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Initial Responses of *Quercus serrata* Seedlings and Forest Understory to Experimental Gap Treatments

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ABSTRACT: *Pinus thunbergii* plantations in Pohang-si, Gyeongsangbuk-do, Korea, are of low ecological quality, with arrested succession and a high proportion of ruderal species. To improve the quality of the habitat, we created canopy gaps (～ 42 m^2) and monitored changes in abiotic (light availability, canopy openness) and biotic (survival and growth of seedlings and understory communities) variables in 2007 and 2008 in plots that had received one of five types of treatment: cutting of canopy trees and removal of the understory (CU), cutting of canopy trees only (C), girdling of canopy trees and removal of the understory (GU), girdling of canopy trees (G) or control. Each treatment was applied to three replicate plots. Abiotic variables did not significantly differ among treatments. Survival rates of target species were slightly lower in the CU, G and control conditions. Based on logistic regression analysis, the only significant growth factor affecting survival was height growth. Positive effects of seedling height and leaf area growth on survival were also detected, but did not reach statistical significance. In treatment G, gradual improvement of overstory conditions and mitigation of competition by limitation of disturbance to the understory community were likely to have promoted seedling growth. There were no significant effects of gap treatments on changes in species abundance (cover and richness) and composition of understory between the study years. This result implies that the small gaps created in our study may be below the threshold size to affect understory growth. However, the results of this study are based on a short-term investigation of only two years. Long-term research is strongly recommended to clarify the effects of gap treatment on plant communities in afforested areas.

Key words: Afforestation, Gap, Mudstone, *Pinus thunbergii*, *Quercus serrata*, Restoration, Understory, Yeongil

INTRODUCTION

Pinus thunbergii (black pine) plantations in lowland and hilly habitats in Pohang-si, Gyeongsangbuk-do, Korea, are currently of low ecological quality, with arrested succession, a high proportion of ruderal species, and no stratification. In lowland areas of Pohang, most black pine stands were established during the Yeongil erosion control project, which was implemented to control severe soil erosion in mountainous areas in the early 1970s (Gyeongsangbuk-do 1999). Black pine stands are primarily found in coastal areas of Korea, China and Japan, and in South Korea, natural and artificial stands are restricted to coastal and adjacent inland areas (Kim and Kil 1983, Murai et al. 1992, Kim et al. 2002). Various tree plantations established in the Young-il erosion control project have become oak-dominated or co-dominated forests as a result of natural succession (Cho 2005).

After black pine forests were planted in Pohang, succession by natural processes was arrested in inland hilly and lowland habitats with mudstone bedrock and in patches isolated from core natural forest land as a result of the low availability and dispersal of propagules of potential dominant oak species due to landscape and site characteristics. Local soil and bedrock (mudstone) properties with low soil pH and nutrients, as well as management activities (thinning), prevented vegetation development and soil formation (Chung 1979). Potential natural vegetation for the afforested sites in lowland areas of the Yeongil erosion control district includes oak, such as *Quercus serrata* (Hong 1982, Cho 2005). This area was classified physiognomically as belonging to the *Q. serrata*-dominated warm-temperate summer-green broadleaved forest zone (Kim and Lee 2006). However, the low availability of propagules of *Q. serrara* necessitates the introduction of the species into target habitats.

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Gaps are openings in the forest canopy (Watt 1947). Gap regeneration (Runkle 1981) or gap dynamics (van der Maarel 1988) have important consequences for forest regeneration. The current paradigm of forest dynamics emphasizes the role of small canopy gaps in maintaining forest diversity (Clinton 2003). Putz (1983) and Schaetzl et al. (1989) reported that the mode of death of gap-making trees (e.g., dead standing, snapped-off, or uprooted) affects the gap environment and the species composition in the gap. The implementation and utilization of natural processes like succession and gap dynamics for forest management is a common practice in modern forestry (Coates and Burton 1997, van der Meer et al. 1999, York et al. 2003, Zhu et al. 2003, Huth and Wagner 2006). Experimental gap formation, like enrichment planting, is a simple, low-cost forest-restoration tool requiring minimal structural disturbance of the stand (Coates and Burton 1997, Inman et al. 2007), making this method suitable for rehabilitating vulnerable and low-quality habitats. Thus, we selected artificial forest gap formation as a restoration tool to facilitate the establishment and growth of the target species, *Q. serrata*, in black pine plantations in Pohang.

It is not realistic to expect that rehabilitation activities will result in a complete restoration of the pre-disturbance ecosystem and or replication of the reference model because much of the damage to the target environment is irreversible (Choi 2004, Choi et al. 2008). However, the habitats may be rehabilitated to more closely resemble natural forest environments through the introduction of potential dominant species. In this study, we examined the effects of fine-scale gap creation 1) on abiotic environments (canopy openness and light availability), 2) on growth of target species (radial, height and leaf area), and 3) on understory community properties (total cover, species composition, and diversity).

