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Budget and distribution of organic carbon in *Taxus cuspidata* forest in subalpine zone of Mt. Halla

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Abstract

Background: In order to investigate organic carbon distribution, carbon budget, and cycling of the subalpine forest, we studied biomass, organic carbon distribution, litter production, forest floor litter, accumulated soil organic carbon, and soil respiration in *Taxus cuspidata* forest in Halla National Park from February 2012 to November 2013. Biomass was calculated by using allometric equation and the value was converted to CO_2 stocks.

Results: The amount of plant organic carbon was 13.60 ton C ha^{-1}year^{-1} in 2012 and 14.29 ton C ha^{-1}year^{-1} in 2013. And average organic carbon introduced to forest floor through litter production was 0.71 ton C ha^{-1}year^{-1}. Organic carbon distributed in forest floor litter layer was 0.73 ton C ha^{-1}year^{-1} on average and accumulated organic carbon in soil was 51.13 ton C ha^{-1}year^{-1} on average. In 2012, Amount of released CO_2 from soil to atmosphere was 10.93 ton CO_2 ha^{-1}year^{-1}.

Conclusions: The net ecosystem production based on the difference between net primary production of organic carbon and soil respiration was −1.74 ton C ha^{-1}yr^{-1} releasing more carbon than it absorbed.

Keywords: Allometric, Carbon budget, Subalpine forest, *Taxus cuspidate*, Mt. Halla

Background

The main cause of global warming is CO_2, a greenhouse gas, released into the atmosphere through both natural and human activities. The increase in the CO_2 concentration greatly affects the lives of people and ecosystem (Jang et al. 1998). Recently, annual CO_2 emission increased approximately by 80% from 1970 to 2004 due to high usage of fossil fuels and felling (IPCC 2007). Moreover, CO_2 level increased by about 40% to 391 ppm in 2011 compared to pre-industrial era (IPCC 2013). In Korea, atmospheric CO_2 concentration (405 ppm) was higher than the global average (400 ppm) in 2015 (Korea Meteorological Administration 2016; WMO 2016). According to the observational data from six observation stations (in Seoul, Incheon, Gangneung, Daegu, Mokpo, and Busan) between 1912 and 2009, the annual mean temperature

has risen by 1.7 °C in that time. This figure was more than double the increase in global average temperature which was 0.74 °C (Korea Meteorological Administration 2009; IPCC 2007).

Therefore, various methods, such as United Nations Framework Convention on Climate Change (UNFCCC), are being discussed by the authorities in order to reduce greenhouse gases worldwide with focus on high level of CO_2 concentration in the atmosphere. In 2012, Kyoto Protocol was revised by UNFCCC to commit state parties (developed countries) to significantly reduce greenhouse gas emissions from 2013 to 2020. In Paris Agreement announced by United Nations Climate Change Conference in 2015, not only advanced countries approve reduction of CO_2 emission but also developing countries do. Korea also set a goal that amount of CO_2 emission reduces up to 37% contrasted in Business As Usual.

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Atmospheric CO_2 concentration is absorbed by marine and terrestrial ecosystem. Especially, more carbon is absorbed by terrestrial ecosystem than marine ecosystem (Ito and Oikawa 2004). There are about 160GtC from human sources that are accumulated in terrestrial ecosystem (IPCC 2013).

The greatest terrestrial carbon sinks occur in forest ecosystem through interaction of vegetation (Park et al. 2005).

It is stored in form of aboveground biomass, belowground biomass, dead trees, forest floor litter, and organic matters in soil but litter accounts for large portion of organic matter accumulated on the forest floor of the forest ecosystem (Ovington and Heitkamp 1960; Dixon et al. 1994; Hu and Wang 2008). Thus, forest ecosystem is getting the attention as the main carbon storeroom that can reduce CO_2 level and many researches are under progress to analyze and enhance the carbon storage capability of forest ecosystem to prevent global warming (Law et al. 2001; Sohngen and Mendelsohn 2003; Richards and Stokers 2004; McKenny 2004).

Soil respiration is the second biggest flux in the global carbon cycle and soil respiration of the forest is an index that represents edaphon and root activities. Furthermore, an analysis of soil respiration is essential in order to calculate net primary production (NEP) and many studies have been carried out abroad already in order to accurately analyze the carbon cycle of forest ecosystem by quantifying CO_2 released from the soil (Raich and potter 1995). The ability of forest ecosystem to reduce CO_2 and store carbon is very important but most of the domestic studies on CO_2 put their focus of emission of CO_2. As result, there are not many studies on carbon budget of forests (Lee et al. 2013; Lee 2014).

Range of the subalpine zone boundaries is from timber line where commercial timber production is possible, to tree line that does not show tree upper 4–5 m height (Kim 1976; Kong 2002). And subalpine zone appears in the region with below 45 of warmth index (Yim 1977; Lee KS et al. 2013). These subalpine zones were more influenced by the increase in CO_2 concentration than any other ecosystems (LaMarche et al. 1984). Therefore, the purpose of this study was to comprehend the social costs of natural resources that will be caused by climate change by quantitatively analyzing the carbon budget and distribution of *T. cuspidata* forest in subalpine zone of Mt. Halla.

