Effects of air pollution on vegetation in rural areas of Central Honshu, Japan -A record of monitoring study over past 30 years-

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Effects of Air Pollution on Vegetation in Rural Areas of Central Honshu, Japan -A Record of Monitoring Study over Past 30 Years-

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Abstract - A long-term monitoring study has been conducted for past 30 years since 1974 on the effects of air pollution to the vegetation in rural areas of Sakai-gun, Fukui Prefecture, located on the Japan Sea side of Honshu. The degree of visual injury has been recorded in the foliage leaves of various tree species, with the main emphasis on *Cryptomeria japonica*, the Japanese Cedar, at selected permanent monitoring sites. Major causes of foliage injury have been also analyzed, in connection with the levels of soluble sulfur fractions in foliage leaves and foliar tannin. A dendrochronological study was also carried out to evaluate the effects of air pollution on the increment growth of the Japanese Cedar in the past years.

I. Introduction

Today, the effects of air pollutants (SO_x, NO_x, ozone, etc.) and also acid rains to the deterioration of forest vegetation are wide-spread phenomena all over the world, especially in the industrialized countries in Europe, northeastern Asia, and North America. An increasing amount of evidence as concerns influences to forestlands has been accumulated since early 1970s.

However, in general, the quality of the atmospheric environment has been expressed using physicochemical parameters such as concentrations of sulfur dioxide, nitrogen dioxide, and suspended particulates. These cross-sectional parameters (expressed per given hour basis) are, however, available only in limited areas, and thus we could not always learn accurately the cumulative effects of air pollution on the ecosystem and its component organisms of particular areas as a whole only by physicochemical analyses.

In order to solve this problem, we have adopted woody plants as indicators of atmospheric environmental changes that would reveal the cumulative effects of air pollution in particular areas under consideration. Some woody species, including the Japanese Cedars that are abundantly present in any districts of Japan, have been known to be very sensitive to air polluted areas [1].

II. A Record of Monitoring Study for Past 30 years, and Examinations of Physiological Disorders in Woody Species

We report here the results of a monitoring study continued for past 30 years since 1974 on the effects of air pollutants primarily discharged from two thermoelectric power stations to woody plants abundantly growing in the surroundings of rural communities, i.e., Awara-machi and its surroundings in Sakai-gun (county) in Fukui Prefecture, Honshu, Japan.

In the study districts, no other episodes of air pollution have been known before September, 1972 when the first power station (350 MW) was constructed in the town (Mikuni-machi) adjacent to the west of Awara-machi. Pollution control measures such as usage of crude oil of lower sulfur concentration, reduction of factory wastes through chimneys, were introduced in the power station since 1975. The second power station (250MW) was commissioned next to the first one in September, 1978. The anti-air pollution measures mentioned above were in force since its commission.

A. Topography and vegetation of the study area

The study area is in and around the town of Awara-machi, which is located in the northern extremity of Sakai-gun (county), and part of town faces the ocean on the west side. The greater part of the town is composed of a flat of paddies, except for the northern area, where faces the ocean and is a foothill rising to about 50m above sea level. Most area of the foothills, occupying ca. 16% of the Awara-machi, is covered with two pine species, *Pinus densiflora* and *P. thunbergii*, and the Japanese Cedar, *Cryptomeria japonica*, but part of the hilly areas is used as farmland (15.6%). In the flat area, there are paddies (45%) and scattered communities (9.1%), and in the center of the area there is a hot spring resort, Awara-Spa.

B. Atmospheric environments of the study area

Since the power stations are the major users of crude oil in this area, they have definitely contributed substantially to the peak hourly maximum value of sulfur dioxide in 1973 when the power station first operated for a whole year and in the following years. Yearly changes in atmospheric sulfur dioxide concentration have been monitored since 1972 by conductometry.

