Environmental Pollution (Series B) **2** (1981) 21–35

AGE-SPECIFIC LEAD DISTRIBUTION IN XYLEM RINGS OF THREE TREE GENERA IN ATLANTA, GEORGIA

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ABSTRACT

Tree ring analysis was studied as a means of constructing historical environmental pollution records. Lead in xylem from Liriodendron tulipifera, Quercus alba*, and* Carya *spp. trees growing near a road and in a forest was measured by atomic absorption graphite furnace techniques. Lead concentrations in xylem formed before and after 1924 were compared among species, within species, and between sites.* Carya *had the highest xylem lead and was the only species sensitive to low-level, post-1923 lead exposures. Evidence of lead movement among rings was found in* Carya *and* Liriodendron*. The mean rate of xylem lead increase after 1932 in the ring-porous species compared well with traffic growth rate along the road, but the variability of this parameter among trees and its inverse correlation with distance from the road suggests the necessity of many intra-specific replicates to relate temporally patterned xylem lead concentrations to pollution histories.*

INTRODUCTION

The global historical record of atmospheric and environmental lead pollution has been studied through analysis of Antarctic snow strata (Murozumi *et al*., 1969) and lake sediments (Edington & Robbins, 1976) and has been related directly to the combustion of coal since the beginning of the industrial revolution and the use of lead alkyl additives in anti-knock gasolines since 1924. However, the utility of these two media in determining environmental lead pollution or in constructing pollution histories for lead near smelters, coal-burning steam plants, and roadside ecosystems

† Operated by Union Carbide Corporation under contract W-7405-eng-26 for the United States Department of Energy.

Environ. Pollut. Ser. B. 0143-148X/81/0002-0021/$02·50

is very limited. It has been suggested that trees offer a likely solution to this problem (Lepp, 1975).

Tree bark has been shown to be very sensitive to environmental lead pollution. Barnes *et al*. (1976) found bark lead concentrations of various tree species to be greatest in areas of high traffic density. Laaksovirta *et al.* (1976) found a highly negative correlation between lead concentration in white pine bark and distance from the road and a highly positive correlation with traffic density. Ward *et al.* (1974) found bark lead concentrations higher on the sides of trees facing a road with heavy traffic than on sides facing away. Additionally, the downwind bark had significantly higher lead concentrations than the upwind bark.

While bark appears to be a sensitive monitor of environmental lead, the question of whether tree ring analysis is useful in constructing pollution histories remains. Sheppard & Funk (1975) had qualified success in relating metal concentrations in ponderosa pine xylem rings to mining activities along the Spokane River in Idaho. Szopa *et al*. (1973), working in Missouri, were unable to document lead ore hauling activities or the closing of a road through analysis of black oak, white oak, and shortleaf pine xylem. Barnes *et al.* (1976) were unable to determine the occurrence of lead pollution from analysis of xylem from several tree species in forests and parklands in Great Britain. Tian & Lepp (1978) related lead concentrations to xylem growth rates in larch and sycamore, but were unable to observe evidence of environmental contamination from past mining activity.

These studies notwithstanding, successes have been reported. Ault *et al.* (1970) found higher lead concentrations in outer xylem rings of a red oak in New Jersey. Rolfe (1974) found higher xylem lead levels in young sugar maple and red oak rings than in older, historical rings. The relative difference between recent and historical rings was greatest in trees bordering an interstate highway with a traffic density of 15,000 vehicles day^{-1}. Ward *et al.* (1974) found generally increasing xylem lead concentrations since 1923 in six tree species bordering a thoroughfare averaging 11,500 vehicles day^{-1} in New Zealand. Hall *et al.* (1975) showed a steady increase in xylem lead in more recent rings of oak and ash trees growing within 0·5 m of a road carrying 21,000 vehicles every 16h. In Sweden, Kardell & Larsson (1978) found increasing xylem lead concentrations in oak trees over the period 1925-1975. The lead accumulation pattern in one oak bore a striking resemblance to the traffic growth rate of the nearby road which had a traffic density of 40,000 vehicles day^{-1}. They could find no pattern of increasing xylem lead in an oak 26 m from a road which averaged less than 50 vehicles day^{-1}.

A review of the above reports suggests that studies will be unsuccessful if the trees are located in areas of relatively low aerial lead concentrations or where soil lead is the primary source to the tree. Success is more likely near roadways with heavy traffic. However, there appears to be much variability among species with respect to their sensitivity to environmental lead and their ability to maintain an accurate historical record. This study is designed to study the relative sensitivity of several tree genera to environmental lead and to examine their ability to maintain an accurate historical record in an area where the actual lead pollution history is known.

