Selection of Pollution-tolerant Plants and Restoration Planning to Recover the Forest Ecosystem Degraded by Air Pollution in the Industrial Complex

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To restore the forest ecosystem severely damaged by air pollution around industrial complexes, plants tolerant to the polluted environment were selected by transplant and pot culture experiments. A restoration plan by arranging those tolerant species was prepared based on the ecological diagnostic results on an area that requires restoration. Transplant experiment in Ulsan and Yeocheon areas, the representative industrial complexes in Korea, selected eight tolerant species of *Quercus aliena, Q. acutissima, Q. dentata, Q. mongolica, Q. serrata, Ligustrum japonicum, Styrax japonica,* and *Poncirus trifoliata.* Cultivation in the polluted soil transported from the Ulsan and Yeocheon industrial complexes chose five tolerant plants of *Q. aliena, Q. acutissima, Q. serrata, Styrax japonica,* and *Alnus firma.* A plan to restore the forest ecosystem of Mt. Dotjil, which experienced the severest ecosystem degradation in the Ulsan industrial complex, was prepared by applying those tolerant species along with treatment for soil amelioration. Arrangement of the tolerant species was designed by considering their ecological characteristics including distribution range on topography and shade tolerance. Soil amelioration was focused on the improvement of fertility and moisture conditions.

Pollutants discharged beyond the limits of the buffering capacity of an ecosystem prevent it from maintaining its normal structure and function. In Korea, forest vegetation in the vicinity of industrial complexes began to show symptoms of decline in the 1970's when active industrialization was initiated (NIER, 1981; Lee, 1992). These symptoms also appeared in urban areas that have experienced chronic air pollution since the 1990's (Kim, 1991; Lee, 1992; Kim, 1994; Rhyu, 1994; Rhyu and Kim, 1994). Considering the fact that industrialized and urbanized areas have been continuously expanding, forest areas manifesting such symptoms are likely to increase even more in the future. Symptoms of vegetation decline are due to indirect impacts from soil acidification as well as to the direct effects of air pollutants (Freedman, 1986; Kitajima, 1988; Kim, 1991; Rhyu and Kim, 1994; Gunn, 1995). Moreover, vegetation decline induces structural simplification and functional weakening of plant communities, and consequently leads to negative effects on other biotic communities as well (Freedman, 1986; Smith, 1990). Restoration of degraded ecosystems is, therefore, urgently required to prevent the spread of such additive pollution damage (Gunn, 1995).

The Society for Ecological Restoration (SER) defines restoration as the intentional alteration of a site to establish a defined indigenous, historic ecosystem. The goal of this process is to emulate the structure, functioning, diversity, and dynamics of the specified ecosystem (Aronson et al., 1993). That is, ecological restoration is the return of an ecosystem to a close approximation of its condition prior to disturbance (National Research Council, 1991), and it can also be defined as the re-creation of naturalistic and self-maintaining ecosystems (Berger, 1993).

In order to restore the degraded ecosystem, we must get guidance from various scientific principles because holistic and synthetic alternatives must be prepared (Aber, 1987). When we seek to restore an ecosystem damaged by environmental pollution, we can achieve this goal through improvement of the environment by either preventing pollutants from pollution source or by planting of plants tolerant to pollutants (Bradshaw, 1992; Dobson et al., 1997; Gunn,

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Table 1. Soil chemical properties in experimental sites around Ulsan and Yeocheon industrial complexes

Site	Organic matter (%)	pH	Al^{3+} (ppm)	Total-S (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	K^{+} (ppm)	Mn^{2+} (ppm)
Ulsan								
Control	14.0* (3.0)	4.76 (0.84)	343.4 (15.1)	41.7 (16.8)	267.1 (95.9)	132.9 (38.8)	97.8 (27.4)	1.7 (1.3)
Polluted	10.8 (5.2)	4.08 (0.26)	448.6 (25.7)	57.2 (37.2)	151.1 (33.9)	45.8 (25.9)	78.5 (33.2)	3.2 (1.3)
Yeocheon								
Control	13.9 (3.3)	4.95 (0.75)	365.7 (17.5)	31.4 (11.2)	254.3 (94.9)	332.9 (55.2)	69.9 (10.9)	1.5 (1.4)
Polluted	10.4 (2.0)	4.28 (0.36)	475.3 (23.4)	50.4 (10.7)	145.3 (78.5)	31.2 (28.0)	55.1 (12.0)	0.7 (0.4)

* Data were obtained from mean values of three samples and values in parenthesis indicate standard deviation.

