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Thinning Effects on Litterfall Inputs and Litter Decomposition in *Pinus densiflora* S. et Z. and *Quercus variabilis* Blume Stands

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Abstract

This study was conducted to examine litter inputs and litter decomposition rates following thinning, which is among the most important forest management activities that enhance the beneficial functions in Korean forests. Litter inputs and litter decomposition rates following a 2-year elapse from thinning in *Pinus densiflora* and following a 7-year elapse from thinning in *Quercus variabilis* stands were measured for 2 years from 16 sites in three regions (Sancheong-gun, Uiryeong-gun, and Jinju-si) in Gyeongsangnam-do, Korea. Annual needle litter inputs in *P. densiflora* stands were significantly decreased following thinning, whereas annual broadleaved leaf litter inputs in *Q. variabilis* stands were not significantly different between thinned and unthinned treatments. The annual mean total litter inputs in both tree species were significantly lower in the thinned (*P. densiflora*: 3,653 kg ha^{-1} year^{-1}; *Q. variabilis*: 4,963 kg ha^{-1} year^{-1}) compared to the unthinned stands (*P. densiflora*: 5,138 kg ha^{-1} year^{-1}; *Q. variabilis*: 5,997 kg ha^{-1} year^{-1}) during the study period. The mass loss rates from decomposing needle litter in *P. densiflora* stands were significantly lower ($p<0.05$) in the thinned stands than in the unthinned stands for two sampling dates of the eight included in the study, whereas the decomposition rates from decomposing leaf litter in *Q. variabilis* stands were not affected by thinning. The results indicate that thinning effects on total litter inputs remained clear following a 2-year elapse from thinning in *P. densiflora* stands and following a 7-year elapse from thinning in *Q. variabilis* stands.

Key Words: canopy removal, litterfall, litter decomposition, thinning, tree removal

Introduction

Litterfall inputs and litter decomposition represent a key component in the biogeochemistry of forest ecosystems because significant amounts of organic matter and nutrients in the soil can be transferred during the litter decomposition processes with litterfall inputs (Berg and Laskowski 2006; Bravo-Oviedo et al. 2017; Krishna and Mohan 2017). The amount of litterfall inputs and litter decomposition processes depends on several ecological factors and forest management activities, such as tree species, climate, site quality, stand age, stand density, fertilization, and thinning (Park et al. 2008; Kim et al. 2012a; Bueis et al. 2018; Çömez et al. 2019).

Understanding litterfall quantity and litter decomposition following thinning is important because changes in litterfall inputs and litter decomposition can alter nutrient cycling processes in forest stands (Kim et al. 2012a, 2012b;

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Lado-Monserrat et al. 2016). Thus, the change in litterfall inputs and litter decomposition following thinning has received considerable research attention (Kim et al. 2012a; Lado-Monserrat et al. 2016; Bravo-Oviedo 2017; Çömez et al. 2019). For example, litter inputs following thinning tend to decrease roughly in proportion to the degree of thinning intensity (Kim 2016; Çömez et al. 2019), whereas litter decomposition rates were increased (Piene and Van Cleve 1978), were not changed (Kim et al. 1996a; Lado-Monserrat et al. 2016) or decreased (Blanco et al. 2011; Kim et al. 2012b). Litter decomposition rates following thinning could be attributed to soil environmental variables (Kim et al. 2012b), litter quality (Kim 2016), and abundance of soil organisms (Blanco et al. 2011). However, it is difficult to expand spatial scales from these studies because the results in most thinning studies are based on a single site one and two years after thinning treatments.

Thinning is one of the most important forest management activities conducted by the Korean government. An area of 558 thousand ha was managed by thinning between 2014 and 2018 to enhance economic and ecological services in Korean forests (Korea Forest Service 2019), but little is known about the underlying changes between litter inputs and litter decomposition rates in response to thinning based on local spatial scales.

The objectives of this study were 1) to evaluate the effects of litterfall inputs, and 2) to determine litter decomposition rates following thinning in *Pinus densiflora* S. et Z. and *Quercus variabilis* Blume, which are representative conifer and deciduous hardwood tree species distributed widely in Korea.