Methods
Study site
Taxus cuspidata forest in the study site is located 1648 m above sea level by Yeongsiloreum in Mt. Halla with tree density of 3700 No ha^{-1} (Fig. 1). Mt. Halla (1950 m) is the highest mountain in South Korea and it is a typical volcanic island. The annual average rainfall in the site is 1975 mm making it the area with highest rainfall in South Korea. Temperate zone can be observed from 600 m above sea level and subalpine zone can be observed from 1100 m where various vegetation are found according to vertical distribution. The temperature of Yeongsil region was the highest in August reaching approximately 16.7 °C and lowest in December going down to −2.5 °C. Relative humidity was the highest in August which was 89.5% and lowest in March and April which was 0.5% (Song 2011). There are plants of small height in subalpine zone of Mt. Halla compared with temperate forests (Fig. 2). In the tree layer of *T. cuspidata* community, there are *T. cuspidata (*dominant species*)*, *Rhododendron schlippenbachii* and *Berberis amurensis* var. *quelpaertensis*. In the herb layer of *T. cuspidata* community, there are *T. cuspidata, Lycopodium chinense, Sasa quelpaertensis*, *Primula modesta* var. *fauriae, Galium pusilum, Prunella vulgaris* var. *lilacina, Geranium thunbergii* etc.
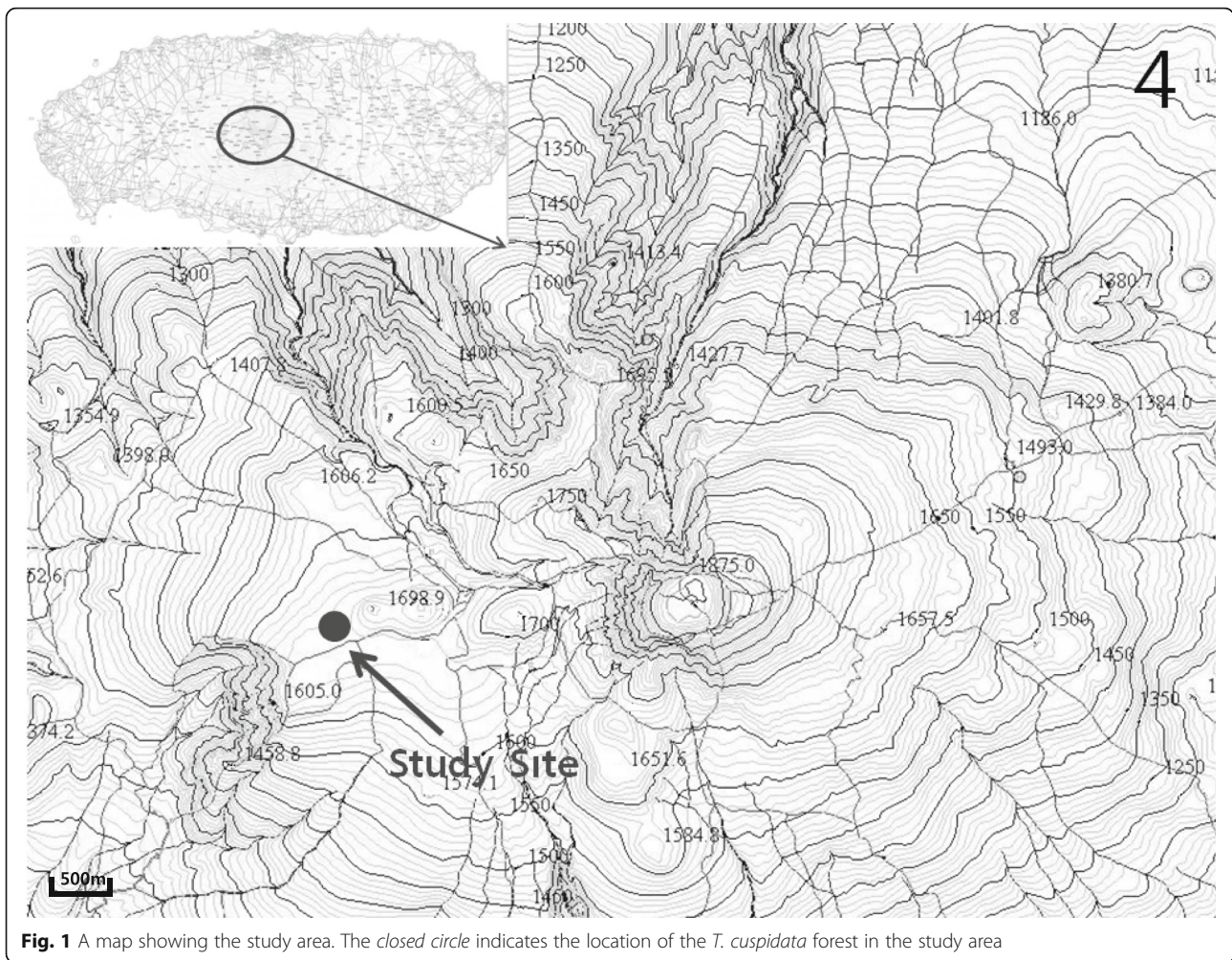
Study period and plot
In temperature forest, the shrubland and the tree layer forest were used with a quadrate of 9–25 m^2, 100–200 m^2 size, respectively (Yeocheon Ecological Research Society 2005; You et al. 2015; Barbour et al. 1999). Because of *T. cuspidate* community height in subalpine zone of Mt. Halla is 3 m, we used quadrate of 10×10 m size which was used for community studies (Jeong 2015; Lee and Mun 2001).

Quadrate was installed in February 2012 and study was conducted until November 2013 according to seasons. The study was conducted in spring (May), summer (August), and fall (November) each year because snowfall reaches over 1 m during winter.