1995; 1996). Species tolerant to environmental pollution can persist through growth and reproduction, or even expand their distribution range in the polluted environment. On the contrary, sensitive species disappear from such environments. These processes consequently lead to changes in species composition at the community level (Barret and Bush, 1991).

Appropriately designed stress tests can be important ecological techniques in the selection of species most capable of surviving in difficult environmental conditions to rehabilitate the damaged ecosystems. In particular, transplant experiment and culture in pot with the polluted soil can provide significant applicable information. On the other hand, restoration planning prepared by using those tolerant species can contribute to recover an ecosystem degraded by environmental pollution. This study has two goals. The first is to select tolerant plants by comparing their growth between polluted and control sites and between polluted soil plot transported from the Ulsan and Yeocheon industrial complexes and soil plot ameliorated by addition of dolomite. The other is to prepare a plan to restore the damaged forest vegetation around the industrial complex by synthesizing ecological characteristics of a district that restoration requires and tolerant plants selected by stress tests.

Methods

In order to select plants tolerant to the polluted environment, we carried out two experiments; one is transplant experiment and the other is that by pot culture. Sample plants were transplanted in the polluted and unpolluted sites in the former and were cultivated in the polluted soil and ameliorated soil plots in the latter. Environmental characteristics of both sites and plots were shown in Tables 1 and 2, respectively. The polluted site was located 500 m away from the pollution source and was under the direct influence of air pollut. The unpolluted site was 6 km away from the source and escaped the direct effect of air pollutants. Polluted and unpolluted sites selected for the transplant experiment had the same environmental characteristics except for that related to pollution. The polluted soil was transported from the Ulsan and Yeocheon industrial complexes and the ameliorated soil was prepared by dolomite treatment.

Soil properties were diagnosed on the bases of pH, and organic matter, Al^{3+}, total-S, Ca^{2+}, Mg^{2+}, K^{+}, and Mn^{2+} contents. Soil pH was measured with a bench top probe after mixing the soil with distilled water (1:5 ratio, w/v) and filtering the extract (Whatman No. 44 paper). Organic matter content was obtained from the loss after ignition for 4 h in muffle furnace of 400℃. Total-S, Ca^{2+}, Mg^{2+}, K^{+}, and Mn^{2+} contents were measured from the extract by 1 N ammonium acetate solution of pH 7.0 by ICP (inductively coupled plasma atomic emission spectrometry; Shimadzu ICPQ-1000). Extract solution of pH 4.0 was used for determination of Al^{3+} content.

Table 2. Chemical properties of soil used to select tolerant plants in greenhouse

Site	Organic matter (%)	pH	Al^{3+} (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	K^{+} (ppm)	Mn^{2+} (ppm)
Ulsan							
Control	14.4 (4.6)	4.93 (0.68)	308.2 (35.1)	264.3 (68.9)	40.1 (38.8)	93.3 (27.4)	0.9 (1.3)
Polluted	15.0 (4.3)	5.41 (0.75)	348.7 (54.3)	1108.5 (138.5)	151.2 (45.7)	94.5 (23.2)	0.8 (0.3)
Yeocheon							
Control	16.6 (5.4)	4.36 (0.68)	313.9 (41.5)	271.5 (64.7)	44.0 (27.1)	94.8 (16.3)	1.2 (0.4)
Polluted	15.4 (3.3)	5.56 (0.74)	248.6 (34.9)	1318.2 (265.6)	159.7 (78.5)	92.9 (21.3)	1.4 (0.4)

Table 3. Tolerance index of sample plants transplanted around the Ulsan and Yeocheon industrial complexes

Species	Ulsan			Yeocheon		
	Tolerance ratio		Tolerance index	Tolerance ratio		Tolerance index
	Leaf area	Biomass		Leaf area	Biomass	
Quercus aliena	0.84	3.40	2.12	1.60	1.00	1.30
Q. serrata	1.32	2.43	1.88	0.80	0.94	0.87
Q. acutissima	1.18	1.50	1.34	0.92	1.19	1.06
Poncirus trifoliata	1.10	1.45	1.28	-	-	-
Q. dentata	1.20	1.33	1.27	0.57	0.71	0.64
Q. mongolica	1.23	1.27	1.25	0.98	0.72	0.85
Ligustrum japonicum	0.98	1.40	1.19	1.00	0.88	0.94
Styrax japonica	1.14	1.09	1.14	1.26	1.03	1.15
L. obtusifolium	1.49	0.29	0.89	-	-	-
Alnus firma	1.09	0.67	0.88	0.93	0.29	0.61
Celtis sinensis	0.72	0.11	0.42	1.00	0.75	0.88
Eurya japonica	-	-	-	0.59	0.09	0.34

