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Notes on the biomass expansion factors of *Quercus mongolica* and *Quercus variabilis* forests in Korea

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Abstract

Biomass expansion factors, which convert timber volume (or dry weight) to biomass, are used for estimating the forest biomass and accounting for the carbon budget at a regional or national scale. We estimated the biomass conversion and expansion factors (BCEF), biomass expansion factors (BEF), root to shoot ratio (R), and ecosystem biomass expansion factor (EBEF) for *Quercus mongolica* Fisch. and *Quercus variabilis* Bl. forests based on publications in Korea. The mean BCEF, BEF, and R for *Q. mongolica* was 1.0383 Mg/m^3 ($N = 27$; standard deviation [SD], 0.5515), 1.3572 ($N = 27$; SD, 0.1355), and 0.2017 ($N = 32$; SD, 0.0447), respectively. The mean BCEF, BEF, and R for *Q. variabilis* was 0.7164 Mg/m^3 ($N = 17$; SD, 0.3232), 1.2464 ($N = 17$; SD, 0.0823), and 0.1660 ($N = 8$; SD, 0.0632), respectively. The mean EBEF, as a simple method for estimating the ground vegetation biomass, was 1.0216 ($N = 7$; SD, 0.0232) for *Q. mongolica* forest ecosystems, and 1.0496 ($N = 8$; SD, 0.0725) for *Q. variabilis* forest ecosystems. The biomass expansion factor values in this study may be better estimates of forest biomass in *Q. mongolica* or *Q. variabilis* forests of Korea compared with the default values given by the Intergovernmental Panel on Climate Change (IPCC).

Keywords: biomass conversion factor, biomass expansion factor, *Quercus mongolica*, *Quercus variabilis*, root/shoot ratio

INTRODUCTION

The magnitude of forest biomass plays a key role influencing the global carbon cycle and assisting in meeting greenhouse gas emission targets (Ciais et al. 2008, Li et al. 2010b, Nabuurs et al. 2010). With a large number of statistically valid plots, forest inventories have been recognized as appropriate data for identifying the size and spatial patterns of forest biomass at a regional or national scale (Schroeder et al. 1997, Choi et al. 2002, Son et al. 2007b, Guo et al. 2010, Li et al. 2010b). Most forest inventories only record the merchantable timber volume and exclude non-commercial components, such as branches, foliage, and twigs (Fang and Wang 2001). Biomass expansion factors (BEF) that convert, expand, or reduce the volume (or dry weight) of the biomass estimate are normally used for predicting tree biomass as a function of stand structural variables to estimate forest biomass and account for the non-commercial components (Fang et al. 2001, Lehtonen et al. 2004, Somogyi et al. 2007, Son et al. 2007b).

BEF have been introduced in recent decades to estimate forest biomass on a landscape or regional level (Fang et al. 1998, Van Camp et al. 2004, Somogyi et al. 2007). For example, BEF were obtained by compiling data from the literature to estimate country-level biomass (Fang et al. 1998, Van Camp et al. 2004). Reliable estimation and rep-

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resentativeness of BEF are crucial for accurately estimating changes in forest biomass and carbon stock. BEF have also been strongly recommended by the Intergovernmental Panel on Climate Change (IPCC) guidelines (IPCC 2003, 2006). The IPCC (2006) revised the volume-based BEF and weight-based BEF into the biomass conversion and expansion factors (BCEF) and BEF, respectively.

Q. mongolica and *Q. variabilis* are two of the most common oak species that are widely found in natural deciduous and mixed forests throughout Korea (Yi 2003, Son et al. 2004a, 2007a, Park et al. 2005a, Kwon and Lee 2006b) and play an important role in ecological, social and economic aspects in terms of increased biodiversity, cultural significance, and wood production across the country. Over the past several decades, data sets on biomass and productivity of *Q. mongolica* and *Q. variabilis* forests have been published with the large accumulation of field survey data (Song et al. 1997, Park et al. 2003, 2005a, Son et al. 2004b). Son et al. (2005) first calculated and tested the values of root to shoot ratio (R) and BEF for *Q. mongolica* and *Q. variabilis* by age classes using e destructive method. However, there is still a lack of information on the BEF for the two tree species.

This study estimated the biomass expansion factors (BCEF, BEF, R, and ecosystem biomass expansion factor [EBEF]) for *Q .mongolica* and *Q. variabilis* forests based on Korean data. The definition and equation for calculating the BEF were determined based on the IPCC guidelines (2003, 2006) and one publication (Li et al. 2010a).