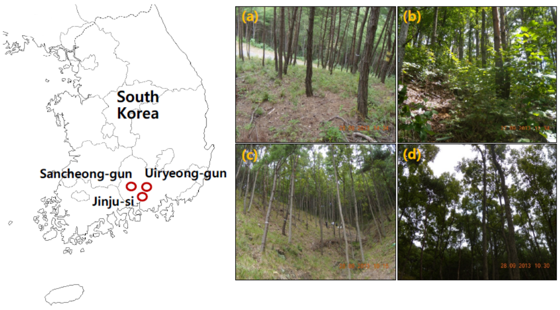

Fig. 1. Location of the study site [thinned (a) and unthinned (b) treatments in *P. densiflora* stands; thinned (c) and unthinned (d) treatment in *Q. variabilis* stands].

Material and Methods

The study was conducted at three local spatial scales (Jinju-si, Sancheong-gun, and Uiryeong-gun) in Gyeongsangnam-do (Fig. 1), southern Korea. The annual mean precipitation and temperature for 30 years in the study area are 1,556 mm year^{-1} and 12.8°C for Sancheong-gun, 1,493 mm year^{-1} and 13.5°C for Jinju-si, and 1,436 mm year^{-1} and 13.6°C for Uiryeong-gun, respectively (Korea Meteorological Administration 2019). The soils in the study site are well-drained, slightly wet, or dry brown forest soil (mostly Inceptisols, USDA soil taxonomy) originating from granite in Sancheong-gun and Uiryeong-gun, with a loamy texture. The soils in Jinju-si are slightly dry, dark reddish brown forest soil (mostly Inceptisols, USDA soil taxonomy) originating from sandstone or shale. The study site consisted of approximately 45-year-old natural *P. densiflora* and *Q. variabilis* stands (Table 1). The experimental design consisted of eight 20 m×20 m plots with four thinned and four unthinned stands in two adjacent *P. densiflora* and *Q. variabilis* stands (total of 18 plots), respectively. Thinning with the removal of approximately 30% of the basal area was applied two years ago (2012) in *P. densiflora* stands and 7 years ago (2007) in *Q. variabilis* stands from thease study sites (Table 1).

To measure litterfall inputs, three circular litter traps with a surface area of 0.25 m^2 were installed 60 cm above the forest floor at each plot on March 14, 2014. Litter was collected at three-month intervals between March 2014 and March 2016 (24 June, 19 September, and 13 November 2014; 12 March, 10 June, 10 September, and 27 November 2015; 12 March 2016). The litter from each trap was transported to a laboratory and then oven-dried at 65°C for 48 h. All dried samples were separated into needles, broadleaved leaves, branches, and miscellaneous components, and each portion was weighed.

Needle or leaf litter decomposition rates were measured using the litterbag technique (Krishna and Mohan 2017). Fresh needles and leaf litter from each treatment were collected from the forest floor in late November of 2013. After collection, the litter was air-dried for 14 days, and a sample of approximately 10 g was weighed to the nearest 0.01 g and placed in a 30 cm × 30 cm nylon net bag with a mesh size of 0.1 mm. Sub-samples from the litter were also taken to de-

Table 1. General characteristics of thinned and unthinned treatments in *Pinus densiflora* and *Quercus variabilis* stands

Species	Stand age (yrs)	Treatment	Location	Elevation (m a.s.l.)	Slope (°)	Aspect (°)	Stand density (tree ha^{-1})	Thinning year
P. densifora	40	Unthinned	35°22′13″N 128°10′35″E	430	25-30	130	1,275	-
		Unthinned	35°22′13″N 128°10′35″E	418	25-30	135	1,125	-
		Thinned	35°22′14″N 128°10′36″E	414	25-30	135	825	2012
		Thinned	35°22′14″N 128°10′37″E	402	25-30	160	625	2012
	46	Unthinned	35°12′31″N 128°10′27″E	160	25	270	2,100	-
		Unthinned	35°12′27″N 128°10′26″E	188	30	260	1,975	-
		Thinned	35°12′27″N 128°10′24″E	184	30	260	1,500	2012
		Thinned	35°12′370 N 128°10′23 E	154	35	315	925	2012
Q. variabilis	45	Unthinned	35°22′27″N 127°51′12″E	474	25-30	250	625	-
		Unthinned	35°22′28″N 127°51′11″E	475	25-30	260	900	-
		Thinned	35°22′26″N 127°51′10″E	460	20	270	450	2007
		Thinned	35°22′29″N 127°51′11″E	470	25-30	270	250	2007
	46	Unthinned	35°12′30″N 128°10′26″E	159	15-20	270	1,125	-
		Unthinned	35°12′32″N 128°10′27″E	163	15	235	1,950	-
		Thinned	35°12′29″N 128°10′27″E	164	10	270	850	2007
		Thinned	35°12′38″N 128°10′23″E	154	35	110	600	2007