Three dominant tree genera of an urban forest ecosystem in Atlanta, Georgia, which were growing near a road with heavy traffic and in the forest interior, were sampled with an increment corer and the rings analysed for lead. The sites were chosen because it was felt that the roadside ecosystem is a high lead exposure area and the forest interior, approximately 1000 m from the road, is an area of much lower lead exposure (Smith, 1976). Further, it was expected that rings from both sites would show increasing lead concentrations only after 1923 because tetraethyl leaded gasoline was introduced in the next year and there are no known lead-emitting industries in the metro-Atlanta area. Also, information on traffic growth rates in Atlanta are available for comparison with tree ring lead accumulation patterns.

MATERIALS AND METHODS

Trees were sampled between April and June 1976 at sites that were believed to receive high and low exposures of lead from automobile exhaust. Deepdene Park, the high-exposure site, is bordered along its southernmost boundary by Ponce de Leon Avenue, a major traffic artery (30,000 vehicles day^{-1}) between downtown Atlanta and Decatur, Georgia. Fernbank Forest, the low-exposure site, is a protected Piedmont forest ecosystem approximately 6·4 km northeast of downtown Atlanta and 1000m north of Ponce de Leon Avenue (Fig. 1). There are no major traffic routes bordering the forest and, therefore, no significant acute lead exposures from automobile exhaust. However, the forest probably receives a relatively low chronic lead exposure from its urban environment. Both sites were originally one contiguous forest ecosystem before an urban housing development separated Deepdene Park from Fernbank Forest between 1920 and 1930.

Liriodendron tulipifera, *Quercus alba*, and *Carya* spp. were selected for study because these three species are dominant in Fernbank Forest (Skeen, 1974). Trees sampled were selected for old age, vigour, and (at Deepdene Park) proximity to the road (Table 1). Each tree was marked at breast height at 120 °, 240 °, and 360 ° from a north-south axis to give three uniform replicate samples with a minimum of damage to the tree. Additionally, the 120° and 240° cores faced toward and the 360° core faced away from Ponce de Leon Avenue at Deepdene Park. Xylem cores were taken at each mark with a 46 cm stainless steel increment corer 4·3 mm in diameter. Previous to insertion, the corer and extracting spoon were washed with a 10% solution of the quartenary ammonium chloride ‘Aliquat 336-S’ (Moore, 1972) in 2-heptanone and rinsed with acetone to remove any surface lead contamination. The extracted xylem cores were stored in sealed plastic tubes until analysis. After

