韓國大氣保全學會誌 第2卷 第3號
J KAPRA 2-3(1986) pp.1～10

〈論 文〉

大氣汚染에 依한 麗川地域의 森林群集變化에 關한 研究

A Study on the Changes in Forest Community by Air Pollution at Yocheon District

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INTRODUCTION

Nowadays, air pollution by increasing consumption of fossil fuels resulting from rapidly growing population and industrialization has caused the adverse effects on terrestrial ecosystems and become one of the most serious problems causing environmental discriptions.

Air pollution such as SO_2, HF, NO_x, fly ash, ozone and PAN might influence plant growth, reproduction, nutrient cycling, photosynthesis and predisposition to entomological and pathological stresses on plants. [20] Furthermore, accumulation of those toxic substances in forests might cause subtle or serious changes in the structure and function of forest ecosystems.[3,8,9,11,12,18,19]

Since 1970s, a number of large industrial complexes had been constructed as a part of industrialization plan in Korea. Accordingly, the forest ecosystems around them has been under chronic influences of air pollution and effects of air pollution on plants became a matter of concern. In Yocheon Industrial Complex which consisted of lots of petrochemical plants and a phosphatic fertilizer manufacturing plant, forests has been exposed to chronic air pollution, mainly HF and SO_2 gas. Various reports were available to investigate the potential effects of air pollution on crops and forest trees in Yocheon. Kim and Kim [5] surveyed vegetation by naked eye method and reported 71 families, 150 genera and 158 species were growing within a 2 km from air pollution sources in 1981. Needle injuries on *Pinus* spp. in the polluted area wear reported by Kim, *et al.*[4] and Kim, *et al.*[6] Kim, *et al.*[7] investigated the primary production of *Pinus thunbergii* forests in the polluted area and verified that growth inhibition of *Pinus thunbergii* was attributable to air pollution.

Thus, previous reports suggested that forest ecosystems around Yocheon Industrial Complex were influenced adversely by air pollution. The objective of this study was to investigate the subtle ecological changes in forest community exposed to chronic air pollution in Yocheon.

MATERIALS AND METHODS

The study area included a 10 km section from Namhae Chemical Corp. in Yocheon Industrial Complex where Mt. Horang and Mt. Youngchwi over 400 m high at the sea level

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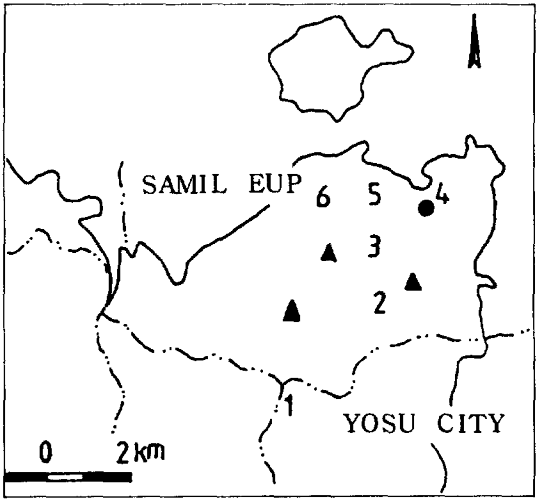
stretched away to the southwest. Although the study area belonged to subtropical forest zone *Pinus thunbergii* was dominant tree species. Six stands of *Pinus thunbergii* were selected at different intervals from Namhae Chemical Corp., 4 of which were distributed to the southwest and 2 to the northwest (Fig. 1). The stands were confined to sites having similar soils and aspects and were not disrupted by previous logging or fire.



1,2,3--- : the experimental stand
● : Namhae Chemical Corp.
Fig.1 Location map of the experimental stands

In August, 1983, vegetation in each stand was surveyed through 3 arbitrary strata, that was overstory, subcanopy and understory. Overstory and understory were respectively defined as canopy trees and woody plants of 30 cm to 2 m tall. Subcanopy was defined as woody plants between overstory and understory. Five rectangular plots were established in each stand and plot size was 10 x 10 m for overstory and subcanopy but 5 x 5 m for understory. The number of stems was tallied and crown projection map was drawn out for tree species in the overstory through understory, from which density, coverage and frequency were estimated for each plot. Environmental gradients such as slope, aspect, altitude, soil moisture and soil depth were also investigated. Small amount of soil at 10 cm and 20 cm below the soil surface was obtained to examine the chemical properties of soils.

