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Wood Anatomical Characteristics of Pine Tree (*Pinus densiflora* S. *et* Z.) Damaged by Air Pollution*1

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大氣汚染 被害 소나무의 木材 解剖學的 特性*1

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[要 約]

大氣汚染이 극심한 것으로 알려져있는 溫山 및 麗川 지역의 소나무(*Pinus densiflor*)를 대상수종으로, 해부학적 특성을 조사하였던 바, 지난 10년간 전반적인 생장의 감소를 확인할 수 있었으며, 이 생장감소의 시작년대와 上記 지역에서의 工團의 가동 年度가 거의 일치하고 있음을 年輪年代學的 고찰을 통해 입증할 수 있었다. 대기오염 피해지역의 소나무에 있어서 반경방향의 생장의 감소는 지난 10년간 溫山의 경우 70%, 麗川의 경우 60%에 달하였다. 이들 소나무는 春材의 형성이 억제된 반면 피해기간 중의 秋材率은 약 30% 정도 증가되었다.

대기오염 피해기간중 형성된 年輪內의 最大密度는 건전재의 그것에 비해 약간 낮게 나타났다. 가도관의 치수의 경우 假導管長의 變異는 찾아볼 수 없었으나, 피해기간중 가도관壁의 두께와 그 직경은 감소하였다. 이같은 변화에도 불구하고 微視構造의 관찰결과, 하등의 異常組織이나 微生物을 發見할 수 없었다.

Summary

Some anatomical characterisitcs of Japanese red pine (*Pinus densiflora* S. *et* Z.) collected from pollution-exposed areas in Korea were investigated. These sites were reportedly the most severe air polluted areas in Korean peninsular.

A decline in overall growth rate was apparent since the late 10-year period of growth. *P. densiflora* in Onsan and in Yeochon recorded in the radial growth reduction of approximately 70 and 60% respectively. The formation of earlywood in the period of air pollution was restricted, whereas the percentage of latewood increased. The maximum wood density was lower in xylem rings formed during a period of air-pollution than in rings found without pollution. Most of pine trees damaged by air pollution showed the classical type of length-on-age curve for tracheids. However, reduction in cell wall-thickness and diameter was revealed in the wood exposed to air pollutants. Nor anomalies in microstructures nor microorganisms in wood structures were found in the damaged trees.

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1. INTRODUCTION

Tremendous amount of research programs have been recently initiated in several countries to understand the effect of air pollutants directly on the fine needles of forest trees[19,32,38] and indirectly via soil to the roots[16,35]. It seems possible that the impact of air pollution is not only restricted to the metabolic activities of plants but affect also consequent wood properties, since various physiological and metabolic responses to pollution in long terms adversely affect the tree growth and development[34]. Consequently, economically important question has been raised; what kind of changes might occur in the wood of pollution-damaged trees which in turn would lead to negative consequences with regard to wood quality and utilization. In this context, two questions are of major interest; (1) are there any anatomical and chemical alterations initiated in the cambium at the time of wood formation and thereafter secondary damages in the wood tissue of damaged trees? (2) are there any differences in physical and technological wood properties between healthy and damaged trees? The present study is, therefore, intended to investigate some anatomical characteristics of Japanese red pine (*Pinus densiflora* S. *et* Z.) collected from pollution-exposed areas in Korea.

2. MATERIALS AND METHODS

2.1 Plant materials and sampling site

The sampling sites were Onsan and Yeochon in Korea, where industrial estates were established since mid and late seventies respectively. The large sources of pollution such as aluminum, zinc, copper plants, smelters and chemical pulp factory have been operated in the industrial estate in Onsan, whereas fertilizer and refinery plants in Yeochon. Five red pines from each site were collected for anatomical, physical and chemical investigations. All the trees showed the so-called "tipburning" and/or yellowing in needles and also showed the premature shedding of old needles, giving branches a tufted appearances[32,38,39] but not dead.

In addition, two cores in 5mm diameter were taken by increment borer at breast hight from 20 trees for the investigation of ring width and density. Some trees of *Cryptomeria japonica* in Yeochon were also collected for the comparision.