MATERIALS AND METHODS

Publication data

Studies on biomass were reviewed in the literature by tree species in Korea, and biomass data sets reported for *Q. mongolica* and *Q. variabilis* with diameter at breast height (DBH) < 6 cm were omitted, because small DBH trees are considered saplings (Korea Forest Service 2009). In total, 39 data sets ($N = 39$) for *Q. mongolica* (Table 1) and 17 data sets ($N = 17$) for *Q. variabilis* were obtained (Table 2). Notably, not all publications reported stand volume, tree root biomass, and ground vegetation (including herbs and shrubs) biomass for the two tree species. For those studies, stand volume was estimated based on the reported mean DBH and height by multiplying the mean stem volume by the stand density using a revised volume table (Korea Forest Service 2009). The data of stem volume over the bark in the studies was usually determined using Smalian's formula (Avery and Burkhart 1983, Park et al. 2005b, Li et al. 2011).

Biomass conversion and expansion

The general characteristics of *Q. mongolica* or *Q. variabilis* forest stands from most of the previous studies indicated the overstory vegetation was relatively or purely dominated by *Q. mongolica* or *Q. variabilis*, and little biomass information on other overstory species was reported (Song et al. 1997, Park et al. 2003, 2005a, Son et al. 2004b). Thus, we assumed that the overstory vegetation was purely dominated by *Q. mongolica* or *Q. variabilis* in the reported oak forests. According to the IPCC (2003, 2006), total tree biomass in *Q. mongolica* or *Q. variabilis* forests was calculated based on Eqs. (1) and (2).

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

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

where B is the total tree biomass (Mg/ha), V is the merchantable volume (m^3/ha), 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 tree stem (over bark) biomass ratio, which is dimensionless.

In addition, EBEF, the ratio of forest ecosystem biomass (total tree biomass plus ground vegetation biomass) to total tree biomass, is used to estimate ground vegetation biomass of *Q. mongolica* or *Q. variabilis* forest ecosystems (Li et al. 2010a).

RESULTS AND DISCUSSION

The mean BCEF, BEF, R, and EBEF for *Q. mongolica* was 1.0383 Mg/m^3 ($N = 27$; standard deviation [SD], 0.5515), 1.3572 ($N = 27$; SD, 0.1355), 0.2017 ($N = 32$; SD, 0.0447), and 1.0216 ($N = 7$; SD, 0.0232), respectively. The mean BCEF, BEF, R, and EBEF for *Q. variabilis* was 0.7164 Mg/m^3 ($N = 17$; SD, 0.3232), 1.2464 ($N = 17$; SD, 0.0823), 0.1660 ($N = 8$; SD, 0.0632), and 1.0496 ($N = 8$; SD, 0.0725), respectively. According to Son et al. (2005), the mean values of BEF and R over age classes were 1.4200 and 0.2643 for *Q. mongolica*, and 1.2007 and 0.2453 for *Q. variabilis*, which were different from our results. The discrepancy appeared to be due to the young age classes (<20 years old) that were excluded from our study (Tables 1 and 2). Compared to our findings, different BCEF values of 0.87

Table 1. Stand characteristics and biomass (Mg/ha) of *Quercus mongolica* forests in Korea.