Biomass
Summation method is probably the best method to measure the biomass, but it is difficult to measure the biomass by felling in Mt. Halla National Park. Therefore, summation method was used for herb layer.

The estimation made using diameter at breast height (DBH) and allometric equation between each organ. The biomass of leaves and reproductive organ were measured from the litter collected in the litter trap each year. DBH was measured in April each year using measuring tape. The belowground biomass was calculated by applying 25% to the aboveground biomass (Johnson and Risser 1974). Allometric equation (Yasuhiro 2006; Kwak et al. 2004; Lee et al. 2004) used to estimate biomass of tree layer in this study is as follows Table 1.

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Fig. 1 A map showing the study area. The *closed circle* indicates the location of the *T. cuspidata* forest in the study area

Litter production

Five litter traps, sized 0.5 × 0.5 m, were installed in permanent quadrate in February 2012 to quantify the amount of organic carbon accumulates on forest floor. The litter was collected and separated into leaves, wood, reproductive organs, and others each season which were measured after being dehydrated at 65 °C in the dryer

for more than 48 h. The litter production per unit area were then calculated based on the dry mass of the collected litter each year.

Forest floor litter

Four smaller quadrate, sized 25 ×25 cm, were installed additionally outside the permanent quadrate in

Fig. 2 View of the study site
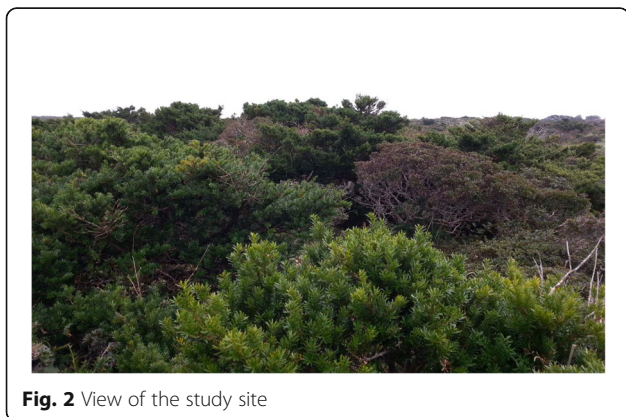
Table 1 Allometric equations for each biomass component against the diameter at the breast height and tree height in different tree sizes

Species	D range	Allometry	Ref.
T. cuspidata	Ws	0.0361 (D2H) 0.9184	Yasuhiro 2006
	Wb	0.0155 (D2H) 0.8979	
Rhododendron schlippenbachii	W	0.0471 (D) 2.8498	Lee et al. 2004
Berberis amurensis var. *quelpaertensis*	Ws	0.667 log (D2H)-0.419	Kwak et al. 2004
	Wb	0.553 log (D 2004 2H)-0.6419	

D diameter at the breast height, *Wi* (dry weight of each part), *H* stem height, *s* stem, *sb* stem bark, *b* branch

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study site to measure forest floor litter in each season without interference of existing quadrate. The litter was distinguished into L (litter) layer and F (fermentation) layer depending on the degree of decomposition. It was collected separately and measured after being dehydrated at 65 °C in the dryer for more than 48 h in the laboratory. This figure was used to calculate the amount of forest floor litter per unit area (ha).

Amount of organic carbon
The amount of organic carbon of plant biomass, litter production, and forest floor litter was estimated to be 45% of the dry mass (Houghton et al. 1983).

However, it was not possible to collect soil up to 30 cm in depth, which is general practice, as the layer of soil in the study site was extremely shallow. For this reason, the average soil depth (30 cm) of the study site was calculated and soil was collected accordingly to estimate the amount of organic carbon in soil. The soil collection was performed in the area close to quadrate that has similar soil properties to the study site because the region had permanent quadrate installed and study had to be conducted without any disturbance.

Soil was collected in intervals of 10 cm up to 30 cm in depth at three different spots. They were then sealed in envelops and taken to the laboratory. Five grams of air-dried soil was weighed after being dehydrated at 105 °C in the dryer for more than 48 h. Then, it was baked in the electric furnace for about 4 h in order to calculate the amount of organic carbon by subtracting ash content from dry weight. The value obtained from subtraction was divided by 1.724 to convert it to organic carbon content (Black 1965).

Soil was collected at 10 cm intervals by using a cylinder soil sampler (diameter = 5 cm, length = 5.1 cm) to measure the bulk density of soil which was sealed and taken to the laboratory. The collected soil was dehydrated at 105 °C in the dryer until it reached constant weight and the value was divided by the volume to calculate bulk density. The gravel content was measured by filtering gravels from the collected soil using 2 mm net and were weighed to calculate the ratio of gravel weight to the total weight.

The amount of accumulated organic carbon in soil per unit area was calculated from the values obtained above. The equation of Wang et al. (2002) was used considering the ratio of gravel between *T. cuspidata* forest and *J. chinensis var. sargentii* forest.

$$SOC(kg/m^2) = Bulk\ density(ton/m^3) \times Organic\ carbon\ content\ (g/kg) \times Soil\ depth\ (m) \times (1 - Gravel\ ratio)$$

Soil temperature and soil respiration
Soil temperature was automatically monitored hourly over the study period by placing T&D Thermo Recorder (TR-71) on top layer of soil (5 cm). Amount of CO_2 released into the atmosphere from soil respiration was measured by using most widely used closed chamber method with a portable infrared gas analyzer (IRGA; EGM-4 PP system, UK). Cylinder chamber (diameter 100 mm, height = 150 mm) attached to the equipment was installed in the soil after removing the litter on forest floor. Soil respiration was measured three times at five different spots in the area where crowns overlap and root respiration was calculated by 46% of the total soil respiration.

