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Evaluation of Regeneration Potential for an Artificial Larch Forest Using Light Condition, Plant Species Diversity, and Plant Coverage and Biomass of the Forest Understory

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In order to evaluate the natural forest regeneration potential of the forest understory, light environment, plant species and diversity, plant coverage and biomass and their interrelationships were examined. The clear–cut, mid–forest, and forest edge sections in the understory of an artificial larch forest in Korea were targeted. The light condition (canopy openness, relative photosynthetic photon flux density) of the clear–cut and forest edge sections was higher and the plant biomass and the plant coverage rate were larger than those in the mid–forest section, however, only a few pioneer and/or sun plant species were dominant in the former sections, resulting in a low plant diversity in the section. The plant coverage rate was smaller but the number of herbaceous species was larger in the mid–forest section than in the other sections, because of the larger number of shade tolerant species in the mid–forest section. For regenerating the natural forest, the plant biomass of native tree species should be increased in the understory without lowering of the plant diversity. The mid–forest section has a better potential for the regeneration. In the section, the regeneration can be attained by improving the light condition through a gradual thinning.

Key words: Clear–cut, Gradual thinning, Korean national parks, Natural forest regeneration, rPPFD

INTRODUCTION

Artificial forests are widely distributed in Korean national parks. Tree species of the forests are Korean pines, pitch pines and larches etc., and the forests (15,963 ha in area) occupy 4.26% of the total area of continental national parks of Korea (Kim, 2010). Designation of the national park in Korea was made between 1967 and 1988. During this period, some state–run artificial forests were converted to the national park, resulting in the artificial forests to coexist with the natural forest in the park. These artificial forests are located sparsely in the national park, and its forest types and landscapes are different from neighboring natural forests and have low plant diversity (Lee *et al*., 2009). In addition, the role of the artificial forests of timber production does not match with that of national park, i.e. preservation of ecosystem, biodiversity and natural landscapes (Oh *et al*., 2005). Therefore, the artificial forest should be replaced with the natural forests, and a technique for the replacement should be established (Oh *et al*., 2008; Lee *et al*., 2009).

To replace an artificial forest with a natural forest, clear–cutting or thinning operations are often performed (e.g., Kon *et al*., 2007; Yamagawa *et al*., 2009), but these operations change greatly the forest floor conditions, for instance, of light, moisture, temperature and nutrition of soils (Turner, 1990). If the light intensity became higher, soil temperature rises, and buried seeds of plants are germinated, changing the early plant succession (Washitani and Takenaka, 1987). Klinka *et al*. (1996) showed that the number of plant species and the plant coverage rate were inversely proportional to the canopy openness in the understory of coniferous forests.

Zhu *et al*. (2008) showed that the number of herbaceous plant species in the understory was larger at one–year old thinned section than at the non–thinned section at a larch forest. Kon *et al*. (2007) also indicated that the number of plant species at the understory of artificial forest of *Abies sachalinensis* was larger at 11–18 years old thinned sections than the non–thinned section. On the other hand, Ruben *et al*. (1999) showed the understory of a 25–year–old thinned section had no difference in the number of plant species with that of non–thinned section on a broadleaved forest. From these studies, number of plant species is likely relating to the light condition of the understory. Further, not only the number of plant species but also species itself is important for the regeneration of natural forest. However, these characteristics were not studied well up to now.

In this study, therefore, light condition, plant species and diversity, and plant cover and biomass on the forest understory and their interrelationships are examined. Here, clear–cut, forest–edge, and mid forest sections are targeted at an artificial larch forest of Korean national park, and the potential of each section's understory to regenerate natural forest are evaluated .

MATERIALS AND METHODS

Study area

The study area was the Nogodan area of Jirisan National Park in Korea (N35°17′ E127°31′), where larches and Korean pines were afforested with an area of 1.75 ha in 1983. A cross shaped cut–over area and its

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surrounding area appeared by a trial cutover were targeted. The cutover area had a 0.44 ha (horizontally 150 m long and vertically 90 m long with 20 m wide, respectively) (Kim, 2010). The cutover area is located near the mountain top. The elevation of the cutover area is 1365 m–1426 m, its slope aspect is southwest, and slope gradient is 3–15°, respectively.

Three kinds of sections of clear–cut, forest edge, and mid–forest sections were selected from the study area. The clear–cut section is in the midst of cutover area, the forest edge section is located technically in cutover area but just 5 m away from the forest edge, and mid–forest section is located in the forest with 15 – 20 m away from the forest edge. Three sectional areas were selected for each kind of section for replication, thus total 9 sectional areas were selected.

