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Effects of Forest Tending Works on Carbon Storage in a *Pinus densiflora* Stand

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ABSTRACT: We conducted research to determine the effects of forest tending works (FTW) on forest carbon (C) storage in Korean red pine forests by estimating changes in the quantity and distribution of stored organic C in an approximately 40-year-old red pine stand after FTW. We measured organic C storage (above- and belowground biomass C, forest floor C, and soil C at 50 cm depth) in the Hwangmaesan Soopkakkugi model forest in Sancheonggun, Gyeongsangnam-do before and after the forest was thinned from a density of 908 trees/ha to 367 trees/ha. The total C stored in tree biomass was 69.5 Mg C/ha before FTW and 38.6 Mg C/ha after FTW. The change in total C storage in tree biomass primarily resulted from the loss of 19.9 Mg C/ha stored in stem biomass after FTW. The total C pool in this red pine stand was 276 Mg C/ha before FTW and 245.1 Mg C/ha after FTW. Prior to FTW, 71.5% of the total C pool was stored in mineral soil, 25.2% in tree biomass, and 3.3% in the forest floor, where as after FTW 80.5% of the total C pool was stored in mineral soil, 15.7% in tree biomass and 3.7% in the forest floor. These results suggest that the development of site-specific tending techniques may be required to minimize the loss of tree biomass C storage capacity in red pine stands from FTW.

Key words: Carbon cycle, Carbon pool, Carbon storage, Forest tending work, *Pinus densiflora*

INTRODUCTION

Carbon (C) storage by forests has received considerable attention because of the role of CO_2 in global climate change (McPherson and Simpson 1999, Kim and Jeong 2001, Jandl et al. 2007). Forests have been considered as potential C sinks that may play a role in storing atmospheric CO_2 (Fox 2000, Watson et al. 2000, Janssens et al. 2002). Therefore, evaluation of C storage in forest ecosystems is important for understanding and possibly improving atmospheric C sequestration (Fox 2000). Many studies have reported that forest management activities may influence C dynamics in forest ecosystems (Larporte et al. 2003, Lal 2005, Jandl et al. 2007). However, the role and the importance of forest management activities in promoting C storage by forest ecosystems is likely to vary with forest type, type of intervention (e.g., thinning, harvesting, or fertilization), site environmental factors and soil conditions (Johnson 1992, Kim and Cho 2004, Jandl et al. 2007).

Forest tending works (FTW) have become one of the most important forest management activities conducted by Korean forest police and managers since 1998 (Woo 2003). Article 3.4 of the Kyoto Protocol allows the use of forest management for C sequestration and development of National Forest Inventories (Watson et al. 2000, Jandl et al. 2007). FTW can affect the quantity and distribution of stored C in an ecosystem because management may involve removal of a considerable amount of aboveground tree biomass from forest stands. Indeed, the removal of aboveground trees, or thinning, is common in forest tending operations during FTW (Woo 2003). A better understanding of the impacts of FTW on C storage will allow managers to select the most appropriate forest management strategies to increase C storage given that the potential for temporary and long-term C storage by forest biomass and soils may be affected by different forest management practices. In particular, information about changes in tree component biomass C distribution in response to interventions is required to select the most appropriate forest management strategies for increasing C storage.

Red pine (*Pinus densiflora*) forest is the dominant type of coniferous forest throughout Korea. Pine stands are also among the most productive types of temperate forest (Peichel and Arain 2006). There has, however, been little attempt to study quantitatively the effects of FTW on C storage in red pine stands. The objective of this study was to determine how FTW affects C storage in a model forest by comparing the quantity and distribution of stored organic C (above- and belowground biomass C, forest floor C, and soil C at 50 cm depth) before and after FTW.

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MATERIALS AND METHODS

The study was conducted in the Hwangmaesan Soopkakkugi model forest (35° 29' 04" N, 127° 58' 16" E, 723 m), which is located in Sancheonggun, Gyeongsangnam-do and administered by the Hamyang National Forest Station, Korea Forest Service. This forest was thinned, a representative FTW practice, in 2005. Annual average precipitation in the study area is 1,479 mm/yr and annual average temperature is 12.9℃. The soil in the study site is a well-drained, slightly wet brown forest soil originating from granite, with a loamy texture and pH 4.6～4.8. The study site consists of an approximately 40-year-old natural red pine (*Pinus densiflora*) stand. Dominant understory species in the study site include *Rhododendron mucronulatum*, *Quercus serrata*, *Q. mongolica*, *Lindera glauca*, and *L. erythrocarpa*.

