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The decline of lead in tree rings of *Carya spp.* in urban Atlanta, GA, USA

H.L. RAGSDALE & C.W. BERISH
Biology Department, Emory University, Atlanta, GA 30322, USA

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Abstract. Lead (Pb) concentrations in wood ring segments of *Carya spp.* in two urban forests in Atlanta, GA, have decreased approximately 20 percent in the last decade. This pattern is consistent with reduced atmospheric Pb over the same period. We have determined that changes in Pb concentrations in wood of urban hickory trees dramatically documents the historical periods of early urbanization, the addition of Pb to gasoline, and the recent period of restricted use of leaded gasoline.

Introduction

Environmental Pb concentrations for US urban areas in 1977 were estimated as about 200 ng Pb/g for trees and for human food, 1 to 50 ng Pb/l in fresh water, and 1000 to 20,000 ng Pb/m^3 in air (EPA 1977). The air and fresh water Pb concentrations in contemporary US urban areas are three to five orders of magnitude greater than concentrations found in contemproary remote areas. Widespread contamination of the environment with Pb has resulted in a 10-to-100 fold increase in Pb burdens of most living flora and fauna (Nriagu 1978; Needleman & Landrigan 1981).

Concern for Pb in human food cycles or in the ambient environment is based on the many detrimental effects Pb has on human tissues (NAS 1980). Since the implementation of restrictions on the addition of leaded alkyl derivatives to gasoline in the United States (1974) and Sweden, decreasing environmental Pb concentrations have been reported in moss tissue (Ruhling & Tyler 1984), soils and river sediment (Trefrey et al. 1985), the atmosphere (Hunt 1982), and human blood (Annest et al. 1983).

Tree ring analysis has been used to reconstruct past climates (Fritts & Gordon 1982; Kelly 1982), and to document both historical and recent environmental contamination by toxic materials (Rolfe 1974; Phillips et al. 1977; Baes & McLaughlin 1984). Trace metal concentrations in urban tree wood have shown more rapid increases during this century than has concentration in wood from more remote forests (Baes & Ragsdale 1981; Berish

& Ragsdale 1985). The deposition of Pb from automobile exhaust has been characterized as a local, roadside phenomenon. Soils and plants sampled along heavily traveled highways show that Pb contents decrease with increasing distance from the highway (Chow 1970; Motto et al. 1970; Lagerwerff & Specht 1970; Wheeler & Rolfe 1979), although leaded aerosols may be mixed into the atmosphere and dispersed well beyond the roadside.

Methods

Hickory trees (*Carya spp.*) were sampled in the summer of 1983 at 2 sites in urban Atlanta, GA: Deepdene Park and Fernbank Forest. Deepdene Park has a potentially high chronic Pb exposure because it is bordered to the south by a major traffic artery, Ponce de Leon Avenue, which has a daily traffic flow of approximately 30,000 vehicles per day (J. Robinson, pers. comm., Atlanta Traffic Engineering Division). Fernbank Forest has a lower exposure to airborne pollutants relative to Deepdene because it is not bordered by a major traffic artery. Fernbank Forest has, however, chronic exposure to atmospheric Pb from the Atlanta urban environment.

Carya spp. were selected for study because ring porous hickory trees are highly reflective of changes in environmental Pb (Baes & Ragsdale 1981; Berish & Ragsdale 1985) and because hickories are a dominant canopy tree in the forests studied (Skeen 1974). Twelve hickory trees were cored in Deepdene Park and six in Fernbank Forest. Trees smaller than 15 or greater than 32 cm dbh were excluded from the study in order to standardize sampling. Both very old and very young hickory trees were excluded by sampling only hickories in the dominant or codominant crown classes.

Each randomly selected tree was cored across slope, approximately a north–south axis, at breast height (140 cm). Cores were taken with a 4.3 mm diameter teflon coated increment corer. Prior to insertion, the corer surfaces were washed with a 10% solution of quaternary ammonium chloride Aliquot 336-S (Moore 1972), in 2-heptanone and rinsed with acetone and distilled water to remove surface Pb contamination. Wood cores were stored under refrigeration in sealed, acid-washed plastic tubes.

Wood rings were examined under magnification and sectioned into 5-year intervals. Corresponding wood sections from each pair of cores were composited to represent each tree. Sections were washed for 30 s in 0.1 N HNO_3 to remove any surface Pb contamination, dried for 24 h at 100 °C and weighed to 0.1 mg in a desiccated atmosphere. Weighed samples, 0.15–0.6 g dry weight, were ashed at 400 °C for 48 h to avoid reported Pb loss at temperatures exceeding 430 °C (Webber 1974), acidified with 5 ml concentrated HNO_3, heated and brought to volume.