Importance percentage was calculated to estimate the dominance of each species in the community as described in Park[14]. Shannon diversity index (H') was calculated according to the procedure given by Pielou[2]: 1) $H' = -\Sigma(n_i/N) \log (n_i/n)$ where n_i was the number of it species and N was the total number of all individuals. To compare the individuals' distribution among species, Evenness (E) was computed to the method proposed by Williams[11]: $E = 1 - \sqrt{\frac{S\Sigma p_i^2 - 1}{S - 1}}$ where S was the number of species in a stand and p_i was the proportional abundance of the ith species.

Comparisons of species composition were made between the stand 1 and each of the other stands on the basis of their Coefficient of Community (CC) : $CC = 200\ S_{1j} / S_1 + S_j$ where S_1 and S_j was the number of species observed in the stand 1 and the jth stand, and S_{1j} was the number of species common to the stand 1 and the jth stand.

RESULTS AND DISCUSSION

1. General discription of environmental gradients

According to the data observed at Yosu meteorological station, annual mean temperature was 13.8°C and average monthly temperature ranged from 1.6°C in January to 25.7°C in August. Annual mean precipitation was 1406.6mm, of which 700.2mm came down from June to August, which indicated the typical features of concentrated rainfall during summer in

Korea. Warmth index was 111.2 and coldness index was -5.9. Prevailing winds were NE (13.4%) and NW (13.1%) but were generally from NE to SW with 13% during summer. Each stand varied from 10° to 25° slope and were faced toward the pollution sources (Table 1).

Table 1. Environmental gradients of experimental stands

Stand No.	Aspect	Slope (o)	Altitude (m)	Soil depth	Soil moisture	Distance from sources (km)
1	SE	10	100	medium	mederate	10
2	E	15	140	do.	do.	6.7
3	E	20	80	deep	do.	1.8
4	E	25	100	medium	do.	0.5
5	NE	15	50	do.	do.	2.3
6	NE	15	40	do.	do.	3.5

Most of the stands consisted of sandy loam soil and soils were strongly acidified with high accumulation of sulfur and aluminum in soils (Table 2). It was reported that soils were more acidified with distance from air pollution sources.[13)] But was not found similar trend in this study, which was probably because coniferous forests were naturally acid and acidity developed very slowly. Leaching of calcium and the other nutrients from the lower horizons and concomittant mobilization of Al ions within these soils were thought to be prompted by acid deposition.

Table 2. Soil characters of experimental stands

Stand No.	Soil Texture	pH (H_2O) 1:5	Organic Matter	Total N (%)	Available P_2O_5 (ppm)	C.E.C (me/100g)	Exchangeable Bases (me/100g)				Al (ppm)	S (ppm)
							Ca^{++}	Mg^{++}	K^+	Na^+		
1	sandy loam	4.06	2.72	0.16	14	12.8	0.18	0.06	0.32	0.29	1,347	75
2	sandy loam	3.76	4.80	0.28	15	19.8	0.50	0.12	0.09	0.14	1,486	50
3	sandy loam	4.35	1.56	0.09	6	8.0	0.51	0.11	0.52	0.44	119	63
4	sandy loam	4.47	4.47	3.46	11	14.2	1.23	0.29	0.65	0.41	939	30
5	sandy loam	3.96	4.91	0.28	12	20.1	0.95	0.14	0.12	0.20	108	82
6	sandy loam	3.96	3.35	0.20	2	14.3	0.96	0.22	0.13	0.13	1,611	43

Such a acid deposition might cause a reduction of decomposition rate of forest litter and decrease the number of micro-organisms within the upper soils horizons of forest soils. Nyborg[12] reported that toxic ions such as Al and Mn increased when soils was acidified by SO_2 deposition and that when soil pH was 5 to 4, the number of species in the understory was reduced and when 4 to 3, only a few plant species could grow.

2. Effects on the forest community structure

Structural simplification of the stands investigated was made in terms of density, coverage and frequency within each strata (Table 3). Stand density through strata decreased nearer to the pollution sources (Fig. 2). The significant reduction of density at overstory in the vicinity of pollution sources was likely a direct results of early decline of *Pinus densiflora* which was reported to be more sensitive to air pollutants exposure than *Pinus thunbergii*[21)] Along with reduction of density, coverage at overstory was also diminished, which might cause the changes of biotic and abiotic environment of the forest ecosystems and the capacity of plants to compete for resources in a limited space of subcanopy or understory.

