J. Plant Biol. (2010) 53:381–386
DOI 10.1007/s12374-010-9134-7

REVIEW

Biomass Expansion Factors of Natural Japanese Red Pine (*Pinus densiflora*) Forests in Korea

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Received: 24 March 2010 / Revised: 21 October 2010 / Accepted: 22 October 2010 / Published online: 11 November 2010

Abstract Biomass expansion factors, which convert the timber volume (or dry weight) to biomass, are used to estimate the forest biomass and account for the carbon budget at the national or regional level. This study estimated the biomass conversion and expansion factors (BCEF), root to shoot ratio (*R*), biomass expansion factors (BEF) of natural Japanese Red Pine (*Pinus densiflora* Sieb. et Zucc.) forests based on direct field measurements and publications in Korea. This study attempted to fit the non-linear relationships between the biomass expansion factors (BCEF and BEF) and main stand factors [stand age, tree height, and diameter at breast height (DBH)]. The relationship between BEF and each main stand factor was expressed as a simple logarithmical equation. The BCEF was also expressed as a logarithmical equation of the tree height, DBH, and stand volume, whereas there was no significant relationship between BCEF and stand age. The mean value for BCEF, BEF, and *R* was 0.5821 Mg m^{-3} (n=22, SD=0.1196), 1.4465 (n=22, SD=0.2905), and 0.2220 (n=17, SD=0.0687), respectively. The values of the biomass expansion factors in this study may indicate much representativeness to estimate forest biomass in natural Japanese Red Pine forests of Korea than the default values given by the IPCC (2003, 2006).

Keywords Biomass conversion and expansion factor · Biomass expansion factor · Default value · Japanese red pine · Root/shoot ratio

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Introduction

The forest biomass size plays an important role in influencing the global carbon cycle and assisting in meeting greenhouse gas emission targets (e.g., Fang and Wang 2001; Lehtonen et al. 2004; Jalkanen et al. 2005; Somogyi et al. 2007). Biomass expansion factors, which 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 (e.g., Brown et al. 1989, 1999; Alexeeyev et al. 1995; Isaev et al. 1995; Turner et al. 1995; Fang et al. 2001; Camp et al. 2004; Son et al. 2007). Most forest inventories focus on the merchantable timber volume with information on non-commercial components, such as branches, foliage, and roots, often omitted (Fang and Wang 2001). Therefore, in addition to wood volume data, biomass expansion factors that account for the non-commercial components are used to estimate the forest biomass and carbon storage (Brown et al. 1989; Schroeder et al. 1997; Fang and Wang 2001). Biomass expansion factors are also strongly recommended by the IPCC (Intergovernmental Panel on Climate Change) guidelines (IPCC 2003, 2006). The IPCC (2006) revised the volume-based biomass expansion factors and weight-based biomass expansion factors in the biomass conversion and expansion factors (BCEF) and biomass expansion factors (BEF), respectively.

Japanese Red Pine is one of the most important tree species in the natural coniferous and mixed forests of Korea, in terms of high-value wood products and cultural significance and covers approximately 23.1% (1,473,000 ha, 55.0% of the coniferous forest area) of Korea's total forest area, playing a very important role in the national and regional ecosystem (Statistical Yearbook of Forestry 2009; Noh et al. 2010). Many studies on local biomass measurements and biomass equations have been examined in natural Japanese Red Pine forests during the past three decades (e.g., Lee 1985; Park and Lee 1990; Jeong et al. 2010), including the first study of BEF in relation to ecotype and stand age (Park et al. 2005). However, there is still a lack of information about the biomass expansion factors.

This study estimated the biomass expansion factors (BCEF, BEF, and R) for natural Japanese Red Pine forests based on direct field measurements and publications in Korea and made the first attempt to analyze the relationships between the biomass expansion factors (BCEF and BEF) and main stand factors [stand age, tree height, and diameter at breast height (DBH)]. 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, a direct field measurement data set and a data set from publications, were used in this study.

Direct Field Measurement Data Set

Direct field measurements were conducted in a naturally occurring Japanese Red Pine forest at the Inje area (38°59′ N, 128°11′ E, elevation 600–811 m), which is located in central Korea. The forest overstory is composed relatively purely of Japanese Red Pine trees. The climate of the region is humid continental with hot, humid summers and cold, dry winters. The average annual precipitation of 1,172 mm is distributed mainly in summer. The average temperatures in January and July are −2.7°C and 20.6°C, respectively. The soil texture is sandy clay loam.