Our experiments were conducted in three 20 m × 20 m experimental plots. The mean tree density in the plots was 367 trees/ha and the mean tree diameter at breast height (DBH) was approximately 25.7 cm. All trees > 6 cm DBH in each sample plot were measured to determine the DBH distribution and to estimate tree biomass. In addition, cutting height diameter (CHD) at 20 cm above ground was measured to allow us to estimate the relationship between DBH and CHD in red pine stands, because DBH in the study plots was not measured before FTW.

To measure C storage in tree biomass in the study plots, five red pine trees representing the DBH range of the stand were destructively sampled from a red pine stand adjacent from the study plots to develop biomass prediction equations for tree components. Each sample tree was cut 20 cm above the ground between 16 and 17 August 2007, and separated into its components (needles, branches, and stems). All fresh tree components were measured in the field and subsamples were taken from each tree component to determine the fresh-to-oven-dried biomass ratio at 85℃. The roots of two of the five sampled trees were excavated and subsamples were collected to determine the dry root biomass. We developed allometric equations for each above-ground tree component (stem wood, stem bark, branches, needles), and used these equations to estimate the biomass of the red pine trees in the sample plots, but the root biomass was estimated by the basal area ratio method. Tree C storages were then calculated assuming a C concentration of 50% of the biomass (Davis et al. 2003).

We collected forest floor samples from five random points from each plot using a 900 cm^2 aluminum template (30 cm × 30 cm) in November 2006. The forest floor samples were oven-dried at 65℃, ground with a Wiley Mill and passed through a 40 mesh stainless sieve. The organic C content of the forest floor was then determined by the loss on ignition at 375℃ over 16 hours (Soon and Abboud 1991).

Soil samples were collected in November 2006 from three randomly selected points in each plot. At each point, we dug an 80 cm × 80 cm soil pit and collected soil samples at four depths (0～10 cm, 10～20 cm, 20～30 cm, 30～50 cm). Samples were dried at 105℃ in 100 cm^3 stainless steel cans, and then soil bulk density at each depth was determined. Five bulk soil samples from each of the four depths were then used to measure soil C content. The samples were air-dried and sifted through a 2 mm sieve prior to soil C analysis. Soil organic C was measured using the Walkley and Black procedure (Nelson and Sommers 1982).

RESULTS AND DISCUSSION

Regression analysis detected a significant linear relationship ($y= 0.745x + 2.082$; $p<0.05$) between DBH (y) and CHD (x) of trees within the study site (Fig. 1). Therefore, the DBH of red pine trees removed during FTW could be estimated from CHD using the regression equation with a high and significant determination coefficient (r^2=0.908).

Allometric regression equations for the different red pine tree components are shown in Table 1. All parameters of the regression equations were significant ($P<0.05$) with DBH accounting for 87～99% of variation in aboveground biomass. As expected, the best fits were obtained for stem wood and branches, followed by needles and stem bark. Park and Lee (1990) and Brown (2002) report that regression equations based on DBH alone were the best predictors for biomass estimation in pine stands for practical purposes because DBH is the parameter with the least measurement error (less than 3%; Gregoire et al. 1989).

Fig. 2 shows the DBH distribution of trees removed or left standing during FTW. The DBH classes of trees in this study site

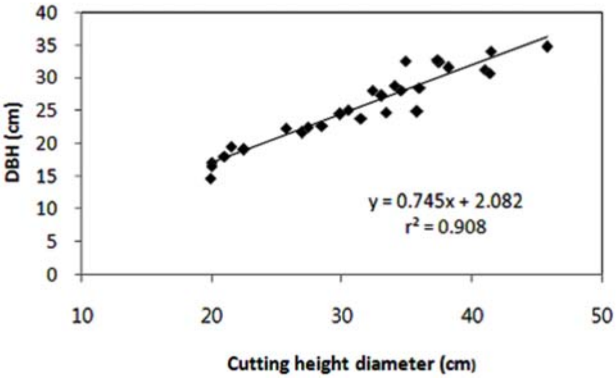

Fig. 1. The linear relationship between diameter at breast height (DBH) and cutting height (20 cm above ground) diameter in a red pine stand.