In general, canopy tree were considered to be more susceptible to air pollution due to the graeat amount of respiring tissues in relation to photosynthetic tissues.[19,20)] Strikingly reduced density in the stand 4 was affected by not only air pollution but also oppression of *Pueraria thunbergiana.* Archibold[1)] and Freedman and Hutchinson[3)] presented that the density of understory increased in response to environmental release following decrease of overstory density in the airpolluted area. But was not found such a trend in this study because the investigation was confined to woody plants only. Species richness, the number of species, was increased with distance from Namhae Chemical Corp. (Fig. 3). In the stand 1 which was the farthest

Table 3. Density, coverage and frequency by species, stratum and stand.

(D: Density C: Coverage F: Frequency)

	Species \ Stand	1			2			3			4			5			6		
		D	C	F	D	C	F	D	C	F	D	C	F	D	C	F	D	C	F
Overstory	*Pinus densiflora*	13	13.6	100	13	21.4	100										7	13.8	100
	Pinus thunbergii	100	83.6	100	43	66.8	100	34	57	100	28	32	100	95	71.5	100	74	69.2	100
	Quercus acutissima				1	3.0	20										2	2.4	20
	Pueraria thunbergiana										11	10	80						
	Total	113	97.2	200	57	91.2	220	34	57	100	39	42	180	95	71.5	100	83	85.4	220
Subcanopy	*Styrax japonica*	1	0.9	20															
	Rhus trichocarpa	4	4.7	60				1	0.4	20									
	Elaeagnus umbellata	4	2.0	40													2	1.9	40
	Stephanandra incisa	2	1.0	40										13	13.7	100			
	Juniperus rigida	2	1.1	40															
	Symplocos chinensis for. *pilosa*	7	4.7	80				2	0.5	40									
	Indigofera kirilowi	2	1.4	40													1	1.0	20
	Smilax china	5	2.0	60	1	0.5	20							15	9.2	100			
	Viburnum erosum	1	0.1	20															
	Eurya japonica	7	2.4	60	2	0.9	40	2	0.7	40									
	Pinus densiflora	11	5.4	100	15	7.7	100										19	7.6	100
	Lindera obtusiloba	2	2.6	20															
	Pinus thunbergii	22	8.5	80	35	15.3	80	5	0.9	40	3	8.5	80	14	17.1	100	22	10.4	100
	Quercus aliena	1	8.5	80				4	0.8	20				5	2.8	60			
	Quercus acutissima	1	0.9	20	2	1.3	20										10	9.2	100
	Castanea crenata				1	1.7	20										1	0.5	20
	Zanthoxylum piperitum							3	1.0	40									
	Quercus serrata							4	1.0	20				23	17.2	100	1	0.8	20
	Reynoutria elliptica							18	11.5	80									
	Pueraria thunbergiana										14	2.0	40						
	Cocculus thilobus													5	4.3	40			
	Total	72	38.2	700	56	27.4	280	39	16.9	300	17	10.5	120	75	64.3	500	56	31.4	400

