

Ecological responses of natural and planted forests to thinning in southeastern Korea: a chronosequence study

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Abstract

Effects of forest thinning on community level properties have not been understood yet in Korea. We investigated regeneration patterns and trajectories after a disturbance by applying a chronosequence approach. Light availability, litter and woody debris cover, and species composition were determined for twenty 50 m line-transect samples representing a disturbance duration gradient (within 11 years). Environmental factors such as light availability and coverage of woody debris and litter changed abruptly after thinning and then returned to the pre-disturbance state. Although species richness was gained at shrub and ground layer in a limited way in both forests, cover of various functional types revealed diversity in their responses. Notably, *Alnus firma* stands exhibited a larger increment of cover in woody plants. Ordination analysis revealed different regeneration trajectories between natural and planted stands. Based on ordination analysis, rehabilitated stands showed movement to alternative states compared with natural ones, reflecting lower resilience to perturbation (i.e., lower stability). Our results suggest that community resilience to artificial thinning depends on properties of the dominant species. But to get more explanatory ecological information, longer-term static observations are required.

Key words: *Alnus firma*, broadleaved forest, disturbance, *Quercus serrata*, resilience, succession, thinning, understory vegetation

INTRODUCTION

In Korea, forest tending works (thinning) for natural and planted forests have been conducted on a broad scale after International Monetary Fund (IMF) financial support (Woo 2003). In this operation, canopy compositors (as the dominant species) are partially removed (by visually selecting healthy or degrading individuals), and sub-canopy and shrub layer species are eliminated to improve growth of target species and environmental factors such as water retention capacity and soil physical properties. Canopy openness remained at 50-80% compared with the

pre-thinned state (Korea Forest Service instruction No. 890). Thus, structural and environmental changes due to thinning are smaller than to clear cutting.

Management activities (clear cutting, thinning and so on) in forest ecosystems are broadly applied in most nations. Tremendous disturbances such as clear-cutting usually alter the structure and function of forest communities. As a result, various successional stages commonly appear. Thinning also changes understory vegetation indirectly by modifying overstory openness and density

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and their effects on understory microclimate, light, and soil water (Dodson et al. 2008, Jung et al. 2008). In addition, thinning may result in higher availability of water and mineral nutrients through the formation of root gaps (Parsons et al. 1994) and increased competitive performance of residual or invaded species. In managed forest ecosystems, residual species and rapidly establishing invaders are primary contributors to secondary succession after disturbances (logging) (Halpern 1988, 1989).

Forest operations result in various responses of plant communities, such as increasing (Metlen and Fiedler 2006, Dodson et al. 2008), decreasing (Metlen et al. 2004, Fulé et al. 2005) species richness or neutral response (Nelson et al. 2008). Responses of species cover also varied among functional types, suggesting differences in tolerance or resilience to disturbances (Halpern 1988, Metlen et al. 2004, Metlen and Fiedler 2006, Moore et al. 2006). In understory vegetation, various consequences of secondary succession after forest management are predictable, but the emerging patterns and pathways of disturbed forests are not yet clarified in natural and planted forests in Korea.

Communities may be considered stable if these pathways, after management activities, result in a return to the initial composition within an appropriate time scale (Sutherland 1981). In this perspective, understory communities play a central role in the dynamics and functioning of forest ecosystems by influencing long-term patterns of vegetation development (D'Amato et al. 2009). Understory vegetation is also a critical component of forest ecosystems, typically supporting the vast majority of components of total ecosystem floristic diversity (Halpern and Spies 1995, Thomas et al. 1999, D'Amato et al. 2009).

As was mentioned above, the effects of forest management practices in Korea such as clear cutting and thinning on species diversity and composition have not been understood sufficiently (but see Cho et al. 2011). This insufficiency and lack of basic information reflects the paucity of community-level studies in natural and managed stands. Combined with emerging principles in the landscape and in restoration ecology of natural or managed ecosystems, changes in the society's conceptions of a broader range or monotonous forest management options are causing a reassessment of forestry practices. Forest and natural resource managers are making an effort to balance economical and ecological values of the forest by applying alternative models of forest management. In this viewpoint, the introduction and founding of management and operation options and policies surely require a

fundamental understanding of vegetation processes and conceptual models that can predict responses to perturbations in target systems.

