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The Three-year Effect of Thinning Intensity on Biomass in *Larix kaempferi* and *Pinus koraiensis* Plantation

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Abstract

This study aimed to figure out and compare the increment of biomass by thinning intensity focused on the plantation of the two major coniferous species (*Larix kaempferi* and *Pinus koraiensis*) of South Korea. The inventory interval was three years under the effects of three types of thinning treatments; control (no thinning), light (20% thinning) and heavy (40% thinning). The results showed standing biomass increment of both species decreased as thinning intensity increased (heavy<light<control). Biomass increment of each tree compartment (roots, stem, branches and foliage) also followed the increment pattern of the total biomass. In contrast, the rate of biomass growth increased as increasing thinning intensity (heavy>light>control). Meanwhile, the lowest of on-site biomass changes occurred in the control plot, and the greatest was in the heavy thinning plot because thinning was involved with leaving the felling residual biomass (leaves, branches and roots) on the site. According to the results from this short-term study, unthinned stands is preferable for maximizing standing biomass as well as carbon sequestration. However long-term investigation should be considered in order to see more clear results.

Key Words: thinning intensity, standing biomass, on-site biomass, residual biomass, carbon sequestration

Introduction

Forest management involves the integration of silvicultural practices in order to maximize both quality and quantity of the forest productivity. Thinning is a common management activity used to manipulate the growth rate, size, and form of individual trees, as well as the structure and yield of forest stands (Smith 1986). One of the most important objective of thinning is to accelerate size or diameter at breast height (DBH) of the residual trees by removing nearby competing trees (Smith 1986; Oliver and Larson 1996; Fujimori 2001). There are number of studies found this positive relationship through establishing permanent plots and repeating periodic measurements (Mäkinen and Isomäki 2004a; 2004b; 2004c; Pfister et al. 2007; Nishizono et al. 2008; Pelletier and Pitt 2008; Wallentin and Nilsson 2011; Choi et al. 2014; Kim et al. 2016).

Forests which are an important component of the global carbon cycle store over 80% of global terrestrial aboveground carbon. Much attention has turned to forest man-

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agement as a means of mitigating climate change (Dixon et al. 1994; D'Amato et al. 2011). Especially woody biomass is a crucial renewable energy sources as an alternative to fossil energy in recent time because of global warming problems originating mostly from fossil fuel combustion. With the dramatically increasing interest in biomass energy, such biomass harvesting guidelines are necessary to ensure sustainability (Abbas et al. 2011). Forests which are an important component of the global carbon cycle store over 80% of global terrestrial aboveground carbon and attention has turned to forest management as a means of mitigating climate change (Dixon et al. 1994; D'Amato et al. 2011). Especially woody biomass is a crucial renewable energy sources as an alternative to fossil energy in recent time because of global warming problems originating mostly from fossil fuel combustion.

Efforts have focused on how much forest management influences carbon or sequestration (Hoover and Stout 2007; Harmon et al. 2009). Repeated thinnings over the course of a forest rotation increased carbon stores compared to stands that were clearcut on short rotations (Thornley and Cannell 2000; Hoover and Stout 2007; Harmon et al. 2009; Profft et al. 2009). In contrast, some studies have demonstrated that thinning reduces aboveground carbon stores relative to unthinned stands (Finkral and Evans 2008; Campbell et al. 2009). However, the influence of repeated thinnings and different thinning methods on biomass growth and long-term patterns of carbon sequestration has not been fully studied (Hoover and Stout 2007; Ryan et al. 2010).

Meanwhile, Japanese larch (*Larix kaempferi*) and Korean white pine (*Pinus koraiensis*) are major timber species that appear in coniferous forests of the Republic of Korea. According to statistical yearbook of forestry reported by Korean Forest Service (2017), the forest areas of *Larix kaempferi* and *Pinus koraiensis* in 2015 contributed approximately 7% of total forest areas which cover on 272,800 ha and 170,905 ha, respectively. In South Korea, these species have been widely planted, in 2016, *Larix kaempferi* was planted in 2,598 ha and *Pinus koraiensis* in 513 ha (Korean Forest Service 2017). Focused on these two major coniferous species, this study aimed to figure out and compare the increment of biomass by thinning intensity for three years after thinning.