2.2 Methods

Growth rings were measured on the cores and arithmetic means of both cores were calculated using chronologically matched increment. Ring-width indices were obtained by dividing each ring width by arithmatic mean of growth ring in each core. Measurements of wood density within the growth ring were obtained from 5 increment cores at each site by Soft X-ray and densitometry. The X-ray film negative (Fuji softex FG film) was then scanned with a laser densitometer (LKB). The operation condition of X-ray apparatus was 20 Kv, 15mA (tube current), 165 seconds for photographing and 60cm for focus-distance. Cellulose acetate as standard was used for the calibration of density. The arbitrary value of $0.5g/cm^{-3}$ in the densitograms was chosen as the limit between early wood and latewood[11,25].

Fifty tracheids per smaple point were measured for the determination of tracheids in the usual way with a calibrated ocular micrometer from macerated materials obtained via Franklin's method (incubation in a hydrogen peroxide and glacial acetic acid mixture). Quantitative data generally refers to average values, unless otherwise specified. For the light microscopical observations, air-dried samples were boiled, sectioned and stained with astra blue (1% in water) and safranin (0.5% in alcohol) successively. Small blocks obtained from the outermost part of growth rings were prepared asceptically for scanning electron microscopy (JEOL) after the fixation in FAA for the observation of colonization of microorganisms and microstructures in sample woods.

3. RESULTS AND DISCUSSION

3.1 Width of growth ring

Dendrochronological analysis showed that there were severe radial growth depressions in the trees exposed to air-pollution. A decrease in width of growth ring was apparent throughout the growth period 1973-1985 in all the trees observed in the Onsan area (Fig. 1). Indices of growth ring showed that radial increment in this site has been declining since mid seventies (Fig. 2). Extremely narrow annual rings were found in the outermost part of growth rings; four growth rings were formed successively within only 1mm-width, and only 8-10 cell layers were formed in each growth ring (Fig. 7-A and 7-B). The mean annual increment of damaged trees during the period of 1976-1985 was 0.67±0.35mm, which was about 80% less than those of the healthy trees (mean 3.44±0.70mm).

Japanes red pine in the area of Yeochon also showed the reduction of radial growth since late seventies and this reduction was approximately 60% greater than that of healthy ones (Fig. 3). Not only Japanes red pine but Japanes fir (*Cryptomeria japonica*) collected from same site also showed the declining in the radial growth since late seventies (Fig. 3).

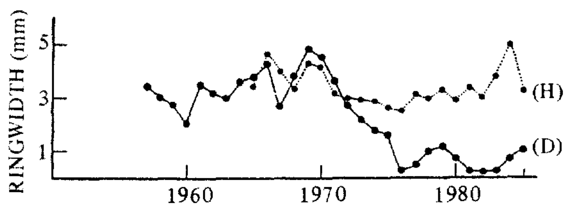

Fig. 1. Average ringwidth (mm) of *Pinus densiflora* in the site of Onsan. Solid line; damaged trees (D), broken line; healthy trees (H).

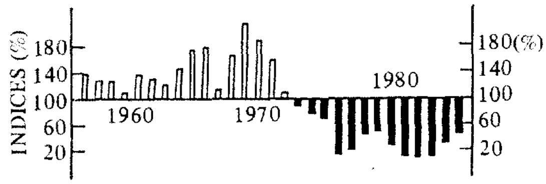

Fig. 2. Indice of growth rings in the period of 1957 to 1985 in the site of Onsan.

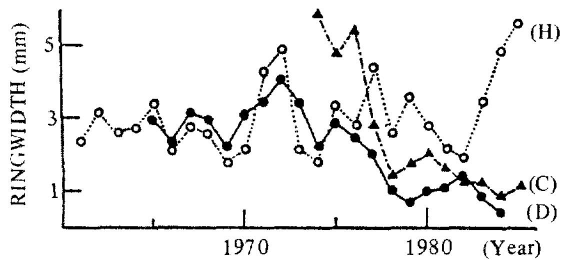

Fig. 3. Average ringwidth (mm) of *Pinus densiflora* and *Cryptomeria japonica* (C) in the site of Yeochon. Solid line; damaged pine tree (D), broken line; healthy trees (H).

