Effects of thinning intensity on understory vegetation in *Chamaecyparis obtusa* stands in South Korea

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ABSTRACT
The study was conducted to analyze the effects of thinning intensity on understory vegetation in *Chamaecyparis obtusa* stands. The site was located on Mt Moore in Gochang-gun, South Korea and consisted of five treatment plots: 5 m × 5 m quadrats were installed in each plot. The total flora of the *C. obtusa* stand included 47 families, 60 genera, and 70 species. Three classes of floristic regional indicator plants were verified: six taxa in class I, one taxon in class II, and one taxon in class III. Also, *Phytolacca americana* and *Robinia pseudoacacia* appeared as naturalized plants in heavy thinning and control plots, respectively. Their Naturalized Index and Urbanization Index were shown as 1.00% and 0.74%, respectively. Within the treatment plots, the greatest number of species appeared in the heavily thinned plots (31 species). *Chamaecyparis obtusa* showed the highest dominance index of 4.67. Regarding species richness of understory vegetation, there was a very distinct difference between the thinned and non-thinned plots, whereas there was no significant differences among the treatment plots such as light thinning, normal thinning, heavy thinning, and super heavy thinning plots. Thus, understory vegetation was influenced by the presence of thinning, but not influenced by thinning intensity in this study.

Introduction
Thinning generally involves removal of enough trees to reduce competition for sunlight and nutrients for remaining plants in the stand (Burton 2000), so thinning has focused on the growth of individual trees to harvest as much timber as possible and earn a profit (Ares et al. 2010). However, the ideal methods of forest management including thinning should consider increasing whole biodiversity (Hartley 2002). Especially, new thinning strategies must take into account further knowledge concerning the effects of thinning procedures on structural diversity and spatial variation of understory vegetation (Ares et al. 2010) as understory vegetation acts as a major contributor to species diversity in ecosystems, and is influenced by the overstory plants (Son et al. 2004).

The effect of thinning on the growth of understory vegetation is mainly influenced by environmental factors such as wind, temperature, soil moisture, microclimate, and sunlight (Dodson et al. 2008; Jung et al. 2008). Also, thinning increases the utilization of water use (Bredda et al. 1995) and nutrients (Parsons et al. 1994) in trees. Thinning generally means cutting down enough of the trees to reduce competition for sunlight and nutrients for plants remaining in the stand (Burton 2000). Thus, thinning increases levels of sunlight and consequently impacts on growth of understory vegetation. For this reason, it is possible that the use of different management plans will have various effects on the growth of understory vegetation by controlling sunlight in managed forests.

Goo and Lee (1991) analyzed the understory vegetation and layered structure of an artificial forest of *Chamaecyparis obtusa* planted in the 1930s. They recognized similarities in the understory vegetation of several *C. obtusa* stands, and assumed that these similarities arose from the environmental conditions in these stands. Gwak and Kil (1994) predicted that some specific chemicals released from *C. obtusa* influenced its understory vegetation. After that chemical became known as phytoncide, numerous studies have been conducted regarding various aspects of its biological activity. Phytoncide suppresses growth of neighboring plants through allelopathy. Whereas various physiologic functions of phytoncide have been studied quite well, research into the effects of forest management practices on understory vegetation is still limited in South Korea.

However, these studies are very important (Lee et al. 2015) because the biomass of understory vegetation increases through time (Harrington and Edwards 1999; Gilliam 2007; Sullivan et al. 2008), and supports the majority of components of flora and biodiversity (Halpern and Spies 1995; Thomas et al. 1999; D’Amato et al. 2009). Especially, seedlings of broadleaf tree species can appear and grow as understory vegetation in a thinned plantation of coniferous species, and can also promote ecological succession (Son et al. 2004; Kang et al. 2014). In other studies, the influence of forest management, especially thinning, on understory vegetation has been evaluated by using short-term approaches (Nelson et al. 2007; Peterson and Anderson 2009), chronosequence approaches (Puettmann and Berger 2006), retrospective studies (Bailey et al. 1998; Lindh and Muir 2004), and the Density Management Study (DMS) (Cissel et al. 2006; Peterson and Anderson 2009).

Recently, interest in the effects of thinning has increased. Cho et al. (2011) analyzed the influences of thinning on understory vegetation and abiotic variables in natural and
planted broadleaved forests using a chronosequence approach. Son et al. (2004) found some management implications from relatively short-term observations in *Larix leptolepis* plantations. However, a longer-term approach is more appropriate in order to understand the effects of thinning on understory vegetation (Moore and Allen 1999).