	Species \ Stand	1			2			3			4			5			6		
		D	C	F	D	C	F	D	C	F	D	C	F	D	C	F	D	C	F
Understory	*Vitis thunbergii*	1	0.4	100	2	0.7	20	2	0.5	20	2	1.8	40	10	8.5	100			
	Rhus trichocarpa	7	2.8	60	1	0.3	20	6	2.0	40	1	1.0	20						
	Quercus aliena	9	4.6	80	58	18.9	100	8	1.8	60	2	2.0	20	18	4.5	100	28	7.4	100
	Symplocos chinensis for. *pilosa*	12	6.0	100	1	0.5	20												
	Stephanandra incisa	3	1.3	40										33	35.1	100			
	Juniperus rigida	3	0.9	40	1	0.8	20												
	Cocculus trilobus	3	1.4	40	1	0.3	20	10	2.8	40	4	4.9	60	5	3.0	40	1	0.2	20
	Rhododendron mucronulatum	137	34.4	100	1	0.4	20										8	1.8	40
	Smilax china	15	7.0	100	12	3.1	80	27	4.1	80				18	10.6	100	11	4.0	80
	Elaegnus unbellata	1	0.4	20	2	0.7	20												
	Indigofera kirilowi	5	2.4	40	13	2.5	60										8	3.9	60
	Eurya japonica	39	13.4	100	13	2.4	80	14	4.5	80									
	Lespedeza maximowiczii	5	2.3	80	2	0.7	20												
	Lindera obtusiloba	3	1.0	40	1	0.6	20	1	0.3	20									
	Ligustrum obtusifolium	2	0.4	40															
	Albizzia julibrissin	2	1.1	40															
	Pinus densiflora	7	0.8	60	29	5.1	100	3	0.8	20							6	1.5	60
	Pinus thunbergii	13	2.0	80	63	12.3	100				21	12.0	80	15	9.9	60	13	4.9	60
	Castanea crenata				1	0.5	20												
	Styrax japonica				1	0.4	20												
	Quercus serrata							21	6.4	100				38	23.5	100	6	2.3	40
	Rubus crataegifolius							4	2.2	20	14	21.0	60						

	Rosa multiflora							2	0.3	40									
	Zanthoxylum piperitum							5	0.8	20	2	0.8	20						
	Parthenocissus tricuspidata													3	1.3	40			
	Quercus acutissima							1	0.2	20							20	8.1	100
	Reynoutria elliptica							36	12.3	60									
	Pueraria thunbergiana										19	27.0	80						
	Total	267	82.6	1,220	211	54.4	800	130	39.0	620	65	70.5	380	140	96.4	610	101	96.4	640

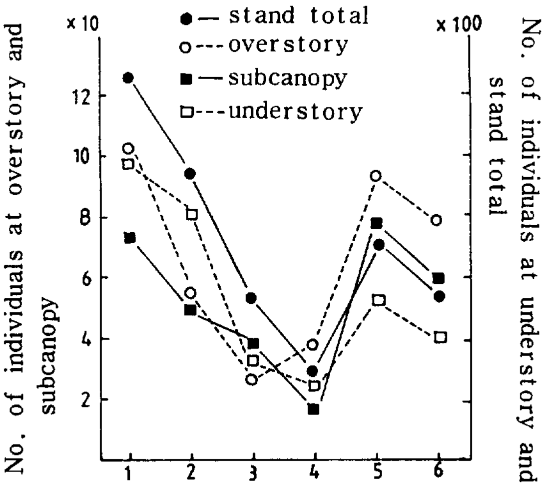


Fig.2 Variations in stand density by stratum

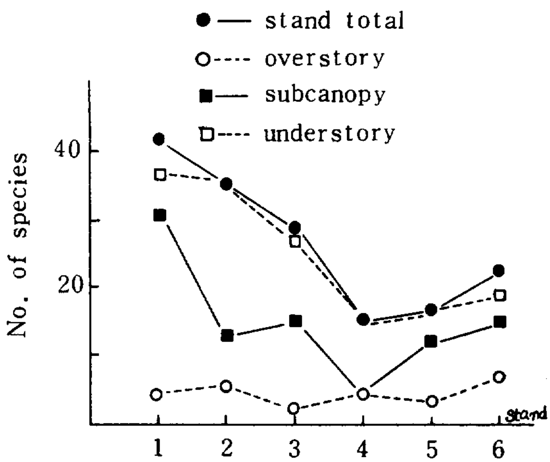


Fig.3 Changes in species richness by stratum within stand

from the pollution sources, 21 species of woody plant were observed but only 8 in the stand 4 and 5. As air pollution exposures increased in the vicinity of the pollution sources *Pinus densiflora, Eurya japonica, Lindera obtusiloba, Rhododendron mucronulatum* and *Styrax japonica* became extinct with emergence of *Rubus crataegifolius, Pueraria thunbergiana* and *Zanthoxylum piperitum*. It was reported that the number of species of woody plant was only 3 at the severely polluted area but 20 species at the area 7 km far from pollution sources in Ulsan.[9]

Shannon species diversity (H'), as shown in Table 4 and Fig. 4, decreased nearer to the pollution sources. But at the understory, H' fluctuated as the air pollution sources approached because of development of *Pinus* spp. seedlings by partial release with decline of *Rhododendron mucronulatum* and *Eurya japonica* which were dominant in the stand 1. In the stand 4 which was located nearest to the pollution sources, H' was depressed by decline of *Pinus* spp. as well as some sentivive plant species. Woodwell[20] proposed that ecologically stable forest ecosystems have high diversity index because there would be a large number of species. Therefore observed decline of species richness and H' was thought to be influenced by extinction of sensitive plants and reduction of number of individuals by air pollution.