STUDY AREA

This study was carried out in a *P. thunbergii* plantation in Heunghae-eup, Pohang-si, Gyeongsangbuk-do (N 36° 4' 49" and E 129° 21' 18", > 50 m above sea level). The study stand was planted 34 years before the study was initiated. The total basal area and density of woody species in the black pine plantation were 19.8 m^2 and 1,141 individuals per ha, respectively, with tree diameters at breast height (dbh) ranging from 16 to 23 cm, and heights ranging from 13 m to 15 m. Our field experiments were conducted from February 2007 to October 2008. Our use of nomenclature follows Park (1995), Lee (1999), the Korean Plant Names Index (Korea Forest Service 2003), and Illustrated Grasses of Korea (Korea National Arboretum 2004).

Canopy openness and light availability in the black pine plantations are three times higher than those of naturally occurring *Q. serrata* stands (Cho 2009), because of thinning and the limited vertical structure of the stand interior. The low abundance of forest species (i.e., shade-tolerant species) as a result of management activities also creates challenges in enhancing structural and compositional diversity. The properties of black pine plantations and the low tree growth rate [the height-age equation in study area was $y = 1.95\ln(x) - 1.18$ ($n = 78$; $r = 0.74$, $p < 0.001$; y as height; x as age)] suggested that introduction of potential dominant broadleaved tree species and facilitation of growth of the species might be effective in improving forest quality. In addition, *P. thunbergii* plantations, as big monotonic landscape elements, are particularly vulnerable to fire, so reducing this vulnerability was an additional consideration in the decision to promote the establishment of broadleaved forest in the area via active introduction of broadleaved species to *P. thunbergii* plantations in the Pohang area.

METHODS

To establish oak-dominated stands and to facilitate succession, we introduced fine-scale forest gaps and controlled the mode of death of the gap-making trees (by cutting to simulate uprooting, or girdling to induce standing death). We also conducted additional experiments by removing various levels of understory vegetation because environmental heterogeneity in gaps may also affect the regeneration processes. Unfortunately, the selection of trees for small patch cutting or girdling for our experiments could not be based on the range of natural variation in forest gaps because the black pine stands in the study area are young (< 35 years) and information about gap formation in naturally occurring forests of this type is not available. We examined the effects of artificial gap creation on growth of the target species (*Q. serrata*) and on the responses of the understory community (i.e., understory species composition and species abundance).

Experimental gaps were created by cutting (C) or girdling (G) canopy trees in 5×5 m (25 m^2) quadrats in the mid-slope of carefully-selected *P. thunbergii* stands in February 2007. We also conducted additional treatments (gradients of disturbance and light availability, or spatial heterogeneity for treatments C and G) by removing all woody species from the understory (either by cutting-CU-or girdling-GU) in 5×5 m quadrats (Fig. 1). Thus, five treatments were applied (CU, C, GU, G and Control) and replicated three times. Gap sizes, which was calculated by extended gap measurement (Runkle 1992), was highest in the CU-treated quadrats (47.3 ± 11.8 m^2), followed by the G (42.3 ± 4.5 m^2), C (41.5 ± 5.1 m^2) and GU (36.8 ± 8.8 m^2) treatments, but there were no significant differences among the gap sizes ($F = 0.05$, $p = 0.979$). Survival rates of girdled *P. thunbergii* individuals declined from 100 %

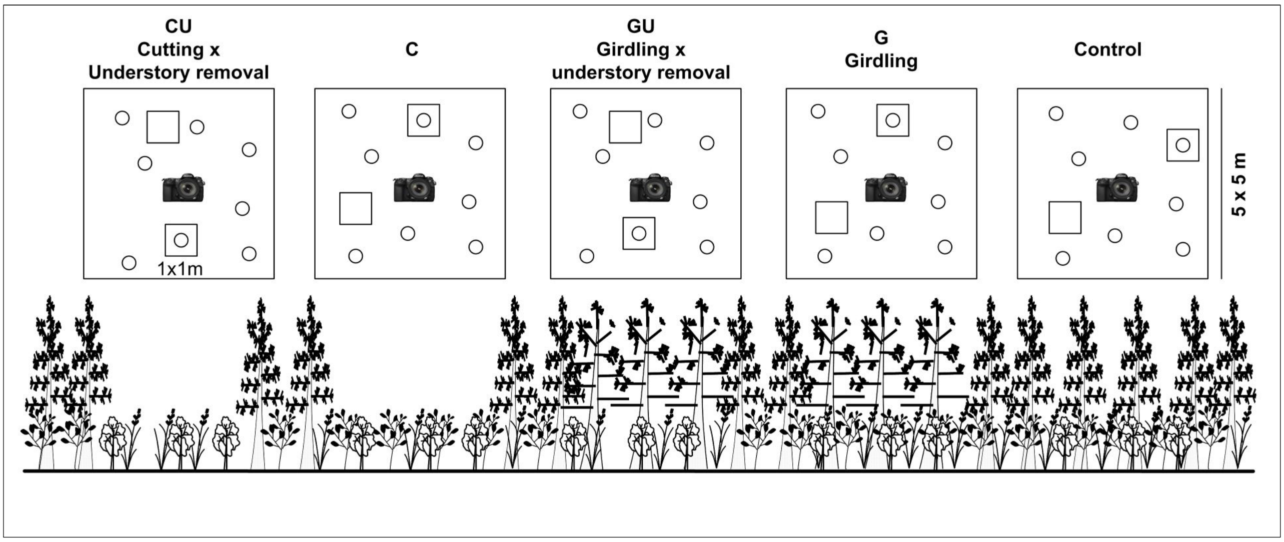

Fig. 1. Schematic diagram for experimental gap regeneration treatment blocks in *Pinus thunbergii* stands.