On the other hand, since its introduction from Japan in 1904, *C. obtusa* has been selected as a major planting species and has been planted in the southern region in South Korea since the 1960s. In 2013, *C. obtusa* stands accounted for 27.37% of the total plantation area (10,378 ha) (Korea Forest Service 2014). Most of the *C. obtusa* forests are currently 40–60 years old, and only a few have been regularly managed. To achieve healthier forests it is necessary to increase their productivity and biodiversity through management techniques such as thinning, pruning, and removal of vines.

In the present study, the effects of thinning at different stand densities on understory vegetation were analyzed to inform the resources needed for managing *C. obtusa* forests by investigating total flora, floristic regional indicator plants, species richness, and dominance index 20 years after thinning.

### Materials and methods

#### Materials

The data used for this study were gathered from the *C. obtusa* stand in a Thinning Demonstration Research Area designated by the Korea Forest Service and National Institute of Forest Science (NIFOS), located at Mt Moonsu of Gochang, South Korea (35°24′17.64″N, 126°43′15.03″E). This demonstration site was created in 1976 at a mean altitude of 300 m, and was planted with 3-year-old seedlings at a density of 3000 trees per hectare. The purpose of this site was to support research on improving the regeneration and tending management system based on location and stand characteristics.

Gochang, the county in which the study site was located, has a mean temperature of 14.3 °C and a mean annual precipitation of 1003.6 mm. The geographical conditions of the site are as follows: soil type is brown forest soil; topography is ridge; climate zone is warm temperate; parent rock is metamorphic; aspect is northeast; slope is 20°–25°; and geographical location from the main forest road is > 100 m.

The site included five types of treatment plots with various levels of thinning intensities: non-thinning control; light thinning (LT); normal thinning (NT); heavy thinning (HT); and super heavy thinning (ST) (Table 1). Two plots of 20 m × 20 m size were designated for control, and three plots were designated for each treatment. Thinning was carried out once when stand age was about 27 years old in 2000. Table 1 specifies the criteria for each thinning type. Thinning weight is usually expressed by the removal of the proportion of basal area (BA) (Korea Forest Research Institute 2012). Trees were cut down at 30%, 40%, 50%, and 60% of BA for LT, NT, HT, and ST treatments, respectively. Thinning from below was also conducted, with smaller trees being removed from all plots to promote growth of larger trees.

Forest inventory measurement was done for all trees with diameter at breast height (DBH) and height in August 2014. DBH was measured at 1.2 m above ground using Mantax Blue Caliper (Haglof, Sweden), and height was measured using Clinometer PM5/360PC (SUUNTO, Finland). Mean DBH increased as thinning intensity increased (Table 2). For example, control had the lowest DBH of 16.3 cm, and ST had the greatest DBH of 23.0 cm. BA of ST showed the lowest value at 32.56 ± 11.24 m² ha⁻¹, and BA of NT had the highest value at 53.93 ± 6.09 m² ha⁻¹. Height was not significantly different among the control and treatment plots. Light intensity measurement was repeated five times using SpectroSense (Skye Instruments Ltd, UK). Each measurement was conducted for 30 min and averaged. Light intensity was lowest at 205 ± 8 μmol m⁻² s⁻¹ in control, increasing with thinning intensity: 355 ± 34 μmol m⁻² s⁻¹ for LT; 475 ± 14 μmol m⁻² s⁻¹ for NT; 649 ± 43 μmol m⁻² s⁻¹ for HT; and 1478 ± 357 μmol m⁻² s⁻¹ for ST.

#### Methods used to investigate ecological characteristics

##### Vegetation survey quadrats

Two 5 m × 5 m quadrats were installed in the control and treatment plots for enumeration of the flora in the shrub and herbaceous layers. Species, density, cover, and frequency were measured in each quadrat. Each quadrat was located in the center of each plot, taking into account the dispersion of plants and the conditions of the location. The investigation was carried out in August 2014, at which time plants were growing very well and various species were present.

##### Flora classification

The order of arrangement and scientific names of investigated plants followed the Korean Plant Names Index (Korea National Arboretum and Korean Society of Plant Taxonomists 2007) and the Engler classification system (Melchior 1964). Most species were identified on the spot, and some species difficult to identify in this manner were collected and identified in a laboratory based on the reports of Lee (1996, 2003, 2006). Rare species according to the appraisal standard of the International Union for Conversation of Nature (IUCN) were recognized by using a list of rare plants published by the Korean Ministry of Environment and National Institute of Environmental Research (2008, 2011).

