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Biomass Expansion Factors for *Pinus koraiensis* Forests in Korea

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Abstract : Biomass expansion factors that convert the timber volume (or dry weight) to biomass are used to estimate the forest biomass and account for the carbon budget on a national and regional scale. This study estimated the biomass conversion and expansion factors (BCEF), root to shoot ratio (R), biomass expansion factors (BEF) and ecosystem biomass expansion factor (EBEF) of Korean pine (*Pinus koraiensis*) forests based on direct field surveys and publications in Korea. The mean BCEF, BEF, and R was 0.6438 Mg m^{-3} (n = 7, SD = 0.1286), 1.6380 (n = 27, SD = 0.1830), and 0.2653 (n = 14, SD = 0.0698), respectively. The mean EBEF, which is a simple method for estimating the understory biomass in Korean pine forest ecosystems, was 1.0218 (n = 6, SD = 0.0090). The values of the biomass expansion factors in this study estimated the Korean pine forest biomass with more precision than the default values given by the IPCC (2003, 2006).

Key words : *biomass conversion and expansion factor, root/shoot ratio, biomass expansion factor, ecosystem biomass expansion factor, Korean pine*

Introduction

Forest inventories with a large number of statistically valid plots have been recognized as appropriate data for identifying the size and spatial patterns of forest biomass on a regional or national scale (e.g. Brown *et al*., 1999; Choi *et al*., 2002; Nabuurs *et al*., 2003; Fang *et al*., 2005). However, most forest inventories focus on the merchantable timber volume and often omit information on non-commercial components, such as branches, foliage and twigs (Fang and Wang, 2001). Biomass expansion factors, which convert the timber volume (or dry weight) to biomass, are used to estimate the forest biomass and account for the non-commercial components (Brown *et al*., 1989; Turner *et al*., 1995; Schroeder *et al*., 1997; Fang *et al*., 2001; Lehtonen *et al*., 2004; Son *et al*., 2007a). In the meantime, biomass expansion factors are also strongly recommended by the Intergovernmental Panel on Climate Change (IPCC) guidelines (IPCC, 2003, 2006). The IPCC (2006) revised the volume-based biomass expansion factors and weight-based biomass expansion factors in the BCEF and BEF, respectively.

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Pinus koraiensis Sieb. et Zucc. (Korean pine) is one of the major tree species in Korea because of high-value wood products and nuts, covering about 8.6% of the total forest area in Korea (Statistical Yearbook of Forestry, 2008). Although studies on biomass and nutrients for this species in Korea have been reported (Lee *et al*., 1987; Kim and Kim, 1988; Lee and Kim, 1997; Yi, 1998; Son *et al*., 2001, 2007b; Noh *et al*., 2005; Kwon and Lee, 2006), there is little information on the biomass expansion factors.

This study estimated the biomass expansion factors (BEF, BCEF and R) for Korean pine forests based on direct field measurements and publications in Korea. The definition and equation for calculating the biomass expansion factors were determined based on the IPCC guidelines (2003, 2006).

Data and Methods

Two data sets were used in this study, namely field survey data and publication data.

1. Field survey data

Direct field surveys were carried out at two areas in central Korea. One was located at a Korean pine forest

Table 1. Stand characteristics and biomass (Mg/ha) of Korean pine (*Pinus koraiensis*) forests in Korea.