in the first year to 56.7 % in the second year in the GU quadrats, and from 100 % in the first year to 18.1 % in the second year in the G quadrats. We randomly introduced 6～8 nursery-raised 2-year-old *Q. serrata* seedlings (produced in Forest Practice Research Center in Pocheon-si, Gyeonggi-do) into each quadrat, and measured the seedlings' height and diameter 5 cm above the soil surface after they were planted. We repeated both measurements (height and diameter) in the first and second fall seasons after canopy gap creation (i.e., in fall 2007 and fall 2008). We also counted the number of shoots and leaves, and measured the width and length of the three largest leaves of each individual for calculation of leaf areas (cm^2).

We established two permanent subplots (1 × 1 m) in each plot to measure the responses of understory vegetation to gap creation (-G) and to restoration disturbances such as digging for planting (gap × restoration disturbance, -R), and estimated the percentage cover of all vascular species in the subplots. To estimate light availability and the percentage of canopy openness, we took digital hemispherical photographs at the center of 5 × 5 m plots from a height of 1.8 m using a Nikon D80 digital camera with Sigma 4.5 mm F2.8 EX DC Circular Fisheye HSM lens. Pictures were taken on uniformly overcast days to avoid direct sunlight. We calculated the mean annual total transmitted light or photosynthetic photon flux density (PPFD, $mol \cdot m^{-2} \cdot day^{-1}$) with Gap Light Analyzer 2.0 employing the standard overcast sky model (Frazer et al. 1999, Haugo and Halpern 2007). We took pictures only in the second year and at heights of 1.8 m and 0.7 m to examine changes in light availability resulting from understory regeneration.

We classified understory species recorded by their growth forms, i.e., as trees, shrubs, forbs (including ferns), tallgrasses, grasses or vines, and estimated the correlation between the change in total cover and richness and the change in functional groups. Changes in species richness between the first and the second years were estimated by constructing species-area curves and first-order jackknife estimates (McCune and Mefford 1999). We used the Nonmetric Multidimensional Scaling (NMS) method to draw changes in the species composition of samples (Kruskal 1964). In addition to NMS, we also used multiresponse permutation procedures (MRPP) (Biondini et al. 1988) to test whether the species composition differed after treatments were applied. MRPP is a nonparametric procedure that avoids the distributional assumptions of normality and homogeneity of variance, which are not commonly met in ecological data. It produces the *A*-statistic (the chance-corrected within-group agreement) with an associated probability of statistical significance (McCune and Grace 2002). To test for variation in target species growth (diameter, height and leaf area) and understory responses (changes in total cover and richness) to restoration treatments, we conducted repeated-measures analysis of variance (ANOVA) (Underwood 1997). We examined the relationships between species growth parameters and understory responses and overstory environments (canopy openness and light availability) in the second year using correlation analysis. Where significant treatment effects were detected, post hoc comparisons were made to compare group means. Finally, we used logistic regression analysis to determine the effects of growth parameters (diameter and height), the number of leaves and stems in the first year, and leaf area in the first year on the survival of target species in the second year. An alpha level of 0.05 was used as the criterion for statistical significance. We used SPSS ver. 15.0 and PC-ORD ver. 4.0 (McCune and Mefford 1999) for univariate and multivariate analyses, respectively.

RESULTS

Overstory Characteristics and Survival and Growth in Experimental Gaps

Light availability (PPFD, mol · m^{-2} · day^{-1}) at 1.8 m was highest in C-treated plots (29.7 mol · m^{-2} · day^{-1}), followed by the CU (28.4 mol · m^{-2} · day^{-1}), G (24 mol · m^{-2} · day^{-1}), GU (23.8 mol · m^{-2} · day^{-1}) and Control (13.2 mol · m^{-2} · day^{-1}) treatments, but with no significant differences among treatments (Fig. 2a). The difference between the 1.8 m and 0.7 m measurements was highest in CU-treated plots, which showed rapid vegetative regeneration after understory clearing. Canopy openness (%) at 1.8 m height from the ground was highest in C-treated plots (48.9 %), followed by the GU (48.1 %), CU (47.9 %), G (45.5 %) and Control (32.7 %) treatments, but with no significant differences among treatments (Fig. 2b).

The mean survival of *Q. serrata* seedlings in the first and second years was highest in the C- and GU-treated plots (94.4 %), followed by the G (91.5 %), Control (86.1 %) and CU (75 %) treatments (Fig. 3). The logistic regression analysis found that only height growth had a significant effect on survival (coefficient of regression $B = 0.09$, *Wald statistic* = 5.435, $p = 0.009$).