Material and Methods

Study areas and data collection

This study was conducted in permanent monitoring sites located in Gangwon and North Gyeongsang Province of South Korea (Fig. 1). These permanent monitoring sites were established by Forest Resource Monitoring Center on Climate Change (FRMCCC) found by Kangwon National University. In this study, we have 36 sites of *Larix kaempferi* and 26 sites of *Pinus koraiensis* which were located covering on even-aged stands dominated by these major coniferous species growing on average slope with 25° (5°-42°). All sites were established in the public plantation forest areas under maintaining of Korea Forest Service (KFS) which had no recent evidence of past disturbance or

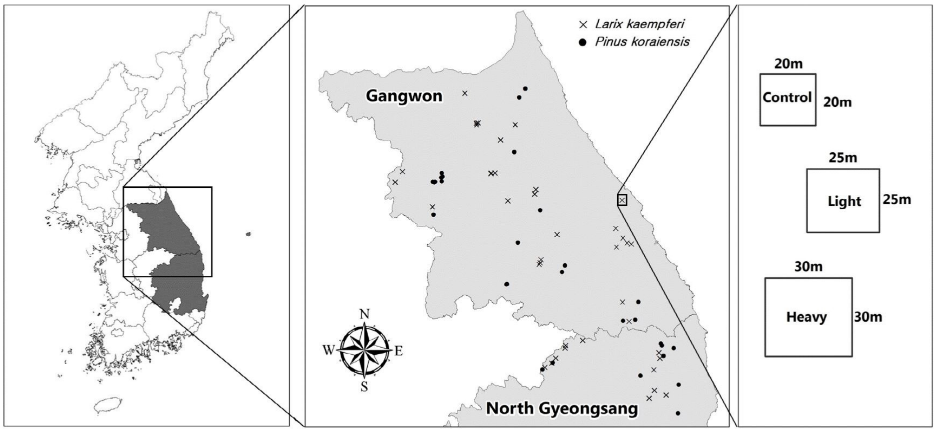

Fig. 1. Location of permanent monitoring sites and layout of plots.

harvesting. The monitoring permanent plots were installed and inventoried from 2012 to 2014 and the thinning were conducted in the year when the plots were installed. Diameter and height were measured using D-tape and Haglof Hypsometer respectively and one dominant tree each site was felled and used for stem analysis.

In the year of the first inventory, *Larix kaempferi* stands ranged from 19 to 60 years old (mean age 36) and *Pinus koraiensis* stands ranged from 15 to 77 years old (mean age 39) (Table 1). Each site consists of three types of plot considered as unthinned or control plot, light thinning plot, and heavy thinning plot. These three types of plots are demarcated as squared with size of 20 m×20 m×25 m×25 m, and 30m×30m, respectively (Fig. 1). Thinning treatment was conducted in each plot with different thinning intensities based on basal area within the plot, no thinning or 0%, 20% and 40%, respectively.

Data analysis

We used the existing biomass allometric equation that has been developed by Korea Forest Research Institute (KFRI). The allometric prediction equation based on DBH was used to estimate the biomass both species. Each tree compartments such as stem, branch, foliage and root were used the same equation, but with different parameter. The biomass equation (KFRI 2012) is:

$$Biomass = \alpha DBH^{b}$$

Total biomass of each plot is expanded into the value per hectare by divided to its own corresponding plot size that adjust with slope correction. The reason of using this adjustment area size is because total biomass is expressed on the horizontal projection terrain. The calculation of adjustment plot size with slope is:

$$S_{slope} = [(cos\theta) \times y] \times x$$

Where S_{slope} is the horizontal plot area (m^2), θ is angle of plot slope (°), y is a tape length dimension of plot measured along slope (m), and x is another tape length dimension of plot measured across slope (m). Carbon uptake was converted by default carbon fraction value from biomass (0.51) by Intergovernmental Panel on Climate Change, 2007 (Eggleston et al. 2006).

One-way analysis of variance (ANOVA) was carried to statistically verify the significant difference among the three treatments. Duncan's new multiple range test ($\alpha = 0.05$) was used to analyze the difference among the treatments. All the data were computed and generated by using the Microsoft Excel 2016 and SAS 9.4 program for windows.

