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Estimation and Change in Carbon Stock of *Robinia pseudoacacia* in Seoul, Korea

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This study aimed to measure the changes of the carbon stock of *Robinia pseudoacacia* stands in Seoul, Korea from 2000 to 2010. The area of *Robinia pseudoacacia* stands in the city occupied 33.7 km^2 (5.5%) of the total area of Seoul (605 km^2) as of 2010. Its carbon stock was calculated through using an allometric equation recommended by Korea Forest Research Institute. The result showed that the carbon stock of *Robinia pseudoacacia* in Seoul decreased for the last 10 years: from 231,753 tC in 2000, 185,204 tC in 2005 and 185,111 tC in 2010. *Robinia pseudoacacia* are a plant species that absorbs carbon (in an era of climate change) and also plays a role of a nectar–source plant. Since the carbon stock has been reduced in Seoul, it is required to consider the preservation and management of *Robinia pseudoacacia*. One of the ways to increase carbon stock is to preserve and manage trees. It is necessary to have a plan to maintain the current size of forests and enhance carbon stock by taking advantage of the favorable characteristics of *Robinia pseudoacacia*.

Key words: Carbon storage, Carbon sink, Allometric equation, Climate change, Biotope map

INTRODUCTION

Global temperature and sea level rise increases project to create various unusual weather patterns which deviate from current weather conditions. Climate change can lead to alterations in weather patterns, rises in average temperatures, altercation of rainfall patterns, increases in the frequency of severe unusual weather phenomena and rises in sea level. These changes create an urgent need for measures to be taken for the preservation and protection of trees as a source of carbon storage. As a result, tree species having capacities of high carbon stock have been paid especially high attention recently. Typical examples of these species include *Pinus densiflora, Quercus mongolica* and *Robinia pseudoacacia*. Of them, *Robinia pseudoacacia* is a leguminous plant which has a symbiotic relationship with microorganisms through nitrogen fixation; it is widely distributed, even on barren lands, globally (Soni *et al*., 1989; Cierjacks *et al*., 2013).

Robinia pseudoacacia is a rapid growth tree in Korea characterized with hard and solid wood, and having more specific gravity in oven dry than any other rapid growth trees (*Populus euramericana* 0.34 g/cm^3, *Alnus japonica* 0.52 g/cm^3, *Robinia pseudoacacia* 0.74 g/cm^3), so its absorption of carbon dioxide is relatively high (Son *et al*., 2014). Also, the flower of *Robinia pseudoacacia* is a major nectar–source which brings a revenue of more than 300 billion won per year (as of 2010) to bee farmers. The *Robinia pseudoacacia* is valuable for carbon storage and nectar source.

Carbon stock can be precisely measured without using biomass (Singh *et al*., 2011). Biomass of a tree is calculated in an allometric equation and by easily measurable variables (DBH: diameter at the breast height) or tree height (Muukkonen, 2007). An allometric equation is used to measure the biomass of a tree sample on spot by examining the changes of its DBH or height (Zianis *et al*. 2005; Basuki *et al*. 2009; Ebuy *et al*., 2011). The equation is, however, limited to small areas, and it can be difficult to use this method for carbon stock assessment in a broad area. To overcome this limitation, previous studies have used remote–sensing data to measure carbon stock (Patenaude *et al*., 2005; Myeong *et al*., 2006; Cierjacks *et al*., 2010). These studies did not use NDVI (Normalized Difference Vegetation Index) of a specific plant, but a variety of plants to measure general carbon stock. It is necessary to conduct a study using a biomass allometric equation as well as the spatial data of a specific plant.

This study uses *Robinia pseudoacacia* to examine the carbon changes within a city. This study aimed to understand the changes in the forest stand of *Robinia pseudoacacia* by season and to estimate and examine the changes in the actual carbon stock of *Robinia pseudoacacia* in a city. In addition, this study attempted to provide basic data for policy making on the management of *Robinia pseudoacacia* in urban areas in the era of climate change.