The repeated-measures ANOVA analysis of the experimental canopy gap treatment detected no significant short-term effect of the treatment on species growth, although a significant effect of 'time' was detected for height ($F = 8.55$, $p = 0.015$) and leaf area growth ($F = 18.06$, $p = 0.002$) (Table 1). Growth of *Q. serrata* seedlings after treatment is shown in Fig. 4. The increase in the mean radial growth between the first and second years was highest in the Control (0.8 mm) and C (0.6 mm) treatments (Fig. 4a). The increase in the mean height was greater in the second year in the G (5.9 cm), GU (4.1 cm) and C (3.3 cm) treatments than in the Control treatment (2.9 cm), and negative growth was detected in the C treatment (Fig. 4b). Leaf area (cm^2) increased in all treatments and the increase was highest in the G treatment (699.4 cm^2), followed by the C (573.8 cm^2), GU (9.9 cm^2), CU (345 cm^2), and Control (283.8 cm^2) treatments (Fig. 4c). Overall, growth (height and leaf area) of target species was higher in treated plots than in the Control plots, although the effect was not significant. The only significant relationship detected between growth and environmental parameters was between leaf area growth and light availability ($r = 0.69$, $p = 0.005$).

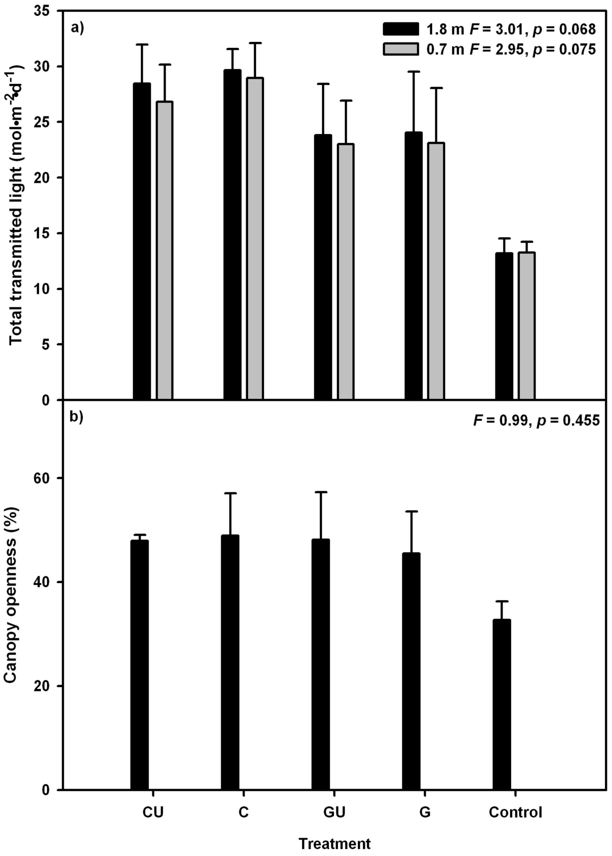

Fig. 2. Mean total transmitted light (PPFD; photosynthetic photon flux density) and canopy openness at 1.8 m and 0.7 m from the ground in each treatment.

Table 1. Effects of treatment (CU, C, GU, G, and Control) and time (1^{st} and 2^{nd} year after gap creation) on growth of the target species *Q. serrata* from repeated-measures ANOVA

Source of variation	*df*	Change in diameter growth (mm)		Change in height growth (cm)		Change in leaf area (cm^2)	
		F	*p*	*F*	*p*	*F*	*p*
Treatment	4	0.52	0.724	0.28	0.883	1.75	0.210
Time	1	4.01	0.073	**8.55**	**0.015**	**18.06**	**0.002**
Time × treatment	4	0.32	0.859	1.07	0.419	0.46	0.764

Note: *p* values are in boldface for significant ($p < 0.05$) main effects. Error degrees of freedom (*df*) = 10 for between-subject analysis of main effect (time), and error *df* = 10 for within-subject analysis of treatment and its interaction with main effect (time × treatment).

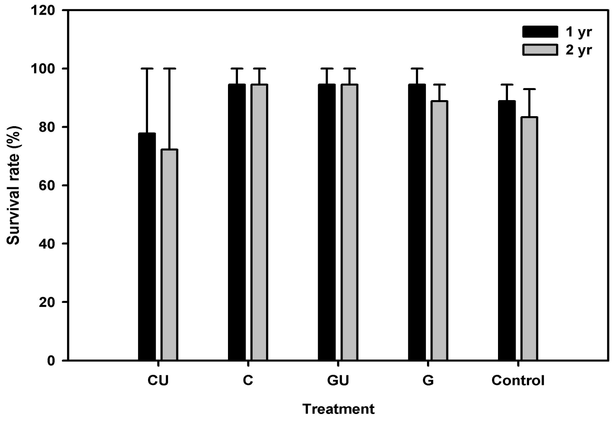

Fig. 3. Changes in mean survival rate (%) between the first and second study years for the five experimental treatments.