Chemical element analyses were performed on a Perkin Elmer 306 Atomic Absorption Spectrophotometer. Solutions of xylem section samples destined for Pb analyses were injected into an HGA-2100 graphite furnace, dried, charred and atomized according to optimized conditions. Triplicate analyses were performed for each sample. As a quality control measure, standards of all elements were compared to National Bureau of Standards reference orchard leaves (SRM-1571) and tomato leaves (SRM-1573) before wood samples were analyzed (NBS 1981). Pb recovery was between 90 and 96%.

Results and discussion

Lead concentrations measured in wood ring segments of the two urban forests in Atlanta have decreased since the late 1970's. Peak Pb concentrations in hickory wood occurred about 1975 at both Fernbank Forest and

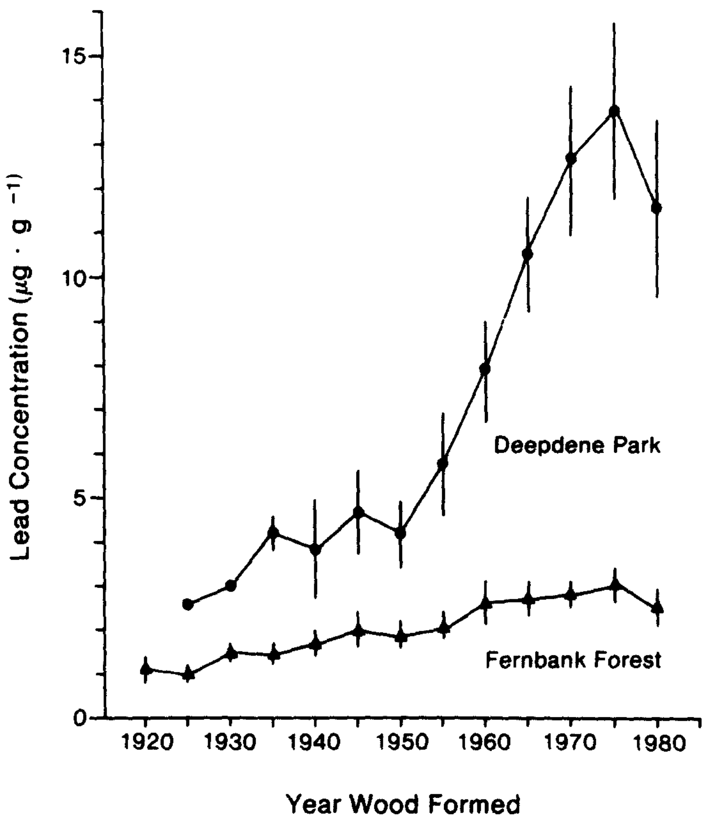

Fig. 1. Mean lead concentrations (ppm) and S.E. measured in 5-yr wood intervals from trees sampled in Deepdene Park and Fernbank Forest.

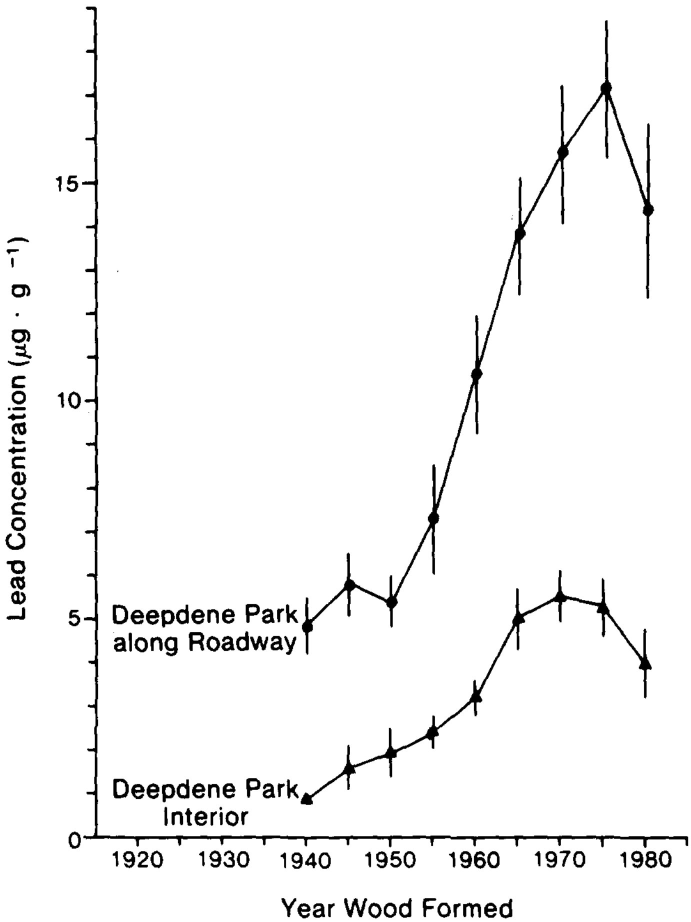

Fig. 2. Mean lead concentrations (ppm) and S.E. measured in 5-yr wood segments from trees sampled in Deepdene Park along the roadside, and trees sampled within (> 10 m from the forest edge) Deepdene Forest.