Results and discussion
Distribution of plant organic carbon
Organic carbon distribution was 13.60 ton C ha^{-1} and 14.29 ton C ha^{-1}, respectively, in 2012 and 2013 with the average of 13.94 ton C ha^{-1}. And it increased by 0.69 ton C ha^{-1} from 2012 to 2013. Organic carbon distribution per organ was in descending order of stem, root and branch, then leaf. Average organic carbon distribution were as follows: stem of tree layer, 8.05 ton C ha^{-1} (57.73%); branch of tree layer 2.55 ton C ha^{-1} (18.29%); root, 2.65 ton C ha^{-1} (19.00%); leaf and reproductive organs, 0.63 ton C ha^{-1} (4.48%); and herb layer, 0.07 ton C ha^{-1} (0.50%) (Fig. 3).

Organic carbon distribution of *Pinus densiflora* forest in subalpine zone of Kevo was 17.39 ton C ha-1 and birch trees of Hardangervidda plateau in Norway was 15.81 ton C ha^{-1} (Kjelvik and Karenalmpi 1975). Moreover, organic carbon distribution of *Abies koreana* forest in Mt. Halla was 48.74 ton C ha^{-1} and it was 41.17 ton C ha^{-1} in 2013 which was higher than *T. cuspidata* forest (Jang et al. 2014). Low height is one of the characteristics of *T. cuspidata* forest in subalpine zone of Mt. Halla. Thus, it seems that organic carbon distribution is relatively low compared to other tall trees because organic carbon of woody plants are mostly stored in the stem. Organic carbon distribution of trees vary between species but it seems that tree height also is a factor.

Amount of organic carbon accumulated on forest floor through litter production
The amount of organic carbon introduced to forest floor from litter production was 0.67 ton C ha^{-1}year^{-1} in 2012 and 0.74 ton C ha^{-1}year^{-1} in 2013 with average of 0.71 ton C ha^{-1}year^{-1} (Fig. 4). The litter consisted of leaves (79.1%), wood (10.0%), reproductive organs (5.2%), and others (5.7%). In this study, most litter production occurred in fall.

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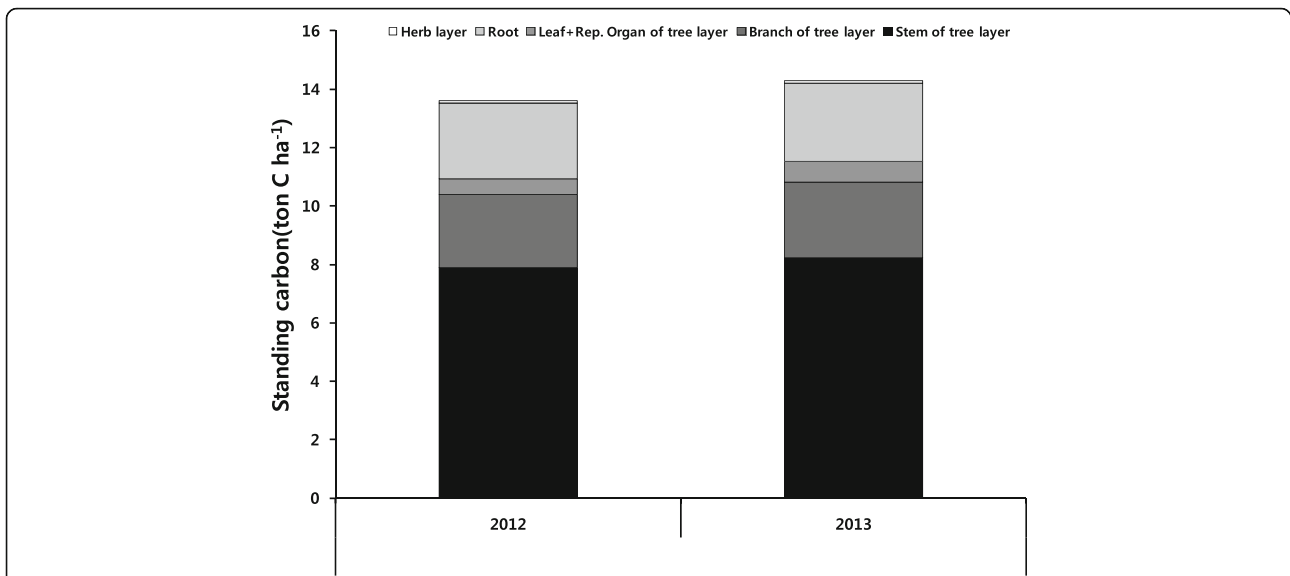
Fig. 3 Amount of annual organic carbon (ton C ha^{-1}) of *T. cuspidata* forest in the study area