The coincidence between radial growth of Japanes red pine trees and the establishments of industrial plants at each site clearly indicated the effect of cumulative stress of air pollutants, confirming that reduced photosynthetic capacity of trees due to air pollutants could result in decreased annual incremental growth from one year to next[11,26,33,36]. Analysis of ring width patterns is, therefore, very useful in diagnosing the pollution effects on the growth of trees. It has been well documented that the loss of radial growth in symptomatic and asymptomatic trees has been positively correlated with industrial output such as sulphur dioxide, nitrogen oxide and photooxidants in Europe and U.S.A.[1,2,3,7,8,9,12,40].

3.2 Percentage of latewood and Variation of maximum density

The effect of air pollution on the formation of early-and latewood showed that not only the radial growth but the earlywood formation also restricted by air pollution (Figs. 4 & 7-B). The restricted formation of earlywood during the period of air pollution, inversely, leads to the increased percentage of latewood formation; the increase of latewood percentage in the damaged trees on Onsan area during 1976-1985 was approximately 30% in comparision with that of non-damaged trees.

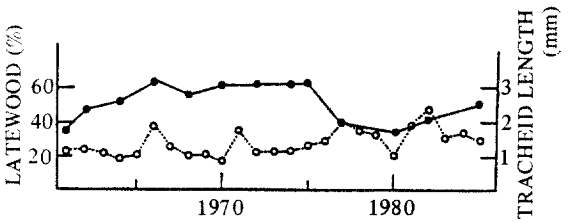

Fig. 4-1. Length-on-age variation of tracheid (solid line) in *Pinus densiflora* and percentage of latewood (broken lines) in site of Onsan.

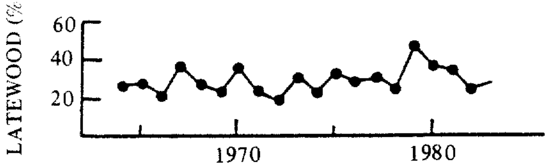

Fig. 4-2. Percentage of latewood of *P. densiflora* in the site of Yeochon.

There exists contrasting results in the literatures on the effect of air pollutants on the latewood formation. Liese *et al*[23] for example, observed the increase of latewood percentage by 50% in the spruce damaged by air pollution. Bosshard *et al*[5], De Kort[6] and Keller[18], however, observed the significant decrease of latewood percentage in norway spruce, silver fir and Douglas fir. The decrease of latewood percentage was also revealed in the so-called "starved wood" of Japanese red pine[29]. It might be speculated therefore that the percentage of latewood could be varied depending on tree species, stage of development in trees, exposure time and kinds of air pollutants.

The maximum density (density of latewood) in healthy trees increased rapidly in the first few years from the pith, and exhibited the maximum density without much variation. However, the density of latewood formed during the period of air pollution showed the decreased tendences (Fig. 5). The decrease of maximum density in the species of Japanese red pine was slight (Fig. 5-A), while this decrease in Japanese fir was significant (Fig. 5-B). The abrupt decrease of maximum density in the species of Japanese fir during the period of air pollution was also observed by Ohta[24]. In comparision with the decrease of maximum density during the period of air pollution, that of earlywood (minimum density) maintained its density with little flucta-

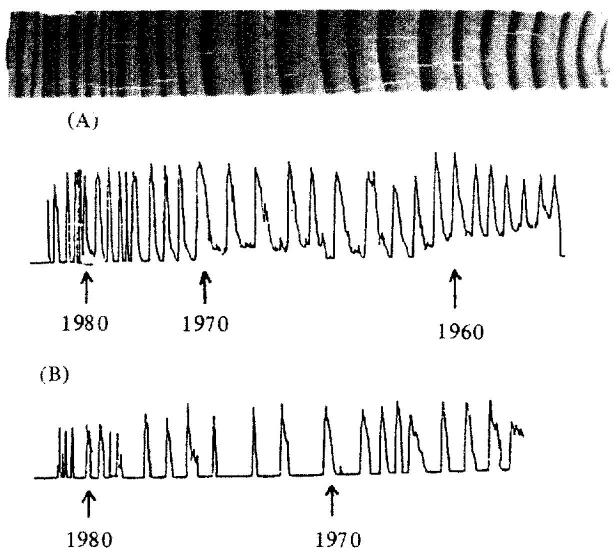

Fig. 5. X-ray photograph and density profiles of the wood of the Japanese red pine (A) and Japanese fir (B).

tion. The values calculated by substracting minimum from maximum density, therefore, was reduced in the period of air pollution (Fig. 6). Ohta[24] considered these reduced values as one of the indicators suggesting the damage of air pollution in the forest trees.