Tolerance index was calculated from the mean ratio of value in polluted site to value in control site

Two year old healthy seedlings of 11 species were prepared as sample plants (refer to Tables 3 and 4). Most of those sample plants were selected as tolerant plants from a field survey around the Ulsan and Yeocheon industrial complexes (Kim et al., 1996). In the polluted site, the sample plants were planted in bare land. In Ulsan, such bare land was formed by vegetation loss due to severe pollution damage, while it was prepared by removing the existing vegetation dominated by *Miscanthus sinensis* in Yeocheon and control sites of both regions. The sample plants were planted regularly at interval of 50 cm. To reduce bias deriving from planting location, we rotated the order of sample plants in each line. They were planted in April, 1996.

The response of sample plants after the transplant was inspected by comparing growth measured as leaf area (LA), and biomass (B) calculated by stem diameter and height, D^2H between both sites (Long and Hallgren, 1987). The measurements were carried out at one-month interval for 5 months from May to September, 1996, and done for 3 individuals per species. The measurements in pot culture were done at 2 weeks interval for 2 months from May to July, 1996. We obtained growth equations of leaf area, and biomass from those measurements and obtained tolerance ratios (tolerance ratios of leaf area, Tr_{LA} and biomass, Tr_B) of each species from the ratios of growth coefficients in the experimental site and plot to those in the control ones (Equations 1 and 2).

$$Tr_{LA} = \frac{\text{Growth coefficient of leaf area in the polluted site (or plot)}}{\text{Growth coefficient of leaf area in the control site (or plot)}} \quad (1)$$

$$Tr_B = \frac{\text{Growth coefficient of biomass in the polluted site (or acid plot)}}{\text{Growth coefficient of biomass in the control site (or ameliorated plot)}} \quad (2)$$

$$Ti = \frac{Tr_{LA} + Tr_B}{2} \quad (3)$$

We obtained tolerance index of the sample plants from the mean of these two tolerance ratios (Ti, equation 3). We regarded species whose index is more than 1 as tolerant species.

Results

Tolerant species selected by transplant experiment

There were eight tolerant species selected from the experiment in Ulsan industrial area (Table 3). Among them, five oaks, which dominate forest vegetation as endemic species in Korea, one *Styrax japonica* that

Table 4. Tolerance index of plants to the acid soil sampled in Ulsan and Yeocheon industrial complex.

Species	Ulsan			Yeocheon		
	Tolerance ratio		Tolerance* index	Tolerance ratio		Tolerance index
	Leaf area	Biomass		Leaf area	Biomass	
Alnus firma	8.21	0.28	4.25	2.71	0.64	1.68
Styrax japonica	1.50	1.60	1.50	0.26	0.87	0.57
Quercus aliena	1.47	1.10	1.29	2.03	1.89	1.96
Q. mongolica	1.40	0.74	1.07	1.32	0.65	0.99
Ligustrum obtusifolium	1.46	0.49	0.98	0.52	0.49	0.51
Q. serrata	0.56	1.30	0.93	2.28	12.98	7.63
Q. acutissima	0.73	0.33	0.53	1.00	0.45	0.73
L. japonicum	0.54	0.37	0.46	0.86	0.37	0.62
Q. dentata	0.39	0.36	0.38	0.63	1.40	1.02
Celtis sinensis	0.25	0.29	0.27	0.74	0.15	0.45

* Tolerance index was calculated from the mean ratio of growth coefficients of leaf area and biomass in acid soil to those in soil ameliorated with dolomite. Growth coefficient of leaf area was obtained from growth equation that shows a change of leaf area during cultivation from May to July, 2000 in green house. Growth index of biomass was obtained from the difference of bimass during in experimental period

forms a luxuriant pure stand around the polluted industrial complex, and two evergreens of *Ligustrum japonicum* and *Poncirus trifoliata* are included (Table 3). Oaks include *Q. serrata, Q. aliena, Q. acutissima, Q. mongolica,* and *Q. dentata.*

Three tolerant plants were chosen in the Yeocheon industrial area (Table 4). Two oaks of *Q. aliena* and *Q. acutissima* and one *Styrax japonica* fall in this category.