Similar result was observed from studies on *Abies koreana* and *Pinus densiflora* which are also coniferous trees. The composition varied for each plant community but leaves always had the highest ratio (Jang et al. 2014; Lee et al. 2013; Jeong et al. 2013). As result, we could see that deciduous trees litter and produce most litter in fall just like coniferous trees.
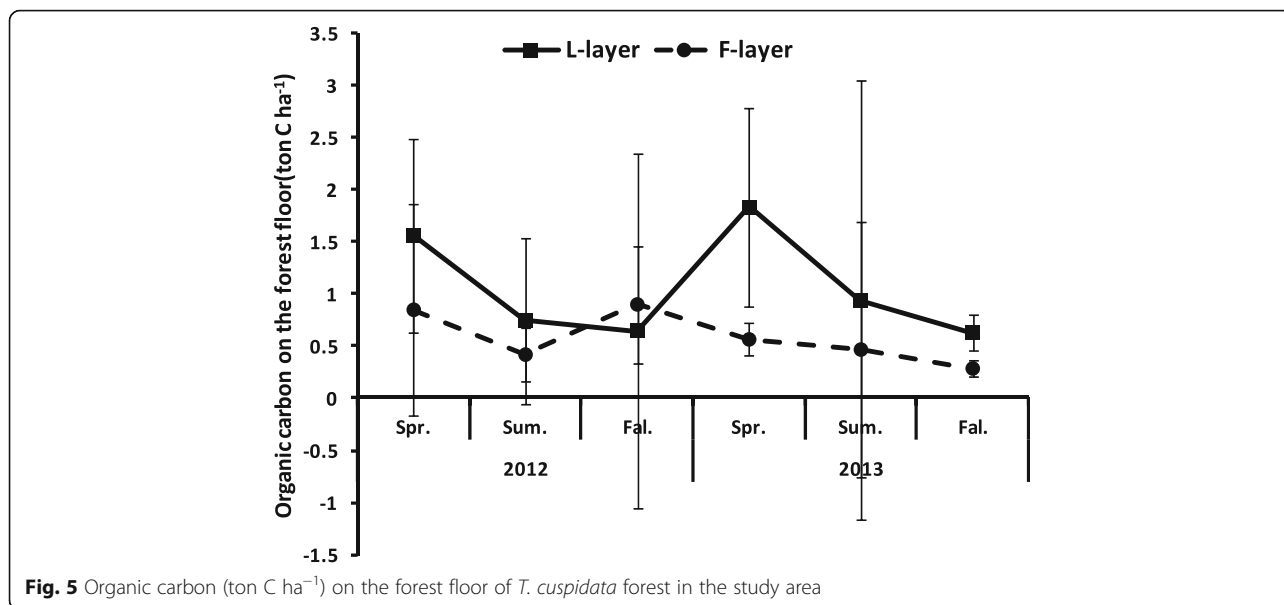
Amount of organic carbon of forest floor litter
The average amount of organic carbon distribution in forest floor litter was 0.76 ton C ha^{-1} in 2012, 0.70 ton C ha^{-1} in 2013, and the average was 0.73 ton C ha^{-1}. Average amount of organic carbon in L layer was 0.47 ton C ha^{-1}, 0.21 ton C ha^{-1} greater than F layer which was only 0.26 ton C ha^{-1} (Fig. 5). Overall amount of organic carbon of forest floor litter in 2013 decreased from 2012. *Abies koreana* forest, distributed in subalpine zone of Mt. Halla, also showed similar pattern even though its L layer seem to have a lot of forest floor litter (Jang et al. 2014). However, L layer was lower than F layer of *Pinus densiflora* forest in Mt. Worak even though it was the same coniferous tree. Such phenomenon could be observed not only from
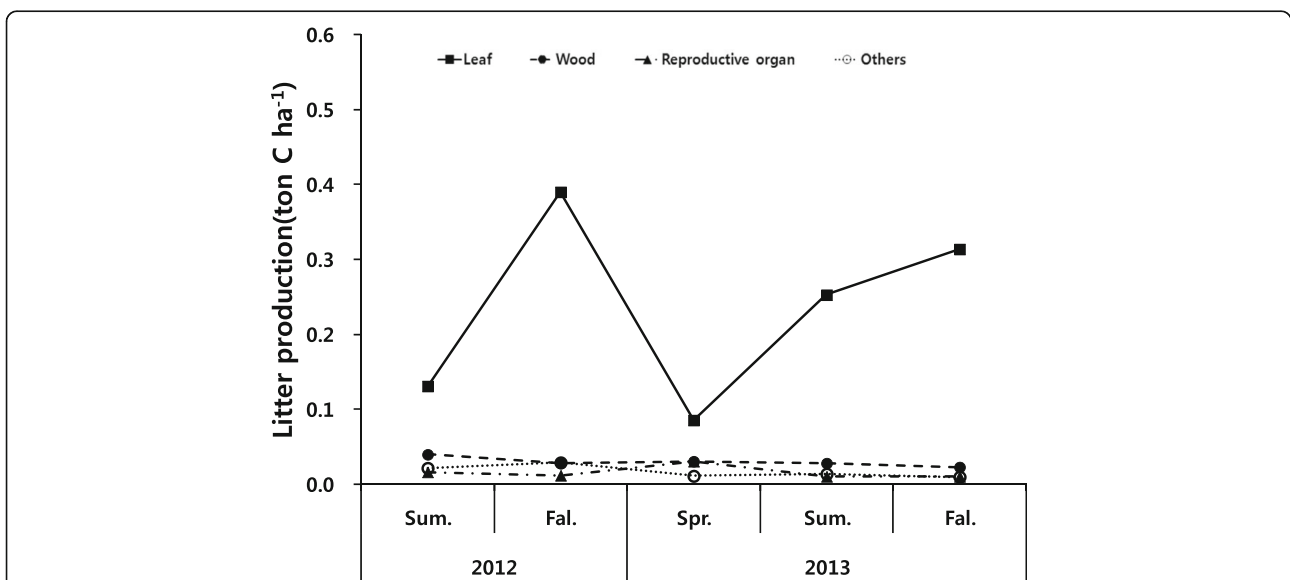
Fig. 4 Seasonal changes of organic carbon of litter production (ton C ha^{-1}) of the *T. cuspidata* forest from 2012 to 2013 in the study area