C. Plant indicators and monitoring sites

(i) *Visual injury of the Japanese Cedar and other woody species*

The degree of injury of Japanese Cedars and other woody species has been examined at 60 study sites since 1974. All tree species at 8 selected permanent sites for monitoring in Awara-machi were marked and their degree of injury has been recorded for past 30 years since 1974. The more complete monitoring has been conducted above 8 permanent sites plus 12 additional sites (a total of 20 sites) for 28 years since 1976 (Fig. 1). Criteria used to evaluate the tree decline in this study are as follows: 0, trees with normal conic crown shape and healthy green leaves: 1, trees in column-like crown shape, having partial withering or reddish-brown foliage leaves; 2, trees metamorphosed in crown shape, with completely withered large branches; 3, trees showing obvious foliage loss in major branches, totally altered in shape and reddish-brown foliage leaves; 4, more than half of the branches loosing their foliage leaves, and major branches are almost naked and thus the trunk is exposed; 5, trees with no leaves or only stumps which were cut down because of complete dieback. Here, criteria are shown as referred to Japanese Cedars (Fig.2). All the data thus far obtained and summarized are demonstrated in Figs. 3, 4, and 5, in which rapid declines in tree vigor (or increase in injury) have been noted not only on the Japanese Cedars, but also many other tree species, such as two pine trees, *Pinus densiflora* and *P. thunbergii*, evergreen broad-leaved trees, such as *Castanopsis cuspidata* var. *sieboldii*, *Machilus thunbergii*, and also deciduous broad-leaved trees, such as *Zelkova serrata*, *Prunus yedoensis*, and *Acer palmatum* ssp. *matsumurae*, etc. [2, 3, 4].

In particular, the Japanese Cedar, *Cryptomeria japonica*, is highly sensitive to the changes in the atmospheric environments, and as early as in 1973, just one year after power stations' operation, foliage leaves so suddenly became reddish-brown in color, loosing leaves at the top of the crown or on the major portions of the branches. It was very shocking to see that many extremely old Japanese Cedars, some exceeding even 300 years old or more in age, so suddenly became withered (for example, those in the front- and back-yards of Takidanji, a temple ranked as a National Historical Treasure of Japan, and also in Mikuni Shrine, one of the oldest and largest shrines in Hokuriku district).

It is remarkable to see that rapid deterioration and loss of foliage leaves of the Japanese Cedars were concentrated in the areas within a range of 5~7km from the power stations, especially along the flood plain of the Kudzuryu River, and its branch streams, Hyogo and Takeda Rivers (Figs. 3, 5) [2,3,4].

Yearly changes in proportional distributions of trees with different degrees of injury are demonstrated in Fig. 4 A, B, C, and D, with a five years interval [4]. The diagrams in Fig. 4 are illustrated in reference to the criteria shown in Fig. 2.

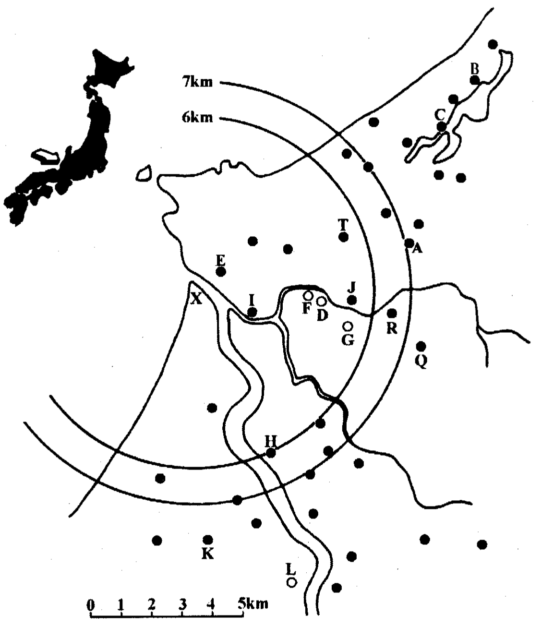


Fig.1. Study area and sampling sites of leaves. The degree of visible injury in *Cryptomeria japonica* has been recorded at 8 permanent sites (A, D, F, J and Q-T) since1974. A total of 47 specimens of *C. japonica* leaves were collected from 47 trees at 37 sites (●) in June 1976. Seasonal changes in the levels of foliar tannins were studied for current-year leaves of *C. japonica* at 10 sites (A-J) in 1977. Predation damage of *C. japonica* leaves by larvae of a herbivorous moth was also estimated at 10 sites (A-C, E-H and J-L), in November, 1977.
X: The thermoelectric power stations.