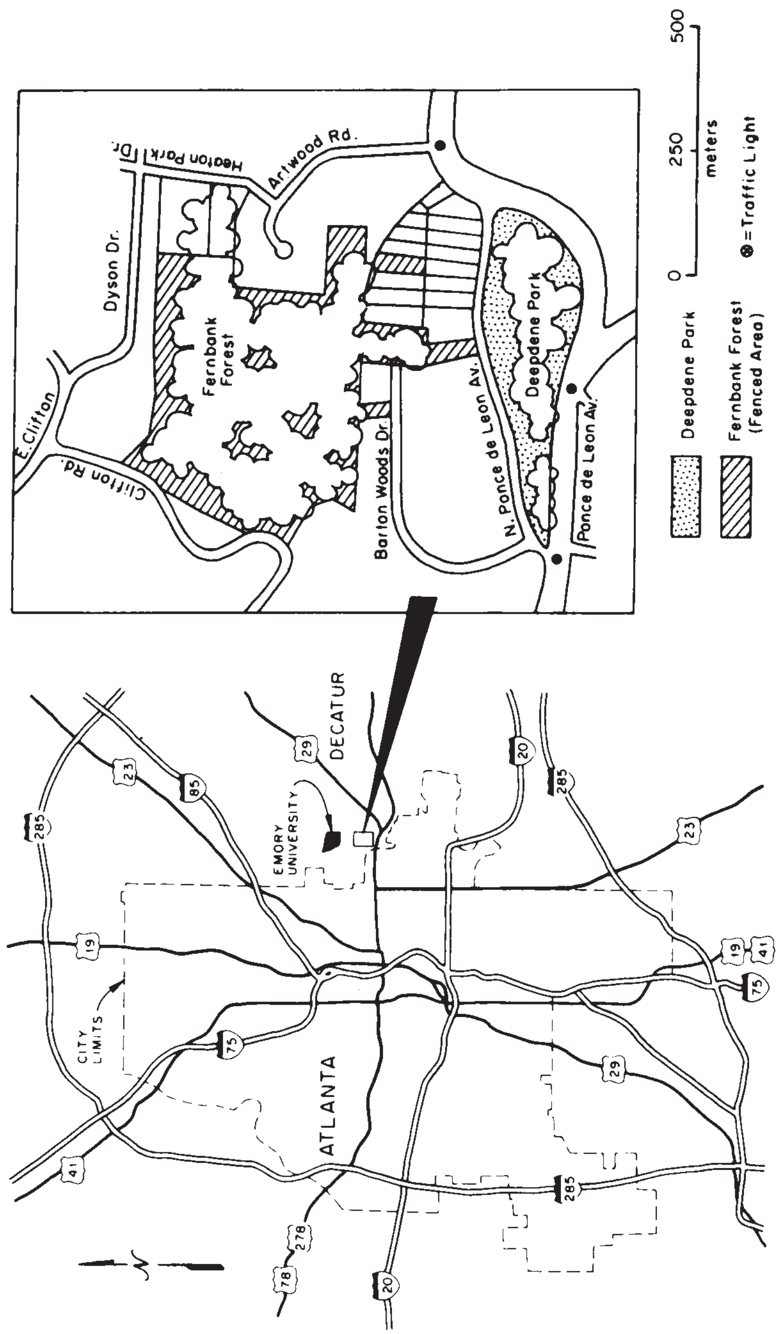


Fig. 1. Map of Fernbank Forest and Deepdene Park.

TABLE 1
DESCRIPTION OF TREES AND SOIL SAMPLED AT DEEPDENE PARK AND FERNBANK FOREST

Tree species	*Tree*	*Year of first ring*	*DBH*[a] *(cm)*	*Distance from road (m)*	*Soil pH*[b]	*Soil lead*[c] *(µg/g)* 0–15 *cm*	15–30 *cm*
				Deepdene Park			
Liriodendron	1	1866	81·8	16	5·94	150 (80·9)	38·6(4·95)
	2	1923	69·6	10	5·63	78·5(17·8)	27·6 (6·50)
	3	1907	68·3	12	4·78	99·5(20·5)	26·3
	4	1927	65·3	23	5·29	97·3(25·6)	17·5
	5	<1920[d]	89·2	12	5·46	163 (14·9)	ns[e]
Quercus	6	<1911[d]	86·1	13	4·99	131 (37·1)	95·7(67·7)
	7	<1900[d]	88·1	13	5·02	110 (11·1)	80·9
	8	1833	78·5	99	4·42	49·7(14·9)	17·3(12·2)
	9	1840	62·7	39	4·59	71·2(13·1)	27·1(19·2)
	10	1841	72·6	28	4·77	94·9(67·1)	49·5
Carya	11	1918	42·3	44	5·66	94·0(25·9)	52·4(14·2)
	12	<1880[d]	51·6	93	4·44	53·0(25·6)	25·5 (4·47)
	13	1836	48·8	92	4·47	37·5 (2·28)	18·0 (1·52)
	14	1832	45·5	65	5·03	50·4 (3·45)	23·3 (1·35)
	15	1850	38·9	42	4·47	43·2 (5·81)	18·0 (2·47)
				Fernbank Forest			
Liriodendron	16	1864	70·9		5·13	48·6	21·2 (1·21)
	17	1856	78·7		5·54	32·6 (3·56)	19·5 (2·58)
	18	1854	54·1		5·62	38·6 (2·35)	20·9 (4·27)
	19	1849	65·5		5·31	38·2 (2·15)	20·6 (0·84)
	20	1848	83·1		5·53	39·0 (1·44)	26·0 (2·52)
	21	1819	83·6		5·49	39·5 (3·12)	20·4 (3·98)
	22	1869	72·6		5·79	47·1(10·9)	25·9
	23	1828	74·7		5·37	35·9	19·0 (0·35)
	24	1826	93·5		5·35	35·7 (3·83)	19·7 (1·41)
	25	1823	89·4		5·46	65·1(28·2)	37·2(18·6)
Quercus	26	1846	42·9		5·18	43·0 (8·72)	22·0 (1·84)
	27	1845	72·1		5·37	42·6 (6·59)	19·7 (3·72)
	28	1840	65·0		5·16	34·4 (5·58)	22·2 (1·83)
	29	1835	52·1		5·75	41·2 (0·92)	22·4 (1·21)
	30	1834	61·2		5·51	39·8 (1·20)	17·7
Carya	31	1841	56·4		4·99	43·1 (2·55)	23·5 (2·31)
	32	1851	56·6		4·63	38·9 (5·41)	19·6 (2·71)
	33	1865	43·2		4·87	38·7 (2·53)	17·8 (2·44)

[a] Diameter at breast height.
[b] Mean of six.
[c] Mean of three. Values in parenthesis are standard error of the mean.
[d] No core contained the first ring.
[e] Not sampled because of rock strata.

sampling, the bore holes in each tree were sealed with small corks and plastic wood to protect the tree from fungal or insect invasion.

Three soil cores were taken with a soil auger at a distance of 10 m from the base of the tree along the 120°, 240 °, and 360 ° axes used for the xylem cores. Each soil core was divided into a top (0–15 cm) and bottom (15–30 cm) depth fraction, rock strata permitting, and the fractions were placed in plastic bags and sealed until analysis.

The soil cores were dried for 24 h at 100°C and passed through a 500 µm sieve.