A destructive method with direct field measurements was used to calculate the biomass for the sample trees, which was similar to that reported elsewhere (Yi 1998; Son et al. 2001). A total of 30 Japanese Red Pine trees were selected from six different aged stands with 10-year intervals. The DBH values of Japanese Red Pine trees in each stand were divided into five classes, and the sample trees that represented each diameter class were selected at random from 20 m×20-m plots in each stand. The sample trees were harvested at a height of 20 cm above the ground in early September of 2007 in central Korea. 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, current-year twigs, live branches, and dead branches), and all components of the subsamples 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 disk 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 stems) 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, stems, and roots) was calculated. The weights were related to the DBH in the logarithmic regression equation (Park and Lee 1990): $\log Y = a + b \log (DBH)$, to estimate total tree biomass and calculate the biomass expansion factors for each stand.

Publication Data Set

The papers published on Japanese Red Pine biomass studies in Korea were reviewed, and 22 sets of data that were available for analysis were obtained, including direct field measurement (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).

Biomass Conversion and Expansion

This study assumed that the overstory vegetation is purely dominated by *Pinus densiflora* in natural Japanese Red Pine forests because the general characteristics of Japanese Red Pine stands from mostly previous studies indicated the overstory vegetation was relatively or purely dominated by Japanese Red Pine, and little information on other species

Table 1 Site characteristics and biomass of natural Japanese Red Pine forests in Korea (DBH: diameter at breast height)

Location		Forest type	Aspect	Altitude (m)	Slope (°)	Stand age (years)	Mean tree height (m)	Mean DBH (cm)	Stand density (trees/ha)	Biomass (Mg/ha)				References
										Stem	Aboveground tree	Tree root	Total tree	
Gangwon province	38°59′ N, 128°11′ E	Natural	SE	607	40	17	6.5	10.1	1,400	11.5	22.0	7.1	29.1	This study
	37°59′N, 128°11′ E		NE	710	35	28	15.2	20.1	500	50.1	68.9	9.9	78.8	
	37°59′ N, 128°11′ E		NE	699	21	26	15.3	20.1	575	48.9	68.3	19.6	88.0	
	37°59′ N, 128°11′ E		NE	769	15	36	17.4	29.5	325	63.6	102.3	30.7	132.9	
	37°59′ N, 128°11′ E		NE	774	15	38	18.4	26.8	625	125.6	174.5	53.2	227.7	
	37°59′ N, 128°11′ E		N	811	10	73	22.9	49.4	350	241.5	308.8	76.9	385.7	
Gyeongbuk province		Natural	W	480	10	18	8.7	10.1	3,470	42.3	61.3	9.3	70.6	Park et al. 2005
			SW	490	5	33	15.3	18.4	1,230	88.1	109.0	23.1	132.1	
			SW	500	10	48	22.4	31.1	600	168.0	204.0	43.7	247.7	
			SW	350	20	16	4.0	6.4	2,800	8.8	21.1	4.4	25.5	
			SW	450	25	37	7.6	13.1	1,230	25.5	43.6	11.8	55.4	
			SE	450	25	45	13.9	23.8	730	82.3	111.1	34.7	145.7	
Gangwon province	37°47–48′ N, 128°29′ E	Natural	NW	640–700		36	18.6	29.0	682	147.5	198.8		198.8	Lee 1985
Gyeongbuk province	36°29′ N, 129°13′ E	Natural	SE	190	10	42	3.8	7.1	2,520	13.3	23.0	5.1	28.1	Park and Kim 1989; Park and Lee 1990
Jeonnam province	35°03′ N, 127°30′ E		S	110	15	33	11.9	16.6	1,030	68.3	93.6	15.4	108.9	
Joenbuk province	35°24′ N, 127°16′ E		NW	300	10	31	12.1	17.1	1,150	85.7	116.6	15.0	131.6	
Gangwon province	37°34′ N, 128°44′ E		SE	720	20	35	18.2	26.8	723	137.7	181.9	21.3	203.2	
Chungbuk province	36°47–59′ N, 128°02–20′ E	Natural	NE	300	10	48	12.3	22.7	975	87.3	138.1		138.1	Lee et al. 2006
Gyeongnam province	35°29′ N, 127°58′ E	Natural				40	13.3	17.3	1,308	89.8	105.6	17.7	123.4	Kim et al. 2009
Gyeongnam province	37°27′ N, 127°57′ E	Natural	SW	766	20	42	13.8	20.4	1,158	108.2	131.0		131.0	Jeong et al. 2010
	35°12′ N, 127°43′ E		S	555	25	43	17.6	25.1	925	152.4	177.0		177.0	
	35°21′ N, 127°43′ E		SW	746	20	36	14.8	20.2	692	53.7	66.5		66.5	

of the overstory was reported in publications. According to the IPCC (2003, 2006), total tree biomass (excluding the biomass of shrubs and herbs because only four data sets are available to use) in natural Japanese Red Pine forests was calculated based on Eqs. 1 and 2.