Table 1. Allometric regression equations ($\log_{10}Y = a+b\log_{10}X$) relating biomass to diameter at breast height (DBH) for different tree components in a red pine stand

Tree component	a	b	r^2	*P*-value
Stem wood	−0.5286	1.8548	0.9842	0.0008
Stem bark	−1.0769	1.5864	0.8696	0.0208
Branches	−3.3044	3.3380	0.9936	0.0002
Needles	−2.2856	2.2494	0.9828	0.0010

Y: biomass (dry weight, kg); X: diameter at breast height (DBH, cm)

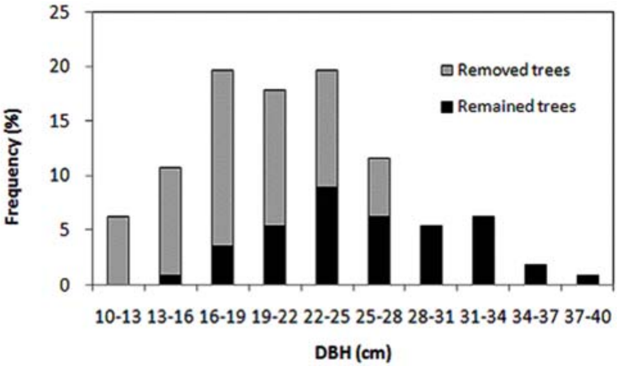

Fig. 2. Frequency distribution of diameters at breast height (DBH) of trees before and after forest tending works (FTW).

showed a normal distribution, which is characteristic of an even-aged pine stand (Park and Lee 1990). About 60% of trees in the study plots were removed during FTW, reducing the tree density from 908 trees/ha to 367 trees/ha. Before FTW, the most frequently represented DBH classes in the study plots were 16～19 cm (19.6%) and 22～25 cm (19.6%), followed by 19～22 cm (17.9%) and 25～28 cm (11.5%). After FTW, however, the distribution of DBH classes changed, as most trees removed were in the DBH classes between 16 and 25 cm (about 39% of total trees), while trees in the DBH classes over 28 cm were generally not removed. This indicates that tree removal during FTW was not random, but rather focused on trees in the small or medium DBH classes, including poorly growing trees and less valuable tree species (Woo 2003).

Fig. 3 shows the change in C storage in tree biomass as a result of FTW. Total C storage in tree biomass (stem, branches, needles, roots) before FTW was 69.5 Mg C/ha. Among the tree components, the most C (43.1 Mg C/ha) was stored in the stem wood, followed by the roots (9.7 Mg C/ha), branches (8.7 Mg C/ha), stem bark (5.2 Mg C/ha), and needles (2.7 Mg C/ha). Peichl and Arain (2006) report that C storage for pine stands in temperate forests ranges from 3 Mg C/ha to 161 Mg C/ha depending on stand age and type, and Park and Lee (1990) report that the total biomass C storage in red pine stands ranges from 14.9 to 102.7 Mg C/ha. Differences in aboveground organic C storage in coniferous stands were attributed to differences in stand basal area due to common forest management practices such as thinning (Kim and Jeong 2001, Kim 2004, Kim and Cho 2004) or differences in regional tree forms in red pine stands (Park and Lee 1990).

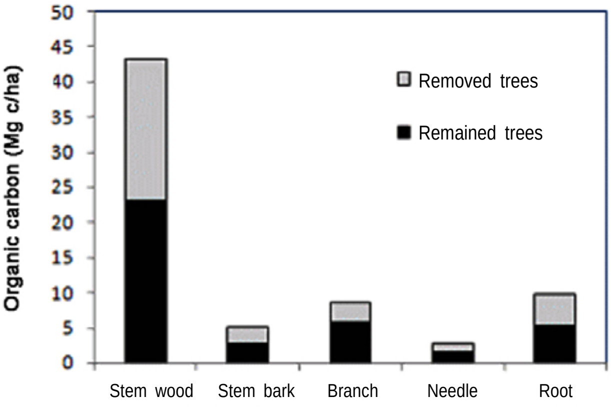

Fig. 3. Organic carbon storage in different tree components before and after forest tending works (FTW).