Results

The results showed standing biomass increment of both species decreased with increasing thinning intensity (Table 2). In other word, both species showed the highest increment in the control plot, while heavy thinning plot produced the lowest biomass (control > light > heavy). The biomass in the *Larix kaempferi* stands increased 32.4 Mg/ha,

Table 1. Summary of stand characteristics in the study areas

Species	*Larix kaempferi*			*Pinus koraiensis*		
Treatment	Control	Light	Heavy	Control	Light	Heavy
Age (year)	36 (19-60)	36 (19-60)	36 (19-60)	39 (15-77)	39 (15-77)	39 (15-77)
Altitude (m)	599 (88-1,010)	589 (88-1,010)	589 (88-1,010)	629 (334-965)	629 (334-965)	629 (334-965)
Slope (°)	26 (5-40)	28 (7-42)	26 (6-39)	23 (4-42)	25 (6-40)	24 (8-38)
DBH(cm)	20.9 (6.3-52.1)	22.1 (8.2-52.6)	23.1 (7.8-51.6)	22.5 (5.9-61.2)	22.9 (6.1-59.3)	23.2 (6.1-54.2)
Ba (m^2 ha^{-1})	31.5 (11.3-52.8)	25.8 (8.0-46.2)	18.3 (8.6-32.8)	35.0 (9.7-66.2)	27.6 (8.0-46.2)	21.3 (8.1-42.4)
Site index* (m)	21 (12-26)	21 (14-26)	22 (16-26)	15 (12-18)	15 (12-17)	15 (12-18)
Thinning rate**(%)	1 (0-6)	20 (13-29)	41 (34-50)	1 (0-5)	21 (13-28)	39 (30-45)

*Mean height of dominant or codominant trees (30% of the tallest trees) was used as site index.

**Thinning rate was based on basal area.

Table 2. Biomass increment per hectare by thinning intensity in the plantation of *Larix kaempferi* and *Pinus koraiensis*

Thinning treatment	1st inventory			2nd inventory	Increment	Growth rate %
	Initial	Harvested	Residual	Standing		
	---------------------------------	---------------------------------	Mg/ha	---------------------------------	---------------------------------	
*Larix kaempferi***						
Control	265.7	0.2	265.5	297.9	32.4^{a}	12
Light	260.1	40.1	220.0	250.2	30.2^{a}	14
Heavy	245.1	84.7	160.4	185.1	24.7^{b}	15
Pinus koraiensis						
Control	208.4	0.4	208.0	233.0	25.0	12
Light	203.8	38.2	165.7	188.9	23.3	14
Heavy	204.8	73.5	131.3	151.7	20.4	16

**Significant at the 0.01 level, the different letter followed by mean increment are significantly different among thinning treatments by Duncan's new multiple range test ($\alpha=0.05$).

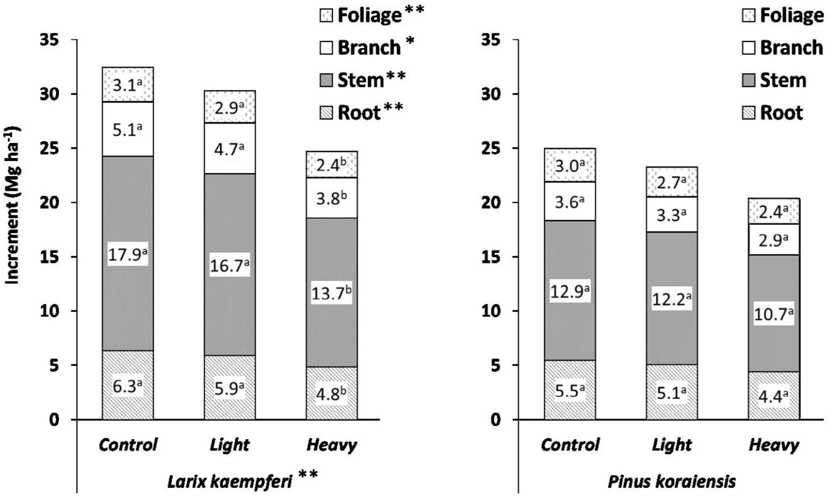

Fig. 2. Biomass increment per hectare of stem, branches, foliage and roots of *Larix kaempferi* and *Pinus koraiensis* by thinning intensity. **Significant at the 0.01 level, *significant at the 0.05 level; the different letter followed by mean increment are significantly different among thinning treatments by Duncan's new multiple range test ($\alpha=0.05$).

30.2 Mg/ha and 24.7 Mg/ha respectively for control, light and hearvy thinning plot. Meanwhile, the biomass in the *Pinus koraiensis* site increased 25.0 Mg/ha, 23.3 Mg/ha and 20.4 Mg/ha respectively.

Furthermore, ANOVA analysis showed that *Larix kaempferi* was significantly different among the three treatments ($p < 0.01$), while *Pinus koraiensis* was not. Followed by pairwise test using Duncan's new multiple range test ($\alpha=0.05$), the biomass increment of *Larix kaempferi* stand in heavy plot was significantly different from control and light plot while the control and light plot were not significantly different.