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**Table 1.** Criteria for each thinning intensity. LT, NT, HT, and ST indicate light thinning, normal thinning, heavy thinning, and super heavy thinning.

| Thinning intensity | Area          | Thinning rate | Remaining trees |
|--------------------|---------------|---------------|-----------------|
| Control            | 0.04 ha × 2 plots | –             | 3000 trees ha⁻¹ |
| LT                 | 0.04 ha × 3 plots | 30%           | 2100 trees ha⁻¹ |
| NT                 | 0.04 ha × 3 plots | 40%           | 1700 trees ha⁻¹ |
| HT                 | 0.04 ha × 3 plots | 50%           | 1500 trees ha⁻¹ |
| ST                 | 0.04 ha × 3 plots | 60%           | 1200 trees ha⁻¹ |

**Table 2.** Data for each plot in the *Chamaecyparis obtusa* stand in Gochang, South Korea in 2014. LT, NT, HT, and ST indicate light thinning, normal thinning, heavy thinning, and super heavy thinning.

| Plot | Age (year) | DBH (cm) | Basal area (m² ha⁻¹) | Height (m) | Volume (m³ ha⁻¹) | Light intensity (μmol m⁻² s⁻¹) |
|------|------------|----------|----------------------|------------|-----------------|-------------------------------|
| Control | 41         | 15.5±1.7 | 49.78±10.92          | 16.3±0.2   | 442.16±48.78    | 205±8                         |
| LT      | 41         | 17.5±1.1 | 46.11±4.97           | 16.8±0.5   | 396.29±43.11    | 355±34                        |
| NT      | 41         | 21.4±0.6 | 53.93±6.09           | 17.7±0.5   | 533.39±68.77    | 475±14                        |
| HT      | 41         | 22.5±0.4 | 52.59±4.22           | 17.4±0.7   | 441.54±25.76    | 649±43                        |
| ST      | 41         | 26.0±0.4 | 32.56±11.24          | 17.3±0.5   | 256.24±74.06    | 1478±357                      |
Endemic plants were diagnosed based on the report of Oh (2005), and floristic regional indicator plants were arranged according to national natural environment survey guidelines (Kim 2000). A total of 1071 taxa were classified into five taxonomic groups according to their appearance in four floristic regions and their appearance at high altitude (Kim 2000; Table 3). The four floristic regions were as follows: the middle province; the southern province; the southern coast province; and Jeju Province. Taxa appearing in three or more of these regions were assigned to class I, taxa growing naturally at altitudes over 1000 m in the Baekdudaegan Mountains were assigned to class II, taxa appearing in two of the regions were assigned to class III, taxa appearing in only one region were assigned to class IV, and isolated taxa were assigned to class V.

Naturalized plants were named using the list suggested by Lee et al. (2011), and the naturalization rate was calculated as the ratio of naturalized plants to total plants appearing in the study area. In biology, naturalization is any process by which a non-native organism spreads into the wild and reproduces sufficiently to maintain its population. Park (1994) reported naturalization in South Korea by 33 families, 176 species, three mutants, and two varieties (181 taxa) in a 1994 report, and by 30 families, 176 species, five mutants, and one variety (182 taxa) in a 1995 book (Park 1995); she reported 267 naturalized taxa in a second edition of the book (Park 2001), and reported 271 during a 2002 study on the distributions of naturalized alien plants in Korea (Park 2002), including 37 families, 150 genera, 254 species, 15 mutants, and two varieties (271 taxa). Recently, Lee et al. (2011) rearranged the naturalized plants of Korea as 321 taxa, including 40 families, 175 genera, 302 species, 15 mutants, and four varieties.

Also, the Naturalized Index (NI) and Urbanization Index (UI) were calculated using the methods of Numata and Kotaki (1975) and Yim and Jeon (1980), respectively, as follows:

\[ \text{Naturalized Index} (\%) = \frac{\text{Total number of naturalized species in study area}}{\text{Total number of vascular species in study area}} \times 100 \]  

\[ \text{Urbanization Index} (\%) = \frac{\text{Total number of naturalized species in study area}}{\text{Total number of naturalized species in South Korea}} \times 100 \]

Naturalized species are those that have become established as a part of the plant life of a region other than their place of origin. To qualify for such status, the species must be foreign, be able to grow on its own, and produce a new generation without watering, fertilizing, pest control, dividing, or weed control. Naturalization is a major cause of extinction of native species (Czech et al. 2000), but the diverse nature of urban land use can have a complex impact on local biodiversity (McKinney 2008). Native species biodiversity can be decreased, however, total species richness can be improved due to urbanization by adding non-native species that grow faster than native species (McKinney 2006).