Table 4. Shannon species diversity index (H') and evenness (E) within stand

	Stand No.	1	2	3	4	5	6
H'	Stand total	0.8621	0.8276	0.8040	0.6591	0.7918	0.8347
	Subcanopy	0.9760	0.4468	0.6544	0.2024	0.7219	0.5979
	Understory	0.8003	0.8534	0.9608	0.7083	0.6894	0.8531
E	Stand total	0.5993	0.5357	0.7345	0.5133	0.7045	0.5674
	Subcanopy	0.7003	0.4011	0.6039	0.3530	0.7777	0.5645
	Understory	0.4945	0.6153	0.7287	0.6326	0.7480	0.7559

To examine the species distribution within a stand, evenness (E) were compared with species

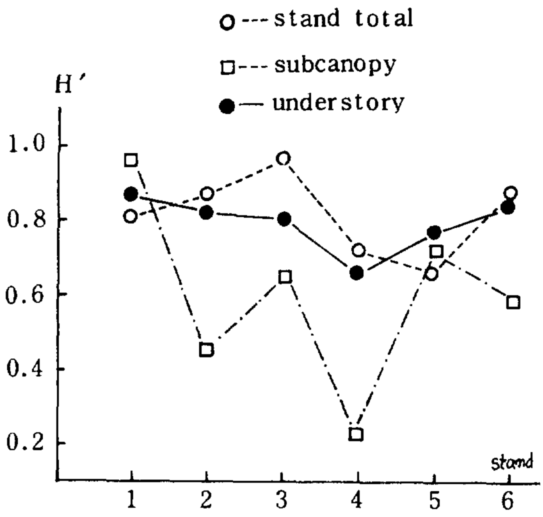


Fig.4 Variations in shannon species diversity index within stand.

richness (Fig. 5). Values for E were indices of species dominance: as E approached 0 the dominance of one or more species was indicated, and higher value of E indicated a more uniform abundance of species. E was relatively high in the stand 3 and 5 and low in the stand 1,2,4 and 6. It indicated that woody plants at subcanopy and understory were developed well in the moderate

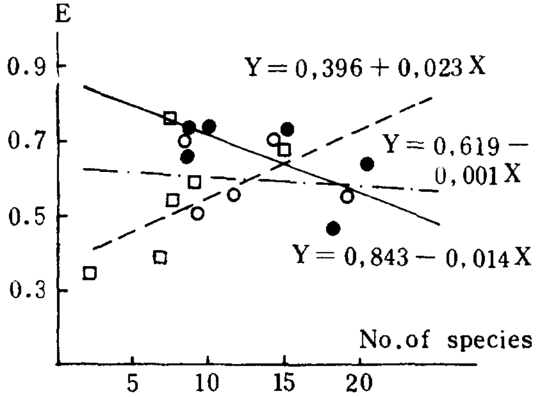


Fig.5 Relationship between speicies richness and evenness by stratum
(—— ; understory
--- ; subcanopy
----; stand total)

zone. In the stand 1, *Pinus* thumbergii and Rhododendron mucronulatum had strong dominance.

In the stand 2 and 6, Pinus thunbergii and Quercus spp. were dominant tree species but in the stand 4, Pinus thunbergii and Pueraria thunbergiana were dominant. It was general that there might be a positive correlationship between species richness and evenness because species-rich forest community had no strong dominant species whereas that with fewer species had dominant species.[18,19] The subcanopy showed a positive correlation (r=0.602) and the understory showed a significant negative correlation (r= 0.085*). Results for understory suggested that certain species dominant in the unpolluted forest declined and thus altered the proportional dominance among species. McClenahen[11] reported that in a deciduous forest exposed to air pollution, the overstory and herb layer showed positive correlationships between species richness and evenness but shrub layer showed a negative correlationship. On the basis of above results, great differences were indicated in the structure of forest ecosystems among stands. The similarities in species composition among stands were shown in Fig. 6. Compared each stand with the stand 1,