Deepdene Park (Fig. 1). At both sites, a statistically significant, 20% decrease in wood Pb concentrations occurred between 1973–1977 and 1978–1982 ($p < 0.05$, T-test, SAS, 1982).

Differences in mean Pb concentration were due primarily to source proximity. At Deepdene Park, some hickories were directly adjacent to a heavily-traveled road, Ponce de Leon Avenue, while others were inside of the closed-canopy forest. Standard error estimates for mean Pb concentrations were much larger at Deepdene Park than Fernbank Forest (Fig. 1). Standard error estimates of mean Pb concentrations at Deepdene Park were reduced by separating the hickory trees into two populations: one in the interior of the forest and the second along the roadside (Fig. 2). In contrast,

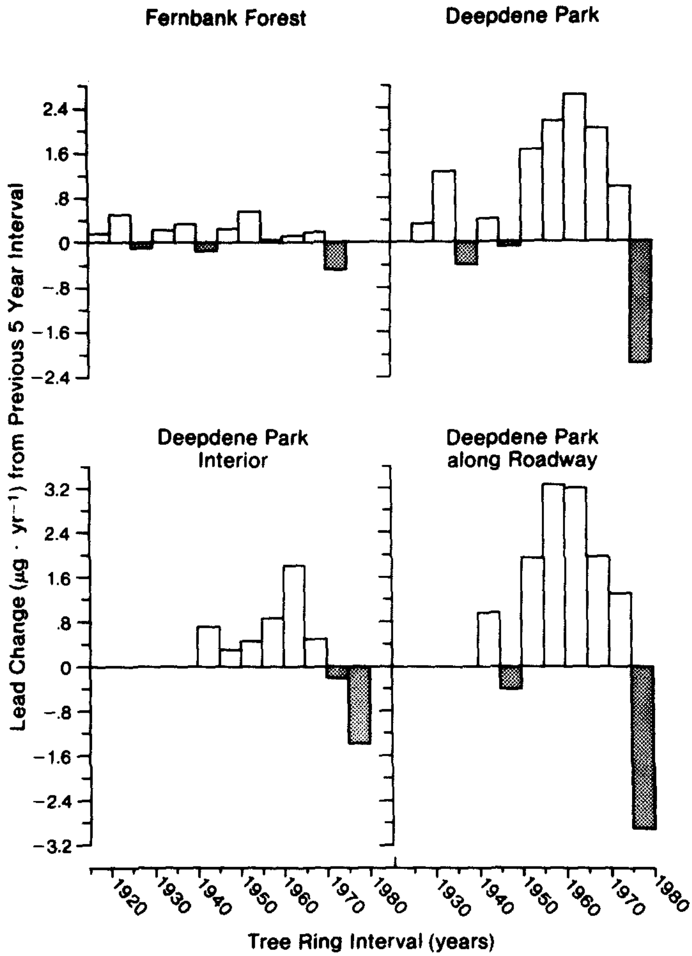

Fig. 3. Mean lead concentration change from one earlier 5-yr growth interval to the next succeeding interval. Non-parametric sign test was significant at the $p < 0.05$ level.

at Fernbank Forest, there is no local point source for Pb. Deposition there was relatively constant, reflecting average urban residential conditions.

Decreased wood Pb concentrations as measured in 5-yr-intervals for both Deepdene and Fernbank Forests were not a random statistical event. The rate of Pb concentration increase for 5-yr-intervals at Deepdene Park peaked at 1960, although the change in concentration rate remained positive until the end of the 1970's (Fig. 3). The changes of wood Pb concentrations in Fernbank Forest were much smaller ($p < 0.05$) than in Deepdene Park, but the patterns of concentration changes were similar for the two sites.

Atmospheric Pb concentrations measured at two urban Atlanta locations, The Georgia Institute of Technology (Georgia Tech) and the Fulton County

Health Department, have declined since the middle 1970s. Mean atmospheric Pb concentrations between 1975–1978 and 1980–1982 decreased 26% (1.5 to 1.1 $\mu g/m^3$) at Georgia Tech and 50% (1.36 to 0.63 $\mu g/m^3$) at the Fulton County Health Department. Similar reductions in atmospheric Pb have been reported elsewhere (NAS 1981; Hunt 1982; Ruhling & Tyler 1984).