**Dominance index analysis**

Ecological dominance is the degree to which a taxon is more numerous than its competitors in an ecological community. Most ecological communities are defined by their dominant species (Kang 2008). Methods to measure dominance are usually divided into two types; one entails the combined use of several standards such as volume, frequency, cover, and density, and the other uses only one criterion that combines some of those listed above. In general, density, cover, and frequency are the most widely used criteria. Density is defined as the number of individuals per unit area, frequency is the number of quadrats in which a particular species appears, and cover is the degree of cover by a given species, classified into five levels: <5% for the first level, 5%–25% for the second, 25%–50% for the third, 50%–75% for the fourth, and >75% for the fifth.

There are various methods for quantifying and/or categorizing dominance that combine several criteria. The first method is that of J. Braun-Blanquet, which combines cover and density and includes seven categories for each: r represents an isolated situation; + represents a few populations with a low covered area; and additional degrees of 1 to 5 coincide with the cover levels mentioned above (Braun-Blanquet 1932, 1964). A second method is the Density-Frequency-Dominance (DFD) index using the sum of density, frequency, and dominance (Cottam 1949). A third method, called the great dominance method, mixes the relative density, frequency, and cover in a manner that emphasizes the interspecific dominance relationship. The last commonly used method is the sum of the dominant rate method, which is based on the mean of several measurement criteria. The J. Braun-Blanquet method was used in the present study.

In this study we suggest a classification of dominance values (DV) that can be used to compare and analyze the dominant degree of understory vegetation according to the thinning intensity. This DV combined cover and density values, and ranged from 0.5 to 10 corresponding to each of the seven categories of J. Braun-Blanquet for both density and cover. These combined values indicate the sum of cover and density, and make it easy to understand and compare the dominance of each species. Additionally, in the present work, after we estimated DV based on the density and cover, we attempted to reclassify and compare the DVs for species in all layers by combining the DVs of the shrub layer and herbaceous layer. This was carried out by using the relative mean dominance value (RMDV) to compare DVs between different layers, calculated by assigning the weight of 1 to the dominance value of the herbaceous layer (HDV) and the weight of 2 to the dominance value of the shrub layer (SDV), as
follows. This was a method developed by Kim et al. (2012), being a modification of the Curtis and McIntosh method (1951):

$$DV = \frac{\text{Density} \times \text{Cover}}{2} + \frac{\text{HDV} \times 1}{3}$$

The MDV value was used in the present work as the dominance index (DI), quantifying the dominance of a species in the study area.

All statistical procedures for ANOVA and Duncan’s multiple range test related to post-equilibrium test were performed using SAS v9.3.

**Results and discussion**

**Flora analysis**

**Total flora**

The total flora of the *C. obtusa* stand in Mt Moonsu comprised flora of 47 families, 60 genera, 70 species, six mutants, and three varieties (Table 4). Of the total 79 taxa, woody plants represented 48 taxa (60.7%) and herbaceous plants represented 31 taxa (39.3%). Also, pteridophyta comprised five families, six genera, and nine species (nine taxa, 11.3%); gymnospermae comprised two families, two genera, and two species (two taxa, 2.5%); and subtotal angiospermae comprised 40 families, 52 genera, 59 species, six mutants, and three varieties (68 taxa, 86.2%).

**Floristic regional indicator plants**

Three classes of floristic regional indicator plants were verified in the study area: six taxa in Class I, one taxon in Class II, and one taxon in Class III (Table 5). Only one species, *Meliosma oldhamii*, out of eight species detected as the floristic regional indicator plants was found at all plots, and three species, *Gynostemma pentaphyllum*, *Mallotus japonicas*, and *Dryopteris varia*, were recorded at four plots including control. *Ilex macrophylla* and *Vaccinium oldhami* of Class I appeared at two plots, and *Dryopteris uniformis* of Class I and *Morus cathayana* of Class II were detected at ST and HT, respectively. There was no significant difference between the emergence of floristic regional indicator plants and thinning intensity. Thus, it is considered that thinning does not have any influence on the understory vegetation in relation to the selective blockage or induction of specific plants among the floristic regional indicator plants.

**Plant naturalization analysis**

Two naturalized plants, *Phytolacca americana* in the HT plot and *Robinia pseudoacacia* in the control, appeared in the study area (Table 6), and its NI and UI were found to be 1.00% among the vascular plants of 199 taxonomic groups (Lee et al. 2011) and 0.74% among the total species of 271 taxonomic groups (Park 2002). Therefore, the correlation between stand density and plant naturalization did not appear clearly. Also, disturbance of the ecosystem by naturalized plants has not yet proceeded seriously in the study area. However, as disturbance has begun, a management plan for avoiding this disturbance should be prepared to protect indigenous species and to prevent damage to the ecosystem of Mt Moonsu in South Korea.