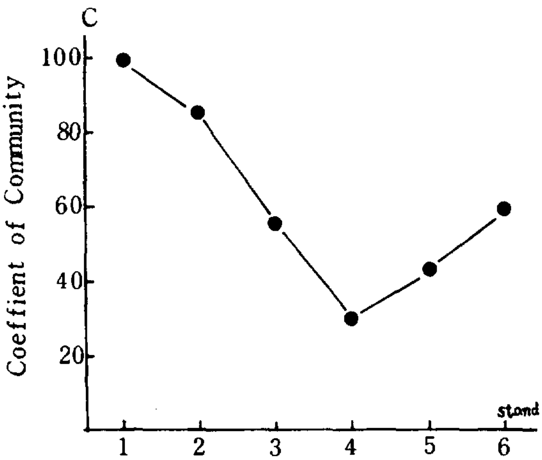


Fig.6 Variations of coefficient of Community compared each stand with the stand 1

CC of the stands decreased nearer to the pollution sources. As CC was based on an estimate rather than a total species inventory these results were largely due to increasing rarity of some species as well as absence of species from certain stands exposed to air pollution. Similar reports were given to explain the changes of forest community structure by air pollution.[8,9,10,12,15] So it was considerable that stand 3, 4 and 5 were highly affected and stand 2 and 3 were moderately affected by air pollution. It was expected that long-term continual air pollution stresses would tend to decrease the total foliar cover of vegetation and species richness, and to increase the concentration of dominance by favoring a few tolerant species.

3. Species importance

The preceeding results suggested that shifts in community structure by air pollution might influence the relative importance of each species in forest ecosystems. The relative importance of species within stands were presented by Importance Percentage (IP) (Table 5). Although *Pinus thunbergii* was a major dominant species in all stands, IP of *Pinus* spp. was the lowest in the stand 4 because of invasion of *Pueraria thunbergiana*. Development of Pinus spp. seedlings augmented its relative importance in the stand 2. Stand variation of IP of *Pinus thunbergii* and *P. densiflora* was noticeable, that was, they maintained codominance in the stand 1, 2 and 6 whereas *Pinus densiflora* lost its dominance in the stand 3, 4 and 5 (Fig. 7). *Quercus* aliena had rather high value of IP at understory in the stand 2, 5 and 6 but Q. serrata in the stand 3, 5 and 6. Relatively high value of IP of *Quercus* spp. in the moderate zone was regarded that *Quercus* spp.

Table 5. Importance percentage of forest vegetation based on density coverage and frequency

Stand	1				2				3				4				5				6			
Species \ Story	O	S	U	T	O	S	U	T	O	S	U	T	O	S	U	T	O	S	U	T	O	S	U	T
Pinus densiflora	26.2	14.2	3.0	17.7	30.6	27.8	11.8	26.5			2.5	0.5									23.2	27.7	7.0	22.0
Pinus thunbergii	74.8	21.1	4.9	45.2	64.7	51.3	21.6	53.0	100.0	10.5		53.6	67.7	23.3	43.4	45.5	100.0	21.8	10.2	58.9	71.7	32.4	12.7	48.7
Quercus acutissima		2.7		0.9	4.8	5.2	6.5	5.2			1.9	0.4									5.1	24.1	20.5	14.0
Vitis thunbergii			0.9	0.2			1.6	0.3			2.2	0.5			5.5	0.9			10.4	1.0				
Rhus trichocarpa		8.8	3.8	3.6			1.2	0.2		3.9	5.5	2.3			2.7	0.5								
Quercus aliena		2.2	5.6	1.7			24.9	4.2		7.2	6.9	3.7			3.9	0.71		7.7	11.1	4.4			22.5	3.8
Stephanandra incisa		3.8	2.1	1.6														19.5	25.2	10.7				
Juniperus rigida		3.7	2.0	1.6			1.5	0.2																
Symplocos chinensis for. *pilosa*		11.1	7.0	4.9			1.3	0.2		7.3		2.5												
Cocculus trilobus			2.3	0.4			1.3	0.2			7.3	1.3			9.4	1.51							1.7	0.3
Elaeagnus unbellata		5.5	0.9	2.0			1.6	0.3										7.2	4.4	3.1		6.6		2.2
Eurya japonica		8.2	13.4	4.9		7.1	6.8	3.5		7.6	11.8	4.6												
Lindera obtusiloba		4.1	2.0	1.7			1.4	0.2																
Lespedeza maximowiczii			4.0	0.6			1.6	0.3																
Albizzia julibrissin	-		1.9	0.3																				
Ligustrum obtusifolium		4.0	1.6	1.7																				
Rhododendron mucronulatum			34.0	5.7			1.2	0.2															6.8	1.1
Indigofera kirilowi			2.8	0.5			6.1	1.0														3.3	7.7	2.8
Styrax japonica		2.2		0.8			1.2	0.2																
Smilax china		6.9	7.8	3.6		3.5	7.1	2.4			14.8	2.5						18.1	13.1	8.2			12.3	2.1
Viburnum erosum		1.5		0.5																				
Castanea crenata						5.1	1.3	1.0														2.8		0.9
Rubus crataegifolius											4.1	0.8			22.4	3.7								
Quercus serrata										7.6	16.4	4.0						25.7	22.4	12.3		3.1	6.6	2.1
Zanthoxylum piperitum										9.0	3.1	3.5			3.3	0.6								
Rosa multiflora											3.0	0.6												
Reynoutria elliptica										46.9	20.5	19.1												
Pueraria thunbergiana													32.3	76.7	29.4	46.6								
Parthenocissus tricuspidata																			3.2	0.6				
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