0		Trees with conic shape and healthy green leaves
1		Column like trees or trees showing partial withering
2		Metamorphosed trees or trees showing wither in large branches
3		Trees showing obvious crown loss and totally altered shape
4		More than half of the branches lose their leaves and the major part of the trunk is exposed to open air
5		Trees with no leaves or stumps of the trees which was cut because of complete dieback

Fig.2. Criteria used for determining the degree of injury.

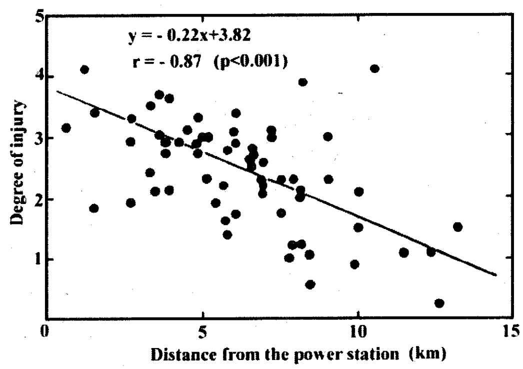


Fig.3. Relationships between the distance from the thermoelectric power station and the degree of injury to *Cryptomeria japonica*, in June, 1974.

It is notable that Japanese Cedars are so sensitive to changes in the atmospheric environments that responses to atmospheric changes were already evident in 1974, two years after the operation of power stations (Fig. 4A). However, within 3 to 4 years after power stations' operation, other coniferous trees (primarily *Pinus densiflora* and *P. thunbergii*) (Fig. 4B), and evergreen broad-leaved trees, such as *Castanopsis cuspidata* var. *sieboldii*, *Machilus thunbergii*, etc., began to loose their foliage leaves and many became completely withered (Fig. 4C); likewise, deciduous broad-leaved trees, such as *Zelkova serrata,* one of the largest deciduous trees, often exceeding 1 meter in diameter, and attaining over 20 meters in height, so rapidly declined its vigor, loosing leaves (Fig. 4D).

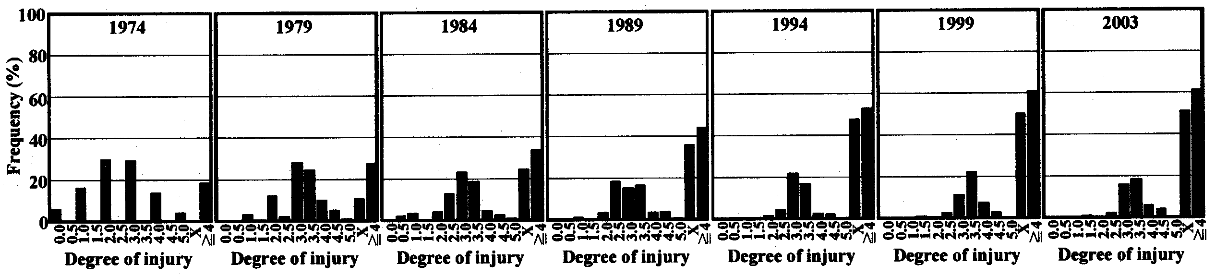
(ii) *Atmospheric sulfur oxides and the levels of foliar soluble sulfate of the Japanese Cedars*

The relationship between the levels of atmospheric sulfur oxides and foliar soluble sulfate of the Japanese Cedars was examined based upon the monitored data by Fukui Prefecture at 12 sites in the study area, and the levels of soluble sulfate of one-year-old leaves [5].