**Community structure change**

**Analysis of species compositions and determination of dominance values**

The number of species appearing in a quadrat of each plot were 14 and nine in control, 25 and 16 in LT, 22 and 17 in NT, 19 and 24 in HT, and 19 and 23 in ST (Table 7). Those appearing in the treatment plots were 31 species in HT, 29 species in each of LT and NT, 28 species in ST, and 17 species in control. A total of 63 species appeared in all quadrats; the first quadrat in LT had the most species at 25, whereas the second quadrat in control had the fewest with nine. Regarding the frequency of individual species, *Athyrium yokoscense* and *Oplismenus undulatifolius* appeared in all quadrats, *Parthenocissus tricuspidata* and *Lindera erythrocarpa* appeared in 90%, and *Thelypteris palustris*, *Smilax china*, and *C. obtusa* appeared in 80%. In addition, 12 plant species were observed in both the shrub and herbaceous layers among all control and treatment plots.

Regarding the DVs of plants considered throughout the study area, *C. obtusa* and *P. tricuspidata* had the greatest (4.4), followed by *T. palustris* (2.3), *A. yokoscense* (2.2), *O. undulatifolius* (2.2), and *Styrax japonicus* (2.2). Considering the different plot types, *P. tricuspidata* had the greatest DV in the control plots and *C. obtusa* had the greatest in all of the thinned plots. *Chamaecyparis obtusa* seedlings were most numerous in ST plots, and did not grow in control plots.
Table 7. Species composition in the Chamaecyparis obtusa stand. LT, NT, HT, and ST indicate light thinning, normal thinning, heavy thinning, and super heavy thinning.

| Community type                  | Control | LT | NT | HT | ST | No. of appearances | Constant ratio |
|---------------------------------|---------|----|----|----|----|--------------------|---------------|
| Serial number                   | 1       | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
| Quadrat number                  | 1       | 2  | 1  | 2  | 1  | 2  | 1  | 2  | 1  | 2  |
| Number of species               | 14      | 9  | 25 | 16 | 22 | 17 | 19 | 24 | 19 | 23 |
| Athyrium yokoscense (Franch. & Sav.) H.Christ | H     | +  | r  | 1.1 | +  | +  | +  | +  | +  | +  | 10 | 100 |
| Ophiopogon planiscapus (Andr.) P.Beaup. | H       | 1.1 | 2.2 | 1.1 | +  | +  | +  | +  | +  | +  | 10 | 100 |
| Parthenocissus tricuspidata (Siebold & Zucc.) Planch. | H       | +  | +  | +  | +  | +  | +  | +  | +  | +  | 9  | 90  |
| Lindera erythrocarpa Makino     | S       | +  | +  | +  | 1.2 | 1.1 | +  | +  | 9  | 90 |
| Thelypteris palustris (Salisb.) Schott | H       | +  | +  | +  | r  | +  | 2.3 | 1.1 | +  | 8  | 80 |
| Smilax china L.                | S       | +  | +  | +  | +  | +  | +  | +  | 8  | 80 |
| Celastrus orbiculatus          | H       | +  | +  | +  | +  | +  | +  | +  | +  | +  | 5  | 50  |
| Quadrat number                 | 1       | 2  | 1  | 2  | 1  | 2  | 1  | 2  | 1  | 2  |
| Serial number                  | 15      | 9  | 30 | 20 | 26 | 19 | 20 | 25 | 23 | 27 |
| Celastrus orbiculatus Thunb.   | H       | +  | r  | +  | r  | +  | +  | +  | +  | +  | 2  | 20  |
| Castanea crenata Siebold & Zucc. | S       | -  | -  | +  | +  | 2.2 | -  | -  | +  | +  | 2  | 20  |
| Solanum lyratum Thunb.         | H       | +  | +  | +  | 1.1 | -  | -  | +  | +  | +  | 2  | 20  |
| Cymbidium goeringii Reichb. fil. | H   | +  | r  | r  | +  | +  | -  | -  | r  | -  | 2  | 20  |
| Carex forficulosa Franch. & Sav. | H | r  | +  | r  | r  | r  | -  | -  | r  | -  | -  | 2  | 20  |
| Asplenium schinifolium Siebold & Zucc. | H | r  | +  | r  | r  | +  | r  | -  | r  | -  | 2  | 20  |
| Total number of species         | 17      | 19 | 29 | 31 | 31 | 29 | 31 | 28 | 28 | 28 |