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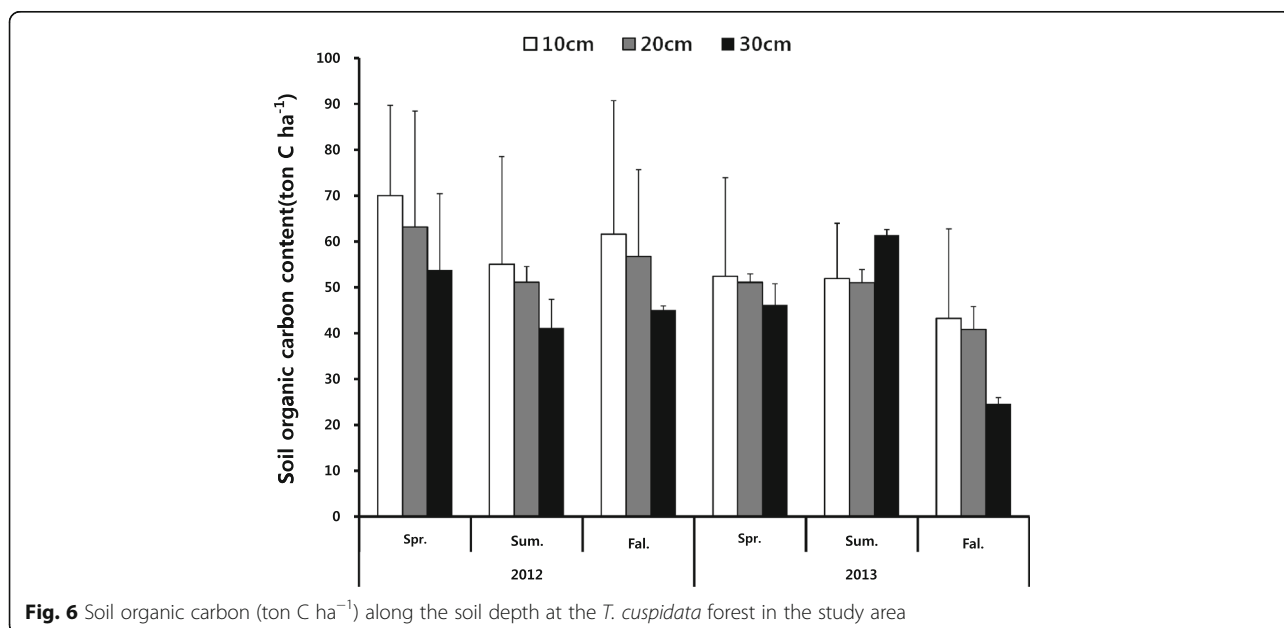**Fig. 5** Organic carbon (ton C ha^{-1}) on the forest floor of *T. cuspidata* forest in the study area

evergreen coniferous trees but also from deciduous broad-leaved trees. Family Fagaceae, *Q. mongolica*, and *Q. variabilis* Blume, which are deciduous broad-leaved trees showed higher value in F layer than L layer but *Q. serrata* showed higher value in L layer (Lee 2014). Forest floor litter of *Pinus densiflora* was greater in L layer than F layer in the study of Lee et al. (2013). Therefore, the amount of organic carbon in each layer of forest floor litter is more affected by geographical characteristics, such as temperature, rainfall, and soil property, than characteristics of species.

Bulk density and accumulated organic carbon in soil

Bulk density of soil was on average 5.57 g/cm^3 at 10 cm underground, 5.23 g/cm^3 at 20 cm, and 4.54 g/cm^3 at 30 cm. Organic carbon at 30 cm soil depth was 55.30 ton C ha^{-1}30 cm^{-1} depth^{-1} in 2012, 46.96 ton C ha^{-1}30 cm^{-1} depth^{-1} in 2013, and the average over the study period was 51.13 ton C ha^{-1}30 cm^{-1} depth^{-1} (Fig. 6). Accumulated organic carbon of soil decreased with depth.

Accumulated organic carbon in soil of *Abies koreana* forest located in Yeongsiloreum region of Mt.

Fig. 6 Soil organic carbon (ton C ha^{-1}) along the soil depth at the *T. cuspidata* forest in the study area

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Halla was 49.53 ton C ha^{-1}20 cm^{-1} $depth^{-1}$ which decreased with depth (Jang et al. 2014). Generally, organic carbon of soil decreases with depth (Eswaran et al. 1995). *Pinus densiflora* forest in Namsan was 60.70 ton C ha^{-1} and 60.70 ton C ha^{-1} (Jeong et al. 2013) in Mt. Worak was 189.439 ton C ha^{-1} which were both greater than the result obtained from this study (Lee 2014). The reason for such result can be attributed to the shallow depth of soil in Mt. Halla that contains low level of organic carbon.