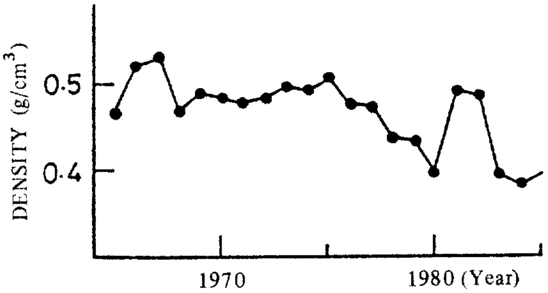

Fig. 6. Difference of maximum and minimum density-profile of Japanese red pine wood in the site of Onsan.

3.3 Dimension of tracheids

Length-on-age variation and dimension in tracheids on Japanese red pine were investigated. Length-on-age variation in tracheids of softwood has been of considerable interest since Sanio's study[30] on tracheid length of Scotch pine. Most of pine trees observed in the present investigations showed the classical type of length-on-age curve for tracheids; they were initially short near the pith, but increased rapidly in length during the early years of growth, and then leveled off to a constant length as the tree matured. Only one tree from Onsan area near to a chemical pulp factory, exceptionally, showed the unusal feature; the decrease of tracheid length as the tree matures (Fig. 4).

Some authors reported that pollution induced shortening of tracheids of gymnosperms as well as vessels and fibres of angiosperms[9,14,17]. In contrast, Grosser *et al*[15] could not find out any significant difference of tracheid length between immission-damaged trees and healthy trees. It could not be determined in the present study that an abrupt decrease of tracheid length in one Japanese red pine in the site of Onsan was due to air pollution or to another environmental factors.

The dimension of tracheids in ***Pinus densiflora*** damaged by air pollution was shorter and thinner than those of healthy ones (Tab. 1). About 40% reduction in thickness of cell wall and 20% reduction in diameter was showen in Japanese red pine. Especially the reduction of diameter in the radial direction was more marked than in the tangential. Reduction of cell-wall thickness and diameter and consequent increase in the number of fibres per mm due to its small dimension were also observed by several investigators[2,9,12,23]. It is generally accepted that cell wall thickness is determined by the availability of the photosynthetic products, while cell diameter is regulated by plant growth hormones[21]. The reduction in thickness and diameter of cell wall in the present study clearly indicates that air quality influences the tree productivity of trees by disrupting the growth hormone production as well as metabolites patheway.

Table 1. Dimension of tracheids in latewood Japanese red pine*

unit: μm

	DAMAGED	HEALTHY
wall thickness	3.05±1.75 (range; 2.5-5.0)	5.18±1.96 (range; 3.8-7.5)
diameter	7-14 x 5.5-8 (T) (R)	10-14 x 8-10 (T) (R)

*: collected from Onsan area.
(T); tangential direction, (R); radial direction

3.4 Microstructures and microorganisms

Anomalies in wood structures and microorganisms in wood tissues could not be found in the air-pollution damaged trees (Fig. 7. C-7. F). Fine structures of cell walls and pits of damaged pines did not differ from those in the healthy