Approximately 10 g of the sieved soil was weighed to the nearest 0·1 mg and added to 10 ml distilled-deionised water, and the 1:1 slurry was measured for pH. The lead was extracted by adding 10 ml concentrated HNO_3 and heating to sub-boiling for 24 h. The samples were then filtered through Whatman No. 42 filter papers and taken up to volume in 50 ml volumetric flasks with distilled-deionised water.

Xylem rings were examined under magnification, counted, and cut into 4-year sections. Four-year sections were selected to provide sufficient sample mass for analysis, minimise the number of samples per xylem core, and yet provide adequate resolution of the historical lead accumulation record. The sections were washed for 30 s in 0·1 N HNO_3 to remove any surface contamination introduced from the coring or handling processes, dried for 24 h at 100°C, and weighed to the nearest 0·1 mg in a desiccated atmosphere to preclude error from hygroscopic weight gain. After weighing, the wood sections were placed in 10 ml volumetric flasks and ashed at 400°C for 24 h. After cooling, the ash was taken up in the flask with 1·0 ml cold 2·0 N $HClO_4$.

All laboratory glassware was acid washed with 6 N HCl, and all reagents and standards were prepared from analytical grade stock solutions with distilled-deionised water. Blank samples were run with every 20–25samples to monitor for lead contamination.

Soil and xylem lead analyses were performed on a Perkin Elmer 306 Atomic Absorption Spectrophotometer at 2833 Å. The soil samples were atomised in an air–acetylene flame injector. The detection limit in the air–acetylene flame mode is approximately 20 ng ml^{-1} (Fernandez & Manning, 1971). Aliquots of 20 µl of xylem section samples were injected into an HGA-2100 Graphite Furnace, dried for 15 s at 110°C, charred for 10 s at 375°C, and atomised for 4 s at 2500°C. An injection of 20 µl of solution containing 0·25 ng (0·25 ppm) lead is near the detection limit in the graphite furnace mode; however, much lower detection limits were achieved by injecting several 20 µl aliquots into the furnace prior to atomisation.

The precision of the xylem section analysis procedure was tested by analysis of eight replicate 1 g homogenised *Liriodendron* wood samples. The coefficient of variation for the replicates was 0·12. The accuracy of the analysis procedure was assessed by spiking eight replicate 1 g *Liriodendron* wood samples with a 1 µg lead spike (as $Pb(NO_3)_2$) before ashing. No detectable loss of lead during sample preparation was observed, and the average difference in predicted and observed results was approximately 2% of the predicted result.

RESULTS AND DISCUSSION

Soils

The results of soil lead analysis (Table 1) indicate that Deepdene Park soils are heavily contaminated with lead and Fernbank Forest soils are less so. The mean lead concentration in the 15–30 cm depth fraction at Fernbank Forest (22 µg/g) is nearly equal to the 20 µg/g baseline value given by Smith (1976) for unmineralised and uncontaminated soils, and thus may be assumed to be the background lead concentration of these soils. The lead concentration in this depth fraction at Fernbank Forest was found to be significantly lower at the $p < 0{\cdot}01$ level than the lead concentration in either the upper 0–15 depth fraction at Fernbank Forest or the lower 15–30 cm depth fraction at Deepdene Park. These results indicate that there is some input of lead to Fernbank Forest, but a much higher lead input to Deepdene Park because lead from automotive sources is bound within the upper few centimetres of soil (Chow, 1970; Motto *et al.*, 1970; Ward *et al.*, 1974) and is rather insoluble within the pH range found at both sites (Olson & Skogerboe, 1975).

Xylem lead concentrations

Analysis of bark samples obtained with the increment corer indicated that lead concentrations were higher on the sides of the tree facing the road than on the side facing away. Although this analysis supports previous work, it is felt that the sampling technique was inappropriate for a representative bark sample, and these results remain inconclusive. However, the differences in the lead concentration among ring sections of the same age from the 120°, 240 °, and 360 ° xylem cores were found to be non-significant ($p > 0{\cdot}05$), and thus all results are based on three cores combined for each tree. This observation, especially with regard to Deepdene trees, indicates that lead is uniformly distributed throughout each wood ring, and xylem is not sensitive to the direction of the lead source.

Xylem lead concentrations are both site- and species-specific (Fig. 2). Within a species, mean lead concentrations in xylem ring sections from trees at Deepdene Park are approximately an order of magnitude greater than lead concentrations in corresponding sections of the same age at Fernbank Forest. The difference in lead content of xylem sections formed after 1923 between high- and low-exposure sites was statistically tested for each species and found to be significant for each of the three species at the $p < 0{\cdot}01$ level. Among species, *Carya* accumulates the highest xylem lead in ring sections of a given age at either site, and generally the order of lead accumulation is *Carya* > *Liriodendron* ≤ *Quercus*. *Carya* has also been shown to be an accumulator of other trace elements (Bowen, 1966).