O: Overstory S: Subcanopy U: Understory

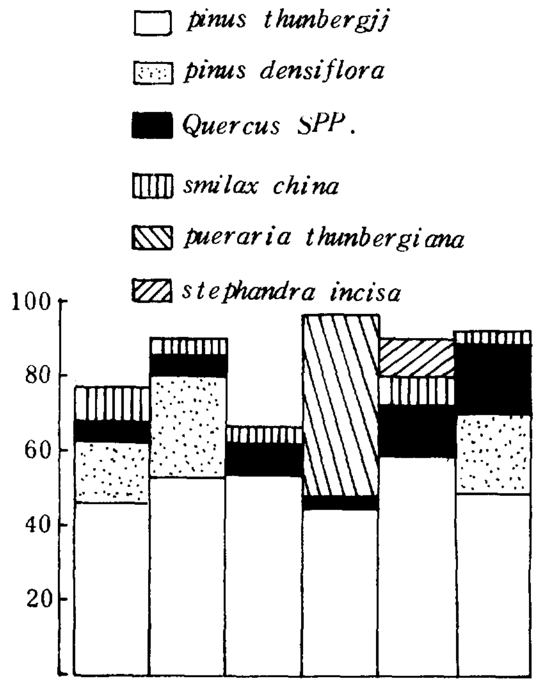


Fig.7 Importance percentage of dominant species in each stand

developed by partial release as the canopy trees were injured by air pollution. But in the stand 3 and 4 where air pollution effects exceeded the partial release, declined the relative importance of *Quercus* spp..

Changes in importance percentage of some species were compared (Fig. 8). *Rhus trichocarpa, Symplocos chinensis* for *pilosa* and *Eurya* japonica hold some quantity of IP in the stand 1, 2 and 3 but absent in the stand stand 4, 5 and 6. *Rhododendron mucronulatum,* which was recommended as indicator plant species to air pollution in the study area, had high value of IP only in the stand 1. On the contrary, *Vitis thunbergii, Cocculus trilobus* and *Smilax* china hold even values of IP in most of the stands. *Pueraria thunbergiana, Rubus crataegifolius* and *Zanthoxylum piperitum* emerged in the vicinity of the pollution sources and showed relatively high value of IP. It was remarkable that *Reynoutria elliptica* was important in the stand 3 in spite o of herbaceous plant.