Note: H = herbaceous layer; S = shrub layer.
from the results of DI of understory vegetation in each treatment plot of the study area. LT, NT, HT, and ST indicate light thinning, normal thinning, heavy thinning, and super heavy thinning.

| Community type | Control | LT | NT | HT | ST | Mean DI |
|---------------|---------|----|----|----|----|---------|
| Number of species | 17 | 29 | 29 | 31 | 28 | |
| Chamaecyparis obtusa (Siebold & Zucc.) Endl. | - | 4.50 | 4.17 | 4.33 | 5.67 | 4.67 |
| Castanea crenata Siebold & Zucc. | - | - | - | 2.67 | - | 2.67 |
| Linderia erythrocarpa Makino | 1.67 | 1.67 | 1.33 | 1.83 | 1.00 | 1.50 |
| Parthenocissus tricuspidata (Siebold & Zucc.) Planch. | 0.83 | 0.83 | 2.00 | 0.33 | 2.33 | 1.27 |
| Zanthoxylum schinifolium Siebold & Zucc. | - | - | - | 0.83 | 1.50 | 1.17 |
| Styx japonicus Siebold & Zucc. | - | 0.33 | 0.67 | 0.67 | 2.67 | 1.08 |
| Linderia glauca (Siebold & Zucc.) Blume | 0.33 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Melissa officinalis L. | - | - | - | - | - | - |
| Rubus coreanofolius L. fil. | - | 1.00 | 0.67 | 1.00 | 1.00 | 0.92 |
| Smilax china L. | 0.17 | 1.00 | 0.33 | 1.00 | 1.00 | 0.70 |
| Viburnum dilatatum Thunb. | - | - | - | - | - | - |
| Prunus sericosa (Koidz.) Koehne | - | - | - | 0.67 | - | 0.67 |
| Dryopteris uniformis (Makino) Makino | - | - | - | - | - | - |
| Stephanaia incisa (Thumb.) Zabel | - | - | - | 0.67 | - | 0.67 |
| Ilex macropoda Miq. | - | 0.67 | - | - | - | 0.67 |
| Aralia elata (Miq.) Sieemann | - | 0.67 | - | - | - | 0.67 |
| Prunus persica (L.) Batsch | - | - | - | 0.67 | - | 0.67 |
| Morus bombycis Koiz. | - | - | - | - | - | - |
| Hydrangea serrata f. acuminata E.H.Wilson | - | 0.67 | - | - | - | 0.67 |
| Callicarpa japonica Thunb. | - | - | - | 0.67 | - | 0.67 |
| Boehmeria spicata (Thunb.) Thunb. | - | - | - | - | - | - |
| Celtis sinensis Pers. | - | - | - | 0.67 | - | 0.67 |
| Oplismenus undulatifolius (Franch.) M.Kata | 0.42 | 1.00 | 0.50 | 0.83 | 0.50 | 0.65 |
| Carex forskaliae Franch. & Sav. | 0.17 | - | - | - | - | 0.58 |
| Thelypteris palustris (Salsib.) Schott | 0.33 | 0.33 | 0.25 | 1.00 | 0.50 | 0.52 |
| Solanum lyratum Thunb. | - | 0.67 | - | - | - | 0.50 |
| Phryma leptostachya var. asiatica H.Hara | - | - | - | 0.33 | - | 0.50 |
| Athyrium yokoscense (Franch. & Sav.) H.Christ | 0.25 | 0.50 | 0.33 | 0.83 | 0.33 | 0.45 |
| Lindera obtusiloba Blume | 0.17 | 0.83 | - | 0.33 | - | 0.44 |