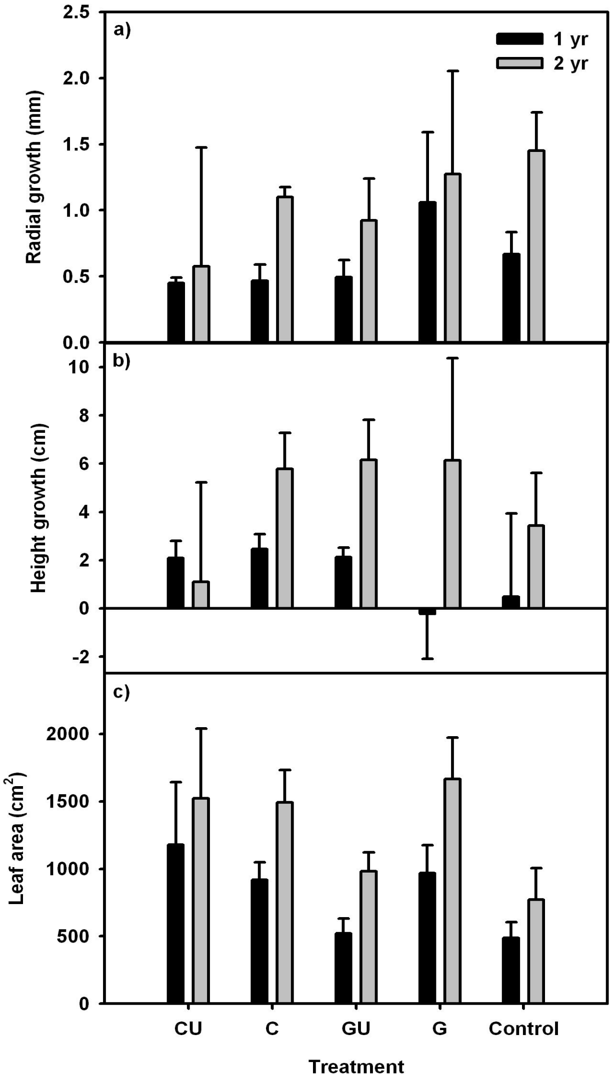

Fig. 4. Changes in growth (radial, height and leaf are) of *Q. serrata* seedlings in the first and second years.

Responses of Species Abundance to the Experimental Gap Treatment

The most common (highest-frequency) species recorded in study plots were ruderal (disturbance related) or transitional species such as *Spodiopogon sibiricus* (tall grass), *Oplismenus undulatifolius* (grass), *Rhus javanica* (as a shrub), *Artemisia keiskeana* (as a forb), *Miscanthus sinensis* (tall grass) and *Arundinella hirta* (tall grass) (Table 2). Partly, changes of coverage of shrub (*Rhus javanica* in GU-G) and vine (*Smilax china* in GU-R) species were higher.

Experimental gap treatments resulted in no significant short-term effect of treatment on total cover and species richness in the subplots, but detected significant effects of time on the change in total cover in gap ($F = 7.03$, $p = 0.024$) and gap × restoration ($F = 12.36$, $p = 0.006$) treatments (Table 3).

Subplots treated by understory removal showed larger changes in cover (16% for CU and 20% for GU) than Control plots (7%) (Table 4). Total cover was also higher in CU (16%) and GU (17%), but than Control (14 %) plots, but the differences were slight (Table 4).

The changes in total cover observed were correlated with changes in coverage of shrub ($r = 0.64$, $p < 0.001$) and vine ($r = 0.47$, $p = 0.008$) species. The changes in richness were correlated with changes in tree ($r = 0.43$, $p = 0.018$), shrub ($r = 0.42$, $p = 0.02$), grass ($r = 0.37$, $p = 0.041$) and vine ($r = 0.6$, $p < 0.001$) species richness.

Responses of Species Diversity and Composition to the Experimental Gap Treatments

We observed little change in the species richness for each treatment, with slight decreases in species richness in the C and GU treatments (Table 5). Overall richness was reduced by disturbances to the understory community (Fig. 5). In the gap disturbance samples, estimated richness decreased after overstory modification from 48.9 to 42.2 species. In gap × restoration disturbance samples, estimated richness also decreased from 48.9 to 38.5 species.

The MRPP analysis and the NMS ordination analysis did not detect significant differences among treatments in the change in species composition between the first and second years (Table 6; Fig. 6). Among the gap disturbance samples, G treatment had the largest change in species composition relative to the Control (Fig. 6a). The gap × restoration disturbance affected the understory composition of each treatment differently, as shown in Fig. 6b.

DISCUSSION

We created artificial canopy gaps to introduce target species and facilitate succession to broadleaved forest in a vulnerable and unstable *P. thunbergii* plantation in a lowland area of Pohang. The survival and growth of the target species (*Q. serrata*) was improved

Table 2. Summary table of the summed coverage of species in subplots and frequency of appearance in all study plots