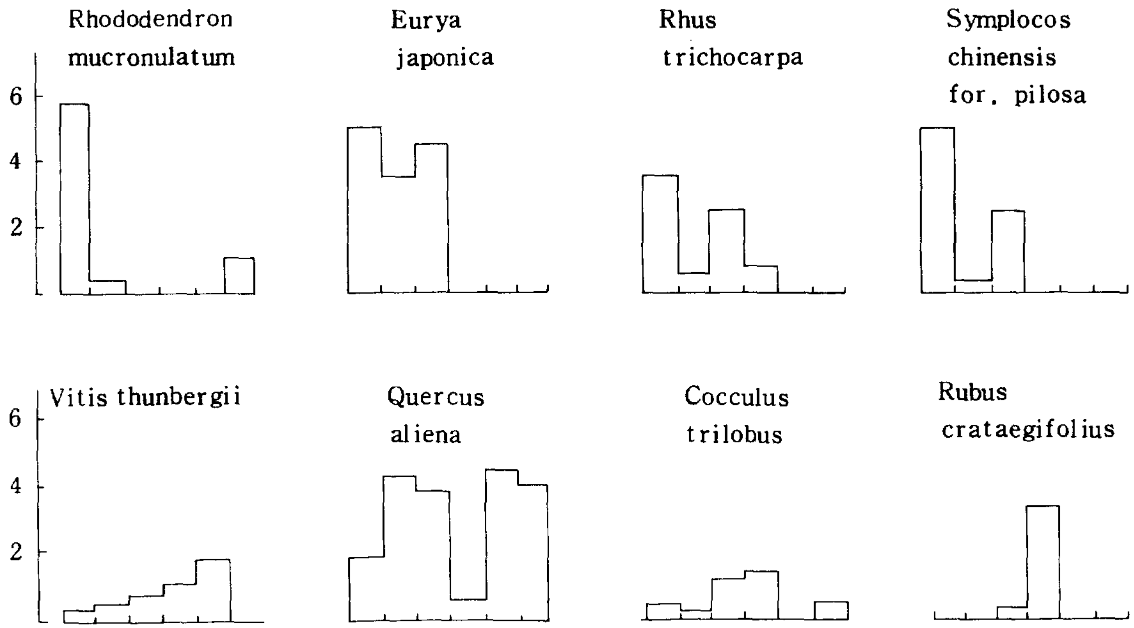


Fig.8 Changes in importance percentage of some important species by stands

According to Park,[13] as pine gall midge attack developed in *Pinus densiflora* forstst *Quercus* spp. became dominant at middle story with development of *Lespedeza* spp. and *Rhododendron* spp. at understory. Kim et al[9] reported that *Smilax china* and *Robinia pseudoacasia* were tolerant and *Quercus variabilis, Q. dentata* and *Rubus crataegifolius* were sensitive to air pollution in Ulsan. Kim and Cho[10] found that *Cocculus trilobus* was the most tolerant, *Pueraria thunbergiana* was intermediate and *Rubus crataegifolius* and *Quercus dentata* were sensitive to HF gas. In this study, *Quercus* spp. developed at subcanopy and understory except the stand 4 but *Rhododendron mucronulatum* declined with development of *Smilax china* and *Cocculus trilobus* in the stand nearer to the pollution sources. These results revealed the different aspects of community changes by air pollution from those by entomological or pathological stresses. Thus air pollution stress would appear to have certain potential qualities that differential tolerance to air pollution influence at the species level might be reflected in altered patterns of succession and species composition at the ecosystem level. Recalling that importance of a plant species in the community, *Pinus densiflora, Rhododendron mucronulatum, Styrax japonica* and Stephandra incisa were considered as sensitive and Pueraria thunbergiana, Rubus crataegifolius, Zanthoxylum piperitum, Cocculus trilobus and Pinus thunbergii as tolerant to air pollution originated from Yocheon Industrial Complex. But these considerations might have some problems. Different plant species and even indivduals of the same species may vary considerably in their sensitivity or tolerance to air pollutants. Although controlled fumigation experiments might give the resistance of plant species to high dosage of air pollutants, it was difficult to list the relative tolerance of tree species only with fumugation experiments because such conditions might not be maintained in the field and experiments were confined to seedlings. Therefore sensitivity or tolerance of tree species observed in this study needed further studies of controlled fumigation experiments along with continuous field assessments.

Synthesizing above results, SO_2 and HF emitted into atmosphere caused serious changes in structure and composition of Pinus thunbergii forests around Yocheon Industrial Complex. And it was expected that *Pinus thunbergii* and *Quercus* spp. would become dominant with development of some tolerant woody plants and herbaceous species in the Pinus thunbergii forest community as air pollution exposure continued.

(原稿援受 '86.10.22)

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