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ORIGINAL ARTICLE

Evidence of century-scale environmental changes: Trace element in tree-ring from Fuling Mausoleum Shenyang, China

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ABSTRACT

In order to detect the response of trees to environmental pollution in Shenyang during the last century, tree rings of two 100+ year old Chinese pine (*Pinus tabulaeformis* Carr.) were analyzed for nine trace element concentrations (K, Ca, Mg, Mn, Cu, Zn, Al, Pb and Cd) and compared to local environmental change. The concentrations of Cu, Zn and Al had significant ($p < 0.01$) increasing trends after 1940s and correlated significantly ($p < 0.01$), with increasing production of nonferrous metal from local industrial processing. Concentrations of nutrient element (K, Ca and Mg) showed significant ($p < 0.01$) increasing trend from heartwood to sapwood with declines in the last three decades. Significant correlation between climatic factors and element concentration in tree rings were also found, in which the temperature (November to May) and relative humidity in April and May showed significant positive correlation with Ca, Zn and Cu ($p < 0.05$) as well as Al ($p < 0.01$) concentrations in tree rings. April rainfall showed significant positive correlation with K and Zn ($p < 0.05$) as well as Al ($p < 0.01$) concentration in tree rings. The results suggest that tree rings from Chinese pine in Shenyang are sensitive to environmental change and have the potential to be used as a biomonitor for the environmental pollution. The results also demonstrate the feasibility of applying dendrochemical techniques to areas with limited samples.

Introduction

Trees can be used as a sensitive biomonitor to record local or global environmental change. Tree-ring width has long been used to reconstruct historical trends in tree vigor and has been shown to be responsive to various environmental factors (Fritts, 1976; Biondi, 1993). More recently, metal element concentrations in tree rings have been used as biomonitors of chemical parameters in the environment, including soil solution chemistry and atmospheric pollution (Padilla and Anderson, 2002; Poszwa et al., 2004). Metal elements enter a tree through the roots, leaves or bark and are then incorporated into the tree (Lepp, 1975; Lukaszewski et al., 1993; Lin et al., 1995). Once metal elements enter trees, they are not necessarily restricted to the tree-ring formation during the current year (Lepp, 1975). Most tree species contain an outer band of living sapwood that surrounds an inner core of dead heartwood. The ascending transported elements from roots may be conducted into several adjacent sapwood tree rings. In some cases, the elements may be translocated across the heartwood–sapwood (H/S) boundary (Brackhage et al., 1996). The concentrations of some elements decline steadily from heartwood to sapwood, others increase toward the sapwood rings, some elements peak at the H/S boundary, and others have no radial tendency (Liang and Huang, 1992). Padilla and Anderson (2002) pointed out that element mobility in trees is confined to the last 1–7 years where the xylem is still active in water conductance. Although the analysis of an individual tree may not pinpoint a specific year of environmental change (Cutter and Guyette, 1993; Prohaska et al., 1998), trees are sensitive biomonitors for environmental variation, when long-term patterns of change are sought (Smith and Shortle, 1996). Dendrochemical techniques have been widely used in studies involving identifying heavy metal pollution in urban and industrial areas (Watmough and Hutchinson, 1996; Anderson et al., 2000; Bellis et al., 2002) as well as in the rural areas (Zhang et al., 1995, 2008). The historical changes in the soil chemistry and acid deposition could also be detected by the radial variations of base cation in tree rings (Kuang et al., 2008).

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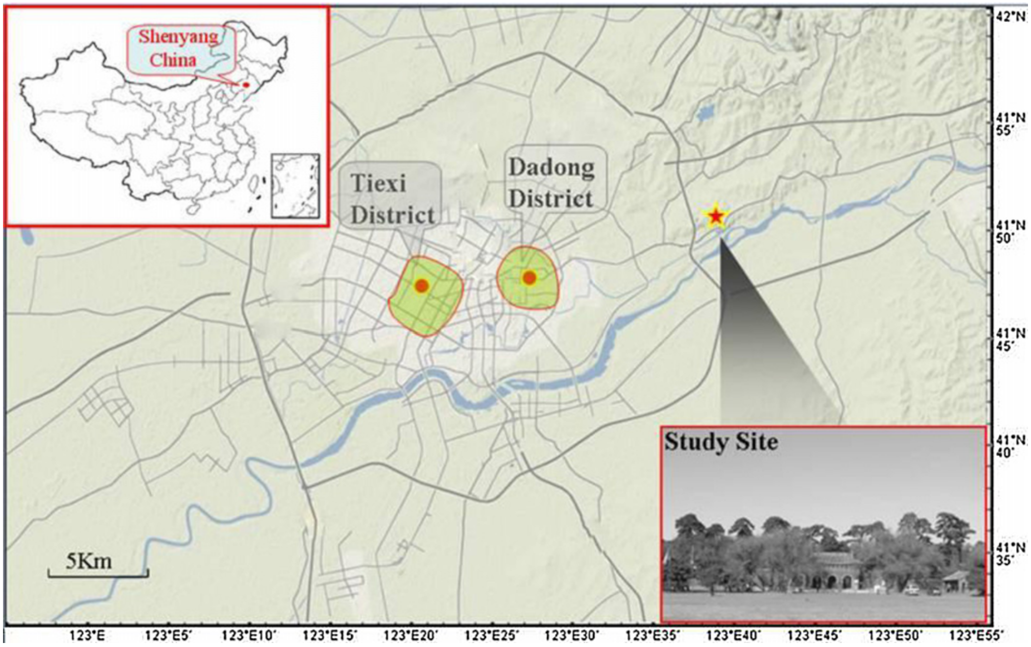