MATERIALS AND METHODS

The study site was in Seoul, the capital of the Republic of Korea, and a biotope map for sustainable development was produced to assess the rapidly changing urban environment (Fig. 1). A biotope map was pro-

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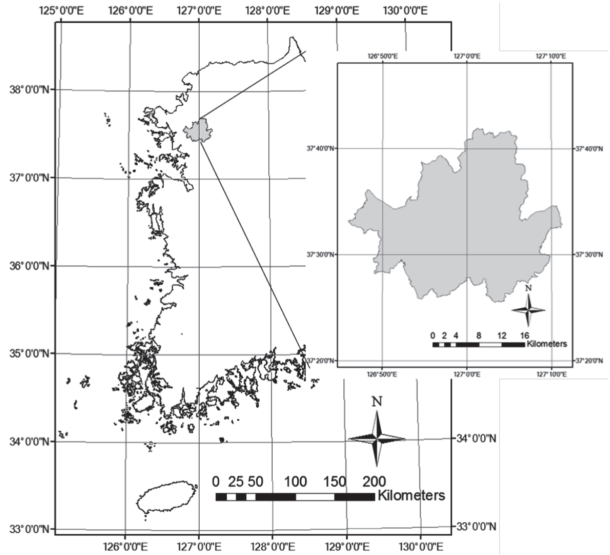

Fig. 1. Study site of Seoul, South Korea.

duced every 5 years for 2000, 2005 and 2010. The biotope makes environmental change and use of the control of reckless development easily identifiable in Seoul. According to the map, forested areas in Seoul have decreased 8.5 km^2 (around 1.4%) of total area in the last 10 years.

The map has the information to take into account the data of the forest stand including average–DBH, average–height and average–area for tall trees, small trees and a shrubs, and average–height and average–area for herbs. Among them, average–DBH, average–height and average–area for tall trees and small trees were used because *Robinia pseudoacacia* is characterized by these variables.

The carbon stock of *Robinia pseudoacacia* can be estimated utilizing 3 procedures: 1) the use of an allometric equation of *Robinia pseudoacacia*, 2) the confirmation of the population of *Robinia pseudoacacia* by forest stand and 3) the estimation of carbon stock by stand.

The biomass allometric equation of *Robinia pseudoacacia* was computed by the equation provided from Korea Forest Research Institute. This equation is reliable as a growth equation obtained from direct harvested trees for diameter at breast height and tree height. The equation is as follows (Equation (1) – (5)). The data of *Robinia pseudoacacia* stand included in the Seoul biotope map stand was used for diameter at breast height and tree height.

$$\mathrm{TB} = B_1 + B_2 + B_3 + B_4 \tag{1}$$

$$B_1 = 0.028 \times D^{1.623} \times H^{1.230} \tag{2}$$

$$B_2 = 0.406 \times D^{2.555} \times H^{-1.266} \tag{3}$$

$$B_3 = 0.233 \times D^{1.840} \times H^{-0.527} \tag{4}$$

$$B_4 = 0.043 \times D^{1.429} \times H^{0.946} \tag{5}$$

Where TB=the total biomass of a *Robinia pseudoacacia*; B_1=the biomass of stem (R^2=0.999); B_2=the biomass of branches (R^2=0.995); B_3=the biomass of leaves (R^2=0.994); B_4=the biomass of roots (R^2=0.998); D=the average–diameter at breast height; H=the average–height of tall tree or a small tree.

The second procedure was to confirm the population of *Robinia pseudoacacia* within the forest stand. The values obtained from the equation above show the biomass of a *Robinia pseudoacacia* for each stand. The area of a stand and the population of *Robinia pseudoacacia* located on the stand vary. Therefore, it was necessary to confirm and the population of *Robinia pseudoacacia* included in stands in each different size. To confirm the population inside a stand, the number of plants (root/ha) and diameter at breast height of *Robinia pseudoacacia*, which were examined in previous research (Korea Forest Research Institute, 2006), were used to set up curved predictive equations to calculate the number of plants (roots) of *Robinia pseudoacacia* by diameter at breast height. Of them, inverse function with the highest coefficient of determination was used.

$$N = -0.806 \;\; \frac{177.213}{D} \tag{6}$$

Where N=the number of *Robinia pseudoacacia* of a forest stand (R^2=0.523).

The last procedure was to acquire the biomass of each stand by multiplying the biomass of a *Robinia pseudoacacia* within each stand by its population. The average carbon content of a xylem (woody part of a plant) and leaves takes 50% of biomass (Ovington, 1956; Ajtay *et al.*, 1979; Chow and Rolfe, 1989). Carbon stock is equal to biomass multiplied by 0.5. Therefore, the carbon stock of each *Robinia pseudoacacia* stand was estimated by biomass of each stand multiplied by 0.5. By applying the method, carbon stock was computed for 3 different time periods (2000, 2005 and 2010) from the stands of *Robinia pseudoacacia*.