Balboa-Murias et al. (2006) report that increased thinning intensity results in a reduction in C storage and sequestration by aboveground biomass in pine stands. Changes in total tree biomass C storage after FTW occur because tree biomass C storage is mostly determined by stem biomass. Accordingly, in this study, total tree biomass C storage after FTW included 23.2 Mg C/ha in stem wood, 5.8 Mg C/ha in branches, 5.3 Mg C/ha in roots, 2.7 Mg C/ha in stem bark, and 1.6 Mg C/ha in needles. The reduction of total tree biomass C storage after FTW was due to the reduction of tree density from 908 trees/ha to 367 trees/ha

Fig. 4 shows the relative contribution of each individual C pool in a red pine stand to carbon sequestration. The total C pool in this stand was 276 Mg C/ha before FTW and 245.1 Mg C/ha after FTW. The pre-FTW total C included 197.3 Mg C/ha (71.5%) stored in mineral soil, 69.5 Mg C/ha (25.2%) in tree biomass and 9.2 Mg C/ha (3.3%) in the forest floor (Fig. 4). However, the proportions of carbon stored in the three individual C pools shifted after the reduction of tree biomass resulting from thinning.

After FTW, 197.3 Mg C/ha (80.5%) of total C was stored in mineral soil, 38.6 Mg C/ha (15.7%) in tree biomass, and 9.2 Mg C/ha (3.8%) in the forest floor (Fig. 4). Although the C stock in logging residues (stems, branches, twig and needles) resulting from FTW was not estimated, forest floor and soil C could increase due to the input of thinning residues and roots from the removed trees after FTW. For example, residues (branches, needle, roots) from

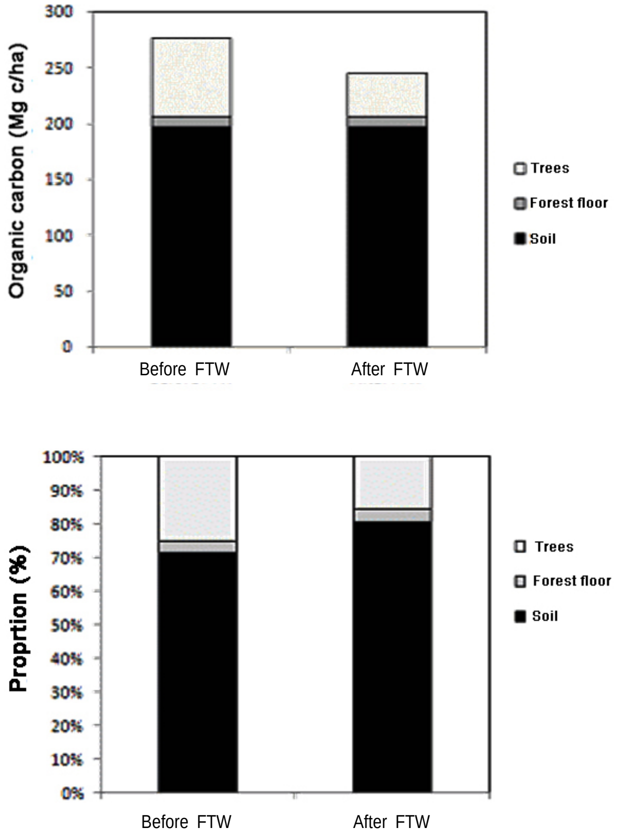

Fig. 4. Individual carbon pool and proportion of total carbon stored in each component of a red pine stand before and after forest tending works.

FTW accumulating on the forest floor of the study area could have transferred up to 12.2% (8.5 Mg C/ha) of the C stored in the stand biomass before FTW to the forest floor or soil because the stand was treated with stem-only harvest methods. Balboa-Murias (2006) reported that logging residues from thinning included up to 11% of the C stored in the stand biomass of radiata pine and maritime pine forests. Residues left behind after FTW may contribute considerably to the long-term C pool (Jandl et al. 2007). Conversely, the collection and removal of thinning residues from FTW stands for sawdust or as raw feed for domestic animals (Woo 2003) could lead to a short- or long- term decrease in the C pool.