| Ampelopsis heterophylla f. citrifoloides Rehder | 0.67 | 0.33 | 0.33 | 0.33 | - | 0.42 |
| Persicaria filiformis (Thunb.) Nakai ex Mori | - | - | - | 0.33 | 0.50 | 0.42 |
| Carex humilis var. nana (H. Lev. & Vaniot) Ohwi | - | - | - | 0.33 | - | 0.33 |
| Actinidia polygama Planch. ex Maxim. | 0.33 | - | - | - | - | 0.33 |
| Boehmeria platphonifolia Fr. et Sav. | - | - | - | 0.33 | - | 0.33 |
| Paederia scandens (Lour.) Merr. | - | 0.33 | 0.33 | - | - | 0.33 |
| Osmunda japonica Thunb. | - | - | - | 0.33 | - | 0.33 |
| Vitis filicifolia var. sinuata (Regell) H.Hara | - | - | - | 0.33 | - | 0.33 |
| Asplenium inundatum Thunb. | - | 0.33 | - | - | - | 0.33 |
| Trachelospermum asiaticum Nakai | - | - | - | 0.33 | - | 0.33 |
| Rhus sylvestris Siebold & Zucc. | - | 0.33 | - | - | - | 0.33 |
| Vitis flexuosa Thunb. | 0.33 | 0.33 | - | - | - | 0.33 |
| Dryopteris varia (L.) Kunze | 0.33 | 0.33 | - | 0.33 | 0.33 | 0.33 |
| Dioscorea japonica Thunb. | - | - | - | 0.33 | - | 0.33 |
| Lysimachia clethroides Duby | - | - | - | 0.33 | - | 0.33 |
| Mallotus japonicus (Thunb.) Muell. Arg. | 0.17 | 0.17 | 0.17 | - | 0.67 | 0.29 |
| Quercus serrata Thunb. | 0.17 | 0.17 | 0.17 | - | 0.67 | 0.29 |
| Lithocarpus spinatus (Thunb.) Loureir | 0.33 | - | - | - | - | 0.25 |
| Ampelopsis brevipedunculata (Maxim.) Trautv. ex Maxim. | - | 0.33 | - | 0.17 | - | 0.25 |
| Smilax sieboldii Miq. | - | - | 0.33 | 0.17 | - | 0.25 |
| Disporum smilacinum A. Gray | 0.17 | - | 0.17 | - | 0.33 | 0.22 |
| Rhus trichocarpa Miq. | - | 0.17 | - | - | - | 0.17 |
| Celastrus orbiculatus Thunb. | 0.17 | 0.17 | - | - | - | 0.17 |
| Sambucus williamsonii var. coreana Nakai | - | - | - | 0.17 | 0.17 | 0.17 |
| Dioscorea batatas Decne. | - | - | - | 0.17 | - | 0.17 |
| Phytolacca americana L. | - | - | - | 0.17 | - | 0.17 |
| Cymbidium goeringii Reichb. fil. | - | 0.17 | - | 0.17 | - | 0.17 |
| Cryptomeria japonica (L. fil.) D.Don | 0.17 | - | - | - | - | 0.17 |
| Smilax nipponica Miq. | 0.17 | 0.17 | 0.17 | - | - | 0.17 |
| Calamagrostis arundinacea (L.) Roth | - | 0.17 | - | 0.17 | - | 0.17 |
| Crepidiostrium dentilatum Pak & Kawano | - | 0.17 | - | - | - | 0.17 |
| DePortia conifera (Franch. & Sav.) M.Kata | 0.17 | - | - | - | - | 0.17 |
| Cornus controversa Hemsld. ex Prain | 0.17 | 0.17 | - | 0.17 | - | 0.17 |
| Humulus japonicus Siebold & Zucc. | - | - | - | 0.25 | - | 0.25 |