$$B = V \times BCEF \times (1 + R), \tag{1}$$

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

where B is the whole biomass (megagrams per cubic hectare); V is the merchantable volume (cubic meters per hectare); R is the root to shoot ratio, which is dimensionless; WD is the basic wood density; $BCEF$ is the aboveground tree biomass to stand volume ratio (Mg m^{-3}), and BEF is the aboveground tree biomass to stem biomass ratio, which is dimensionless.

Results and Discussion

The mean BCEF, BEF, and R was 0.5821 Mg m^{-3} (n=22, SD=0.1196), 1.4465 (n=22, SD=0.2905), and 0.2220 (n=17, SD=0.0687), respectively. Considering that the relationships between biomass expansion factors and main stand factors are heteroscedastic and non-linear, comparisons of the main function forms were made to obtain the best fit for these relationships. In this study, the relationship between BEF and each main stand factor was expressed as a simple logarithmical equation (Fig. 1). The BCEF was also expressed as a logarithmical equation of the tree height, DBH, and stand volume, whereas there was no significant relationship between BCEF and stand age (Fig. 1). There was no significant relationship between R and main stand factors and between biomass expansion factors and stand density.

Since the biomass is one of the key variables in forest ecosystem studies, researchers attempt to not only use biomass expansion factors to facilitate its estimation, but also establish the correlations between biomass expansion factors and stand factors. For example, Lehtonen et al. (2004) reported that BCEF was dependent on the stand age. In contrast, the results from other studies (Fang et al. 2001; Schroeder et al. 1997) suggested that the BCEF can be expressed as a function of the stem volume. In this study, the logarithmical relationships between biomass expansion factors (BEF and BCEF) and main stand factors (stand age, tree height, and DBH) suggest that not only stand age and volume, but also other main stand factors, such as tree height and DBH, have a significant effect on the BEF and BCEF, whereas there was no correlation relationship between BCEF and stand age for naturally Japanese Red Pine forests. This study also revealed a logarithmical relationship between the BCEF and stand volume (Fig. 1), which was not consistent with the reciprocal equation developed by Fang and Wang (2001) and the power equations reported by other researches (Schroeder et al. 1997; Lehtonen et al. 2004). In general, these different relationships between the BCEF and stem volume are conveniently used to scale up the direct field measurement coupled with forest inventories to estimate the forest biomass at the regional and national level (Brown et al. 1999; Fang et al. 2001). For example, Fang and Wang (2001) introduced a consistent BCEF method based on the relationship between the BCEF and stand volume, and promoted a large-scale sight of forest biomass estimation.

The IPCC (2003) provides tables of the default values for the BEF (Table 3A.1.10), R (Table 3A.1.8). The IPCC (2006) also provides default values for the BCEF (volume 4, Table 4.5). For a better understanding of applicability of the biomass expansion factors in Korean case, the mean values of BCEF, BEF, and R 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 0.5821 Mg m^{-3}, which is lower than the mean default value of BCEF (0.7375 Mg m^{-3}). The mean BEF value of 1.4465 was higher than the mean default value of BEF (1.3000). The R value of 0.2220 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: $\mathrm{Er} = (F_1 - F_2)/F_2 \times 100$, where F_1 and F_2 denote the default values and the values in this study, respectively. The results of the relative error are 21%, −11%, and 34% for the BCEF, BEF, and R, respectively. The uncertainties may indicate that the values of the biomass expansion factors in this case give much representativeness to estimate forest biomass in natural Japanese Red Pine forests of Korea than those using the default values.

The values in this study were also compared with the results from other studies. Son et al. (2007) estimated the total forest biomass of Korea using a BEF value of 1.29 for whole coniferous trees, which was lower than the mean BEF value (1.4465) in this study. The mean BCEF value was 0.566 Mg m^{-3} ranging from 0.48 to 0.69 for all coniferous species in Europe (Camp et al. 2004), which was very close to the mean BCEF value (0.5821 Mg m^{-3}) in this study. Lehtonen et al. (2004) reported that the mean BCEF value of Scot Pine was 0.7029 Mg m^{-3} ranging from 0.690 to 0.710 across all age classes in Finland. Compared with 0.5821 Mg m^{-3} in our study, Scot Pine had a relatively higher value in Finland. The discrepancy of two mean values appeared to be due to from different species.