According to the observation by Oh *et al.* (1997) in the national park area, the annual average temperature was 6.0°C, and the warmth index was 50.5. The average, and average minimum temperatures of the coldest month of January were 5.3°C and –6.2°C, respectively. The average, and average maximum temperatures of the warmest month of August were 25.2°C and 30.6°C, respectively. The average annual rainfall was around 1900 mm, and 60% of which concentrated in June – August. The area is windy throughout the year, and the prevalent southeasterly wind blows in spring to summer, and which negatively impacts the plant growth. This area belongs to a subalpine forest area, where plant community of Royal azalea (*Rhododendron schlippenbachii*), Mongolian oak (*Quercus mongolica*) and Korean fir (*Abies koreana*) are often observed (Oh *et al.*, 1997; Kim, 2010).

Field investigation

The light condition (relative photosynthetic photon flux density, canopy openness) and the values on plant (plant coverage rate, number of plants) were measured for respective understory section. The measurement was done in July, 2010 on a square spot (5 m×5 m) established in respective sections. Three square spots in total were targeted in each section. The measurement for the plants was done on plants growing below 0.6m in height. The most plants were below the height.

The plant coverage rate was measured by using 1–to–9 dominant degrees proposed by Dierssen (1990). Another small square spot (0.5 m×0.5 m) was established to measure the whole biomass of understory plants nearby the 5 m by 5 m square spot, because, the plants, grown in the 5 m by 5 m square spot, were prohibited to dug out. All plants grown there were collected, and the dry weight (i.e. biomass) was measured according to the division of leaves and the other parts.

The light condition was measured by the following way. Hemispherical photograph of the understory was taken at the height of 0.6 m from the forest floor facing right upward by using a digital camera (Coolpix 5400, Nikon Inc.) equipped with fish–eye lens (FC–E9, Nikon Inc.). The photograph was taken at each of three 5 m by 5 m square spots and they were averaged. The photo image was analyzed by the Gap Light Analyzer software (Frazer *et al.*, 1999), by which canopy openness and the relative Photosynthetic Photon Flux Density (rPPFD) were calculated.

Plant diversity index was shown by Shannon–Weaver index (Shannon and Weaver, 1998) and Margalef index (Margalef, 1968).

Soil Analysis

The soil samples of 500 g were collected from 10 – 20 cm deep from ground surface at each sectional area, after removing the surface 10 cm soil including leaf litter. The soil collection was done nearby (20–30 cm away from) the each sectional area of 5 m by 5 m square, in order not to disturb the understory.

These soil samples from three replicative areas were mixed together and 500 g of them were taken as a representative sample for each section. This sample was air–dried and sieved through a 2 mm sieve. The sieved sample was used for the soil analysis. The soil pH was measured by the glass electrode method. The total nitrogen content was determined using the micro–Kjeldahl method; exchangeable cations of K, Na, Ca, and Mg were analyzed by the atomic absorption spectrophotometry, after extracting it by using 1 N CH_3COONH_4 solution (Spark *et al.*, 1996).

Data Analysis

The statistical differences in the canopy openness, rPPFD, number of plant species, dry weight, and plant coverage rate between the clear–cur, forest edge and mid–forest sections were tested using one–way ANOVA and Turkey's test (SPSS software, Ver.11). In addition, Pearson's correlation analysis was performed to establish the relationship between the canopy openness, rPPFD, the number of plant species, plant coverage rate, and biomass of leaves and whole plant for all sections.

RESULTS

Light condition in respective understory section

The canopy openness and rPPFD in average were shown in Fig. 1. From Fig. 1, the canopy openness was the highest in clear–cut section (59.5%), followed by the forest edge and the mid–forest sections (41.4 and 22.8%, respectively). The rPPFD was 90.8, 61.0, and 33.6% in clear–cut, forest edge, and mid–forest sections, which was the same order with that of the canopy openness. However, rPPFD increased larger with the understory sections than the canopy openness.

The rPPFD of the mid–forest section, whose understory canopy was closed by visual observation, was a low of 33.6%. In clear–cut section, about 90% of light (direct and diffuse light) was thought to reach the forest floor, due to the clear–cut of tree and shrub layers (Fig. 1).