Species	CU-G		CU-R		C-G		C-R		GU-G		GU-R		G-G		G-R		Control-G		Control-R		Freq. (%)
	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	1 yr	2 yr	
Spodiopogon sibiricus	14	11	7	13	43	54.5	11	5	11	12	10	14	16	11.3	6	2	12.5	25	8	4	78.3
Oplismenus undulatifolius	7	5	11.5	14	9.5	6.3	11	11	4.5	5	3	4.7	5	11	1.5	1	5	5.5	4.5	4	73.3
Rhus javanica	5	4	1	2	4.5	9.5	−	−	38	85	36	33	26	21	18	23	27	29	21	26	60.0
Quercus serrata	5	8	14	24	9	11	14	18	−	−	10	18	14	8	17	9	−	−	6	11	56.7
Artemisia keiskeana	17	21.5	16	22	6	8.7	9	9.5	9	12.3	3	3	−	−	0.5	0.7	1	2.7	−	3	53.3
Miscanthus sinensis	6	11	5	13	12	17	2	5	4	12	4	4	−	5	5	3	9	7	10	5	45.0
Arundinella hirta	6	16	5	19	5	7	0	0.7	9	10	2	3	0.5	−	−	−	5	3	−	8	43.3
Pinus thunbergii	−	−	2	2.5	6.5	5	3.5	4.2	0.5	−	1	−	1	4	4.5	4	0.5	−	−	3	41.7
Smilax china	−	−	14	29	4.5	1	−	2	14	24	30	62	−	−	9	4.4	23	17	2	23.4	40.0
Rhus tricocarpa	−	−	1	0.6	1.5	−	4	3	−	3	8	7	4	4.5	4	0.6	1	0.7	3	−	31.7
Isodon inflexus	−	−	5	2	−	−	−	−	6	6	8	10.7	4	1	2	3	8	21.5	1	5	31.7
Lespedeza bicolor	11	19	0.5	2	1	1	−	−	1.5	1	0.5	0.5	−	−	−	−	2	−	3	19	26.7
Cocculus trilobus	6	−	−	−	2	1	−	−	0.5	7	−	1.5	1.5	−	−	−	7	13	7.5	1	23.3
Rosa multiflora	0.5	−	−	−	−	−	−	−	10	5.2	2	4	1	1	1	−	12	6	1	3	21.7
Pteridium aquilinum	−	11	−	−	−	−	−	−	14	7	−	−	−	−	6	16	25	25	12	7.7	18.3
Festuca parvigluma	4	−	8	−	4	−	1	−	2	−	−	−	1	−	−	−	−	−	7	−	13.3
Lespedeza maritima	−	−	−	−	−	−	−	−	−	−	−	−	4	6	3	3	0	3 .5	−	−	13.3
Dendranthema zawadskii	−	−	−	−	−	−	−	−	1	4	2	3	−	−	1	−	0.5	−	−	1	11.7
Zanthoxylum schinifolium	−	−	0.5	1	−	−	0.5	0.5	−	−	4	−	−	−	0.5	−	−	−	0.5	−	11.7

by gap formation, although the effects of the gap treatments were not significant in our field experiments. The introduced seedlings of *Q. serrata* are expected to function as seed sources because the species typically flowers and fruits in younger stage. As the study sites had limited tree species richness, the seedlings may also facilitate the establishment of a stable forest environment (through shading and stratification). This report is based on a short-term investigation for two years. Longer-term research is strongly recommended to clarify the effects of gap treatment.

Effects of Gap Creation on Abiotic Factors and Survival and Growth of Target Species

We introduced fine scale canopy gaps (< 50 m^2) using different methods to kill trees and form gaps (i.e., cutting off the tree or killing it while standing) and to create understory heterogeneity (understory removal or not). As expected, canopy openness and estimated light availability was slightly higher after cutting treatments (CU and C), although no significant differences among treatments were found. We detected positive effects of artificial gap creation on the target species' growth, and coverage and richness of understory communities exhibited limited variance. However, we did not detect significant differences in environmental factors such as light availability and canopy openness among treatments. Small gaps, such as those created in this study may not result in pronounced environmental changes. Small openings (about 70 m^2) created by the death of one or more canopy individuals are the most common components of forest disturbance regimes (Runkle 1979, 1985). Within gaps, micro-environments may vary from point to point depending on distance from the gap center, radial direction, and microtopography (Collins and Pickett 1987). In this study, however, our focus was restricted to treatment effects on the establishment and growth of target species and on changes in the understory community rather than on micro environmental changes.

During the study years, survival rates of the target species de-

Table 3. Effects of treatment (CU, C, GU, G, and Control) and time (1st and 2nd year after gap creation) on abundance (total cover and richness) from repeated-measures ANOVA

Source of variation	*df*	Cover change in gap treatment		Cover change in gap × restoration treatment		Richness change in gap treatment		Richness change in gap × restoration treatment	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Treatment	4	0.66	0.635	2.29	0.13	0.09	0.982	1.02	0.366
Time	1	**7.03**	**0.024**	**12.36**	**0.006**	2.68	0.132	0.02	0.898
Time × treatment	4	1.11	0.402	1.60	0.248	0.46	0.764	0.02	0.999

Note: p values are in boldface for significant ($p < 0.05$) main effect. Error degrees of freedom (df) = 10 for between-subject analysis of main effect (time), and error $df = 10$ for within-subject analysis of treatment and its interaction with main effect (time × treatment).