Location	Mean age (years)	Mean DBH (cm)	Mean height (m)	Stand density (stems/ha)	Stem volume (m^3/ha)	Tree stem biomass	Total aboveground tree biomass	Tree root biomass	Total ground vegetation biomass	Reference
Hongcheon	19	12.2	6.9	975	38	15.8	34.3	7.6	1.6	This study
Yangpyeong	33	21.3	12.9	650	145	56.9	102.9	16.4	2.3	
	30	20.4	13.1	650	122	49.4	86.2	17.3	2.8	
Hongcheon	35	24.6	15.0	825	274	92.8	157.8	57.4	3.8	
	43	30.5	16.8	550	349	126.3	197.2	56.9	4.6	
	51	28.1	19.3	625	420	146.0	198.4	52.0	2.5	
Gapyeong	13	9.2		1633		19.5	30.6	11.6		Noh *et al.* 2005
	30	20.4		633		61.8	112.5	41.2		
	50	29.2		333		50.3	95.8	34.5		
Hongcheon*	22	12.9		1900		61.2	92.8		3.3	Yi 1998
	34	18.9		844		63.3	95.7		0.6	
	46	24.6		650		86.2	127.8		4.6	
	66	30.1		375		90.0	130.8		2.2	
Yangpyeong	17	10.2		1406		37.8	53.6			Son *et al.* 2001; 2007b
	26	17.3		1168		93.3	139.7			
	36	21.3		805		130.5	209.1			
	46	32.4		488		163.4	279.7			
	57	34.3		491		167.6	291.7			
	68	38.1		484		181.2	324.8			
	74	44.3		256		178.2	339.9			
Jecheon	24	8.5		2250		30.8	47.0			Kwon and Lee 2006
Gwangju*	13	9				23.8	40.4	9.3		Kim and Kim 1988
	18	13.2				48.8	82.2	22.3		
	22	15.0				82.7	122.9	27.2		
	55	16.6				106.7	145.5	22.5		
Gwangju	28	17.6	12.0	840	130	46.6	75.3			Lee and Kim 1997
Gwangju	27					42.6	67.8	18.4		Lee *et al.* 1987

*Excluding samples with diameter at breast height (DBH) < 6 cm.

in the Experimental Forest of Kangwon National University (37º46'-51' N, 127º48'-52' E). The Experimental Forest was established in 1953, and its total forest area was 3146 ha in 2000, 522 ha of which was covered by Korean pine forest. The region has a temperate climate with a mean annual temperate of 9.2ºC and a mean annual precipitation of 1289 mm distributing mainly in summer. The average temperatures in January and July are -6.1 and 24.8ºC, respectively. The soil texture is sandy clay loam. The other was located in a Korean pine forest at the Yangpyeong area (37º30' N, 127º42' E), 40 km west-south of the Experimental Forest, where two about 30-year-old stands were established (Table 1). The characteristics of the area were described in Son *et al.* (2001). Four stands with different age (19-, 35-, 43-, and 51-year-old) were selected from the Experimental Forest (Table 1).

A destructive method with direct field measurements was used to calculate the biomass for the sample trees, which was similar to the work reported elsewhere (Yi, 1998; Son *et al.* 2001). A total of thirty Korean pine trees were selected from six different aged stands (Table 1). In early August 2008, five Korean pine trees representing the stand-specific diameter at breast height (DBH) range were selected and sampled destructively in the six stands (20 m × 20 m). The trees were cut at a height of 20 cm above the ground. Before removing the branch, the diameter of each branch was measured, and five representative branches from the smallest to largest throughout the crown were sampled. All branches were then clipped from the tree, and fresh weights were determined using a balance (spring balance, KERN). The sampled branches were separated into different components (foliage, live and dead branches), and all components of the subsam-

ples were taken to the laboratory to determine the moisture content. The stem of each tree was cut in 2 m sections and weighed on a balance. A disc (approximately 5cm widths) was cut from the stump to the top of each stem section to determine the moisture content. The dry weight of each component (foliage, branches and stem) was calculated for each sample tree. Radial growth along the longest, shortest and intermediate radius on each section was determined to obtain the stem volume over the bark of each tree based on Smalian's formula (Avery and Burkhart, 1983). The volume of each stand was estimated by multiplying the mean volume of sample trees by the stand density.

To estimate the root biomass, two trees were harvested based on their diameter distribution within each stand and the entire root system was washed lightly to remove soil particles, oven-dried, and weighed. The total dry weight of the different components (foliage, branches, stem and root) was calculated. The weights were related to the DBH in the logarithmic regression equation (Son *et al.* 2001): $\text{Log}Y = a + b$ Log (DBH), to estimate whole stand biomass and calculate the biomass expansion factors for each stand.