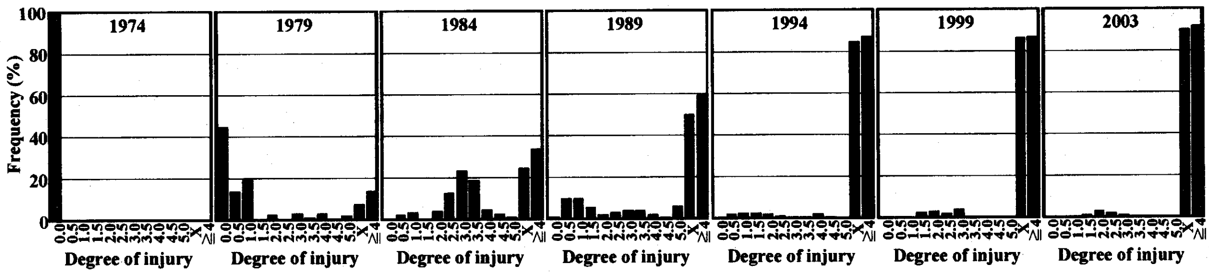
There is a conspicuous increasing trend in the levels of foliar soluble sulfate of the Japanese Cedars growing within a 1.5km radius from these monitoring sites (collected in June, 1976) and the average atmospheric sulfur oxide concentrations from May 1975 to May 1976 (Fig. 6).

(iii) *The levels of foliar soluble sulfate in the Japanese Cedars and physiological disorder in tannin synthesis*

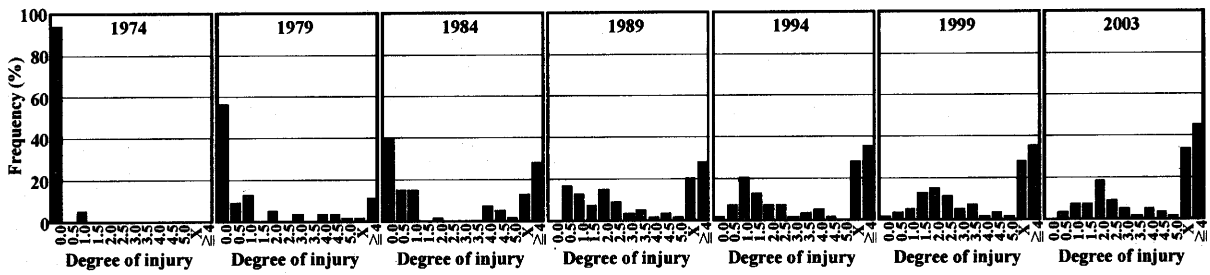
First, the levels of foliar soluble sulfate in-one-year-old leaves of Japanese Cedars collected in June, 1976 were examined. The results obtained showed that higher levels of foliar soluble sulfate, over 250ppm, were primarily found along the flood plains of Kudzuryu River and its branch streams (Fig. 7).



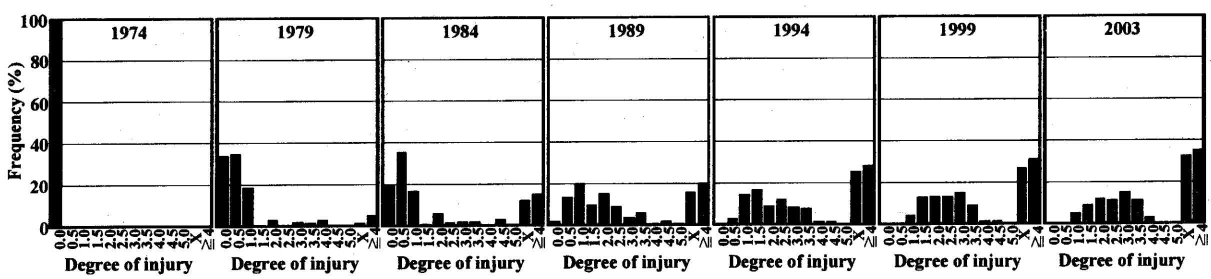
(A) The Japanese Cedars (*Cryptomeria japonica*)



(B) Other coniferous trees (e.g., *Pinus densiflora*, *P. thunberigii*, etc.)



(C) Broard-leaved evergreen trees (e.g., *Castanopsis cuspidata* var. *sieboldii*, *Machilus thunbergii*, etc.)



(D) Broad-leaved deciduous trees (e.g., *Zelkova serrata*, etc.)

