C-2.2 Impact of "acid rain" on plant-environment systems

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Abstract

Essential and non-essential elements in the outer bark(dead secondary phloem)-inner bark(living secondary phloem)-vascular cambium-outer xylem sequence of a coniferous tree, *Cryptomeria japonica*, 360yr old were studied in relation to nutritional status and pollution. High concentrations of Al and Pb on the outside of the bark decreased exponentially toward the inside of the bark, reaching a minimum at the boundary between the outer and inner bark. The concentrations of essential bioelements (Mg, K, P, Cu, Zn) increased in the inner bark, and attained maximum values in the cambium layer (e.g. Mg: 2160 μ g g^{-1}, K: 20300 μ g g^{-1}, P: 1800 μ g g^{-1}). High correlations were found among these elements in the sequence from inner bark to the cambium layer (Mg: P, $r=0.984$ $p<0.01$; P:K, $r=0.972$ $p<0.01$). The concentration of Ca was high in the inner bark (phloem) and cambium layer (1.6-2.2%). SEM-XMA study revealed the distribution of many crystals of calcium oxalate in the inner bark.

Key words: Cambium, Bark, Metal, *Cryptomeria japonica*, Acid rain

Introduction

The natural distribution of the coniferous tree, *Cryptomeria japonica,* or Japanese cedar extends from the northern (Aomori prefecture) to the southern part of Japan (Yakushima island).The decline of *C. japonica* is now a serious problem, especially in large cities and their suburbs.[1]

The nutritional status of trees is one of the important chemical and biological aspects when considering the impacts of environmental pollutants in relation to the direct and indirect effects of "acid rain".[2][3][4]

However, studies on the essential elements of *C. japonica* growing in the field have been limited to the annual rings of the xylem layer and bark for monitoring of heavy metals in air borne particles.[5][6][7][8] Both of xylem and bark are consisted of dead cells with thick cell walls, which have potential to record some chronological change of environments.[9][10]

Both bark and xylem are produced by vascular cambium. The concentration of essential elements in the bark, cambium and xylem layers may differ as a result of differences in the physiological and functional characteristics of these three parts. In particular, the element concentration in the cambium layer seems to be important for indicating the nutritional conditions which are essential for tree growth.

The objective of this study was to clarify the distribution of essential and non-essential elements through the outer bark(dead secondary phloem)-inner bark(living secondary phloem)-vascular cambium-outer xylem layers of *C. japonica*, which has not been investigated previously and to correlate any differences among these layers with air pollution and nutritional status.

Research Methods

The specimens were collected from Nikko, a district located about 100km north of Tokyo. Nikko is famous for the Toshogu shrine, which was built about 360 years ago, when avenues of *C. japonica* were also planted. The number of cedar trees, 350-360yr old, in these avenues are about 13000 now. Many of the trees planted at that time show die-back of the apices and side branches for several meters, although the causes of this have not been clarified.

The specimens of *C. japonica* (tree number L0842) were collected by lifting with a crane in May 1990. Both (tree number L0842 and L6001) were about 35m tall and were divided into 4-

m length. The materials provided for study were two bark cambium-xylem sequences each taken from part of trunk about 4-m from the ground. Each sequence of outer bark-inner bark -cambium-xylem was divided into sub-sections.

The divided thin sections were dried at 60°C for more than 24h, weighed, and then digested with Teflon double-vessel bombs using vapor of nitric acid, which was separated from the sample.[11] The amount of nitric acid in the outer Teflon vessel was 1ml per 50mg of sample in the inner vessel. The nitric acid vapor produced at 140 °C was effective for digesting the samples. The digested samples were dissolved in purified water prepared with a Milli-Q water purification system. The amount of purified water was about 10ml per 50mg sample. Then the solutions were passed through a membrane filter (Sartorius Minisalt NML, pore size 0.45 μm). ICP-AES (Inductively Coupled Plasma Atomic Emission Spectrometry) ICP-MS (ICP Mass Spectrometry) and SSAAS (solid sample Atomic Absorption Spectrometry) were used for the determination of 13 elements (Na, Mg, Al, P, K, Ca, Sr, Ti, Mn, Fe, Cu, Zn and Pb.[12] The thin section of sample before digestion were observed and analysed by SEM-XMA (Scanning electron microscope with X-ray microanalyzer).

Results

Figure 1 and Figure 2 shows the element concentrations in the outer bark-inner bark-vascular cambium-outer xylem sequence divided into subsections.