Qualitative interpretations of urban Pb dynamics for 1975 to 1982 are similar whether using data from urban Atlanta air monitoring sites or Pb concentrations in tree rings. In both cases the Pb concentrations declined significantly with the introduction of Pb-free gasoline. The urban Atlanta air monitoring sites had declines of 26 and 53% as compared to 20% declines in Pb concentrations in two tree populations. This quantitative comparison, although based on a small sample, suggests that tree ring records may underestimate the actual magnitude of decline in atmospheric Pb concentrations.

That Pb concentrations in tree rings can accurately reflect changes in atmospheric Pb concentrations is surprising. Lead deposited in terrestrial ecosystems is tightly adsorbed to organic material on the mineral soil surface (Schnitzer & Skinner 1967; Tyler 1972) producing long retention times (Benninger et al. 1975) and consequently slow Pb uptake and cycling through forest trees. A predominant hypothesis of Pb accumulation in trees is that deposition of Pb in woody tissue occurs as a result of root uptake and upward translocation. The similarity of temporal pattern changes in Pb concentrations for atmospheric data and tree rings suggests, however, that trees respond quickly to changes in ambient atmospheric Pb concentrations.

This observation supports the controversial alternate hypothesis that Pb accumulation in woody tree tissue occurs by absorption through tree leaves. A leaf uptake mechanism has been previously hypothesized for various metals (Little & Martin 1972; Haghiri 1973; Zimdahl 1976). Since the tree ring Pb record accurately reflected a rapid change in atmospheric Pb concentrations and since Pb particles are deposited directly on leaf surfaces, it is reasonable to hypothesize that leaves are a primary, though not singular, pathway for Pb entry into internal tree tissues. The issue, however, is complicated by acid deposition which may acidify the soil solution thereby increasing lead availability to the root system (Ulrich et al. 1980).

Trace metals in tree rings may be expressed as concentration ($\mu g/g$) and as burden ($\mu g/y$). Quantification of trace metals in tree rings as elemental burdens ($\mu g/y$) is especially important since change in tree ring metal concentration can result from constant elemental deposition into annual rings of varying sizes. Declining Pb burdens (Fig. 4) at Deepdene Park, were the result of both declining Pb concentrations and smaller (post-1975) annual growth rings. Tree growth at Deepdene Park has exhibited a reduction following a period of active growth between 1930 and 1950. In contrast,

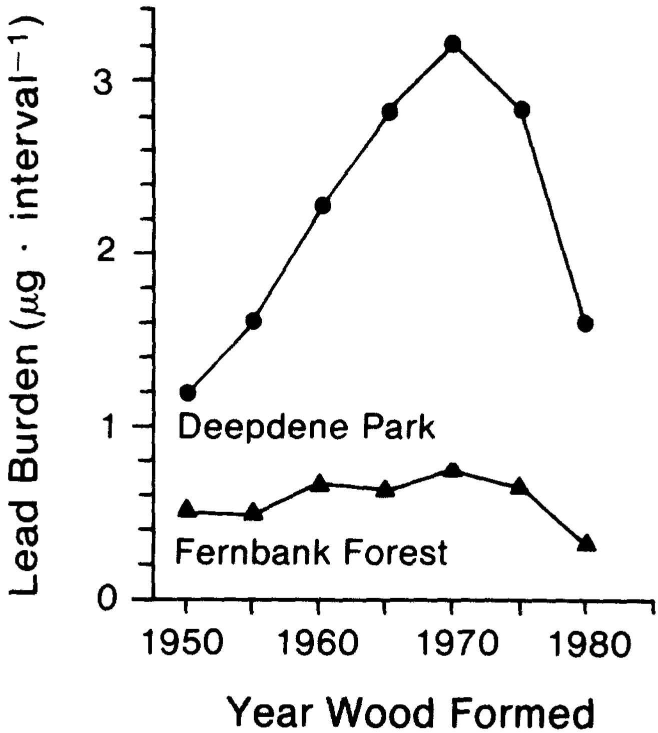

Fig. 4. Calculated lead burden (microgram/interval) in Deepdene Park and Fernbank Forest.

declining Pb burdens in hickory wood at Fernbank Forest primarily resulted from declining Pb concentrations since annual growth has remained fairly uniform. Hickory tree growth in Fernbank Forest over the last 30 years has been fairly slow, constant and typical of an undisturbed, closed-canopy forest.

Hickory trees in Atlanta have a temporal Pb accumulation pattern which documents the increase of ambient Pb levels corresponding to urbanization, the addition of Pb to gasoline in the 1930s, and the reduction in ambient atmospheric Pb levels in the late 1970s due to US EPA restrictions on leaded gasoline. The reduction in urban atmospheric Pb concentrations since the late 1970s has dramatically reduced Pb concentrations in the last decade of tree rings in hickory and presumably other urban tree species.

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