, although it is unlikely that species differences between white and yellow birch would affect the temporal trend.

These results suggest that shifts in tree-ring $\delta^{15}N$ values may provide evidence of the geographic range of historic fire-events, and micro-sampling adjacent to fire-scars from different fire-events may be useful for comparing relative fire magnitudes with respect to nutrient mobilisation in the environment.

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