Soil condition in respective understory section

Table 1 shows the litter depth and chemical properties of soils at each section in average from replicative spots. The litter depth of 0.8–1.61 cm was not consid-

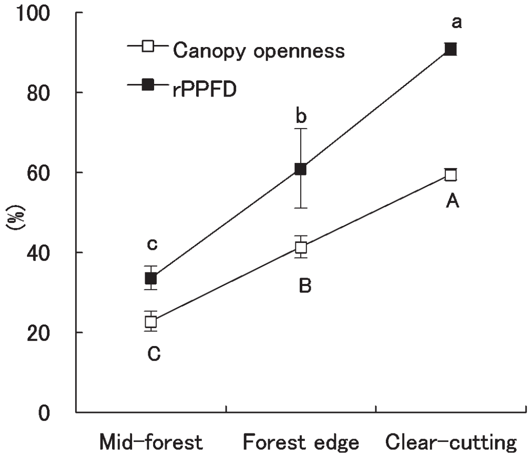

Fig. 1. Changes of canopy openness and rPPFD with the understory sections. Different letters (a–c, A–C) indicate significant difference ($p < 0.05$) among sections. The error bars indicate standard deviations (with 3 replications).

ered to be thick for all sections. The pH of 4.33–4.53 showed the soils were acid and a little more acid than Korean forest average. The total nitrogen (N) and exchangeable bases were a little higher than the averages in Korean forest soils, indicating that the soils of the study area was rather fertile and good for plant growth.

In order to determine if there was a difference of soil properties between the sections, one–way analysis of variance was conducted separately by using all properties shown in Table 1. As a result, no significant difference was observed, which indicated that the effect of soil properties on the plant growth was not different between the sections, therefore, the effect of soil conditions was not examined in this study.

Number of plant species, plant coverage rate and plant biomass in respective understory section

The number of tree species and whole plant species (herbaceous plus tree species), and Shannon–Weaver index, and Margale index are presented in Fig. 2, and the plant coverage rate and plant biomass are presented in Fig. 3. From Fig. 2(I), the number of whole plant species at the mid–forest section (14 species) was the largest, followed by the forest edge and clear–cut sections (7 to 8 species). The number of tree species was a less of 2 to 3 at each section. From Fig. 2(II), the Shannon–Weaver and Margalef indexes were higher in the mid–forest section than in the other sections.

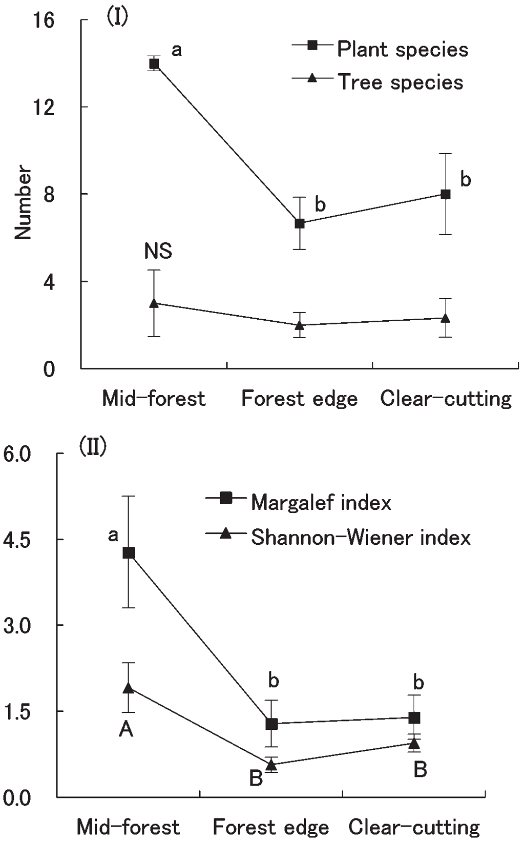

Fig. 2. Changes of the number (I) and diversity (II) of plant species with the understory sections. Different letters (a–b, A–B) indicate the significant difference ($p < 0.05$) among sections. The error bars indicate the standard deviations (with 3 replications).

From Fig. 3, the plant coverage rate was high in the clear–cut and forest edge sections (more than 80%), but low in the mid–forest section (about 50%). The whole plant biomass (g m^{-2}) was the highest in clear–cut section (771), followed by forest–edge (472) and mid–forest sections (207). The leaf biomass (g m^{-2}) was high in clear–cut section (221) and low in forest edge and mid–forest sections (less than 155). The leaf biomass occupied 25–32% of the whole plant biomass in each section, as known from Fig. 3.