In conclusion, FTW affected both carbon storage and distribution in a red pine stand as the result of a reduction of tree biomass C storage. However, FTW can also improve the growing conditions for remaining trees and rates of C allocation at the level of the tree, stand, or both. The development of site-specific FTW practices may be necessary to minimize the loss of biomass C storage capacity while maximizing the increase in the value or stability of the stand resulting from FTW.

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LITERATURE CITED

Balboa-Murias M, Rodriguez-Soalleiro R, Merina A, Alvarez- Gonzalez JB. 2006. Temporal variations and distribution of carbon stocks in aboveground biomass of radiata pine and maritime pine pure stands under different silvicultural alternatives. For Ecol Manage 237: 29-38.

Brown S. 2002. Measuring carbon in forests: current status and future challenges. Environ Poll 116: 363-372.

Davis MR, Allen RB, Clinton PW. 2003. Carbon storage along a stand development sequence in a New Zealand *Nothofagus* forest. For Ecol Manage 177: 313-321.

Fox TR. 2000. Sustained productivity in intensively managed forest plantations. For Ecol Manage 138: 187-202.

Gregoire TG, Zedaker SM, Nicholas NS. 1989. Modeling relative error in stem basal area estimates. Can J For Res 20: 496-502.

Jandl R, Lindner M, Vesterdal L, Bauwens B, Baritz R, Hagedorn F, Johnson DW, Minkkinen K, Byrne KA. 2007. How strongly forest management influence soil carbon sequestration? Geoderma 137: 253-268.

Janssens IA, Sampson DA, Curiel-Yuste J, Carrara A, Ceulemans R. 2002. The carbon cost of fine root turnover in a Scot pine forest. For Ecol Manage 168: 231-240.

Johnson DW. 1992. Effects of forest management and soil carbon storage. Water Air Soil Poll 64: 83-120.

Kim C, Jeong JH. 2001 Change of aboveground carbon storage in a *Pinus rigida* stand in Gwangnung, Gyunggi-do. J Korean For Soc 90: 774-780.

Kim C. 2004. Effects of stand density on carbon dynamics in a larch (*Larix leptolepis*) plantation. J Korean For Soc 93: 355-362.

Kim C, Cho HS. 2004. Quantitative comparisons of soil carbon and nutrient storage in *Larix leptolepis*, *Pinus densiflora* and *Pinus rigitaeda* plantations. Korean J Ecol 27: 67-71.

Laporte MF, Duchesne LC, Morrison IK. 2003. Effect of clearcutting, selection cutting, shelterwood cutting and microsites on soil surface CO_2 efflux in a tolerant hardwood ecosystem of northern Ontario. For Ecol Manage 174: 565-575.

Lal R. 2005. Forest soils and carbon sequestration. For Ecol Manage 220: 242-258.

McPherson EG, Simpson JR. 1999. Carbon dioxide reduction through urban forestry: Guideline for professional and volunteer tree planters. USDA-USFS Gen Tech Rep PSW-GTR-171.

Nelson DW, Sommers LE. 1982. Total carbon, organic carbon and organic matter. In: Methods of soil analysis. (Page AL, Miller RH and Keeney. eds) Part 2. Agron 9. Am Soc Agron. Madison WI. pp 539-579.

Park IH, Lee SM. 1990. Biomass and net primary production of *Pinus densiflora* natural forests of four local forms in Korea. J Korean For Soc 79: 196-204.

Peichl M, Arain MA. 2006. Above-and belowground ecosystem biomass and carbon pools in an age-sequence of temperate pine plantation forests. Agri For Metero 140: 51-63.

Soon YK, Abboud S. 1991. A comparison of some methods for soil organic carbon determination. Commun Soil Sci Plant Anal 22: 934-954.

Watson RT, Novel IR, Bolin B, Ravindranath NH, Verardo DJ, Dokken DJ. 2000. Land use, land-use change, and forestry. Cambridge University Press.

Woo BM. 2003. Achievements of the forest-tending works by national movement of the forest for life under the IMF structural adjustment program in Korea. J Korean For Soc 92: 145-151.

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