Fig. 4. Diagrams showing yearly changes during the past 30 years in the degree of injury in the foliage leaves of (A) the Japanese Cedars (*Cryptomeria japonica*), (B) other coniferous trees (e.g., *Pinus densiflora*, *P. thunberigii*, etc.), (C) broard-leaved evergreen trees (e.g., *Castanopsis cuspidata* var. *sieboldii*, *Machilus thunbergii*, etc.) and (D) broad-leaved deciduous trees (e.g., *Zelkova serrata*, etc.). Histograms demonstrating frequency distributions of the trees with different degrees of foliage leaf injury, as shown in Fig. 2. X specifies trees cut-down; ≧4 specify proportions of total trees showing the degrees of injury 4 or higher. The results are shown in a 5-year interval with an exception of the final period.

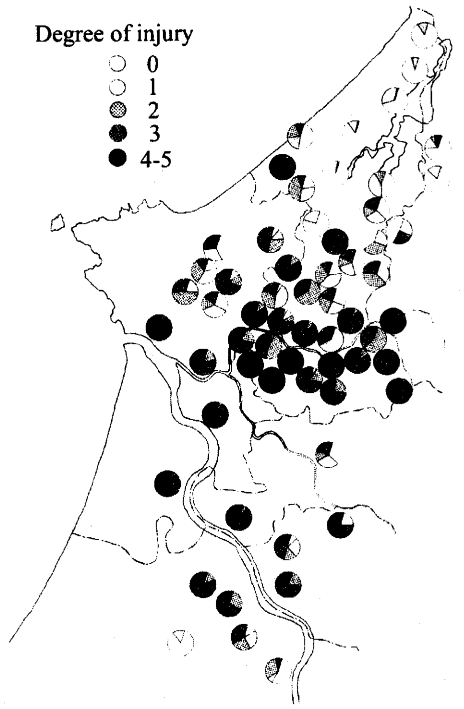


Fig.5. Map illustrating the frequency distribution of the degree of injury for *Cryptomeria japonica* at 61 sites in Sakai-gun, Fukui Prefecture, in 1977. X: The thermoelectric power station.

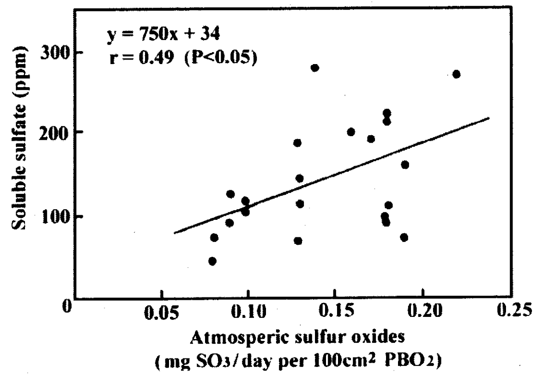


Fig.6. Relationship between atmospheric sulfur oxides and the levels of foliar soluble sulfate of *Cryptomeria japonica* collected in June, 1976. The levels of soluble sulfate of one-year-old leaves of Japanese Cedars growing within a 1.5km radius from the monitoring sites were plotted against the average atmospheric sulfur oxide concentrations from May 1975 through May 1976.

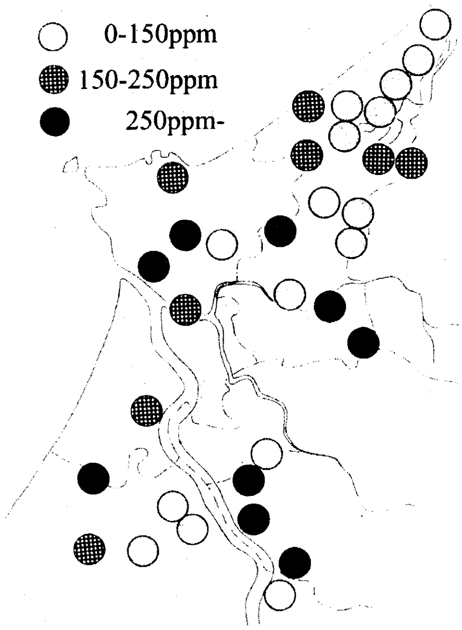


Fig.7. The levels of foliar soluble sulfate in one-year-old leaves of *Cryptomeria japonica* collected in June, 1976. The levels of soluble sulfate were indicated as sulfur.