Table 4. Change in mean total cover (%) in gap disturbance (-G) and gap × restoration disturbance (-R) subplots in the two study years

Total cover (%)		CU		C		GU		G		Control	
		Yr 1	Yr 2	Yr 1	Yr 2	Yr 1	Yr 2	Yr 1	Yr 2	Yr 1	Yr 2
Gap disturbance	Mean	29.7	45.8	40.7	46.1	44.3	64.8	29.5	28.7	47.7	54.6
	se	3.8	8.9	8.5	16.3	2.7	9.1	13.3	11.4	22.2	21.1
Gap × restoration disturbance	Mean	33.2	49.7	20.7	25.0	43.2	60.4	26.3	25.1	31.3	45.3
	se	5.0	9.9	0.9	3.3	5.5	3.6	1.1	4.0	9.7	20.7

Table 5. Change in mean richness in gap disturbance (-G) and gap × restoration disturbance (-R) subplots in the two study years

Richness		CU		C		GU		G		Control	
		Yr 1	Yr 2	Yr 1	Yr 2	Yr 1	Yr 2	Yr 1	Yr 2	Yr 1	Yr 2
Gap disturbance	Mean	7.3	7.3	9.3	7.3	9.0	7.7	7.7	7.0	7.7	7.3
	se	1.2	0.7	0.9	1.8	2.3	1.9	2.2	3.0	1.8	0.9
Gap × restoration disturbance	Mean	9.0	9.0	6.7	7.0	11.0	11.0	7.0	7.0	9.3	9.3
	se	1.0	1.5	0.3	1.5	2.5	2.1	0.6	1.5	1.9	2.4

creased slightly in the CU, G and Control plots. The logistic regression analysis suggested that the height growth of *Q. serrata* seedlings was a significant factor affecting survival, which is consistent with the results of previous studies in abandoned coppice forest in Japan (Matsuda 1989) and in a *Robinia pseudoacacia* plantation in Pohang-si, southeast Korea (Cho et al. 2009). Considering this result, treatment G (girdling only), which resulted in higher growth in height and leaf area of seedlings, may hold the greatest promise to promote the survival of target species among treatments. In CU, a relatively high level of disturbance (cutting and understory removal) was applied, followed by immediate vegetative regeneration by surviving or residual species. Thus, elevated competition for light, available nutrients and soil moisture may have caused deaths among the *Q. serrata* seedlings, although root formation of *Q. serrata* is generally favored by high exposure to light and reduction in soil moisture in controlled experiments (Beon and Bartsch 2003). The observed understory communities in the study sites, which are mainly composed of disturbance-related species that prefer recently-disturbed habitats, are consistent with the above explanation.

The absence of significant relationships between growth parameters (diameter and height growth) and overstory environment (canopy openness and light availability) suggested that other biotic or abiotic factors related to gap creation are primarily responsible for growth, or that the artificial gaps created in this study were too small to affect plant growth. Multiple factors such as light intensity and quality, moisture availability, and competition among species can affect growth and productivity in forest gaps (Wayne and Bazzaz 1993). Gradual improvement of light conditions by girdling (G) mimicked natural gaps produced by standing deaths of gap-makers, and resulted in higher growth in height of the target spe-

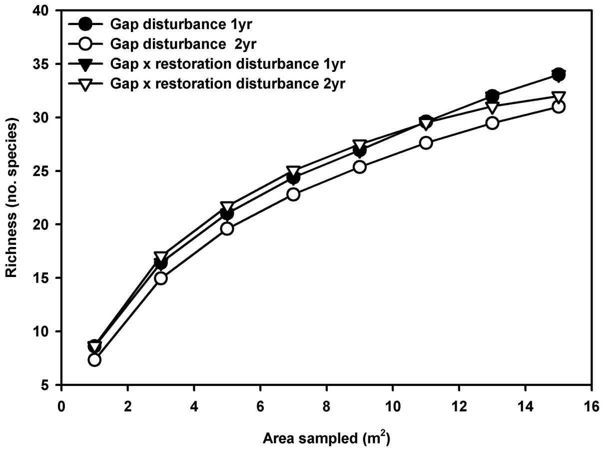

Fig. 5. Species-area curves for understory species (one or two years after treatment). Closed and open symbols indicate years 1 and 2, respectively.

Table 6. Results of the multiple-response permutation procedures (MRPP) testing the differences in species composition between the first and second years in the treatments

Test	Treatments compared	T	A	p
Cutting	CU-G 1 yr, CU-G 2 yr	0.937	−0.077	0.825
	CU-R 1 yr, CU-R 2 yr	1.161	−0.084	0.878
	C-G 1 yr, C-G 2 yr	1.171	−0.127	0.878
	C-R 1 yr, C-R 2 yr	1.064	−0.110	0.857
Girdling	GU-G 1 yr, GU-G 2 yr	1.166	−0.130	0.878
	GU-R 1 yr, GU-R 2 yr	0.761	−0.107	0.766
	G-G 1 yr, G-G 2 yr	1.097	−0.121	0.866
	G-R 1 yr, G-R 2 yr	1.130	−0.129	0.874
Control	Control-G 1 yr, Control-G 2 yr	1.208	−0.143	0.884
	Control-R 1 yr, Control-R 2 yr	0.703	−0.057	0.754

Note: T is the test statistics and refers to the separation between the groups, A is an estimate of effect size and p is the probability of significances among groups.