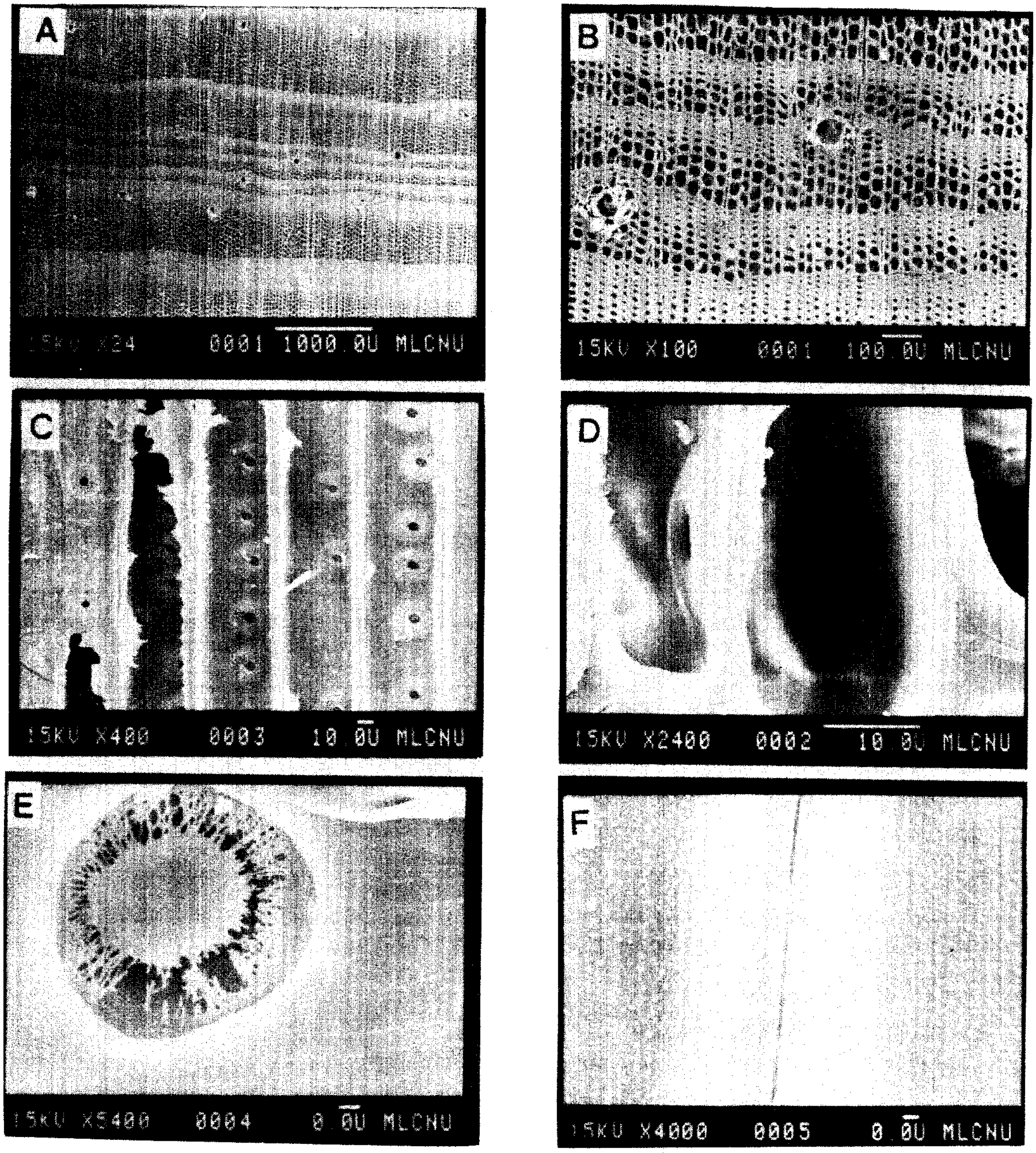

Fig. 7. SEM observation on the annual rings and fine structures of cell walls. (A) Extremely narrow annual rings formed during the year of air pollution (1980–1984) in Japanese red pine trees of Onsan, (B) increased percentage of latewood formation during the period of air pollution. Neither aspiration of pits nor the degradation of cell wall (C; D; E) nor the microorganisms were found in the Japanes red pine trees damaged by air pollution except warts densely covered in cell lumina (F).

trees. The occurrence of trabecular which were frequently observed in the spruce, fir and red beech by Grosser *et al.*[15] was not found in the present study. Neither the wetwood formed by air pollution in fir as a secondary effect, nor the occurrence of bacterial in that wood[4,31), nor the presence of hyphae in the spruce wood[27] were able to detect in our investigations.

All the pits observed were unaspirated; pit aspiration was not observed in the present investigations. Frenzel[10] observed the pit aspiration and fume-like substances on the bordered pit in the spurce, fir and pine damaged by air pollution. He also reported the severe decomposition of lignin in the middle lamella, partial degradation of cell wall and filling in the lumen of latewood. Under high magnification such anomalies could not be detected in our observations. Neither Greune and Fengel[13] nor Sachsee and Harder[28] observed such anomalies in cell wall as those of Frenzel.

The luminal surface in the tracheides of pines was covered with warts (Fig. 7-F) which are reportedly very resistant to chemical treatments[20,22,37]. Saiki and Kawake[29] observed the remarkable reduction of warts in the narrow-ringed wood of suppressed Japanese red pine. However, the fact that the frequent occurrence of the warts in red pine might be related to the air pollution was not determined in our observations.