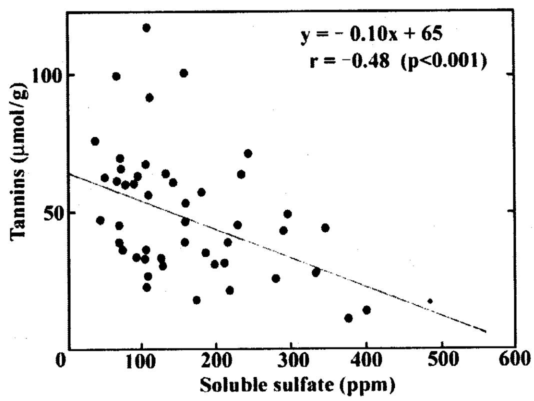


Fig.8. Correlation between soluble sulfate and tannins of one-year old leaves of *Cryptomeria japonica*. Foliage of the leaves were collected from 47 trees at 37 sites, in June, 1976. Gallic acid was used as a standard substance.

Relationships between the levels of foliar soluble sulfate and tannins of one-year old leaves of the Japanese Cedars collected from 47 trees at 37 sites in June, 1976. Tannins were determined by ferrous tartrate method, using gallic acid as standard. We could recognize there is a conspicuous decreasing trend in the levels of foliar tannins against the increasing levels of foliar soluble sulfate (Fig. 8)[5].

Seasonal changes in foliar tannin content of the Japanese Cedars (current-year leaves) were also examined. The current-year leaves of Japanese Cedars were collected from marked individual trees from June to November, 1977, at 10 sampling sites in the study area. A comparison is made here between the trends in increasing foliar tannin levels of Japanese Cedars in the control area in a range of 7-13 km radius from the power station, and those of the polluted area within a 6 km radius from the power station (Fig. 9).

A sharp increase in the levels of foliar tannins was recognized in new *Cryptomeria* leaves from the control area, while a rather blunt increasing trend was found in those from the polluted area (Fig. 9a and b).

As stated above, decreased levels of foliar tannin were observed in foliage leaves of the Japanese Cedars growing in the surroundings of the power stations. Tannin content of the *Cryptomeria* leaves was negatively correlated with the levels of foliar soluble sulfate, and a causal association was suggested between air pollution and inhibition of the shikimate pathway [6]. Observations on predation damage of the Japanese Cedars indicates that increased feeding rate by larvae of a herbivorous moth, *Dasychira abietis argentata*, was associated with low foliar tannin content and the distances of the sampling sites to the power station. Considering the physiological functions of tannins e.g., a defensive factor against insect predation and fungal degradation, it seems that decrease of foliar tannin levels of Japanese Cedars in the polluted areas has relevance to their high susceptibility to air pollution in field conditions [3,5].

D. Dendrochronological analyses and its implications for assessments of the effects of air pollution [7,8,9]

The observations on the injury of trees have been continued for past 30 years since 1974. In early 1970's obvious visible injury had already been observed with the Japanese Cedars, since the power station started its operation in September, 1972, and then the emission of air pollutants in the study area drastically increased. To clarify the effects of air pollution on the Japanese Cedars growth, a retrospective study, i.e., dendrochronological study, was carried out. In a series of this study, the decrease of ring width with increasing tree age was normalized first, and then further standardization was carried out by the multiple regression analysis to correct the effects of climatic factors on growth increment of *Cryptomeria japonica*.

A total of 270 core samples of the Japanese Cedars was collected at 51 sites within the study area (Fig. 10), of which the secular changes of the standardized ring index of 103 specimens for the period from 1931 to 1980 were obtained, as shown in Fig. 13. During the period from 1931 to 1971 without significant air pollution, the average of standardized ring index was around 1.0. However, after the power station's operation, the ring index gradually decreased below 0.7, and the minimum value 0.54 was recorded in 1973.