Table 1. Depth of litter and soil chemical properties in each understory section

Section	Depth of litter (cm)	pH (pH unit)	Total–N (%)	Exchangeable bases (cmol(+) kg^{-1})		
				K	Ca	Mg
Mid–forest	0.80	4.33	0.39	1.17	3.90	2.96
Forest edge	1.43	4.41	0.54	0.95	3.45	2.80
Clear–cut	1.61	4.53	0.64	1.38	4.64	3.21
Average of Korean forest*	–	5.48	0.19	0.23	2.44	1.01

* Jeong *et al.* (2002)

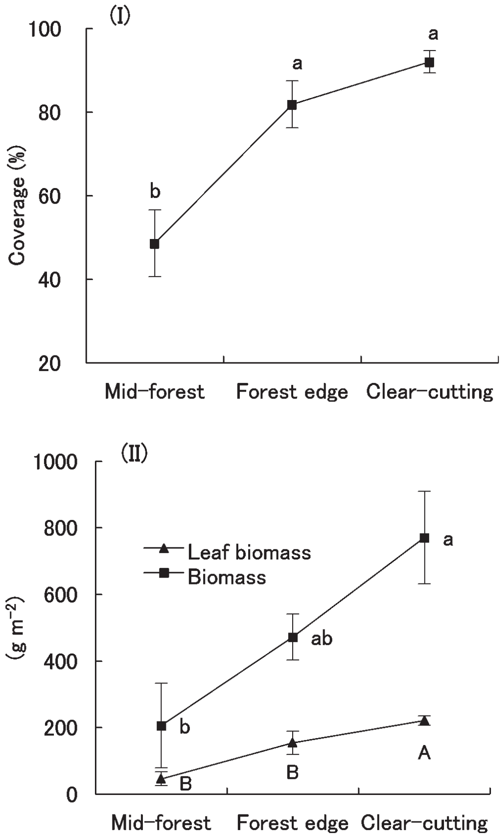

Fig. 3. Changes of the plant coverage rate (I) and the plant biomass (II) with the understory sections. Different letters (a–b, A–B) indicates the significant difference ($p < 0.05$) among sections. The error bars indicate the standard deviations (with 3 replications).

Plant coverage rate at respective understory section

Table 2 shows the plant coverage rate of main herbaceous and tree species, main plant species and whole plant species at the understory sections, respectively. Here, the main herbaceous species are *Calamagrostis arundinacea* (CA), and *Carex breviculmis* (CB), and the main tree species is *Tripterygium regelii* (TR) for every understory section. The plant coverage rate was lower in the mid–forest section than in the other sections, probably because the sunlight intrusion into the understory was obstructed by the larch trees grown in the mid–forest section, inhibiting the growth of the understory plants.

From Table 2, the plant coverage rate of the main herbaceous species was the highest in the clear–cut section (61.0%), followed by the mid–forest section (32.9%), whereas that of the main tree species was by far the highest in the forest edge section (71.8%) compared to other sections. The coverage rate of the main plant species was the highest in the clear–cut section (86.0%), followed by the forest edge section (75.5%) and the lowest in the mid–forest section (34.6%). The coverage rate of whole plant species was the same order with that of the main plant species, and their differences were minor with 14% (mid forest section) and with 6% in the other sections, respectively.

Plant coverage rate at respective understory section

Table 3 shows the correlation coefficient between canopy openness, rPPFD, number of whole plant spe-

Table 2. The plant coverage rate of main herbaceous and tree species, main plant species and whole plant species at the understory sections of mid–forest, forest edge and clear cut, respectively

Understory section	Plant coverage rate (%)		
	Main herbaceous species	Main tree species	Main plant (herbaceous and tree) species
Mid–forest	32.9	1.7	34.6
Forest edge	3.7	71.8	75.5
Clear cut	61.0	25.0	86.0

Table 3. The correlation coefficient between canopy openness, rPPFD, the number of whole plant species, leaf and whole plant biomass, plant coverage rate for the understory of all sections

Understory section	Canopy openness (%)	rPPFD (%)	Number of species	Leaf biomass (g m^{-2})	Overall biomass (g m^{-2})
rPPFD (%)	0.98**				
Number of species	–0.76*	–0.79*			
Leaf biomass (g m^{-2})	0.88**	0.73**	–0.67**		
Biomass (g m^{-2})	0.86**	0.74**	–0.46	0.81**	
Plant coverage rate	0.56	0.62	–0.73**	0.56	0.37

* and **: significant at 5 and 1% levels, respectively

cies, whole plant and leaf biomasses, and plant coverage rate for the understory of all sections. Canopy openness was positively correlated with rPPFD, and these two light conditions were positively correlated with the whole plant and leaf biomass. However, the light conditions were negatively correlated with the number of plant species. Moreover, plant coverage rate was negatively correlated with the number of whole plant species. The leaf biomass was positively correlated to whole plant biomass.