Tolerant species selected from pot culture in the polluted soil

Tolerant species selected from cultivation in the pot with the polluted soil transported from the Ulsan industrial complex were four species including two oaks of *Q. aliena* and *Q. mongolica*, *Styrax japonica* and *Alnus firma*. Those selected in Yeocheon soil were three oaks of *Q. serrata, Q. aliena,* and *Q. dentata,* and *Alnus firma. A. firma* has a capacity of nitrogen fixation through the symbiotic relationship with fungi as an introduced plant from Japan. This plant was afforested widely for protection of landslide in the southern province in Korea.

Discussion

Comparisons of tolerant species selected from different regions and methods

The tolerant species selected by transplant experiments were overlapped with each other between the two regions. *Quercus aliena, Q. acutissima,* and *Styrax japonica* correspond to tolerant species chosen in both regions. But the two regions showed a difference in the number of species selected. Such difference may be due to the different properties of natural and polluted environments (refer to Table 1). This difference in tolerant-species selection between regions suggests that a plan for restoration practice should consider the regional characteristics.

Similarity between the regions of tolerant species selected through the pot culture was about 50%. *Quercus aliena* and *A. japonica* were tolerant in the soil plots from both regions. The difference between soil plots transported from the two regions may be caused by different soil properties originated from the polluted environments of each region. In fact, the soil of those regions indicated differences not only between the polluted plots but also between the degrees of amelioration (Table 2).

The results from the transplant experiments and the pot cultures generally accorded with each other except for *A. firma*. This result implies that both methods can be adopted alternatively depending on situations.

Design for ecological restoration

Restoration aims to recover the healthy nature before degradation (National Research Council, 1991; Aronson et al., 1993) and furthermore, to ensure the pleasant living environment of human by utilizing buffering function of the nature (Freedman, 1986; Smith, 1990). Considering that a complete system can exert such function at a maximum (International Ecology Center, 1995; Lee and You, 2001), a plan to restore the existent imperfect ecosystem to the perfect one should be prepared. Experience in another restoration practice showed that dominant species prior to disturbance could be successfully reintroduced to the disturbed site where restoration is required (Cooper and MacDonald, 2000).

Studies for restoration have chosen species for restoration on the bases of the following criteria: 1) species important for restoring ecosystem function, 2) species that are to be the main components of the final ecosystem, 3) many plants that should make up the final biodiversity of the ecosystem to recolonize by their own efforts (Dobson et al., 1997).

Our reclamation goals are also to reestablish a forest similar to that, which once had covered the existing barren mountain. We, therefore, designed a restoration plan based on such perspectives.

Arrangement of the tolerant plants for restoration practice was planned according to the distribution range in natural environment based on topography as well as the order of tolerance obtained from transplant and pot culture experiments (Tables 3 and 4). That is, we arrayed the tolerant plants considering both natural and artificial factors, which is required necessarily in ecological restoration (Bradshaw, 1992; Gunn, 1995; 1996; Dobson et al., 1997).

The results of vegetation survey can be used to recognize a district that requires restoration and to determine restoration methods depending on the degree of damage (Bradshaw, 1984). In this study, we hypothesized the Ulsan industrial complex as a target area and decided Mt. Dotjil as a district that needs restoration as a result of vegetation survey (Fig. 1). Mt. Dotjil was divided into four zones according to damage degrees evaluated by the results of vegetation survey; bare land, lowland and upland grasslands, and plantation (refer to Kim et al., 1996).

The restoration plan was designed on the basis of not only the damage degrees, but also the environmental condition including topography of each zone and the ecological characteristics of tolerant species (Table 5). Vegetation to be introduced for restoration was designed by envisioning a forest with diverse functions as multi-layer in the future (International Ecology Center, 1995; Lee and You, 2001). To achieve this aim, we arranged subtrees and shrub selected as tolerant species in all zone. The tolerant trees were arranged by considering their distribution range in the natural environment. Arrangements of *Q. mongolica* and *Q. dentata* in the upper grassland and of the other oaks in the bare land and the lower grassland were