The chronosequence approach to study vegetation dynamics has been validated (Foster and Tilman 2000), and has provided significant insights into the patterns and mechanisms of plant succession (e.g., Inouye et al. 1987, Pickett 1989, Lee et al. 2002, 2008, Lee 2006a, 2006b, Hauge and Halpern 2007, Cho et al. 2011). The present study aims to clarify how management activity influences community resistance and resilience. In order to arrive at this goal, we analyzed successional patterns and trajectories (pathways) of understory vegetation and abiotic variables (light availability, woody debris and litter fall) by applying a chronosequence approach after forest thinning in natural and planted broadleaved forests.

MATERIALS AND METHODS

Study area

The study sites were located in rural areas in Pohang-si, Gyeongsangbuk-do, southeastern Korea. The altitudinal distributions of sites were between 150-305 m above sea level (Table 1). The study area is classified as a warm-temperate deciduous broad-leaved forest (such as *Quercus serrata* forest) zone (Lee et al. 1996, Kim and Lee 2006). In this area, the lowland is occupied by oak and artificial (*A. firma*, *Robinia pseudoacacia*, *Pinus thunbergii*, and *P. rigida*) forests. Most plantations in this area were introduced through a large scale forest restoration project called in the Yeongil erosion control project, in the early 1970s. For natural and restored stands, forest-tending works (thinning) to improve resource quality in lowland forests have been practiced from 1998 to date.

Soils were shallow, sandy loams and loams derived from mudstone and shale on the tertiary deposit in the Cenozoic Era based on digital detailed soil maps published by the Rural Development Administration. Annual mean temperature and precipitation (1971-2007) obtained from the Pohang-si weather station, the closest to this study area, were 14.0°C and 1,166.8 mm, respectively.

We explored the study area in a vegetation survey and selected 10 stands in the natural broadleaved forest (dominated by *Q. serrata*). After the field survey, we verified that the stands selected were young vegetation in the early 1970s through orthogonal image interpretation (taken in the early 1970s). Among them, 5 stands remained in their natural state without any treatment; the others were man-

aged (by thinning). In five managed stands, we confirmed the years lapsed after the operation (one 11 year stand; three 4 year stands; one 2 year stand) by counting the age of stems sprouted from the cut stump (Table 1). Natural *Q. serrata* stands were mainly composed of *Carpinus laxiflora* in the canopy layer, *Acer pseudosieboldianum* and *Lindera erythrocarpa* in the subtree layer, *Rhododendron schlippenbachii*, *L. obtusiloba*, and *Viburnum erosum* in the shrub layer, and *Disporum smilacinum*, *Carex humilis*, *Carex gifuensis*, and *Ainsliaea acerifolia* in the herbaceous layer.

For rehabilitated stands, a total of 10 stands were selected in *A. firma* stands, which were introduced through the Yeongil erosion control project. Management history was checked by the same processes as those used for the natural forest. Among 10 *A. firma* stands, 5 remained in the natural state after planting. Managed stands were composed of two 3 year stands, two 8 year stands, and one 4 year stand. Unmanaged *A. firma* stands were composed of *Q. serrata* and *C. laxiflora* in the canopy layer, *Sorbus alnifolia*, *A. pseudosieboldianum* and *L. erythrocarpa* in the subtree layer, *R. schlippenbachii*, *L. obtusiloba*, and *V. erosum* in the shrub layer, and *Oplismenus undulatifolius*, *Disporum smilacinum*, and *Parthenocissus tricuspidata*

in the herbaceous layer.

Vegetation and abiotic variables sampling

Vegetation sampling was conducted from August to September 2008. In selected stands, a 50 m line transect was installed parallel with the contour and was > 30 m from all stand edges. The transect was consisted of five plots (5 m × 5 m) spaced at 5 m intervals and 10 subplots (1 m × 1 m). Within each plot (1-2 m in height) and subplot (< 1 m in height), coverage (%) of all vascular species was recorded. Coverage of litter and woody debris was also determined in subplots. The age of each stand was estimated by counting tree rings from annual ring cores for the biggest tree species in the plot. Mean ages of *Q. serrata* and *A. firma* forests were 36 and 34 years, respectively. Samples of unmanaged natural (*Q. serrata*) and restored (*A. firma*) stands were used as a control (or reference, or pre-disturbed) state in this study.