Outer bark

The outside of the bark showed higher concentrations of Na, Mg, Al, P, K, Ca, Ti, Fe, Cu, Zn and Pb compared with those inside. For example, the concentration of Al in the 0.0 to 0.21mm layer was about 1280 times higher than that in the 1.92 to 0.23mm layer. The correlation coefficients vetween Al and other elements in the outer bark were more than 0.92 ($p<0.01$), except for a value of 0.88 between Al and Na. These elements showed minimum concentrations at the boundary between outer and inner bark.

Inner bark

The element concentrations in the inner bark, having a thickness of about 2mm, were characterized by high concentrations of Na, Mg, P, K and Ca. The concentrations of K, Mg and P increased from outside to inside. In contrast, the concentrations of Ca showed high values in the inner bark, which attaining 1.6 to 2.2%. However, there were no significant correlations between the sequence for Ca and those of the other elements (Mg, K, P, Cu, Zn). SEM-XMA study revealed the distribution of many small crystals of calcium oxalate in this layer.

Vascular Cambium layer

The concentrations in the thin cambium layer were markedly high for K, Mg and P. The concentrations of these elements, which showed maximum values in the bark-cambium-xylem sequence, were attained 2.0% for K, 2160 $\mu g\ g^{-1}$ for Mg and 1800 $\mu g\ g^{-1}$ for P. The molar ratio of these elements was 8.9 (K): 1.5 (Mg): 1 (P).

These were high correlations among Mg, P and K in the inner bark-cambium sequence (Mg: P, $r=0.98$ $p<0.01$; P:K , $r=0.97$ $p<0.01$). Moreover, the trace metals Cu, Zn and Fe showed maximum values in the cambium layer.

Outer xylem layer

The element concentrations in the xylem layer, which transports minerals and nutrients from the soil to leaves, were about one order of magnitude lower than those in the cambium layer.