termine the oven-dried mass after heating at 65°C for 48 h. Thirty litterbags for each treatment plot (total 180 bags) were randomly placed on the forest floor on December 11, 2013. The litterbags were collected eight times (14 March, 24 June, 19 September, and 13 November 2014; 12 March, 10 June, 10 September, and 27 November 2015) from each plot. After collection, each litterbag sample was oven-dried at 65°C for 48 h, weighed, and the mass loss rates were determined. Needle and leaf decomposition (2 years after incubation) were calculated using a single exponential decay model (Olson 1963) as follows:

$$W_t/W_0=e^{-k\cdot t}$$

where W_0 is the original mass (g) of needle or leaf litter, W_t is the remaining mass (g) after incubation time t, k is the decay coefficient (year^{-1}), and e is the base of the natural logarithm.

Air temperature and relative humidity in each treatment were measured using a HOBO external temperature and humidity data logger (Pro v2, Onset Inc., Bourne, MA, USA) for one year (November 2014 to October 2015). The logger recorded data at intervals of one hour.

All data were analyzed with a Student's t-test for significant differences between thinned and unthinned treatments ($p < 0.05$) (SAS Institute Inc. 2003).

Results and Discussion

Litter inputs

The annual litter inputs of needles, broadleaved leaves, branches, miscellaneous, and total litter inputs between the thinned and unthinned stands are shown in Fig. 2. Annual mean needle inputs in *P. densiflora* stands were significantly lower in the thinned (2,263 kg ha^{-1} year^{-1}) than in the unthinned (2,983 kg ha^{-1} year^{-1}) treatments, whereas broadleaved leaf litter inputs in *Q. valiabilis* stands were not significantly different between thinned (3,051 kg ha^{-1} year^{-1}) and unthinned (3,701 kg ha^{-1} year^{-1}) treatments. The reduction of needle litter in *P. densiflora* stands could be due to the reduction of stand density (thinned: 1,510 tree ha^{-1}; unthinned: 2,510 tree ha^{-1}) or basal area (thinned: 29.0 m^2 ha^{-1}; unthinned 42.1 m^2 ha^{-1}) after thinning (Table 2) because there was a positive correlation (r=0.85) between needle litter inputs and stand basal area in *P. densiflora* stands (Kim 2016). Similarly, other studies reported that there was a significant reduction in needle litter inputs following thinning in red pine (*Pinus resinosa*) plantations in Michigan, USA (Kim et al. 1996b), as well as following forest tending works in a *P. densiflora* stand in Gyeongnam province, Korea (Kim et al. 2012a). Although many studies have reported that needle and broadleaved leaf litter inputs are affected by stand density and basal area following thinning (Kunhamu et al. 2009; Kim 2016), the absence of any significant difference in broadleaved leaf litter inputs between the thinned and unthinned treatments in *Q. variabilis* stands may be due to increased broadleaved leaf production during the 7-year elapse in thinned *Q. valiabilis* stands. Thus, a decrease in leaf litter caused by thinning in *Q. variabilis* stands may be progressively compensated from the remaining trees by recovery of the stand canopy.

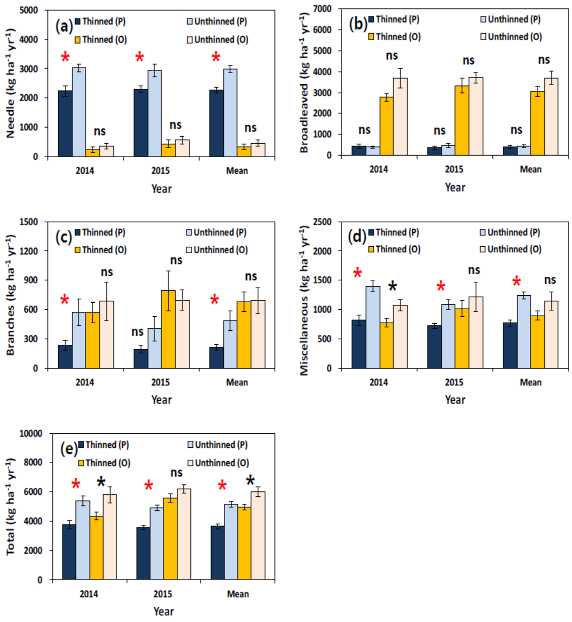

Fig. 2. Annual mean inputs of litterfall components (a: needle; b: broadleaved; c: branches; d: miscellaneous; e: total) of thinned and unthinned treatments in *Pinus densiflora* (P) and *Quercus variabilis* (O) stands. Vertical bars represent standard error. Asterisk on the bars indicates a significant difference between thinned and unthinned treatments in *P. densiflora* (red asterisk) and *Q. variabilis* (blue asterisk) stand at $p < 0.05$. ns: not significant.