In order to estimate light availability and canopy openness (%), we took digital hemispherical photographs at each subplot from a height of 1.8 m using a Nikon D80 digital camera (Sendai, Japan) with Sigma 4.5mm F2.8 EX DC Circular Fisheye HSM lens (Fukushima, Japan).

Table 1. General environmental features of 20 vegetation survey sites

Band number	Stand origin	Stand age	Elevation (m)	Slope (°)	Aspect	Years after thinning
1	Natural	38	150	15	SW	*
2	Natural	33	150	10	SW	*
3	Natural	36	190	25	NE	*
4	Natural	37	175	20	SW	*
5	Natural	34	185	20	W	*
6	Natural	35	205	30	SE	4
7	Natural	44	205	30	SW	4
8	Natural	37	189	25	W	11
9	Natural	36	150	30	NW	4
10	Natural	44	200	25	NW	2
11	Plantation	33	290	25	S	*
12	Plantation	33	290	25	N	*
13	Plantation	33	300	30	NE	*
14	Plantation	33	305	25	S	*
15	Plantation	33	300	25	NW	*
16	Plantation	34	260	20	N	3
17	Plantation	34	275	20	NW	3
18	Plantation	34	215	30	SE	8
19	Plantation	34	225	30	SE	8
20	Plantation	34	245	25	SE	4

S, south; N, north; E, east; W, west.

*Site with no management traces.

Pictures were taken on uniformly overcast days to avoid direct sunlight. Total transmitted light or photosynthetic photon flux density ($\text{mol m}^{-2} \text{day}^{-1}$) averaged over a year was calculated with Gap Light Analyzer 2.0 (Mansfield, CT, USA) employing the standard overcast sky model (Frazer et al. 1999, Haugo and Halpern 2007).

Statistical analyses

Functional types such as growth form and life trait (or habitat affinity) are often used to generalize species' performance (Smith et al. 1987). To compare regeneration patterns after thinning, each species recorded was classified into five growth forms, i.e., tree, shrub, forb (including ferns), graminoid and vine, and mean numbers and coverage of each form to samples of focal successional stage were calculated. Average coverage of litter and wood debris (WD), and light availability were also computed for each successional stage. In addition, in order to assess species diversity, a Shannon index (H') was calculated for each successional stage (Magurran 2003).

To analyze successional pathways of stands, the importance value of each life form in each subplot was calculated. The values were determined by multiplying 100 by the fractional value of each life form to the summed values of all functional types in each subplot. Then, a matrix of importance values for life forms was constructed and that data were fed to ordination analysis. We used Nonmetric Multidimensional Scaling (NMS) (Kruskal 1964) ordination to examine differences in successional pathways due to management activities in the understory of natural and planted stands. NMS ordination was performed using Sørensen's distance measure and we selected the "slow and thorough" autopilot of PC-ORD ver. 4.0 (MjM Software, Oregon, USA) conducting 40 runs that yield one to six dimensional solutions (McCune and Mefford 1999). A Monte Carlo test was performed to compare the stress of randomized data (McCune and Grace 2002). In the result of NMS ordination, the minimum stress configuration included three axes, but the two axes accounting for the most variability in the original data set are presented (NMS I as 22.2% and NMS III as 34.7%). SPSS ver. 15.0 (SPSS Inc., Chicago, IL, USA) and PC-ORD ver. 4.2 (McCune and Mefford 1999) were applied to univariate and multivariate analyses, respectively.