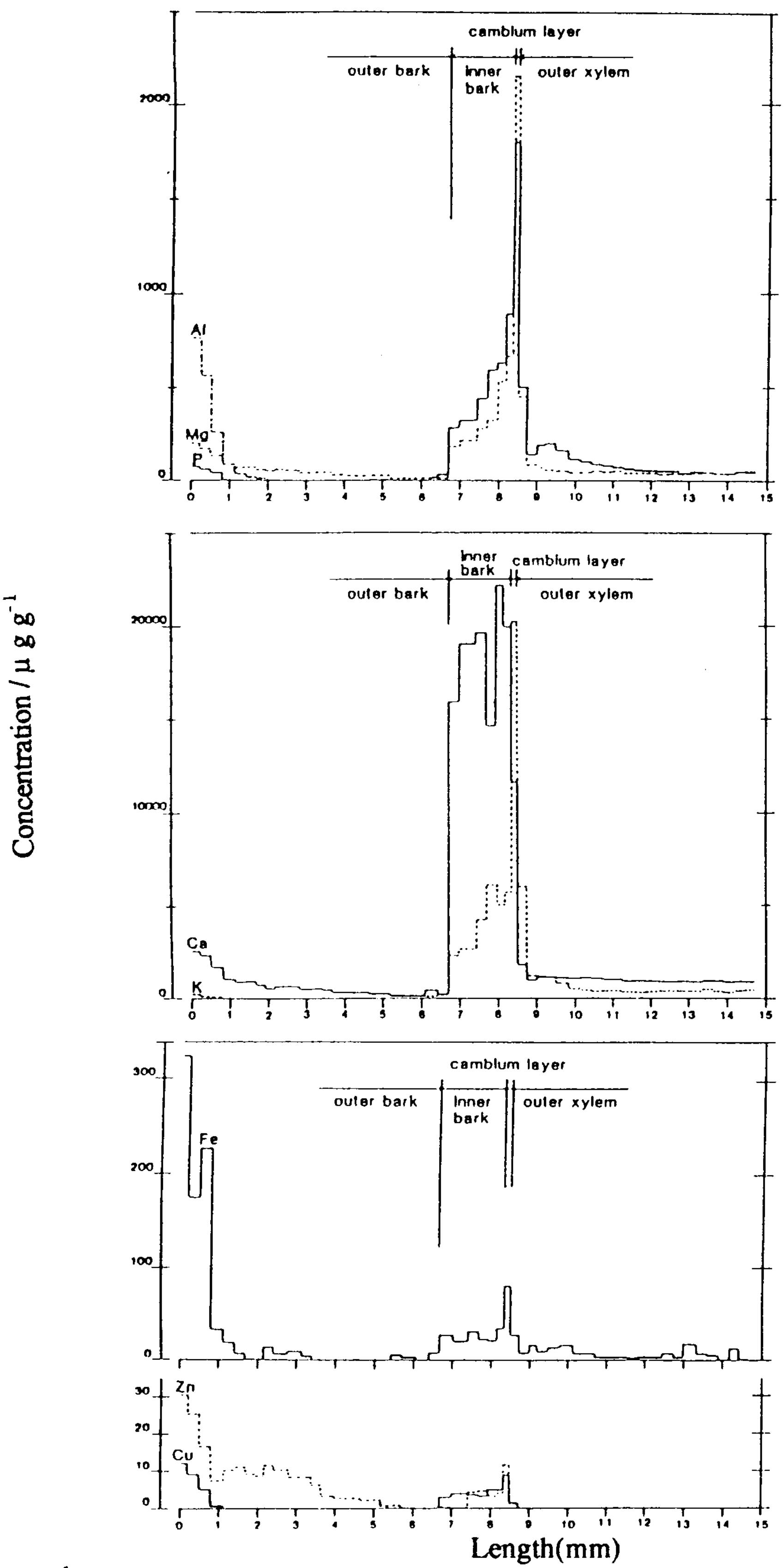

Figure 1
Distribution of Al, Mg, P, Ca, K, Fe, Zn and Cu in the outer bark, inner bark vascular cambium and outer xylem layers in a specimen of *Cryptomeria japonica* collected from Nikko.

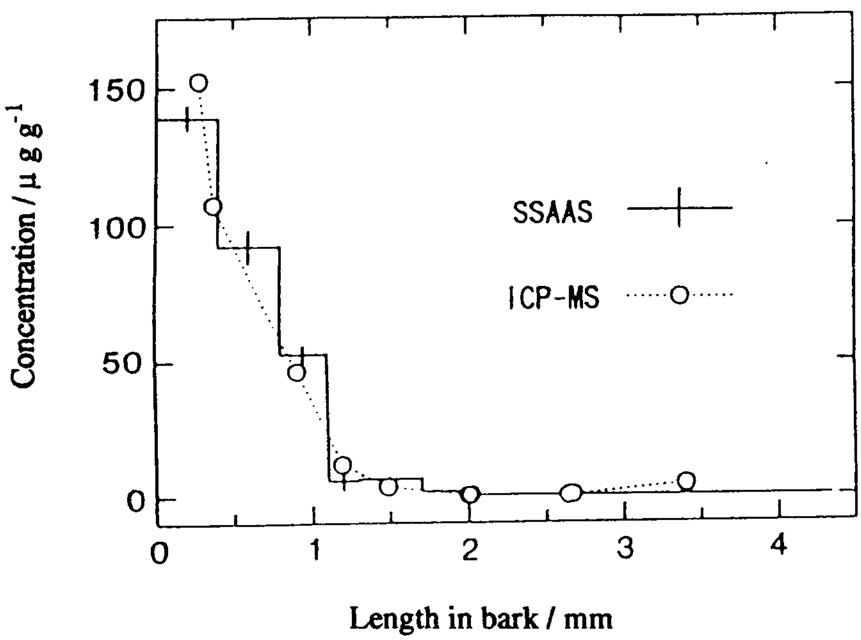

Figure 2
Distribution of Pb in the outer bark of *Cryptomeria japonica* collected from Nikko.

Discussion

There were clear differences among the concentrations of elements in the sub-sections of outer bark, inner bark, cambium layer and outer xylem. The sequence for metal distribution showed two routes for metals, from airborne particles and from the soil by way of the roots.

The high concentrations of elements (Al, P, Mg, Ca, Ti, Fe, Zn, Cu and Pb) on the outside of the bark indicated contamination of the outer bark by airborne and/or soil particles. This is supported by the high correlation coefficients of these elements with Al, which is the main elements in soil particles, and by the exponential decrease in concentration from the outside to the inside of the outer bark.

It has been noted that the bark of *C. japonica* accumulates air pollutants.[7)8)] The amount of elements on the outside of the bark would be expected to indicate the degree of environmental contamination. However, in order to evaluate such pollution quantitatively, the radial distribution of elements in the bark should be studied. Such evaluation may differ according to sample thickness in the same tree. If the sample includes the inner bark, which shows different concentration of elements, the evaluation might be unreliable.