Fig. 1. Location of study site, Fuling Mausoleum, Shenyang, China.

In recent decades, the quantity and intensity of pollution from anthropogenic activities e.g. smelters, fertilizers and vehicles – have all increased trace element concentrations in the environment (Autier and White, 2004; Sardans and Peñuelas, 2005). Some documented data indicated that climatic change not only influenced pollution pathways but also affected plant metabolism and internal distribution of elements in plants, thereby changing the mobilization and translocation of elements within plant organs (Jónsdóttir et al., 2005; Sardans et al., 2008).

Shenyang is the industrial center of Northeast China and is undergoing rapid development and urbanization with severe environmental pollution during last century. The Chinese pine (*Pinus tabulaeformis* Carr.), an important dendrochronological resource, grow well in the outskirts of Shenyang, and also make it possible to indirectly monitor local environmental change. Previous studies showed that the concentration levels of SO_2, Pb, and Al were the main causes for growth decline and increasing death ratio of aging Chinese pine (Shang and Huang, 1997). The objectives of this study are (i) to test whether radial patterns of metal element concentrations in tree rings provide evidence for environmental pollution from the mid-20th century onwards, (ii) to detect the relationship between tree-ring element concentration variations and climate change, and (iii) to discuss the potential and feasibility of dendrochemical studies in sample limited cases.

Materials and methods

Site descriptions

Shenyang (122°25′–123°48′E and 41°11′–43°2′N) is in the southern part of Northeast China, and has a semi-moist, continental monsoon climate regime (Shenyang Municipal Area Environmental Profile, 1998). The average temperatures in summer and in winter are 23.3 °C and −7.0 °C respectively. The average annual rainfall is about 756 mm over the last century, mainly occurring in June, July and August. The modern industry started to develop at the beginning of 20th century. From 1950s onwards, Shenyang was became a key region for heavy industry, comprising of machinery, metallurgy, petrochemical and automobile factories. The industrialization and urbanization process led to severe metal contamination in the soil and vegetation (Yu et al., 2007). Air pollution was mainly caused by burning high sulfur content coal for a principal energy source. For example, the main industrial air pollutants SO_2, NO_x, Pb and smoke/dust accounted for 65.72%, 18.92%, 7.24% and 5.81% of the total air-borne pollutants in 1997, respectively. In the 1980s, Shenyang was one of the 10 heaviest polluted cities in the world (Shenyang Municipal Area Environmental Profile, 1998). The study site is located in Fuling Mausoleum, a suburb northeast of Shenyang city, 15 km and 10 km northeast of the two main pollution source regions Tiexi and Dadong District (Fig. 1), which accounted for 86.37% and 6.94% of total air pollution load in Shenyang (Shenyang Municipal Area Environmental Profile, 1998) respectively.

Sampling and element analysis

Early studies of long-term (more than a 100 years) trace metal variation commonly used 2–6 tree samples in one site and combined individual tree rings into 5 or 10 year segments (Baes and McLaughlin, 1984; Liang and Huang, 1992; Watmough and Hutchinson, 1999). Annual trace element concentrations analysis was conducted on a 350 years old ponderosa pine (*Pinus ponderosa*) to assess macro-trends of environmental change (Padilla and Anderson, 2002). Watmough et al. (1998) suggested that three trees were sufficient in trace element analysis. In our study, we collected two trees and analyzed the metal concentration variation annually, in order to find common trends in metal concentration variation that reflect environmental pollution history. The trees used for this analysis were selected from the Fuling Mausoleum (Chen et al., 2006), and were labeled FT-1 (1787–1998) and FT-2 (1859–1995). The correlation coefficients between the tree-ring width series and the master ring-width chronology are 0.767 FT-1 and 0.567 FT-2 respectively ($p < 0.01$), and the correlation coefficients between FT-1 and FT-2 was 0.729 ($p < 0.01$, $n = 137$). One disc was cut from each tree at about 1.5 m height. The discs