In contrast, the biomass growth rate increased as increasing thinning intensity (heavy > light > control). Both species increased the biomass by 12% and 14% respectively in control and light thinning plot. Meanwhile in heavy thinning plot, the growth rate of *Larix kaempferi* stand was 15%, while *Pinus koraiensis* stand was 16%.

Each tree compartment (roots, stem, branches and foliage) biomass also followed the same increment pattern of the total biomass (heavy > light > control). ANOVA analysis of biomass increment for each tree compartments of *Larix kaempferi* showed significantly different at 0.01 level for stem, roots and foliage, while branches were significant different at 0.05 level. It is noticeable that tree compartment biomass increment in heavy thinning plot was significantly different from the other two plots, control and light, followed by post hoc test (Duncan's new multiple range test;

$\alpha=0.05$) (Fig. 2). It should be noted that three years are too short to see the effect of thinning intensity on biomass increment.

Discussion

Biomass increment

Many studies showed that undisturbed stands produced higher stand biomass production and, therefore, maximized carbon storage (Thornley and Cannell 2000; D'Amato et al. 2011; Kirschbaum 2003; Eriksson 2006; Jhariya and Yadav 2108). Our results supported these findings, as unthinned plot accumulated the greatest biomass. In contrast, heavy thinning plot gave the highest growth rate (Table 2). With this manner, stands in light thinning plot seemed to rank between these two objectives, second largest biomass increment as well as second highest growth rate. Magruder et al. (2013) reported that increasing thinning intensity on red pine plantation could enhance tree-level productivity whereas uncut control plot could produce the greatest biomass production per area, and, as a result, thinning from below at a light thinning intensity was recommended in order to perceive higher benefits of maximum tree size, biomass per area, and level of climatic resilience. In our study non-thinning (control) was the best option to produce the greatest biomass, however, long-term study is recommended to see a clearer result on biomass production according to thinning intensity.

Biomass changes

Change in biomass refers to a combination between net growth of stand and mortality (Oliver and Larson 1996). Dead trees were not remarkable occurred in this short-term study, but felling residues are the major dead biomass on the site after thinning. In this study, biomass changes therefore are included all felling residue biomass (branches, foliage and roots) left on the site.

Felling residuals refer to branches and tops or foliage which were removed from harvested tree. Many biomass harvesting guidelines recommend that felling residues should be left as many as possible on the ground for forest ecosystem conservation purpose (Evans et al. 2010; Abbas et al. 2011). Leaving these the residues on site could serve as soil fertility, wildlife habitat, nutrient recycling, water purification and soil carbon loss protection (Simpson and Martin 2008). In addition, root part or belowground biomass is relatively difficult to remove while harvesting systems are mostly involved in removing portion of the aboveground biomass.

It is important to recognize how much the felling residues biomass will be decomposed per year after left on the

Table 3. Biomass changes (Mg/ha) after three years by thinning intensity for *Larix kaempferi* and *Pinus koraiensis* plantation

Thinning treatment	Residual standing biomass	Standing after 3 years	Standing biomass increment[a]	Felling residue biomass[b]			Biomass change[c]
				Branches	Foliage	Roots	
	--------------------	--------------------	--------------------	--------Mg/ha--------	--------------------	--------------------	
*Larix kaempferi***							
Control	265.5	297.9	32.4	0.0	0.0	0.0	32.5^{a}
Light	220.0	250.2	30.2	6.8	1.1	3.7	41.8^{b}
Heavy	160.4	185.1	24.7	14.1	2.3	7.8	48.8^{c}
*Pinus koraiensis***							
Control	208.0	233.0	25.0	0.1	0.0	0.0	25.1^{a}
Light	165.7	188.9	23.3	5.4	1.3	4.2	34.1^{b}
Heavy	131.3	151.7	20.4	9.8	2.4	8.1	40.8^{c}

[a] Difference between residual standing biomass and standing biomass after 3 years.

[b] Value after deducing mass loss due to decomposition after 3 years (70% for foliage, 49% for roots and 30% for branches).

[c] Sum of felling residual biomass (branches, foliage and roots) and standing biomass increment.

**Significant at the 0.01 level; the differentletter followed by mean increment are significantly different among thinning treatments by Duncan's new multiple range test ($\alpha=0.05$).

site. A limitation with this study is the lack of information on the decomposition rate of those felling residues biomass. However, there is a report on decomposition of logging residues in Finland showed mass loss decreased in order: foliage > roots > branches (Palviainen et al. 2004). They reported mass loss of Scot pine in forest plot was 70% for foliage, 49% for roots and 30% for branches of initial mass after three years. In our study, we applied the above percentage of logging residual mass loss, and heavy thinning stands, as a result for both species, accumulated the highest biomass while the lowest was in control or unthinned stands (Table 3).