**Dominance index results**

From the results of DI of understory vegetation in each treatment plot, **C. obtusa** showed the highest DI value of 4.67 (Table 8). There was a relatively small difference of the frequency of each plot based on the thinning intensities, whereas there was a very distinct difference between the thinned and control plots. Thus, thinning appeared to have a strong influence on natural regeneration. **Castanea crenata** showed the next highest DI of 2.67, with high density and low frequency; it was thus judged to have great resistance to phytoncide and a low natural reproduction rate.

The top 10 species in terms of DI fell into three groups. The first group included species appearing in all treatment plots, having strong tolerance to phytoncide and shade: **L.**.
erythrocarpa, P. tricuspidata, Lindera glauca, and S. china. The second group included species appearing in all thinning treatment plots, having strong tolerance to phytoncide and weak tolerance to shade: C. obtusa, S. japonicus, and Rubus corchorifolius. There was no remarkable correlation between the appearance of species in this group and thinning intensity. The third group included species having high DI and low frequency: C. crenata, Zanthoxylum schinifolium, and Meliosma oldhamii. These species were strongly tolerant to phytoncide and shade, but did not show any specific correlation with the thinning intensity; such a lack of correlation, despite the differences in available sunlight, may have arisen from these species' low reproductive and germination rates.

Changes in species density, cover, and species richness

Degrees of density and cover were similar in all treatment plots (Figure 1). Increased density led to high cover due to the increase in number of plants. The total density and cover of shrub layer were lowest at the control plots (0.5 and 0.5, respectively), and can be divided into two groups. Whereas, herbaceous layer had three groups of both density and cover; ST belongs to the first group with the highest density and cover (8.5 and 9.5, respectively), LT, NT, and HT belong to the second group, and control belongs to the third group with the lowest density and cover (3.9 and 4.4, respectively). It was clear that thinning makes density and cover increase, but any significant difference was not observed between the thinned plots. Among the top 10 species, C. obtusa saplings occurred with a very high density and cover in all thinned plots, but did not appear in the control plots. Thus, further study on the relationship between thinning and natural regeneration may be valuable.

The treatment plots were compared using species richness related to the frequency of the species (Figure 2). Species richness was lowest in the control plots (1.0 in the shrub layer and 11.0 in the herbaceous layer). In both the shrub and herbaceous layers, the increases in overall species richness were limited to 6.5 and 18.5, respectively, despite increased thinning intensity. In integrated layers, total species richness after thinning mainly increased due to the increase in herb species. However, the difference of species richness between the unthinned and thinned plots was larger in the shrub layer.

Overall, integrated layers of shrubs and herbs clearly showed the effects of thinning on understory vegetation. Species richness of the thinned plots was slightly more or less than 20, which is significantly higher than that of the unthinned plots (11.5). Thinning treatment usually had significant effects on the increases in species richness of understory vegetation (He and Barclay 2000; Decocq et al. 2004; Jobidon et al. 2004). However, in this study, thinning clearly showed the effect of improving the species richness of the understory vegetation, but there was no significant difference between thinning intensity and species richness.

![Figure 1](image1.png)

**Figure 1.** Changes in density and cover of major top 10 species in shrub, herbaceous, and integrated layers in Chamaecyparis obtusa stands about 20 years after thinning. (a), (b), and (c) show the total density, and (d), (e), and (f) show the total cover. CON, LT, NT, HT, and ST indicate control, light thinning, normal thinning, heavy thinning, and super heavy thinning plots, respectively. Means with the same letter are not significantly different at α = 0.05 and P < 0.01 (Duncan's post hoc comparisons). Error bars denote standard deviation of mean.

![Figure 2](image2.png)

**Figure 2.** Changes in mean species richness of shrub (a), herbaceous (b), and integrated (c) layers in Chamaecyparis obtusa stands about 20 years after thinning. CON, LT, NT, HT, and ST indicate control, light thinning, normal thinning, heavy thinning, and super heavy thinning plots, respectively. Means with the same letter are not significantly different at α = 0.05 (Duncan’s post hoc comparisons). Error bars denote standard deviation of mean.
Conclusions
A C. obtusa stand on Mt Moonsu in Gochang, Korea showed a total of 79 taxa as 47 families, 60 genera, 70 species, six mutants, and three varieties, including 48 taxa (60.7%) of woody plants and 31 taxa (39.3%) of herbaceous plants. Three classes of floristic regional indicator plants appeared: six taxa in Class I, one taxon in Class II, and one taxon in Class III. There were two naturalized plant species in the C. obtusa stand, P. americana and R. pseudocacia, so early precaution against naturalization is required to prevent indigenous species and to prevent damage to the ecosystem of Mt Moonsu. By the results of the flora analysis, species diversity was increased by thinning. Relatively abundant species diversity generally has complex interactions for ecosystem, landscape, species, communities, and genes. Because of this complexity, especially in the various forest ecosystems, stability and function of forests could be retained. Thus, thinning makes forests healthier and stronger against diseases and insect pests without promoting the introduction of alien species.

Regarding the DI of understory vegetation, C. obtusa showed the highest value at 4.67; C. crenata had the next highest at 2.67 and appeared in high density with low frequency. The top 10 species in terms of DI fell into three groups: species appearing in all plots; species appearing in all thinned plots; and species having great DI and low frequency. These species were strongly tolerant to phytocid and shade, but did not show any specific correlation with thinning intensity; such a lack of correlation, despite the differences in light intensity, may have arisen from these species’ low reproductive and germination rates.

In conclusion, some implications of thinning can be summarized as follows. First, thinning improved the inflow of various plants from the outside by inducing natural reproduction, but does not cause ecosystem disturbance due to the introduction of alien species. Therefore, it is considered that thinning is very effective in inducing natural reproduction based on ecological stability. Second, species diversity of understory vegetation analyzed by density and cover was very sensitive to the presence of thinning, although there was no significant difference according to the thinning intensity. Thus, thinning leads to increases in density, cover, and species richness of understory vegetation and is therefore considered to be a forest management prescription that not only promotes the growth of trees but also improves the health of forests by stabilizing the ecosystem.

Disclosure statement
No potential conflict of interest was reported by the authors.

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