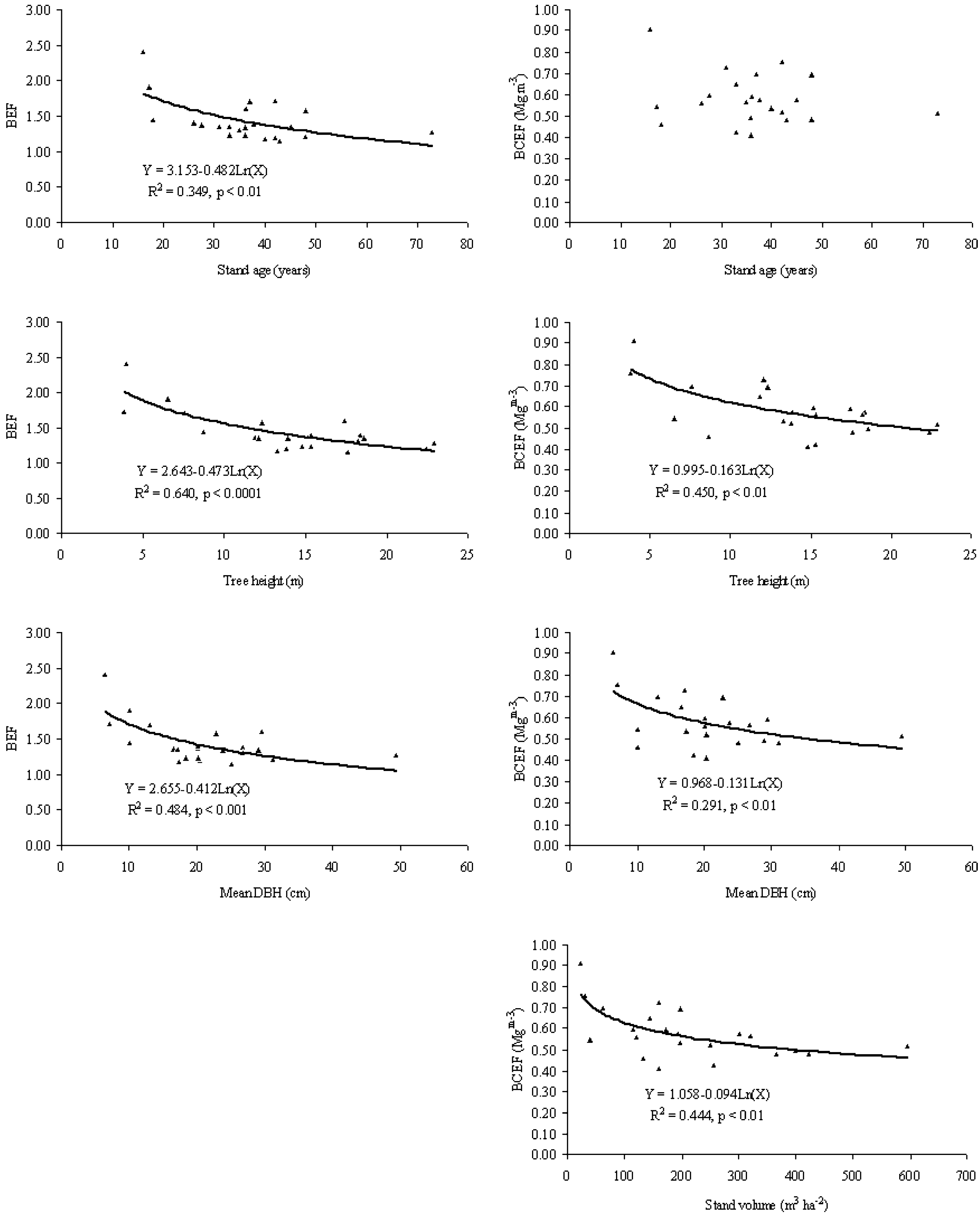

Fig. 1 Biomass expansion factors (BEF) and biomass conversion and expansion factors (BCEF) in relations to main stand factors (stand age, tree height, mean diameter at breast height (DBH), and stand volume, respectively) in natural Japanese Red Pine forests of Korea

Although an estimation of the forest biomass and carbon storage is easily accomplished by applying different biomass expansion factors methods coupled with forest inventories at the regional or national level, many studies normally exclude the understory biomass. Therefore, more biomass data sets from herb and shrub layers will be needed in future research work because they are important components in natural Japanese Red Pine forest ecosystems.

Acknowledgments This study was carried out with the support of “Forest Science & Technology Projects (Project No. S1107L0101)” provided by Korea Forest Service.

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