Three 1 m × 1 m microplots were established within each stand. In each microplot, whole ground vegetation (shrubs and herbs) including roots was harvested. Biomass of each ground vegetation component was air-dried and subsamples were oven-dried at 65°C to calculate dry biomass density.

2. Publication data

The papers published on Korean pine biomass studies in Korea were reviewed, and biomass data reported for Korean pine with DBH < 6 cm was omitted because small DBH was considered as saplings (Korea Forest Service, 2009). Totally 27 sets of data (n = 27) that are available for analysis were obtained, including field survey data (Table 1). It should be noted that not all publications reported the stand volume and below ground biomass. For those studies, the stand volume was estimated based on the reported mean DBH and height by multiplying the mean stem volume with the stand density using a revised volume table (Korea Forest Service, 2009).

3. Biomass conversion and expansion

According to the IPCC (2003, 2006), whole stand biomass (whole trees biomass) for Korean pine forests was calculated based on equations (1) and (2):

$$B = V \times \text{BCEF} \times (1+\text{R}) \quad (1)$$

$$B = V \times WD \times \text{BEF} \times (1+\text{R}) \quad (2)$$

where B is the whole stand biomass (Mg ha^{-3}), V is the merchantable volume (m^3 ha^{-1}), R is the root to shoot ratio, which is dimensionless, WD is the basic wood density, BCEF is the aboveground biomass to stand volume ratio (Mg m^{-3}), and BEF is the aboveground biomass to stem (over bark) biomass ratio, which is dimensionless.

In addition, ecosystem biomass expansion factor (EBEF, dimensionless) is defined as the ratio of the forest ecosystem biomass (whole trees, herbs and shrubs biomass) to the whole stand biomass to estimate the forest ecosystem biomass for Korean pine forests.

Results and Discussion

The mean BCEF, BEF, R, and EBEF was 0.6438 Mg m^{-3} (n = 7, SD = 0.1286), 1.6380 (n = 27, SD = 0.1830),

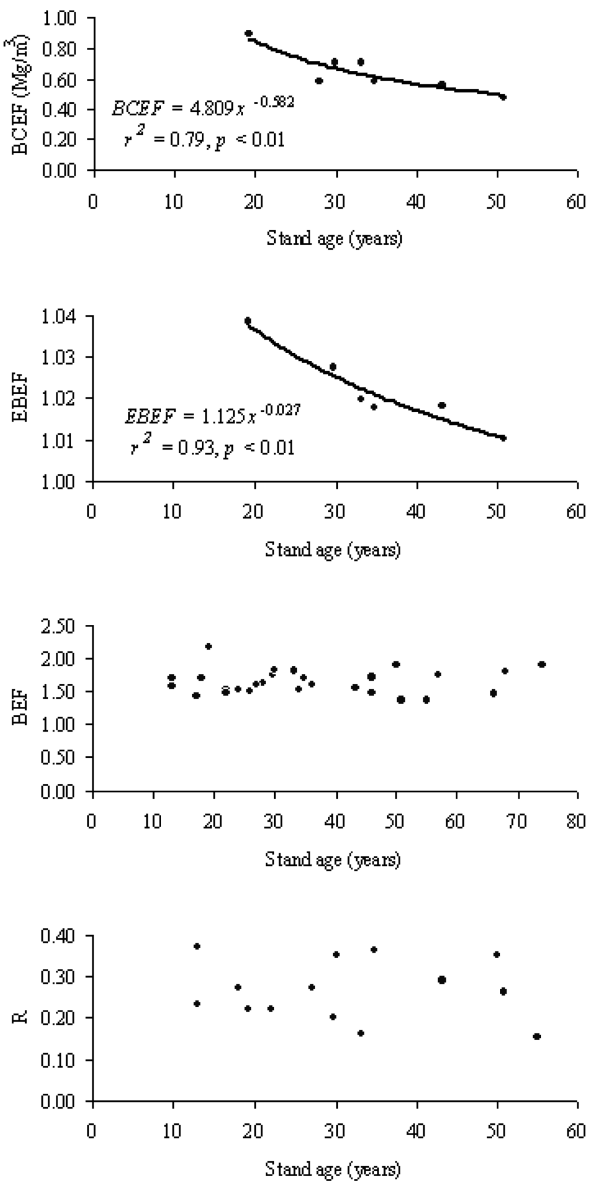

Figure 1. Relationships between biomass expansion factors (BCEF, EBEF, BEF and R) and stand age for *Pinus koraiensis* (Korean pine) in Korea.