RESULTS AND DISCUSSION

The area of *Robinia pseudoacacia* in Seoul was reduced in 2010 by 6,915,608.05 m^2 compared with that of 2000 (Y2000: 40,625,898.80 m^2, Y2005: 34,183,352.78 m2 and Y2010: 33,710,290.75 m^2). The primary reason for this change is that the forested areas were reduced due to urban development. The total size of forest in Seoul decreased by 8.7 km^2 in 2010 compared with 2000 (Fig. 2).

The average biomass of a *Robinia pseudoacacia* tall–tree within a stand was 176.39 kg/tree in 2000 but 163.99 kg/tree in 2010, which decreased by 12.4 kg/tree on average over 10 years. The sum of carbon stock of a tree per stand increased by 145,600.09 kg to 444,405.11 kg from 298,805.02kg over the same period.

The average biomass of a *Robinia pseudoacacia* small–tree within a stand decreased by 2.54 kg/tree to 23.76 kg/tree in 2010 from 26.30 kg/tree in 2000. On the

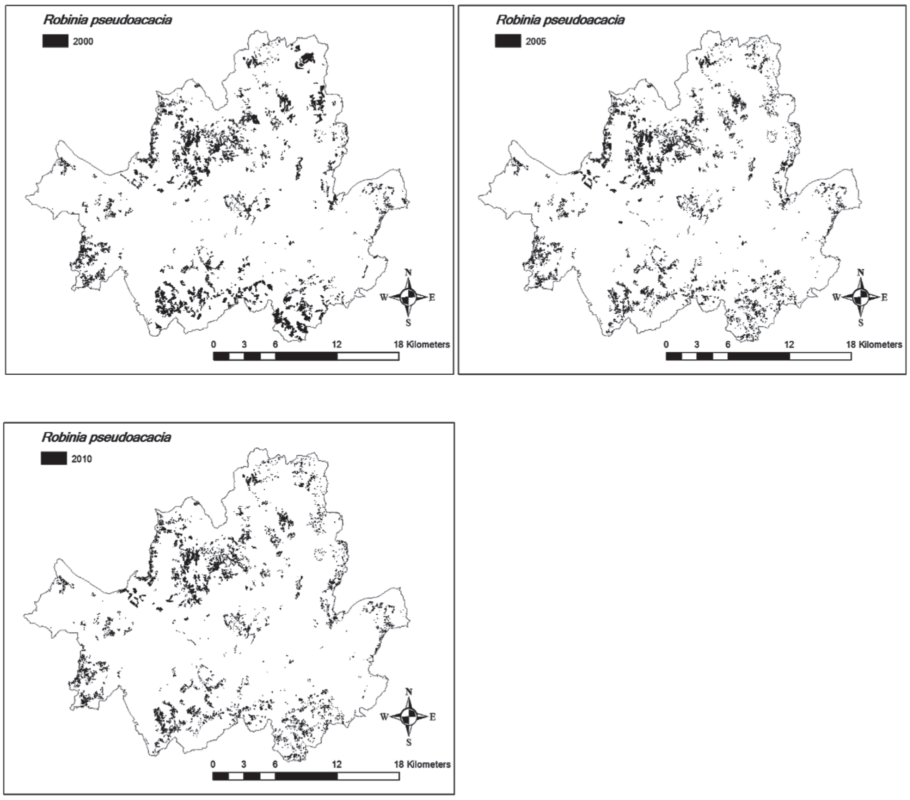

Fig. 2. Changing forest-stands of *Robinia pseudoacacia* in 2000, 2005 and 2010

other hand, the sum of carbon stock of a tree per stand increased by 19,848.41 kg to 64,397.72 kg from 44,549.31 kg over the same period.

Assumedly, these changes resulted from increased occurrences in small forest stands between 2010 and 2000. Urban development accompanies sporadic ruined–lands around the developed areas. The barren areas become suitable places for *Robinia pseudoacacia* to grow as a pioneer species, which occurs in disturbed areas on rich to sterile soil (Cierjacks *et al*. 2013). A *Robinia pseudoacacia* is a leguminous plant, so it grows well in barren lands (Cierjacks *et al*. 2013). Higher segmented stands of *Robinia pseudoacacia* were generated, therefore, the sum of carbon stock of a tree per stand

Table 1. Biomass change of tall trees and small trees according to stands by year (Unit: kg)

Year	Tall tree		Small tree	
	AT [1]	TT [2]	AT	TT
2000	176.39	298,805.02	26.30	44,549.31
2005	160.23	434,211.29	23.66	64,110.36
2010	163.99	444,405.11	23.76	64,397.72

[1] AT = the mean biomass of a tall tree or a small tree by a stand
[2] TT = the sum of the mean biomass of a tall tree or a small tree according to the number of forest stands