RESULTS

Changes in abiotic environments

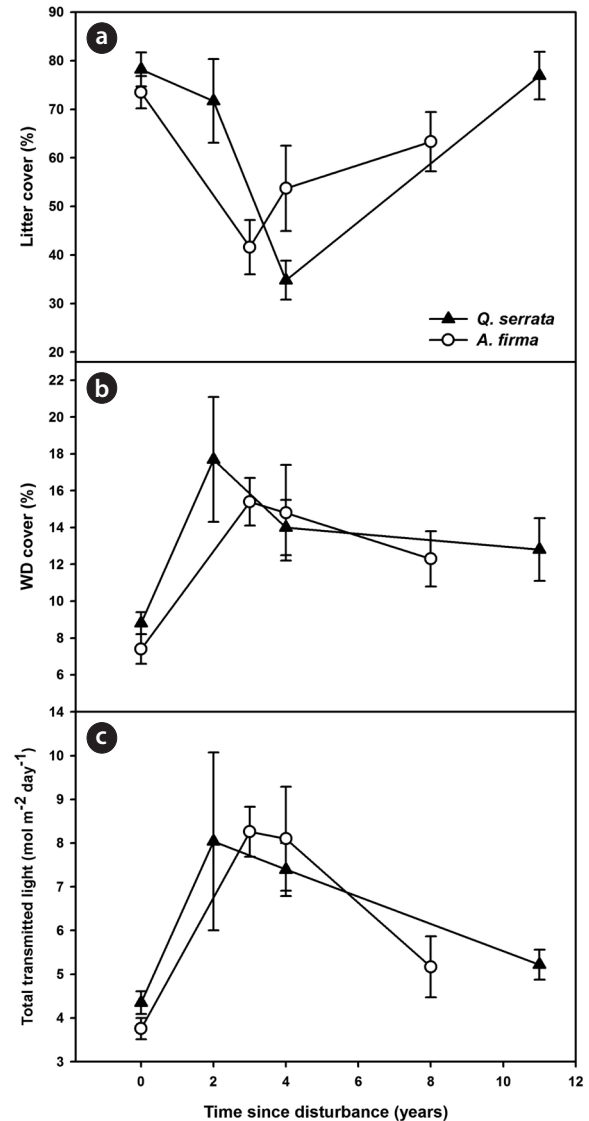


Fig. 1. (a-c) Changes in mean coverage of litter and woody debris (WD) and transmitted light as a function of the lapse of time after thinning in the study area. Vertical bars in the diagram represent mean \pm standard error. *Q. serrata*, *Quercus serrata*; *A. firma*, *Alnus firma*.

Canopy conditions (estimated light availability) and ground conditions (coverage of litter and WD cover) changed dramatically in the earlier stages after thinning, and as years passed, means of environmental variables gradually approached the control state (Fig. 1). Coverage of litter decreased immediately after thinning and then approached a reference state with the passage of time in both *Q. serrata* and *A. firma* stands (Fig. 1a). Immediately after thinning, there were big changes in transmitted light (from $4.3 \text{ mol m}^{-2} \text{day}^{-1}$ to $8 \text{ mol m}^{-2} \text{day}^{-1}$) and in coverage of WD (from 8.8% to 17.7%) in *Q. serrata* stands; the trend was the same for *A. firma* stands (Fig. 1b and 1c).

Regeneration trajectory

Ordination results explained 56.9 % of the variation in the raw data (final stress = 17.3, final instability = 0.0297). NMS ordination of subplots was expressed in mean (\pm standard error) of successional stages (Fig. 2). Variation in vegetation among successional stages was explained by NMS I (22.2%), which represented a gradient from sites with higher coverage of vine species in the negative proportion of the NMS I to those with higher scores of tree species in the positive portion. The arrangement of samples along NMS III, which explained 34.7 % of the variation, ranged from sites with higher coverage of graminoids to sites with higher cover of tree species. NMS ordination revealed different successional trajectories depending on forest type. Understory composition of natural stands (*Q. serrata*) gradually approached reference values (N0), but pathways in planted stands (*A. firma*) differed from natural ones as P8 samples were distributed far away from P0 samples.