Temporal lead accumulation patterns

The temporal lead accumulation pattern is also both site- and species-specific. The highest mean xylem lead concentration in Deepdene *Liriodendron* trees occurs in the 1940 to 1943 section (Fig. 3), and most individual trees have the highest xylem lead concentrations between 1940 and 1960. However, statistical comparison of ring sections formed between 1808 and 1923 (prior to the introduction of tetraethyl lead) to ring sections formed between 1924 and 1975 (after the introduction of tetraethyl lead) in the two trees for which this comparison could be made indicates no significant ($p > 0{\cdot}05$) increase in xylem lead after 1923 in this diffuse-porous species.

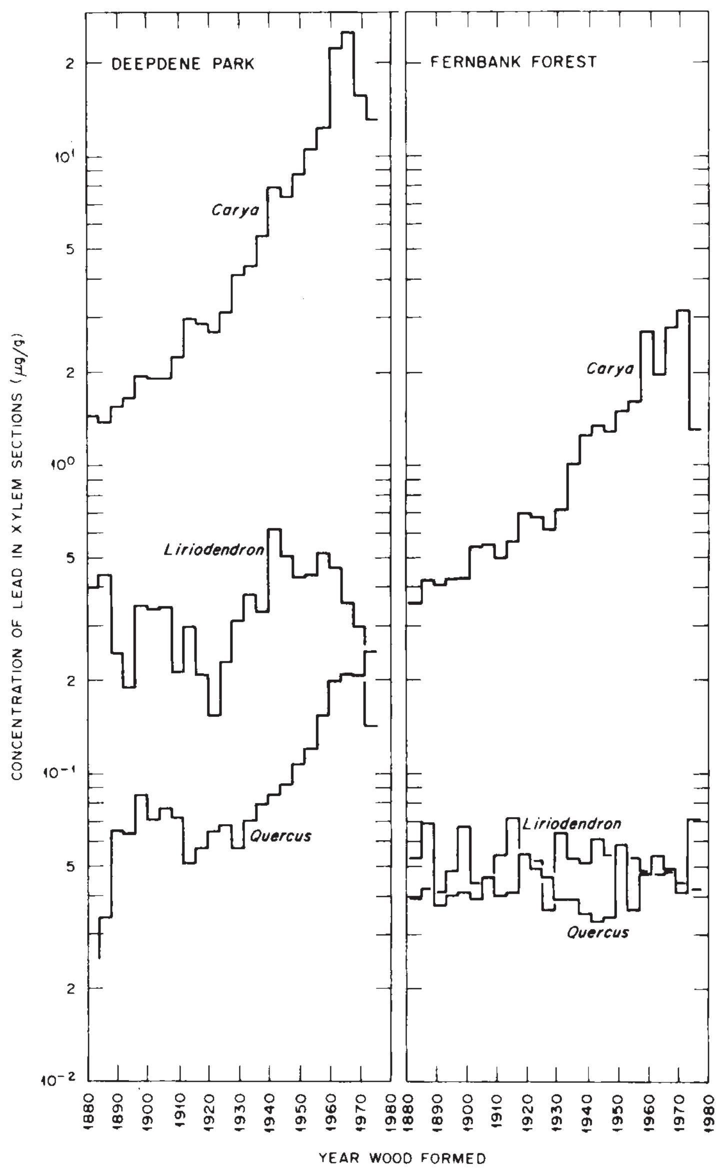


Fig. 2. Mean xylem lead concentrations in trees of Deepdene Park and Fernbank Forest.

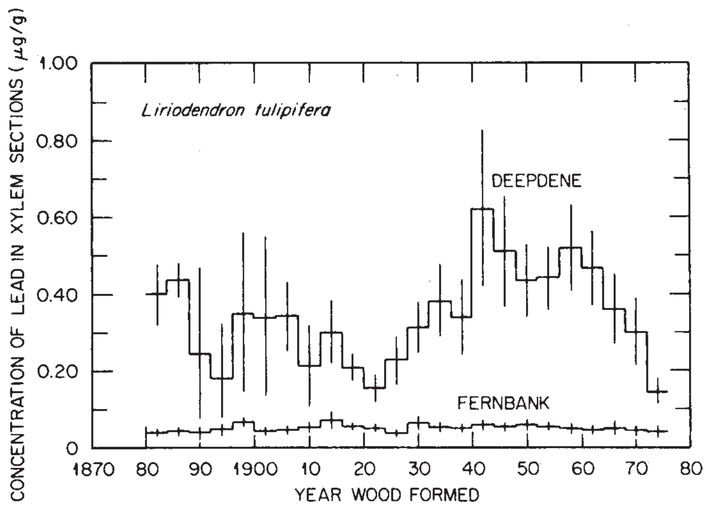


Fig. 3. Xylem lead concentrations in *Liriodendron tulipifera* trees with standard error of the mean indicated. Note: The values from 1880 to 1907 for Deepdene are from a single tree.