0.2653 (n = 14, SD = 0.0698), and 1.0218 (n = 6, SD = 0.0090), respectively. Considering that the relationships between biomass expansion factors and stand age are heteroscedastic and non-linear, we made comparisons of the main equation forms to obtain the best fit for these relationships. Although no equation could be found to fit the relationships between the BEF (or R) and stand age, BCEF and EBEF are expressed as a simple power equation of the stand age for Korean pine (Figure 1), which was not consistent with the exponential equations examined by Lehtonen *et al.* (2004) who reported that BCEF is dependent on stand age and dominant tree species in Finland forests. Different results may be due to different tree species and relatively small scale data in this study, which suggests that further evidence for the relationship between BCEF and stand age will require more data set in future research work.

The IPCC (2003) provides tables of the default values for the BEF and R. The IPCC (2006) also provides default values for the BCEF. The mean values of BEF, R and BCEF for pine species were calculated based on the default values given by the IPCC to compare the mean values in this study. The mean BCEF value in this study was 0.6438 Mg m^{-3}, which is lower than the mean default value of BCEF (0.7375 Mg m^{-3}), whereas the mean BEF value of 1.6380 was much higher than the mean default value of BEF (1.3000). The R value of 0.2653 in this study was also lower than the 0.3367 reported by the IPCC. A simple relative error (Er, %) was defined to calculate the uncertainties between the values in this study and the default values as follows: $Er = (V_d - V_s)/V_s \times 100$, where V_d and V_s denote the default values and the values in this study, respectively. The results of the relative error are -20.63%, 14.56% and 26.94% for the BEF, BCEF and R, respectively. Therefore, the values of the biomass calculating factors in this case might give a more precise estimate of the Korean pine forest biomass in Korea than those using the default values.

Our results were also compared with the results from previous studies. Son *et al.* (2007a) estimated the total forest biomass of Korea using a BEF value of 1.29 for whole coniferous trees, which was less than the mean BEF value (1.6380) in this study. Our mean BCEF value was greater than 0.566 Mg m^{-3} ranging from 0.48 to 0.69 reported for all coniferous species in Europe (Camp *et al.*, 2004). Luo *et al.* (2007) calculated the mean values of BEF, BCEF and R for *Larix* forests in China, and the results were 1.3493, 0.6834 Mg m^{-3} and 0.2456 for BEF, BCEF and R, respectively. The mean values of BEF and R for *Larix* forests were lower than our results, whereas the mean BCEF value was slightly greater than our findings. The discrepancy of these values appeared to be due to from different species.

Although an estimation of the forest biomass is easily accomplished by applying different BCEF methods coupled with forest inventories at the regional or national level, many studies normally exclude the understory biomass. The EBEF was defined in this case, and it is believed that the EBEF is a complementary method for estimating the whole forest ecosystem biomass because herb and shrub layers also are important components in Korean pine forest ecosystems.

Conclusions

The mean BCEF, BEF, R, and EBEF was 0.6438 Mg m^{-3} (n = 7, SD = 0.1286), 1.6380 (n = 27, SD = 0.1830), 0.2653 (n = 14, SD = 0.0698), and 1.0218 (n = 6, SD = 0.0090), respectively. This study attempted to fit the non-linear relationships between the biomass expansion factors and stand age. BCEF and EBEF are expressed as a simple power equation of the stand age for Korean pine, whereas no equation could be found to fit the relationships between the BEF (or R) and stand age. The values of the biomass expansion factors in this study estimated Korean pine forest biomass more precisely than the default values given by the IPCC (2003, 2006). The EBEF is a simple method for estimating the understory biomass in Korean pine forest ecosystems.

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