Amount of soil respiration

Soil respiration is the process of CO_2 being released into the atmosphere from soil within the greater context of carbon cycle in forest ecosystem. Soil respiration is caused by respiration of microorganisms and plant roots in soil. The study site released about 10.93 ton CO_2 ha^{-1} $year^{-1}$ of carbon through soil respiration in 2012. It was highest with 2.42 ton CO_2 ha^{-1} $month^{-1}$ in July and lowest with 0.23 ton CO_2 ha^{-1} $month^{-1}$ in December (Fig. 7). Summer always had the highest soil respiration. It is widely known that soil temperature, moisture, and organic matter content are the main factors that affect soil respiration (Lloyd and Taylor 1994; Raich and Potter 1995). Furthermore, it was revealed that, among those factors, soil respiration is mainly led by soil temperature which has high correlations (Liu et al. 2002). This is probably because the increase in soil temperature accelerates growth of plants and activities of microorganisms that leads to more CO_2 efflux.
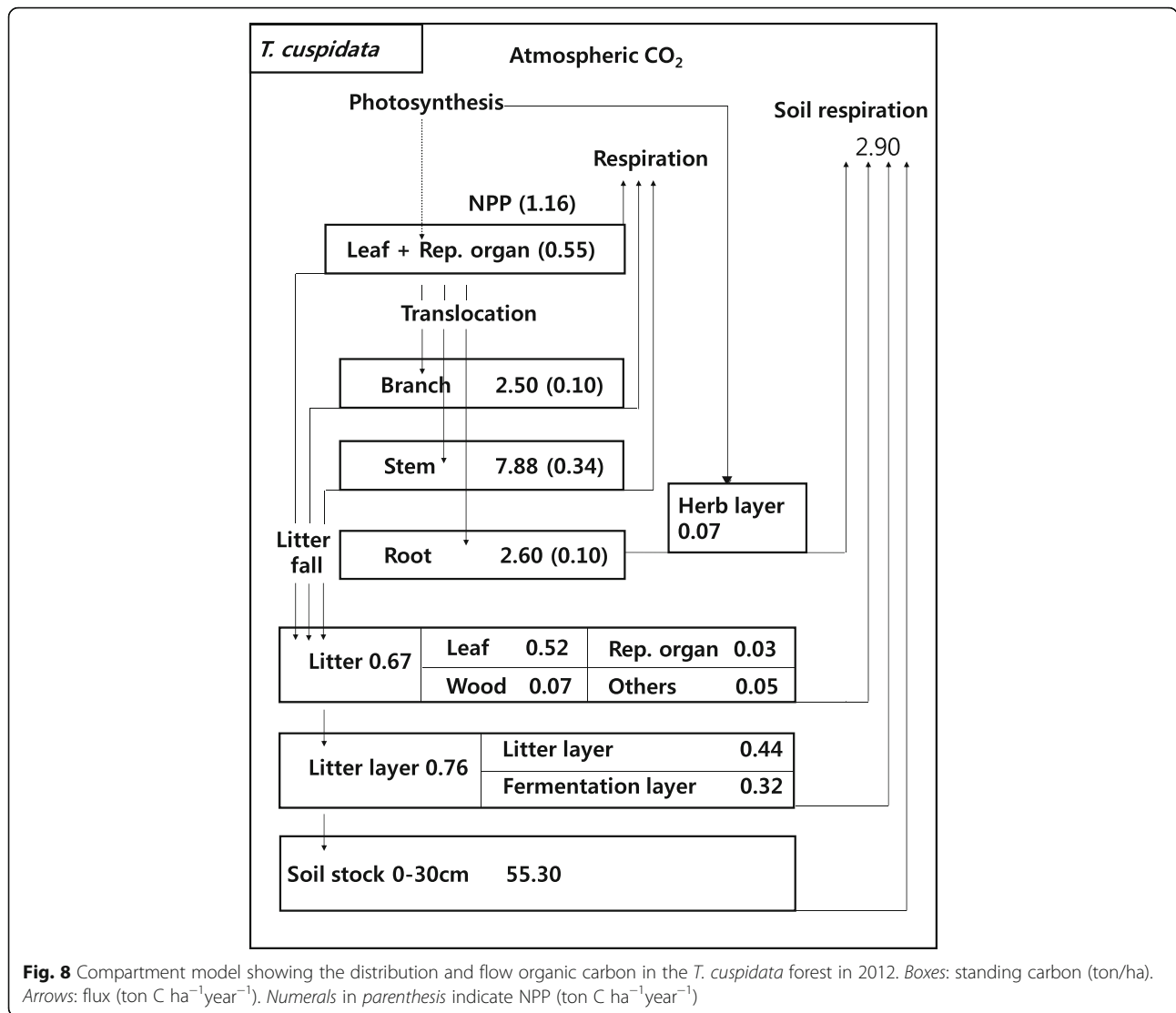
Organic carbon budget and distribution of *T. cuspidata* forest

Figure 8 shows the budget and distribution of organic carbon for each carbon storage in *T. cuspidata* forest. In 2012, total of 1.16 ton C ha^{-1} carbon from the atmosphere was stored in the entire plant: 0.55 ton C $ha^{-1}year^{-1}$ in leaf and reproductive organ, 0.34 ton C $ha^{-1}yr^{-1}$ in stems, 0.10 ton C $ha^{-1}year^{-1}$ in branches, 0.10 ton C $ha^{-1}year^{-1}$ in roots, and 0.07 ton C $ha^{-1}year^{-1}$ in herb layer. In addition, the total organic carbon in the litter was 0.67 ton C $ha^{-1}year^{-1}$ which consisted of the following: 0.52 ton C $ha^{-1}year^{-1}$ in leaves (77.61%), 7.88 ton C $ha^{-1}year^{-1}$ in wood (10.45%), 0.03 ton C $ha^{-1}year^{-1}$ in reproductive organ (4.48%), and 0.05 ton C $ha^{-1}year^{-1}$ in others (7.46%). The average organic carbon in forest floor litter was 0.76 ton C ha^{-1} in total which comprised of 0.44 ton C ha^{-1} in L layer and 0.32 ton C ha^{-1} in F layer. L layer was 0.12 ton C ha^{-1} greater than F layer. 2.90 ton C $ha^{-1}year^{-1}$ of organic carbon was released into the atmosphere through soil respiration (Fig. 8). Net ecosystem production (NEP) of the *T. cuspidata* forest was –1.74 ton C $ha^{-1}year^{-1}$ based on the difference between Net primary production (NPP) and soil respiration. Hence, *T. cuspidata* forest in this study released more CO_2 into atmosphere than it absorbed in 2012 and it acted as a negative (–) factor in the atmospheric environment.