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Literature cited

1. Aszmutat, H., Ch. Klotzenburg & W.J. Weiss, 1986, Holz Roh. W. 44: 301-302.
2. Bauch, J., P. Klein, A. Frühwald & H. Brill, 1979, Eur. J. For. Path. 9: 321-331.
3. Bauch, J., H.G.-Kühn & P. Rademacher, 1986, Holzforschung 40: 281-288.
4. Brill, H., P. Klien, A. Frühwald & J. Bauch, 1980, Mitt. Bund. Forst. Holzw. No. 131: 195-205.
5. Bosshard, H.H., L. Kucera, A. Stoll & K. Mochfegh, 1986. Schweiz. Ztschr. f. Forstwesen, 137: 463-478
6. De Kort, I., 1986, IAWA Bul. 7: 309-318.
7. Eckstein, D., R. Aniol & J. Bauch, 1983, Eur. J. For. Path. 13: 279-288.
8. Eckstein, D., E. Frisse & W. Liese, 1974, ibid., 4: 232-244.
9. Eckstein, D., M. Greve & A. Frühwald, 1981, Holz Roh. W. 39: 477-487.
10. Frenzel, E., 1983, Forstw. Cbl. 102: 186-200.
11. Fritts, H.C., 1976, Tree Rings and Climate, Academic Press, London, 567 pp.
12. Frühwald, A., J. Bauch & H.G.-Kühn, 1984, Holz Roh. W. 42: 441-449.
13. Greune, A. & D. Fengel, 1984, Forstw. Cbl. 103: 297-307.
14. Grill, D., E. Liege & E Windisch, 1979, Phytopathol. Z. 94: 335-342.
15. Grosser, D., H. Schulz & H. Utschig, 1985, Holz Roh. W. 43: 315-323.

16. Hüttermann, A., 1983, Allg. Forstztschr. 38: 663-664.

17. Kartusch, B. & G. Halbwachs, 1985, Angew. Bot. 59: 249-260.

18. Keller, T., 1980, Can. J. For. Res. 10: 1-6.

19. Kim, Y.S., 1985, Zbl. f. ges. Forstwesen, 102: 96-105.

20. Kuo, M.L., & F., G. Manwiller, 1986, Wood Fibre Sci. 18: 239-247.

21. Larson, P.R., 1960, For. Sci. 6: 110-112.

22. Liese, W., 1963, J. Polymer Sci. Part C. No. 2: 213-229.

23. Liese, W., M. Schneider & D. Eckstein, 1975. Eur. J. For. Path. 5: 152-161.

24. Ohta, S., 1978, Mok. Gak. 24: 429-434.

25. Polge, H., 1985, in "Xylorama", L.J. Kucera (ed.), Birkhäuser, Basel, 146-154.

26. Pollanschutz, J., 1971, Mitt. Forstl. B.V.A., Wien 92: 153-206.

27. Pozgaj, A., 1986, 18th IUFRO World Cong. Div. 5: 222-223.

28. Sachsee, H. & F. Hapla, 1986: Forstarchiv 57: 12-29.

29. Saiki, H. & M. Kawake, 1980, Mok. Gak. 26: 707-713.

30. Sanio, K., 1872. Jb. Wiss. Bot. 8: 401-420.

31. Schmidt, O., 1985, Eur. J. For. Path. 15: 2-10.

32. Schütt, P., 1981: Forstw. Cbl. 100: 286-287.

33. Schweingruber, F.H., R. Kontic & A.W.-Seifert, 1983, Ber. Schweiz, E.A.F.V. Nr. 252.

34. Smith, W.H., 1981, Air Pollution and Forests, Springer Verlag, New York., 379 pp.

35. Ulrich, B., 1981, Forst u. Holzwirt. 36: 525-532.

36. Vins, B., 1961, Naturwiss. 48: 484-485.

37. Wardrop, A.B. & G.W. Davis, 1962, Nature 194: 497-498.

38. Wentzel, K.F., 1983, Forst u. Holzwirt. 38: 453-458.

39. Wentzel, K.F., 1985, Forstarchiv 56: 51-56.

40. Yokomori, M. & S. Ohta, 1983, Eur. J. For Path. 13: 30-45.