DISCUSSION

Effect of light condition on the plant growth in each understory section

The positive correlation between rPPFD and canopy openness (Table 3) was commonly observed in some other pine forests of white pine (*Pine strobes*) and red pine (*Pinus resinosa*) forests (Machado and Reich, 1999). As shown in Fig. 1, rPPFD and canopy openness changed in a similar manner with the forest understory, however, the change was more rapid in rPPFD than in canopy openness. Elliott *et al*. (1993) showed that rPPFD was influenced by the location, season, slope gradient, and surrounding shelters, therefore, the rapid change with the sections above mentioned might affected by these factors. Hereafter, rPPFD only is used as a light condition, representatively.

Considering from the positive correlation between rPPFD and plant biomass (Table 3), the plant biomass was perhaps influenced greatly by the light condition. The dominant species is TR in the forest edge section and CA and TR in the clear–cut sections. There was no dominant species in mid–forest section (Table 2). From the dominant species at each section, sun plants of herbaceous and tree species are considered to grow largely in the clear–cut section, leading to its larger plant biomass. Since the number of plant species was negatively correlated with both rPPFD and plant coverage rate (Table 3), it was thought that the sunlight incoming to the section was intense in a clear–cut section, and sun plants grew dominantly, resulting to a less number of whole plant species. Shade tolerant species, being adapted to the mid–forest section, was perhaps died out by the rapid changes in light condition in the clear–cut section.

The plant coverage rate of whole plant species was not different between clear–cut and forest edge sections, and so was the whole plant biomass, and the number of plant species, however, leaf biomass was higher in the clear–cut section than in forest edge section, which was probably because that the leaf biomass of the herbaceous species dominant in the clear–cut section was larger than that of the tree species dominant in the forest edge section. The plant coverage rate of the forest edge section was higher than that of the mid–forest section, presumably because TR, a climbing tree species dominant in the forest edge section, flourished more extensively than the herbaceous species dominant in the mid–forest section.

The plant coverage rate of the main herbaceous species was the highest in the clear–cut section (86.0%), followed by the forest edge section (75.5%), respectively (Table 2). As reported in previous studies (e.g., Wetzel and Burgess, 2001; Yamagawa and Ito, 2006; Yamagawa *et al*., 2009), pioneer or sun plant species flourishes in the understory, when light condition is improved by clear–cutting or thinning. Yahata (1993) mentioned that forest clear–cutting increased the direct sunlight incoming into the understory, making the topsoil drier and inhibiting the germination of plant seeds. In other words, rapid change in light condition by clear–cut will cause the decay of the plants already adapted there. Moreover, plants suitable for an intense light condition flourish in clear–cut section, limiting the growth of other plants being flourished in the section as known from Figs. 2 and 3.

Desirable understory plant composition for regenerating the natural forest

The larch forest cannot be regenerated from any forest understory section targeted here, because no larch seedlings were observed in the sections. Instead, the native tree species were observed and which could be grown larger by a proper maintenance of the species. In order to regenerate the natural forests from the understory of an artificial larch forest at the national park, it is desirable to increase the number and biomass of native tree plants grown there.

Native tree plants are difficult to invade into the understory of an artificial forest where the trees are densely grown, due to the lack of sunlight. If the artificial forests are clear felled, the plant biomass and plant coverage rate in the understory may increase, but the diversity of plant species may decrease, due to the rapid change of sunlight. Therefore, it is desirable to improve the light condition of artificial forests gradually, so that the native tree species can invade and grow in the understory. In addition, to prevent rapid flourishing of pioneer or sun plant species, which occurred in the clear–cut and the forest edge sections, is necessary.

CONCLUSIONS

The following conclusions are drawn from the present study.

1) In the clear–cut and the forest edge sections of forest understory, rPPFD was higher than in the mid–forest section, which enabled dominant growth of pioneer or sun plant species, and which led to increase in the plant biomass and plant coverage rate in the sections.
2) In the understory of clear–cut and forest edge sections, pioneer or sun plants flourished dominantly, leading to a decrease in the diversity of plant species.
3) In order to regenerate a natural forest in an artificial forest at a national park, it is required to avoid rapid change of light condition like clear–cut area, in order to grow the natural tree species without losing plant species diversity in the forest ecosystem.

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