The amount of CO_2 released from *T. cuspidata* forest in this study site was estimated to be about –36,714 KRW/ha based on the value of carbon per ton suggested by Douglas et al. (2001).
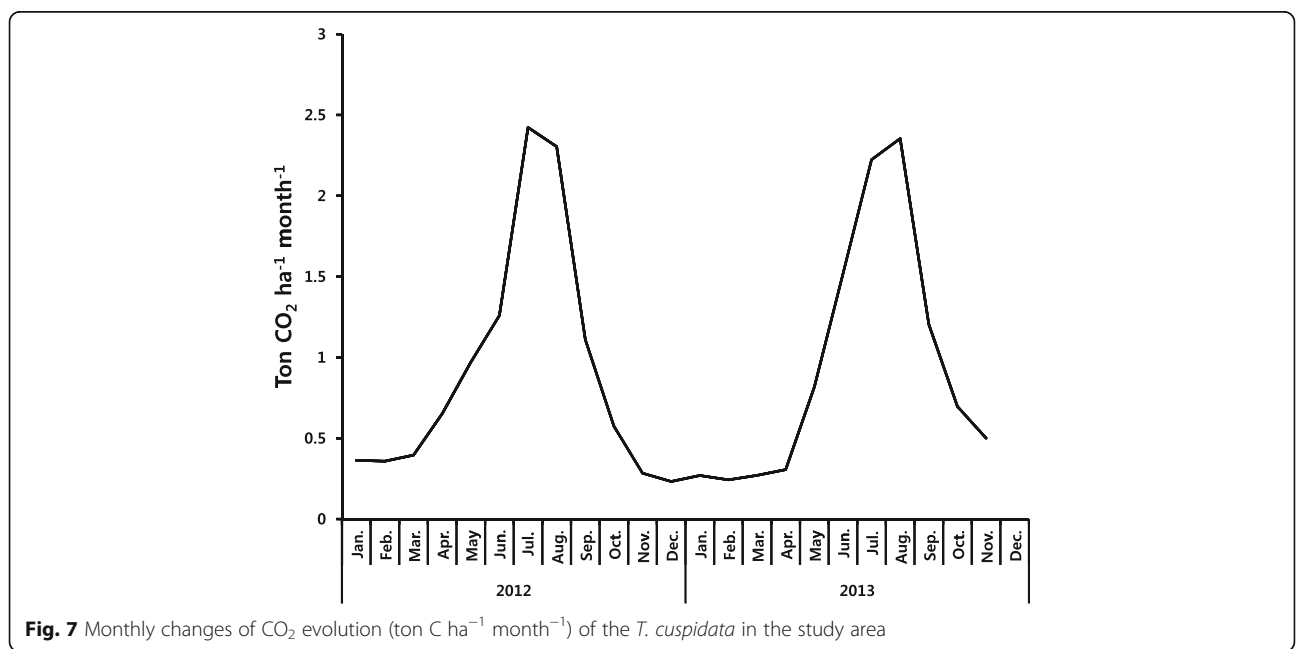
Fig. 7 Monthly changes of CO_2 evolution (ton C ha^{-1} $month^{-1}$) of the *T. cuspidata* in the study area

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Fig. 8 Compartment model showing the distribution and flow organic carbon in the *T. cuspidata* forest in 2012. *Boxes*: standing carbon (ton/ha). *Arrows*: flux (ton C ha^{-1}year^{-1}). *Numerals* in *parenthesis* indicate NPP (ton C ha^{-1}year^{-1})

NPP continually decreased over the last 5 years even in *Abies koreana* community in subalpine zone of the same region due to climate change (Jeong 2015). Climate change affects NEP in various ways. The increase in temperature leads to decrease in soil moisture and increase in plant respiration that causes reduction in NEP (Melillo et al. 1993). Witsaeoreum observatory, in proximity to this study site, recorded average temperature of 5.4 °C in 2012 and 6.5 °C in 2013 with the difference of 1.1 °C. The maximum average temperature was 16 °C and minimum average temperature was 5 °C with increase (Korea Meteorological 2013; 2014. Thus, more carbon is expected to be released in 2013.

Conclusions

In the subalpine zone at Mt. Halla, the amount of plant`s organic carbon of *T. cuspidata* forest had lower than other region that was similar altitude. However, the amount of organic carbon in the soil of forest was higher than other region. The net ecosystem production based on the difference between net primary production of organic carbon and soil respiration was −1.74 ton C ha^{-1}yr^{-1} releasing more carbon than it absorbed. As a result, *T. cuspidata* forest in subalpine zone at Mt. Halla was high function as a carbon pool.

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Availability of data and materials
Not applicable.

Authors' contributions
All authors conducted a survey together during the study period. JRH wrote the manuscript. YYH participated in the design of the study and examined the manuscript. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Consent for publication
Not applicable.

Ethics approval
Not applicable.

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