Annual inputs of branches in both tree species were not significantly different between the thinned and unthinned treatments (Fig. 2c). Other studies reported similar results because this component was affected by climatic factors, such as storms or strong winds with high temporal and spatial variability, rather than tree removal activities (Jiménez

Table 2. Mean stand density, DBH, and basal area between thinned and unthinned treatments in *Pinus densiflora* and *Quercus variabilis* stands

Treatment	*P. densiflora*			*Q. valiabilis*		
	Stand density (tree ha^{-1})	DBH (cm)	Basal area (m^2 ha^{-1})	Stand density (tree ha^{-1})	DBH (cm)	Basal area (m^2 ha^{-1})
Thinned	1,510 (300)	20.0 (2.9)	29.0 (5.2)	840 (182)	21.9 (2.9)	19.4 (3.0)
Unthinned	2,510 (388)	18.3 (2.8)	42.5 (6.4)	1,350 (453)	19.8 (1.9)	33.7 (1.3)

Values in parenthesis are standard error.

and Navarro 2016; Kim 2016). In addition, there was no correlation between branch litter inputs and the basal area in *P. densiflora* stands (Kim 2016). However, miscellaneous litter inputs of *P. densiflora* stands during the study period were significantly lower in the thinned compared to the unthinned treatments, while those in *Q. variabilis* stands were not significantly different between thinned and unthinned treatments, except for in 2014 (Fig. 2d). Kim (2016) reported that the reduction of miscellaneous litter inputs in thinned treatments in *P. densiflora* stands was due to the significant decrease in bark litter inputs in the low basal area.

Total litter inputs in *P. densiflora* and *Q. variabilis* stands were significantly lower in the thinned stands compared to the unthinned stands, except for in 2015 in *Q. variabilis* stands (Fig. 2e). The overall patterns for total litterfall closely reflected the patterns of needle and broadleaved leaf litter inputs (Fig. 2a, b). This result suggests that the reduction of total litter inputs in thinned *P. densiflora* stands could be due to the decrease in needle litter inputs, whereas the reduction of total litter inputs in thinned *Q. variabilis* stands could be attributed to less miscellaneous litter inputs.

The total litterfall in *P. densiflora* stands and *Q. variabilis* stands during the study period averaged 3,653 kg ha^{-1} yr^{-1} and 4,963 kg ha^{-1} yr^{-1} in the thinned and 5,138 kg ha^{-1} yr^{-1} and 5,997 kg ha^{-1} yr^{-1} in the unthinned treatments (Fig. 3), respectively. These values in the unthinned stands fall within the range established for temperate coniferous (Jeong et al. 2009) and oak (Mun et al. 2007) forests in Korea.

Litter decomposition

Reduction in decomposition rates following thinning occurred in the *P. densiflora* stands. Needle litter decomposition rates in *P. densiflora* stands were significantly lower in the thinned (June: 62.9%; November: 53.19%) compared to the unthinned (June: 58.87%; November: 46.08%) treatments for two sampling dates (June 2015, Novermber 2015) of the eight sampling dates (Fig. 3), whereas leaf litter decomposition rates in *Q. variabilis* stands were not affected by thinning. Other studies found similar results, where needle litter decomposed slower following canopy reduction in red pine forests in the USA (Kim et al. 1996a) or following forest tending works in Gyeongnam province, Korea (Kim et al. 2012b). Blanco et al. (2011) suggested that the reduction in decomposition following thinning in *Pinus sylvestris* stands was due to a decrease in mesofauna abundance on needle litter with changes in soil environmental factors, although decreased decomposition rates in needle litter of *P. sylvestris* stands vanished after four years of thinning treatment (Blanco et al. 2011). In contrast to this study, thinning to coniferous