The secular changes of standardized ring index from 1951 to 1980 were analyzed in terms of the distances from the power station (Fig. 11). During the period without any significant air pollution, a similar fluctuation pattern of standardized ring index was observed in the areas within the four concentric circles, i.e., within a 3 km radius, 3 to 5 km area, 5 to 7 km area, and 7 to 9 km area (Fig. 11). All these areas showed no obvious changes in standardized ring index until late 1960's, and then gradual decrease occurred in early 1970's. Since 1972, significant growth inhibition was revealed within a 5 km radius. A clear decrease in the ring index was also revealed within a 5-7 km area from 1973 to 1976. A partial recovery has, however, been noted in this area since 1977.

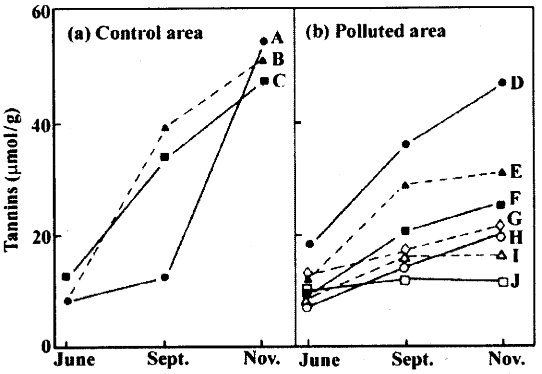


Fig.9. Seasonal changes in foliar tannin content of current- year leaves of *Cryptomeria japonica*. Current-year leaves were collected from marked individual trees from June to November, 1977, at 10 sampling sites in the study area. These sites were divided into control area in a range of 7-13 km radius from the power station (Sites A-C), and the polluted area within a 6 km radius from the power station (Sites D-J). The location of the sampling sites (A-J) were indicated in the Fig.1.

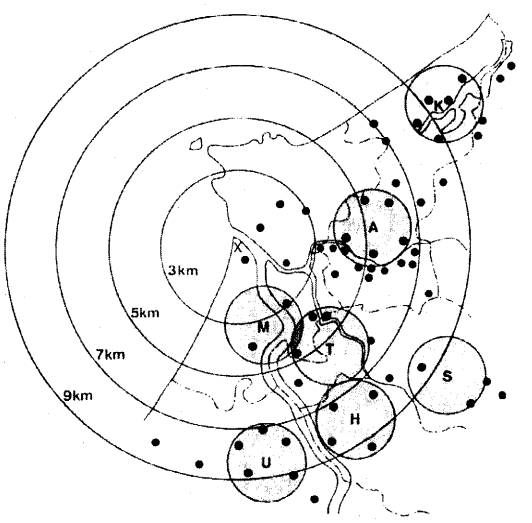


Fig.10. Sampling sites of increment cores of *C. japonica* for dendrochronological analysys. A total of 270 core samples of the Japanese Cedars was collected at 51 sites within the study area. Atmospheric concentration of major air pollutants, e.g., SO2, NO2, O3, were monitored automatically at the 7 monitoring stations (K, A, M, T, S, H and U) within the study area. The shades circles show the areas within a 1.5 km radius from each monitoring station. A total of 94 increment cores were collected from 20 sites within these areas. These cores were further studied with special reference to air pollution. X: The thermoelectric power stations.

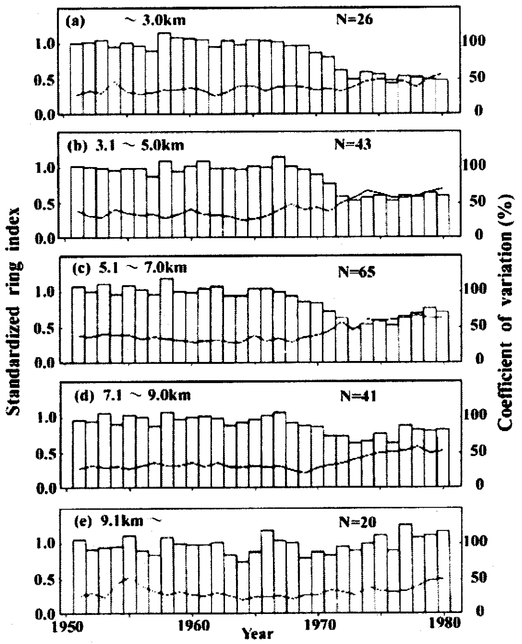


Fig. 11. Variation of average (bar graphs) and CV (solid lines) of standardized ring index. Study area was divided into five regions on the basis of the distance from the thermoelectric power stations.