Changes in species diversity and abundance

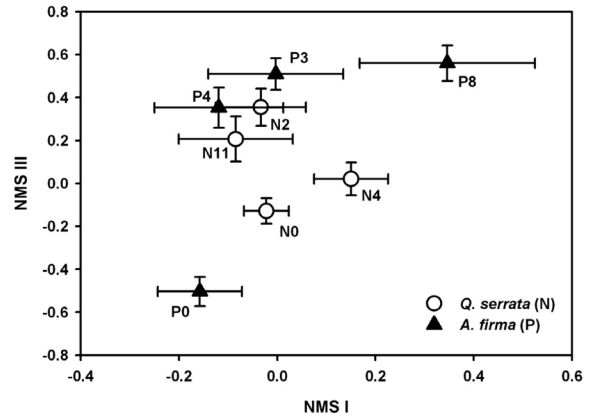


Fig. 2. Non-metric Multidimensional Scaling (NMS) ordination based on ground cover of functional types (growth form) of natural (*Quercus serrata*) and planted (*Alnus firma*) stands. NMS I and NMS III accounted for 22.2% and 34.7% of the variation in composition of functional types, respectively, resulting in a cumulative 56.9% variation in composition. Numbers after letters (N and P) indicate years since management operation. *Q. serrata*, *Quercus serrata*; *A. firma*, *Alnus firma* N, natural; P, planted.

In the shrub layer, the increase in overall richness was limited after thinning (see scale of y axes, Figs. 3a, 3c, and 3e). The change in total coverage was affected largely by

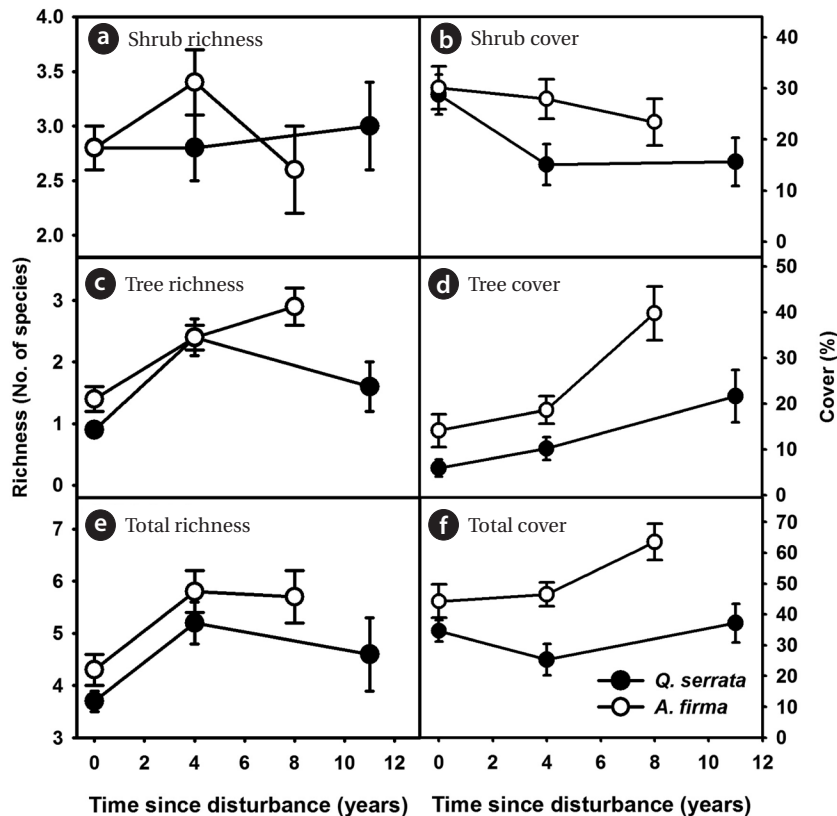


Fig. 3. (a-f) Changes in mean species richness and coverage of shrub layer species with the lapse of time after thinning in natural (*Quercus serrata*) and planted (*Alnus firma*) stands.