All Fernbank *Liriodendron* trees have very uniform xylem lead concentrations, and no temporal trend of lead accumulation is apparent in these trees.

The highest mean xylem concentration (0·25 μg/g) in Deepdene *Quercus* trees occurs in the most recent section (1972 to 1975), and a temporal trend of increasing xylem lead concentration after 1923 is apparent in this ring-porous species (Fig. 4).

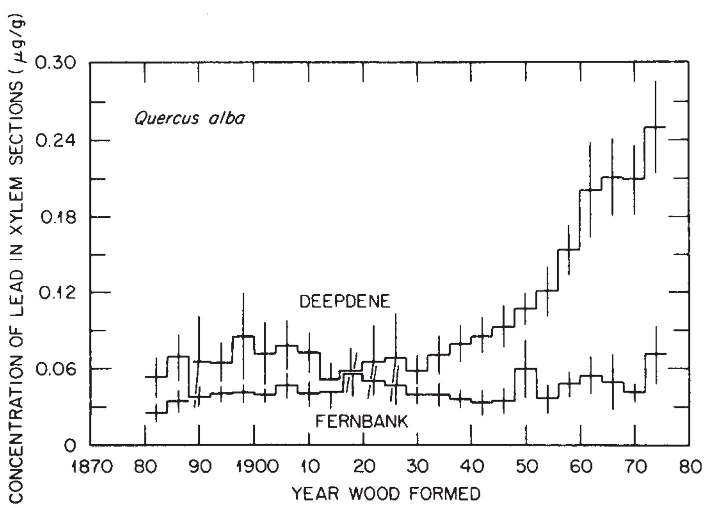
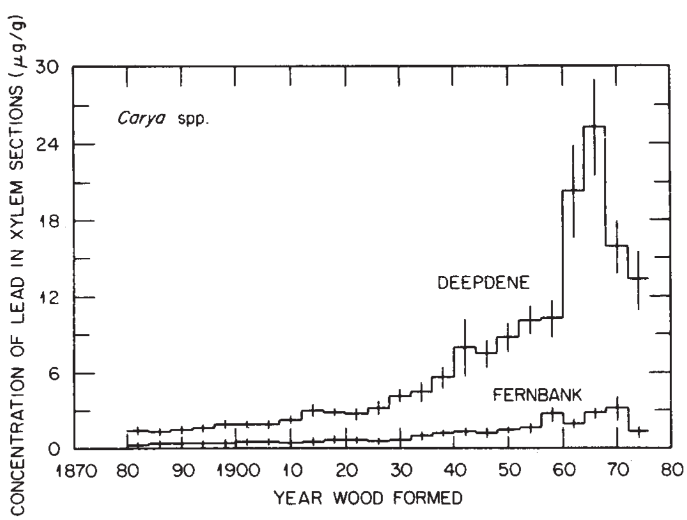


Fig. 4. Xylem lead concentrations in *Quercus alba* trees with standard error of the mean indicated.

This temporal increase at Deepdene Park was tested statistically by comparing pre-tetraethyl lead (1880 to 1923) and post-tetraethyl lead (1924 to 1975) ring sections, and the increase in xylem lead after 1923 was found to be significant at the $p < 0{\cdot}01$ level. The observation that the most recent rings contain the highest lead content is consistent with observations reported by Rolfe (1974) for *Quercus rubra*, Holtzman (1970) for White Oak I and II, and Ault *et al*. (1970) for *Q. rubra*. The accumulation pattern observed for Deepdene *Quercus* trees is strikingly similar to those observed by Hall *et al*. (1975) and Kardell & Larsson (1978) for *Q. rubra*. The lead concentration of the most recent ring sections from Deepdene Park is of the same order of magnitude as the value of 0·34 μg/g reported by Ault *et al*. (1970), but more than an order of magnitude less than the values reported by Rolfe (1974) for *Q. rubra* and Hall *et al*. (1975) and Kardell & Larsson (1978) for *Q. robur*.

Unlike Deepdene trees, Fernbank *Quercus* trees have no apparent temporal pattern of lead accumulation, although the highest mean lead concentration in these trees also occurs in the most recent ring section. A statistical comparison of pre- and post-tetraethyl lead ring sections confirms that there is no significant ($p > 0{\cdot}05$) increase in *Quercus* xylem lead after 1923 in the low-exposure site. This insensitivity of *Q. alba* to low lead exposures supports Kardell & Larsson's (1978) results and, if characteristic of the genus, may explain the lack of success reported by Szopa *et al*. (1973) in relating xylem lead concentrations in *Q. nigra* and *Q. alba* to pollution episodes.