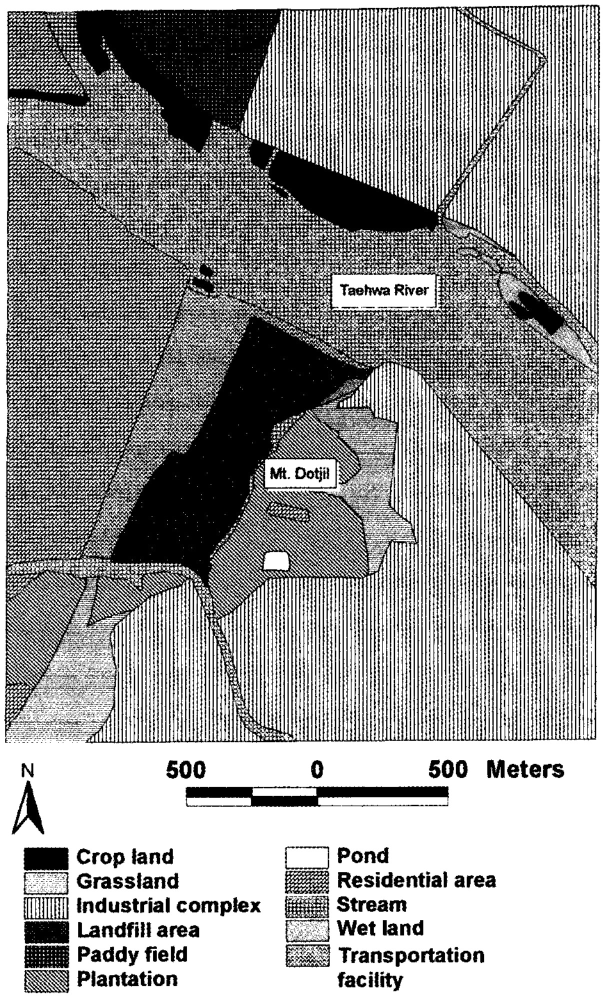

Fig. 1. A map showing the land-use pattern around the Ulsan industrial complex.

made based on this consideration (Choung and Lee, 1965).

On the other hand, a restoration plan in plantation designed by introducing *Q. mongolica*, *Q. serrata*, and *L. japonicum* under canopy of the afforested trees was prepared by considering not only the distribution range on topography, but also shade tolerance based on field observation of the authors (Choung and Lee, 1965; Lee, 1989). This design as a method for replacement of tree species was applied to reduce a drastic change in the existing stands.

Atmospheric environment has improved as the air pollutants discharged from the industrial complexes decreased in Korea (Lee, 1993). But polluted soil is not improved easily (Kim et al., 1996). In fact, the polluted soil usually provides the major problems in most restoration program (Bradshaw, 1992; Dobson et al., 1997). Soil improvement in this study was focused on amelioration of fertility and water holding capacity. In particular, soil amelioration was planned by applying sludge in the bare land, in which soil is barren and dry similar to the very parent material, to insure fertility and moisture necessary for plant growth.

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Table 5. Treatment for restoration of each zone divided by vegetation states on Mt. Dotjil in Ulsan, southeastern Korea

Zone[1]	Tolerant species to be introduced for restoration	Topographic distribution range and life form[2]	Remark
	Quercus serrata	L-M (tree)	Soil amelioration by sludge addition
Bare land	*Q. acutissima*	L-M (tree)	
	Styrax japonica	L-U (subtree)	
	Ligustrum japonicum	L-U (shrub)	
	Alnus firma	L-U (subtree)	
	Q. aliena	L (tree)	
Grassland in lowland	*Q. serrata*	L-M (tree)	
	Q. acutissima	L-M (tree)	
	S. japonica	L-U (subtree)	-
	L. japonicum	L-U (shrub)	
	A. firma	L-U (subtree)	
	Q. mongolica	M-U (tree)	
Grassland in upland	*Q. dentata*	M-U (tree)	
	S. japonica	L-U (subtree)	-
	L. japonicum	L-U (shrub)	
	A. firma	L-U (subtree)	
	Q. mongolica	M-U (tree)	Planting under canopy of the sivicultured tree
Plantation	*Q. serrata*	L-M (tree)	
	L. japonicum	L-U (shrub)	

[1] Divided based on vegetation damage and topographic condition
[2] Evaluated based on the existing references and authors' observation. L; lowland, M; mid-slope, U; upland. Life form was shown in parenthesis.

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