Carbon sequestration

Managed forests generally store less carbon than unmanaged forest due to carbon loss through forest biomass harvests or disturbances (Thornley and Cannell 2000; Kirschbaum 2003; Eriksson 2006), and it is reasonable that higher carbon storage and increment exists at high stand density (Fang et al. 2007). Our results supported the above literature because we found annual carbon sequestration rate increased with increasing stand density (Table 4).

Disturbances, both human-induced and natural, are major driving to change the role of forests from carbon sink to source of carbon emission to the atmosphere (Krankina and Harmon 2006). This implies that thinning treatments have negative effect on carbon storages in the forest. Thinning would enhance tree-level productivity, but tend to decrease level of carbon store and therefore mitigate less to climate change. These such tradeoffs need closed attention to consider about optimal set of management practices that should be applied to the forests (D'Amato et al. 2011). Objectively, clear purpose of forest management should be critical. If the objective is to maximize carbon stock in the forests, unthinned stands should be a preferable option (Eriksson 2006).

Table 4. Annual rate of aboveground and belowground carbon (Mg C ha^{-1}y^{-1}) uptake by thinning intensity for *Larix kaempferi* and *Pinus koraiensis* plantation

Species	Treatment	Aboveground	Belowground	Total
*Larix kaempferi***	Control	4.44^{a}	1.08^{a}	5.51^{a}
	Light	4.14^{a}	1.00^{a}	5.14^{a}
	Heavy	3.38^{b}	0.82^{b}	4.20^{b}
Pinus koraiensis	Control	3.31	0.93	4.24
	Light	3.10	0.86	3.96
	Heavy	2.72	0.75	3.47

The figure was converted by default carbon fraction value from biomass (0.51) by Intergovernmental Panel on Climate Change, 2007 (Eggleston et al. 2006).

**Significant at the 0.01 level;,the different letter followed by mean increment are significantly different among thinning treatments by Duncan's new multiple range test ($\alpha=0.05$)

Increasing interval of disturbances allows for a greater accumulation of carbon in forest stands (Smithwick et al. 2007; Harmon et al. 2009; Yan 2018). This is because the longer interval favors more carbon to accumulate in forest stands (Krankina and Harmon 2006). Our study represented at very short period of measurement interval which therefore carbon increment rate has not yet supported the above notion. There were also a number of studies suggested to reduce harvesting intensity in order to maximize stand-productivity level and reduce impact on forest carbon sequestration (Harmon et al. 2009; Magruder et al. 2013; Yan 2018). Hoover and Stout (2007) compared carbon sequestration rate among four types of thinning treatment, thinning from below, middle, above and non-thinning, and found that the thinning treatment from below had the greatest carbon sequestration rate. It is should be noticed that the study conducted in mixed hardwood stands with 25 years after thinning treatment. Because our study was conducted in short-term period, unthinned forests still the best management option to uptake the highest CO2 from the atmosphere.

Conclusion

Focused on the two major coniferous species; Japanese larch (*Larix kaempferi*) and Korean pine (*Pinus koraiensis*), the objectives of this study were to find out and compare the increment of biomass by three different intensity of thinning treatments namely control (no thinning), light (20% thinning) and heavy (40% thinning). The interval of measurement was three years. The study conducted on 62 permanence monitoring sites (36 sites of *Larix kaempferi* and 26 sites of *Pinus koraiensis*) located in Gangwon and North Gyeongsang Province of South Korea.

The results showed that both species gave the largest amount of standing biomass increment in unthinned plot while the smallest increment occurred in heavy thinning plot. Meanwhile, the biomass growth rate was heavy > ligh t > control for both species *Larix kaempferi* and *Pinus koraiensis*. Thinning operation seems to have negative effect to forest biomass and carbon pool, and unthinned stands, therefore, was the best choice in term of mitigating climate change. However, on-site biomass changes occurred the lowest in unthinned plot, and the greatest in heavy thinning plot because thinning was involved with leaving the felling residual biomass (leaves, branches and roots) on the site. According to the results from this short-term study by thinning intensity, unthinned stand was preferable for maximizing standing biomass as well as carbon sequestration. However further studies should be critical, especially long-term investigation should be considered in order to see more clear results.

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