The ring-porous species, *Carya*, has a statistically significant ($p < 0{\cdot}01$) increase in xylem lead concentration after 1923 in both low- and high-exposure sites, and at each site the highest mean xylem lead concentration occurs previous to the most



recent rings (Fig. 5). These observations are quite similar to ^{210}Pb specific activity patterns reported by Holtzman (1970) for suburban Chicago *Carya* trees and the accumulation pattern observed by Hall *et al*. (1975) for ash. These lead peaks before the latest rings may indicate that some lateral redistribution of lead within the xylem is occurring in these species, if it is assumed that the highest environmental exposures occur in the most recent year.

Lateral lead movement

Stewart (1966) has described the movement of metabolic waste products in trees from sapwood to heartwood along lateral rays. The possibility of lateral redistribution of xylem lead in tree rings by this process may confound interpretation of temporal patterns of xylem lead concentration and may be examined through comparison of pre-tetraethyl lead ring sections between sites for each species. Because Deepdene and Fernbank trees belonged to one contiguous forest ecosystem before 1930 and automotive lead is the only source in Atlanta, it can be assumed that they were exposed to the same low environmental levels of lead before the introduction of leaded gasoline in 1924. If xylem lead is not mobile between adjacent rings, then a ring should have lead concentration relative to the lead exposure in the year in which it was formed, and not to exposures during subsequent (or prior) years. If lead is mobile between adjacent rings, then pre-tetraethyl lead ring sections of trees from Deepdene Park would have higher lead concentrations than those from Fernbank Forest, because the higher lead exposures at the former site since 1924 would contaminate rings formed before this date.

A statistical comparison of pre-tetraethyl lead ring sections between sites gives circumstantial evidence of lateral movement of lead in *Liriodendron* and *Carya* trees, because lead concentrations in these sections are significantly higher ($p < 0{\cdot}01$) at the high-exposure site. There is no significant difference in lead concentration of these same ring sections between sites in *Quercus* trees, indicating little or no lateral redistribution of lead between adjacent rings. Lepp & Dollard (1974) found lateral lead movement in *Alnus*, *Fagus*, *Betula*, *Ulmus*, *Aesculus*, and *Tilia*. Hampp & Höll (1974) found evidence of radial translocation of lead in *Robinia* and *Acer* as well as in *Tilia*. Thus, lateral lead movement among xylem rings may be a fairly common phenomenon in both ring-porous and diffuse-porous trees. However, the evidence presented here indicates that either it does not occur, or occurs only very slightly, in *Quercus*.

Lead accumulations and pollution history

Regardless of the degree of lateral lead movement in *Carya* and *Quercus* trees, it is evident from examination of Figs. 4 and 5 that after 1923 concentrations of lead increased with time in both these ring-porous species at Deepdene Park and in *Carya* at Fernbank Forest. Unfortunately, direct comparison of these temporal lead concentration increases with historical lead pollution events at each site is impossible, because of the absence of actual lead pollution measurements. However, comparisons with traffic patterns on Ponce de Leon Avenue are possible if it is assumed that there is a direct correlation between traffic density on the road and environmental lead pollution at Deepdene Park. Inspection of Figs. 4 and 5 shows that, there are relatively large increases in mean xylem lead concentration of 30 and 100 % between the 1956–59 and 1960–63 ring sections of Deepdene *Quercus* and *Carya* trees, respectively. Ponce de Leon Avenue was widened from two to four lanes between 1950 and 1959 (the actual date of widening is not available). Certainly this widening had a large impact on traffic flow, although this impact cannot be quantified. However, the long-term average annual traffic growth rate has been determined and may be compared with the temporal rate of xylem lead increase among trees and between sites.

The rate of increase in xylem lead concentration after the automobile came into general use in the early 1930s was determined by standardising subsequent xylem sections against the 1928 to 1931 section for each tree and fitting linear regression approximations to the data. The slope of the regression equation may be considered the annual percentage rate of increase in xylem lead and is used to fit a line representing the % increase in xylem lead relative to 1932 (Fig. 6). Previously, the average annual traffic growth rate since this time for Ponce de Leon Avenue (based on Georgia Department of Transportation traffic counts) was determined to be approximately 9·7 % $year^{-1}$ (Baes, 1977). The estimated range of traffic growth in the metropolitan Atlanta area was determined to be between 7 and 12% $year^{-1}$.