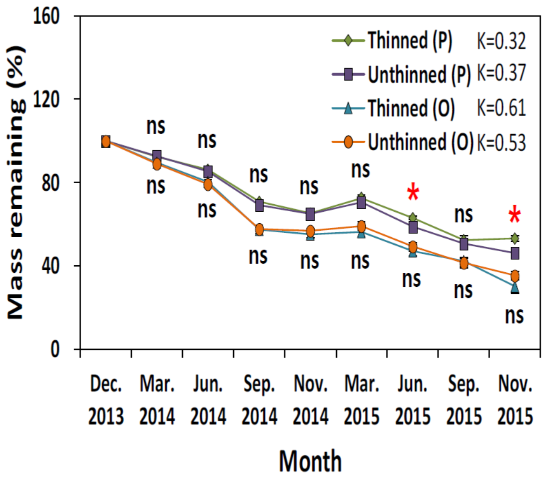

Fig. 3. Needle or leaf litter decomposition in thinned and unthinned treatment in *Pinus densiflora* (P) and *Quercus variabilis* (O) stands. Vertical bars represent standard error. Asterisk on the bars indicates a significant difference between thinned and unthinned treatment in *P. densiflora* (red asterisk) at $p < 0.05$. ns: not significant.

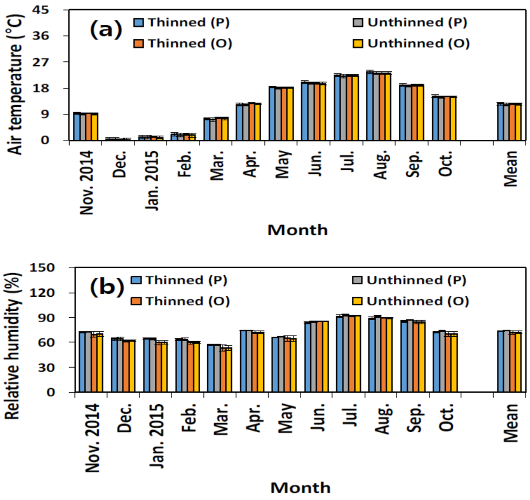

Fig. 4. Air temperature (a) and relative humidity (b) in thinned and unthinned in *Pinus densiflora* (P) and *Quercus variabilis* (O) stands. Vertical bars represent standard error.

forests increased litter decomposition rates (Piene and Van Cleve 1978) because microbial activities were stimulated by the increased amount of sunlight. In contrast to needle litter decomposition, no significant thinning effect on leaf litter decomposition rates in *Q. variabilis* stands could be due to a similar microclimate condition between thinned and unthinned treatments following the 7-year elapse from thinning. For example, the annual mean temperature and relative humidity in *Q. variabilis* stands were similar between thinned (temperature: 12.57°C; humidity: 71.8%) and unthinned (temperature: 12.44°C; humidity: 72.1%) treatments (Fig. 4). Thus, the relative contribution to litter decomposition by changing microclimate conditions following thinning could be minimal in *Q. variabilis* stands. However, annual mean temperature following the 2-year elapse from thinning in *P. densiflora* stands was higher in the thinned (temperature: 12.61°C) than in the unthinned (temperature: 12.35°C) treatments (Fig. 4).

Decay coefficients (k) were different between needle and leaf litter types in response to thinning during the 2-year incubation period (Fig. 3). Needle litter in *P. densiflora* stands had lower decomposition rates in thinned ($k=0.32$) than in the unthinned ($k=0.37$) treatments, whereas the decay coefficient in *Q. variabilis* stands was higher in thinned ($k=0.61$) than in unthinned ($k=0.53$) treatments. Similarly, Bravo-Oviedo et al. (2017) suggested that the rapid decay of oak leaves in thinned treatments is accompanied by a reduction in the immobilization of N and P in leaves, whereas increased immobilization in thinned plots occurred in the needle decomposition processes. However, needle or leaf litter decomposition is seldom affected by thinning because decomposition is a complex process affected by species-specific traits, climate, the decomposer community, and canopy cover following tree removal (Berg and Laskowski 2006; Bravo-Oviedo et al. 2017).

Conclusions

This study determined the effects on litter input and litter decomposition after 2 or 7-years of thinning at local spatial scales. Thinning practices can alter the amounts of needles, miscellaneous, and total litter inputs at the 2-year elapse following thinning treatment in *P. densiflora* stands, and total litter inputs in *Q. variabilis* stands 7-year after thinning treatment. These reduction effects on total litter inputs in *Q. variabilis* stands were attributed to the reduced miscellaneous litter, whereas the effect in *P. densiflora* stands was due to needles, branches, and miscellaneous litter following thinning. Thinning effects in needle litter decomposition remained clear after a 2-year elapse from thinning in *P. densiflora* stands, whereas the effects vanished following a 7-year elapse from thinning in *Q. variabilis* stands. The results indicate that litterfall inputs and litter decomposition following thinning were different between needle and leaf litter types with time elapsed from thinning.

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