The element concentration in the inner bark differs completely from that in the outer bark. The outer bark consists of dead cells, whereas the inner bark comprises living cells, and essential elements supplied from the soil via the roots will remain in the inner bark and cambium layer without translocation to the outer bark.

The fact that the highest concentrations of Mg, K and P were observed in the cambium layer may indicate the importance of these elements for production of bark and xylem. Mg is known to have biological functions including activation of enzymes and a role in macromolecular synthesis. Furthermore many functions of Mg are related to P, including the process of phosphorization and transphosphorylation. Moreover, K, Mg and P are required for the activity of RNA.[13)]

Although the xylem layer consists of dead cells, it contributes to the transport of water, nutrients and elements from the soil to leaves. The lower concentrations of K, Mg and P in the xylem layer compared with those in the cambium layer are due to the fact that these tissues are died and living respectively.

Our results clearly show extremely high concentrations of K, Ca, Mg and P in one of the metaborically active sites of *C. japonica*, together with high concentrations of other essential trace elements, Cu, Zn and Fe. Deficiency of these essential elements may affect the growth of *C. japonica*. "Acid rain" in Japan, which has a pH of about 4.5 to 5.0 has the potential of leaching these essential elements from the soil with Al.[14]

Further studies on the relationships between acid rain and soil chemistry as well as details of the nutritional status of *C. japonica* are required.

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References

1)Katoh, T., Konno, T., Koyama, I., Tsuruta, H. & Makino, H. (1990) Acidic precipitation in Japan. In: Bresser A. H. M., Solomons W.(eds) Acidic precipitation Vol. 5, International overview and assessment. Springer-Verlag, New York, pp. 41-105.

2)Wyttenbach, A. & Tobler, L. (1988) The seasonal variation of 20 elements in 1st and 2nd year needles of Norway spruce, *Picea abies* (L.) Karst. Trees 2: 52-64.

3)Oren, R., Werk, K.-S., Schulze, E.-D., Meyer J., Schneider, B.-U. & Schramel, P. (1988) Performance of two *Picea abies* (L.) Karst. stands at different stages of decline. Oecologia 77: 151-162.

4)Schulze, E. -D. (1989) Air pollution and forest decline in a spruce (*Picea abies*) forest. Science 244: 776-783.

5)Katayama, Y., Okada, N., Ishimaru, Y., Nobuchi, T., Yamashita, H. & Aoki, A. (1986) Determination of trace elemens in annual rings of Yaku Sugi by the thermal neutron activation analysis. Radioisotopes 35: 577-582(in Japanese).

6)Taneda, K., Ota, M. & Nagashima, M. (1986) The radial distribution and concentration of several chemical elements in woods of five Japanese species Mokuzai Gakkaishi 32: 833-841.

7)Tanaka, J. & Ichikuni, M. (1982) Monitoring of heavy metals in airborne particles by using bark samples of Japanese cedar collected from the metropolitan region of Japan. Atmos. Environ. 16: 2015-2018.

8)Tsurumi, M. (1989) Sources of elements in cedar bark collected near a highway (Japan). The sciences of the Total Environment 86: 239-250.

9)Meisch, H.-U., Kessler, M., Reinle, W. & Wagner, A. (1986) Distribution of metals in annual rings of the beech (*Fagus sylvatica*) as an expression of environmental changes. Experientia 42: 537-542.

10)Bondietti, E.A., Bases III, C.F. & McLaughlin, S.B. (1989) Redial trends in cation ratios in tree rings as indicator of the impact of atmospheric deposition on forests. Can. J. For. Res. 19: 586-594.

11)Kojima, I. & Iida, C. Vapor phase digestion of botanical samples with acids in sealed polytetrafluoroethylene bomb. Analytical Sciences 2: 567-570.

12)Satake, K., Nishikawa, M. & Shibata, K. (1987) Elemental composition of the sub-aquatic liverwort *Pellia endiviifolia* (Dicks.) Dum. in relation to heavy metal contamination. Hydrobiologia 148: 131-136.

13)Hughes, M.N. & Poole, P.K. (1989) Metals and Microorganisms. Chapman and Hall Ltd., London, pp. 56-62.

14)Izuta, T., Yokota, F., Miyake, H. & Totsuka, T. (1990) Effects of soil acidification on the growth of Cryptomeria seedlings. Man & Environ. 16: 55-61(in Japanese).