Figure 6 shows that, for both ring-porous species, Fernbank trees have lower and less variable rates of increase in xylem lead concentration than do Deepdene trees

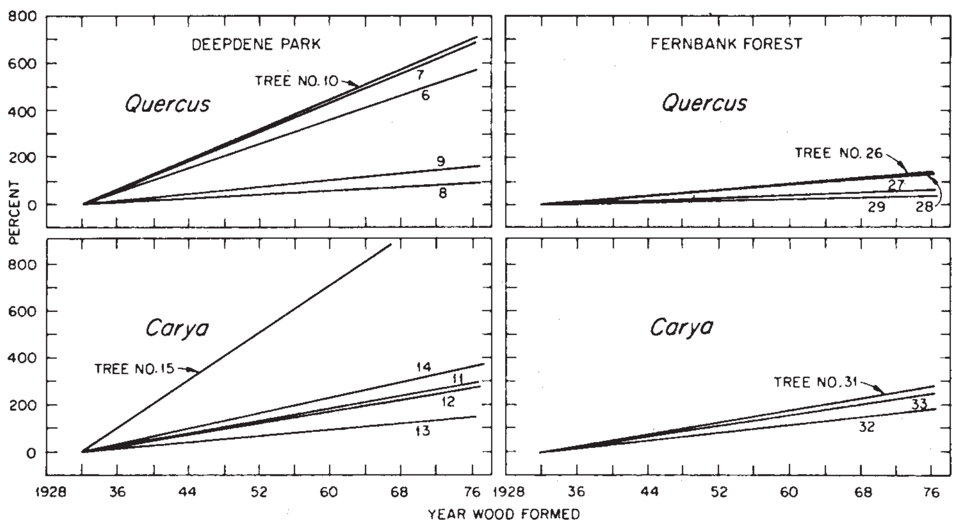


Fig. 6. Percent increase of xylem lead concentration in ring porous species relative to 1932.

(*Liriodendron* trees are not included in Fig. 6 because they did not show a positive rate of xylem lead increase at either site). At the low-exposure site, *Carya* trees have a higher mean rate of increase of xylem lead ($5{\cdot}5 \pm 1{\cdot}0$ % year^{-1}) than *Quercus* trees ($2{\cdot}0 \pm 1{\cdot}2$ % year^{-1}). At Deepdene Park there is a negative correlation between distance to the road and % increase in xylem lead since 1932. This negative correlation is slightly stronger for *Quercus* trees ($r = 0{\cdot}77$) than for *Carya* trees ($r = 0{\cdot}65$). This result might be expected in light of *Quercus*' relative insensitivity to low lead exposures as compared with *Carya*. The mean rate of increase in xylem lead for both species at Deepdene Park is approximately 10% year^{-1}. This value corresponds surprisingly well with the estimated traffic growth rate along Ponce de Leon Avenue. The lower mean rates of xylem lead increase in Fernbank *Carya* and *Quercus* trees may indicate that environmental lead pollution rates have increased less rapidly in the general metropolitan Atlanta area than in areas immediately adjacent to major roads.

The high variability associated with historical xylem lead increases among trees of the same species suggests the necessity of large numbers of replicates of the same tree species in determining historical lead pollution regimes from tree ring analysis. The use of *Quercus* in constructing such histories may be limited by its relative insensitivity to low lead exposures as shown in this study and by Kardell & Larsson (1978). However, lead mobility between xylem rings appears not to be a confounding factor in this species. The use of *Carya* trees in constructing historical lead pollution patterns may require quantification of lead mobility between adjacent rings. However, *Carya* is certainly the most sensitive of the species studied and may be very useful in documenting episodes of lead pollution, if not in reconstructing the chronology of the episode.

SUMMARY

Soil lead analyses indicate that Deepdene Park in Atlanta, Georgia is much more heavily contaminated with lead than is Fernbank Forest. This differential lead exposure at the two sites is also reflected in the lead content of the tree rings. In all species, lead concentrations in comparable xylem ring sections formed since 1923 are approximately an order of magnitude greater in Deepdene trees than in Fernbank trees. These lead concentrations are uniform throughout the xylem section, although the trees may be more heavily exposed on one side than the other. Within each site, *Carya* trees accumulate the highest interspecies xylem lead concentrations, followed by *Liriodendron* and *Quercus*, respectively.

Each species has a unique and characteristic temporal lead accumulation pattern after 1923 at the high-exposure site, but only *Carya* has its characteristic pattern at the low-exposure site. These patterns and comparisons of lead in xylem formed before 1923 between sites give circumstantial evidence of lateral lead movement

between rings in *Carya* and *Liriodendron*. Analysis of the temporal rate of change in xylem lead since 1932 in the ring-porous species, *Carya* and *Quercus*, indicates that xylem lead concentrations in these species can be related to historical lead pollution patterns if a sufficient number of replicate samples are taken. *Carya* appears to be the best candidate for monitoring historical lead pollution episodes because of its high sensitivity to environmental lead; however, the probability of lateral movement of lead in this species may require quantification of this process before accurate reconstruction of historical events can be made.

ACKNOWLEDGEMENTS

This work was done under the auspices of Emory University and we are grateful to Mr Edward Hunt of that institution and Dr James Skeen of Fernbank Science Center for their assistance in sampling the trees. Also, we wish to extend special thanks to Dr Frederick O'Hara of the Oak Ridge National Laboratory for his expert help and advice in the preparation of the manuscript.

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