cies, perhaps because it decreased competition among species by limited disturbance to the forest understory. Natural (canopy gaps) and artificial disturbances are indispensible for the regeneration of *Q. serrata* (pioneer or shade-intolerant) in temperate forests (Masaki et al. 1992, Cho 1992, Abe et al. 1995, Baek and Cho 1996). However, the optimal mode of gap-making for regeneration of *Q. serrata*, has not yet been identified. Species-specific properties often determine how tree species respond to gaps of different sizes and shapes (Bazzaz and Pickett 1980, Gray and Spies 1996). Estimated light levels, which affect photosynthesis, is not expected to strongly influence respiration-dependent growth of *Q. michauxii* in experimental gaps (Collins and Battaglia 2002). Similarly, Korean red pine seedlings planted in artificial gaps in *P. densiflora* forests exhibited increases in height growth rather than diameter growth because photosynthetic products were allocated to height growth rather than to diameter growth in the relatively shady environments of forest gaps (Jin and Lee 2000).

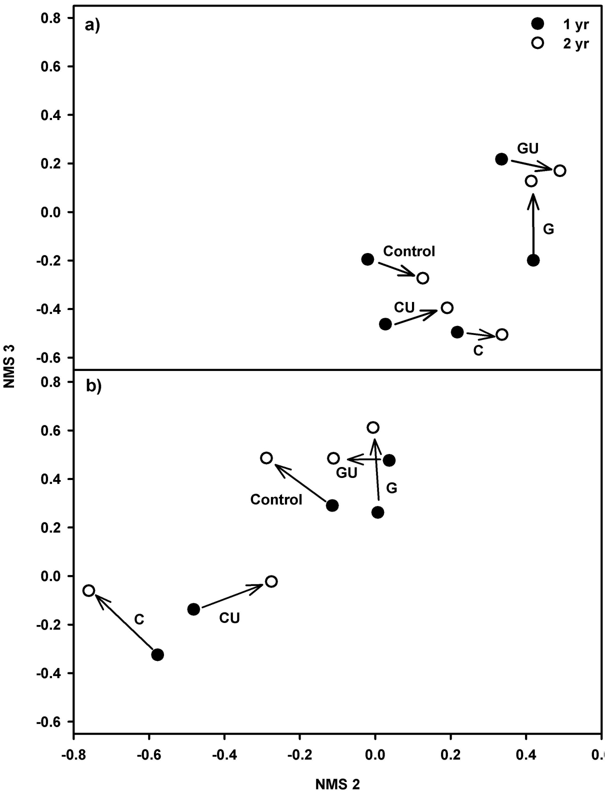

Fig. 6. NMS ordinations (represented by centroids, standard errors were omitted) showing two-year changes in the average species composition of the five treatments. NMS 2 and NMS 3 accounted for 22.9 % and 29.6 % of variation in species composition, respectively, such that the first two NMS axes account for a cumulative 52.5 % of the variation in species composition changes. Samples of gap disturbance (a) and gap disturbance × restoration disturbance (b) are shown separately.

Limited Responses of Understory Community to Experimental Gaps

Because gap regeneration studies have been focused on the performance of gap-fillers and on the effects on abiotic conditions, assessment on understory community responses to canopy gaps has attracted relatively little attention. Changes in canopy and light environments may lead to a variety of responses in terms of the diversity and composition of understory communities. These changes are a function of the type and intensity of disturbance, and may vary with the direction and magnitude of the disturbance. In tropical forest, artificial canopy gaps created by logging and strip clearing in plantations increased the species diversity (Ashton et al. 1997, Duncan and Chapman 1999). However, in mature beech-maple forest in USA, species richness was not affected by gap dynamics but understory cover increased after gap formation (Moore and Vankat 1986).

Given the species composition of *P. thunbergii* stands, abrupt modification of stand structure resulting from clear-cutting or thinning can lead to enhanced growth of ruderal species and promote the establishment of invasive species such as annuals and exotics. in this study, both gap disturbance and the combined effect of gap × restoration disturbance resulted in losses of species richness in artificial gaps. Gap × restoration microplots showed stronger negative effects than gap disturbance microplots. This result stands in contrast with the generalization that gaps are favorable sites for invasion of new species (Busing and White 1997). The observed decline in species richness is likely to be due to competition among species under improved light levels and with limited resources (nutrients and soil water). In the gap × restoration microplots, the exposure of bare soils, rather than interspecific competition, may control species richness by restricting the establishment of new species and the survival of resident species. Chung (1979) reported that limitation of plant establishment in the Yeongil district (Pohang-si and Gyeongju-si at present) originated from low soil pH ($<$ 3.0) and related properties (soil Al contents, 0.15～0.3 %).

Changes in the species composition of the microplots between the first year and the second year did not significantly differ among treatments Changes in the species composition of the understory were detected, but were small, and were primarily due to changes in shrub (such as *Rhus javanica*) and vine (such as *Smilax china*) species, particularly in understory removal samples (CU and GU). In the field, sprouting of cut woody species after understory clearing was frequently observed, and the revegetation process primarily started with vegetative regeneration of the residual woody species rather than herb species after gap formation (Dietze and Clark 2008). Competition between understory shrub or vine species and the target species was inevitable in these study sites. Thus, careful consideration of species competition that can obstruct the growth of target species is necessary in restoration planning.

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