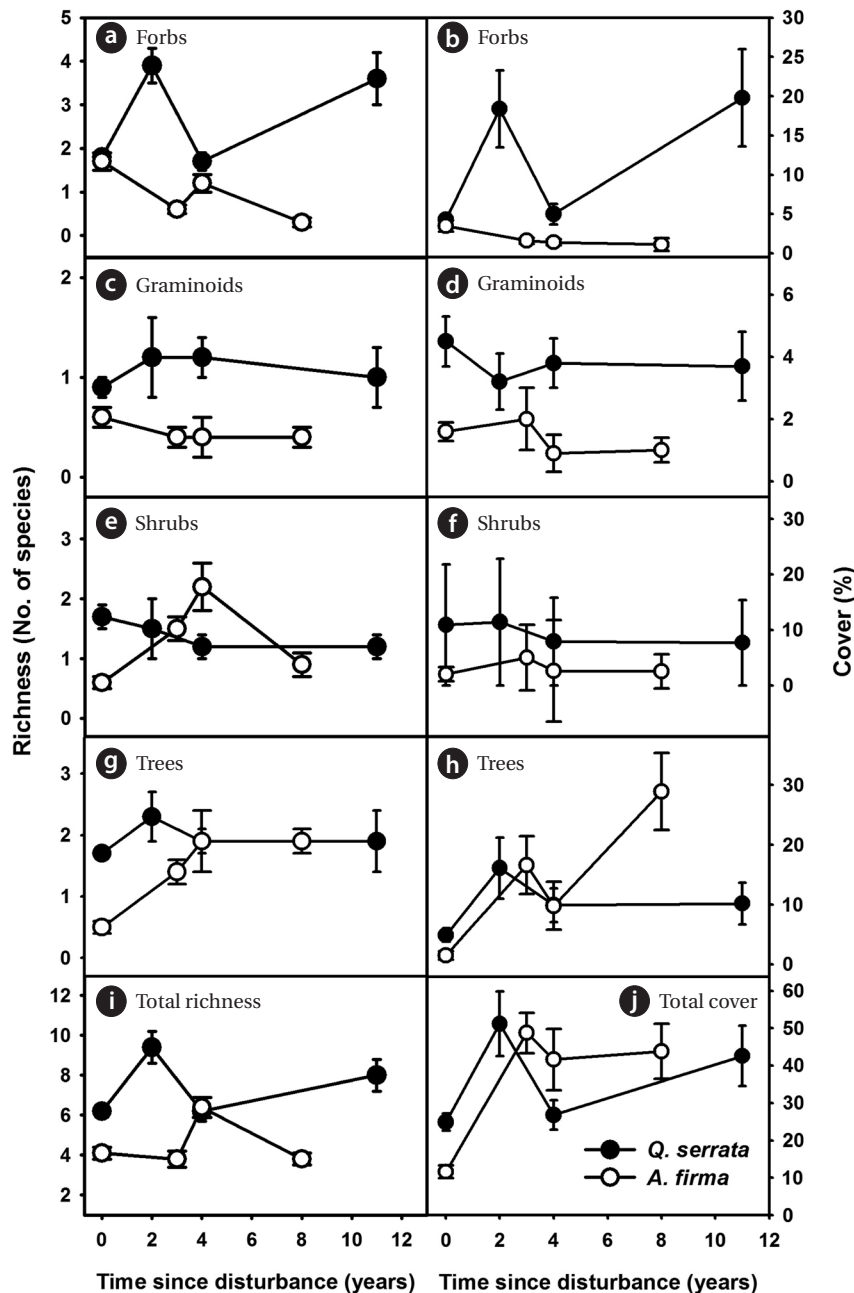


Fig. 4. (a-j) Changes in mean species richness and coverage of ground layer species over time after thinning in natural (*Quercus serrata*) and planted (*Alnus firma*) stands.

the gradual increase of tree species and the decrease of shrubs (Figs. 3b, 3d, and 3f). A limited gain in species richness after thinning was observed in ground vegetation (Figs. 4a, 4c, 4e, 4g, and 4i). Vine species were excluded from analysis because of too little richness and coverage. In *Q. serrata* stands, the increase in total richness after thinning was mainly due to an increase in forb species. In *A. firma* stands, woody (tree and shrub) species slightly increased in cover after thinning. Changes in the diversity

index (H') in natural and planted forests were similar to changes in total species richness and there were limited changes in diversity that ranged from 1.4 to 1.7 in the *Q. serrata* forest and from 0.8 to 1.1 in the *A. firma* forest (Fig. 5).