Table 2. Biomass change of tall trees and small trees according to total biomass by year (Unit: kg)

Year	Tall tree		Small tree	
	MB [1]	TB [2]	MB	TB
2000	234,988.25	398,070,098.48	38,627.71	65,435,343.32
2005	121,458.39	329,152,246.77	15,223.69	41,256,199.26
2010	121,068.74	328,096,287.24	15,544.40	42,125,330.49

[1] MB = the mean biomass in a stand of the total biomass of tall trees or small trees
[2] TB = the total biomass of tall trees or small trees

increased. The number of stands shown on the Seoul biotope map was 1694 in 2000, but was equal to 2710 in both 2005 and 2010.

The total biomass of the tall trees and the small trees, however, decreased. The total biomass of the tall trees decreased by 69,973,811.24 kg to 328,096,287.24 kg in 2010 from 398,070,098.48 kg in 2000. Further, that of the small trees decreased by 23,310,012.83 kg in 2010 from 2000 (Table 1–2). The main reason for the decrease was the reduction of the area of size of *Robinia pseudoacacia* stands. The total biomass of *Robinia pseudoacacia* biomass in Seoul, as a whole, decreased from 2000 to 2010 by 93,283,824.03 kg. However, the change was not remarkable between 2005 and 2010. Resultantly, the number of *Robinia pseudoacacia* turned out to have decreased.

The correlation between the biomass of the tall trees and small trees and the total biomass shows that the tall trees were highly related with the total biomass (0.994 ($P<0.01$)) while the small trees were related to the total biomass is 0.778 ($P<0.01$). The biomass of the tall trees has more effective on the total biomass.

The carbon stock of *Robinia pseudoacaci*a in South Korea was estimated to be 2,517,598 tC (Son *et al*., 2014). The carbon stock of *Robinia pseudoacacia* in Seoul turned out to be around 185,111 tC in 2010 (Table 3). It decreased by 46,642 tC from 2000. The size of Seoul is around 605 km^2, taking 0.6% (99,720 km^2) of the total size of South Korea. The carbon stock of Seoul *Robinia pseudoacacia*, however, took about 7.4% of the total carbon stock of *Robinia pseudoacacia* in South Korea, which was considerably high.

Table 3. Total biomass and carbon stock

Year	MBT [1] (kg)	TBT [2] (kg)	CS [3] (C)
2000	273,615.96	463,505,441.76	231,752,720.88
2005	136,682.08	370,408,446.03	185,204,223.02
2010	136,613.14	370,221,617.74	185,110,808.87

[1] MBT = the mean biomass in a stand including the total biomass of tall trees and small trees
[2] TBT = the total biomass of tall trees and small trees
[3] CS = the carbon stock

The annual absorption of carbon dioxide by *Robinia pseudoacacia* in Korea was 13.79 tCO_2/ha/yr, which is greater than that by oak trees such as *Quercus mongolica, Quercus aliena, Quercus variabilis* and *Quercus dentata* (its annual absorption of carbon dioxide is 12.1tCO_2/ha/yr) (Son *et al*., 2014). *Robinia pseudoacacia* can play an important role not only as a nectar–source plant but also as a tree to alleviate the adverse effects of climate change. Therefore, it is necessary to preserve and manage *Robinia pseudoacacia* since it has been confirmed that the carbon stock of *Robinia pseudoacacia* in Seoul has decreased.

CONCLUSION

This study used the biomass allometric equation of *Robinia pseudoacacia* provided by the Korea Forest Service. Furthermore this study applied the equation to the spatial distribution of *Robinia pseudoacacia* stands in Seoul to measure specific carbon stock. The carbon storage of *Robinia pseudoacacia* in Seoul decreased around 46,642 tC in 2010 from 2000. The reduced carbon stock refers to the reduced area of storable carbon. Although the main cause was due to the decreased area of the total forest in Seoul, which led to the decreased area for *Robinia pseudoacacia* stands, it should be noted that *Robinia pseudoacacia* was shown to be an important source of storing carbon. The Republic of Korea set a goal of reducing greenhouse gas by 30% by 2020 for Business as usual (BAU) or by 4% down versus 2005. Therefore, it is time to pay more attention to increasing carbon stock. Seoul could not currently develop large–scale construction because it could further a few lands. One of the ways to increase carbon stock is to preserve and manage trees. It is necessary to have a plan to preserve the current size of forest as much as possible and increase carbon stock by taking advantage of the favorable characteristics of *Robinia pseudoacacia*.

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