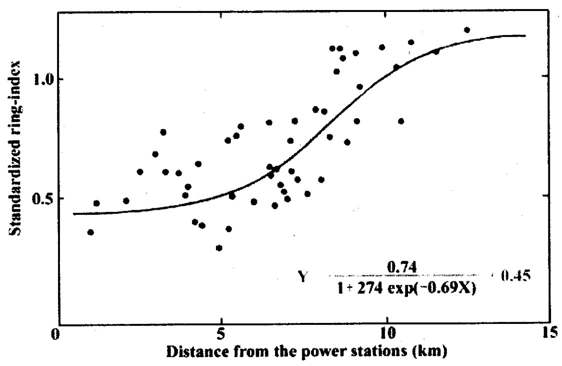


Fig.12. Relationships between standardized ring-index and the distance from the power stations. The four year's mean values (1973 to 1976) of standardized ring-index were plotted against the distance from the power stations to each sampling site.

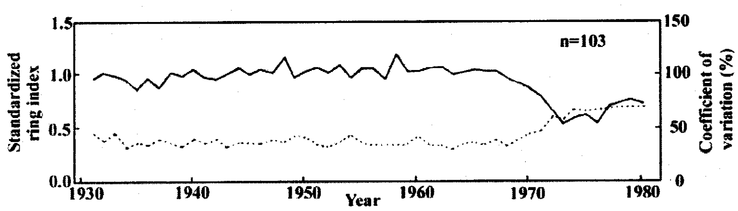


Fig. 13. Yearly changes in standardized ring index of *C. japonica* collected form 34 sites. The effects of tree age and climatic variations were statistically normalized. Solid line and broken line represent the average and the coefficient of variation of the standardized ring-index, respectively.

Since an obvious inhibition of growth increment was found in Japanese Cedars from 1973 to 1976 (Fig. 11), mean values of standardized ring index for these years were plotted against the distance from the power station (Fig. 12). The equation was calculated by logistic regression analysis. Based upon this equation, standardized ring index for the sites, ca. 10 km from the power station, was about 1.0. Similarly, standardized ring index for the sites, 7 and 4 km from the power station, was about 0.7 and 0.5, respectively.

$$SRI = \frac{0.74}{1+274\exp(-0.69X)} + 0.45,$$

where *SRI*: standardized ring index; *X*=distance from the power station (km) [8].

III. Future Perspectives

Currently, we are accumulating additional evidence concerning acid precipitates (H^+, NO_3^-, SO_4^{2-}) contained in dews and fog particles in low montane forests of some other vegetation zones, and their effects to foliages as well as growth of conifers and/or broad-leaved deciduous trees, such as *Abies firma*, *Picea jezoensis* var. *hondoensis*, *Fagus crenata*, etc. [4,10,11,12, Kawano et al., unpubl. obs.]. We are hoping to be able to accumulate more critical information concerning interactions between important forestland components and physico-chemical factors.

Acknowledgement

The authors wish to sincerely thank to the township authority, especially Mr. Grouemon Saito, Mayor of the Township-office (in the starting year of the present project in 1974), and also staffs of the Awara-machi Township Office for their most generous supports for this research project during an extremely long period of 30 years, starting in 1974. The support, both financial during the first 20 years and physical aids in the field surveys and samplings, were indispensable to continue this extremely long term project, which perhaps might represent the world longest monitoring survey of this sort, we believe. Our sincere thanks are also due to Takejirou Hashimoto and many students in Toyama and Kyoto Universities during the beginning 20 years' period for their support in the field survey and laboratory experiments, and also to Professors Minoru Kasuya and Sadanobu Kagamimori for their support and helpful comments during the course of the present project.

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