Overall, total coverage of ground vegetation increased after thinning (Figs. 4b, 4d, 4f, 4h, and 4j). Peak coverage of ground communities appeared during earlier stages in both *Q. serrata* and *A. firma* stands, after then decreased

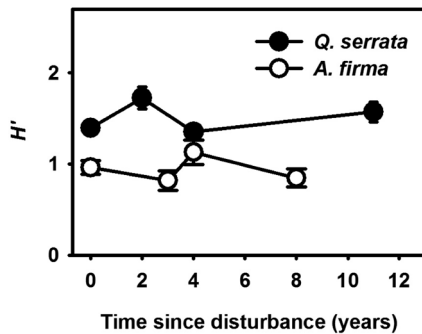


Fig. 5. Changes in the Shannon index (H') with the lapse of time after thinning in natural (*Quercus serrata*) and planted (*Alnus firma*) stands.

and gained again. In *Q. serrata* forests, the increase in total coverage was mainly due to forb species and, in *A. firma* stands, tree species usually contributed to increases in the coverage of ground vegetation.

DISCUSSION

We applied a chronosequence approach to illustrate community resilience and resistance to a thinning disturbance by showing the patterns (changes in species richness and abundance) and pathways of *Q. serrata* and *A. firma* stands. Halpern and Spies (1995) noted that forest management effects can be grouped into two broad categories: 1) initial effects of disturbances associated with logging and site preparation, and 2) effects of subsequent activities (e.g., brush cutting and mowing) that directly or indirectly alter rates or patterns of succession. In our study, subsequent forest activities after forest operation were not observed. Thus, our results showed only earlier sequences in understory regeneration in lowland natural and planted broadleaved forests in Korea. To acquire more explanatory ecological information on various forests in different successional stages, longer-term static observations are strongly recommended.

Tending works brought various changes in forest structure and ground environments. Release of tree density resulted in alteration of light and nutrient products such as decrease of litter fall (Jung et al. 2008). Coverage of ground litter decreased in earlier stages and more than 10 years were required to restore the normal state in both forests (Fig. 1). Increases in ground woody debris in earlier stages are likely due to tree felling operations. Decreases in woody debris in later stages were due to decomposition and reduction of debris production. In addition, loss of rainfall interception because of thinning (Jung et al. 2008)

may increase runoff and consequently, by wash away, can affect the amount of litter and woody debris in forests.

After thinning, species richness and diversity increased in earlier stages (within 4 years) but the magnitude was relatively limited in both *Q. serrata* and *A. firma* stands (Figs. 3-5). Because the disturbance intensity was low (maintaining canopy openness at > 50 %), increments of resources (such as light and water) required to cause species invasion was likely limited. Thinning operations at least do not reduce species diversity because residual species persistence and performance are better (Dodson et al. 2008). A gradual increase of tree cover in the shrub layer and a limited invasion of alien species such as *Bidens frondosa*, support our interpretation. Recorded invasive and ruderal species entry due to increments in available resources such as light, water and nutrients was rarely observed in either natural or planted forests. *B. frondosa*, a ruderal exotic and an annual species, and *Oplismenus undulatifolius*, a ruderal and perennial species, were recorded in thinned *Q. serrata* stands.

In herbaceous vegetation, forb species, which contributed largely to increases in richness and total cover in natural stands, are likely able to take advantage of disturbances in earlier stages. Different patterns of richness and coverage between natural and restored stands are largely explained by domino effects of thinning on *A. firma* individuals as early successional species planted during the Yeoung-il restoration project period (1972-1977). In a field survey of the managed *A. firma* stands, uncut *A. firma* individuals were frequently observed in snapped-off or standing dead states (although we did not check quantitatively). This result would be due to short longevity of *A. firma*. Such a decline in alder species in the canopy layer after thinning can cause additional disturbances on understory composition and structure, light and nutrient availability, soil water and so on.

Community stability (or persistence) may simply reflect the ability of resident species to resist change, or if altered by disturbances, their ability to readjust or recover (Halpern 1988). Different regeneration trajectories of functional type composition between stands reflect the variety of species group responses to disturbances. In addition, resistance and resilience varied between plant communities, and were likely better for natural stands and lower for plantation. The recovery pattern of the understory of *Q. serrata* stands, as they returned towards the pre-disturbance state, shows higher community stability or resilience to thinning disturbances (Fig. 2). As was mentioned above, vulnerability of early successional species, *A. firma* to disturbance affected compositional prop-

erties of understory of plantation, as travel toward alternative stable state.

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