	Location	Mean age (years)	Mean DBH (cm)	Stand density (*n*/ha)	Mean height (m)	Tree stem biomass	Total aboveground tree biomass	Tree root biomass	Total ground vegetation biomass	Reference
Chuncheon		50	26.9	650	20.4	345.0	438.0	57.1	5.2	Park et al. 2003 Son et al. 2007a
Kwangyang		42	33.2	450	10.7	43.1	62.4			Park 2003
Pyungchang		52	37.2	660	12.5	117.6	156.0			
Youngdong		36	33.1	672	9.8	64.7	110.3			
Chungju	37°02′26″-37°04′ 52″ N, 128°03′21″-128°05′57″ E	67	24.0	875	12.1	91.0	130.6		15.8	Song and Lee 1996
Suncheong		36	12.9	1,040	9.7	70.4	97.8	21.0		Park and Moon 1994
Gwangju		34	15.0	705	11.6	40.7	72.1			Park et al. 1996
Pyungchang	37°29′ N, 128°32′ E	54	18.7	1,308	14.4	153.8	212.2	40.7		Lee and Kwon 2006
		66	18.2	1,175	14.8	141.0	177.4	34.9		
Jecheon	36°51′ N, 128°11′ E	34	10.2	2,316	11.1	122.8	157.3	41.9		
Pyungchang	37°27′-37°30′ N, 128°30′-128°33′ E	63	19.5	1,375	12.9	132.6	176.0	35.6		Kwon and Lee 2006b
		47	18.1	1,250	11.4	117.2	168.0	32.3		
		54	18.3	1,600	14.5	153.8	212.2	40.7		
		66	18.2	1,250	14.8	141.0	177.4	34.9		
		49	17.5	1,275	15.2	149.0	213.3	43.4		
		38	14.9	1,200	13.4	163.5	195.0	37.4		
Gwangyang	35°10′-35°21′ N, 127°22′-127°37″ E	53	17.7	1,367	12.1	184.6	250.4	38.0		Kwon and Lee 2006c
		56	12.4	1,533	8.4	157.1	207.9	34.0		
Jeju	33°21′29″ N, 126°31′53″ E	51	15.6	2,319	11.5	242.0	311.8	56.6		
		36	13.5	3,050	9.9	232.9	300.9	63.5		
Pyeongchang	37°29′ N, 128°32′ E	59	17.2	1,375	12.7		208.3	40.4		Kwon and Lee 2006a
		43	20.4	1,250	12.5		194.1	35.9		
		39	15.3	1,600	12.3		216.0	42.3		
		35	18.9	1,250	13.8		200.2	40.0		
		27	13.1	1,750	10.0		222.2	39.2		
		21	17.9	1,200	12.9		191.0	35.8		
Gwangju	37°19′ N, 127°18′ E	31	11.9	1,875	10.1		110.5	29.1		
Jecheon	36°51′ N, 128°11′ E	34	10.7	2,425	10.7		151.6	39.9		
Gwangyang	35°15′ N, 127°35′ E	35	22.0	1,325	14.8		255.7	38.9		
		43	21.0	1,525	13.7		209.1	34.4		
Jeju	33°21′ N, 126°31′ E	36	15.3	2,033	9.7		326.7	54.4		
		30	13.8	2,800	10.0		236.9	56.9		
Gwangyang	35°05′ N, 127°37′ E	36	9.0	3,175	12.7	73.5	83.1	27.2	5.3	Park et al. 2005b
Seoul		46	16.2	775	14.0	188.6	244.3	34.3	0.4	Park et al. 2005a
		46	14.7	900	15.3	101.6	127.1	24.8	0.6	Son et al. 2007a
		52	13.4	1,050	14.3	97.5	121.8	24.8	1.7	
Chungju	37°02′26″-37°04′52″ N, 128°03′21″-128°05′57″ E	39	30.0	907	14.1	72.2	97.7			Park 1999
Gwangju		22	12.4	1,600	10.2	78.3	112.6	35.4	8.0	Lee and Park 1987
Chungju	37°02′26″-37°04′52″ N, 128°03′21″-128°05′57″E	67	24.0	875	12.1	87.6	121.0			Song et al. 1997

DBH, diameter at breast height.

Table 2. Stand characteristics and biomass (Mg/ha) of *Quercus variabilis* forests in Korea.

	Location	Mean age (years)	Mean DBH (cm)	Stand density (*n*/ha)	Mean height (m)	Tree stem biomass	Total aboveground tree biomass	Tree root biomass	Total ground vegetation biomass	Reference
Chuncheon		49	21.4	825	18.1	227.7	279.9	37.5	3.7	Park et al. 2003 Son et al. 2007a
Gongju		41	26.8	1,137	14.4	76.6	91.3			Park and Lee 2001
Pohang		45	36.9	778	15.3	172.9	207.6			
Yangyang		54	30.0	873	12.5	58.8	71.4			
Jinju		20	9.2	4,300	8.1	45.0	53.9			
Chungju	37°02′26″-37°04′ 52″ N, 128°03′21″-128°05′57″ E	62	24.0	883	11.8	100.7	137.4		25.1	Song and Lee 1996
Suncheong	34°58′ -35°01′ N, 127°10′ -127°13″ E	20	11.3	983	9.2	22.0	31.3			Choi and Park 1993
Suncheong		28	14.6	1,280	11.1	95.3	134.9	24.0		Park and Moon 1994
Gwangju		32	14.9	1,129	14.4	72.3	87.0			Park et al. 1996
Gwangju		33	11.8	980	13.0	50.0	61.6			Lee and Kim 1997
Gwangyang	35°05′ N, 127°37′ E	37	9.2	2,450	10.3	61.5	70.8	18.7	18.9	Park et al. 2005b
		38	10.2	2,900	14.3	87.6	100.7	26.4	4.3	
Gwangju		34	16.6	525	17.7	98.3	119.5	13.4	5.9	Son et al. 2004a
		31	12.1	1,425	18.7	154.3	191.2	22.6	2.4	
		33	13.7	1,475	18.3	184.9	224.1	27.0	2.2	
Chuncheon		44	18.3	1,050	18.9	217.0	264.1	36.7	7.9	Son et al. 2007a
Chungju	37°02′26″-37°04′52″ N, 128°03′21″-128°05′57″E	40	30.0	835	13.5	89.8	115.0			Park 1999
Chungju		62	24.0	883	11.8	96.9	124.4			Song et al. 1997

DBH, diameter at breast height.

and 1.02 Mg/m^3 for oak species (*Quercus robur*) in Europe indicated that species-specific BCEF value for oak was more variable than other broadleaf trees (Van Camp et al. 2004).

The IPCC (2003) provides tables of the default values for the BEF of temperate broadleaf forests and the R of temperate oak forests. The IPCC (2006) also provides default values for the BCEF of temperate hardwoods forest. For a better understanding of applicability of the biomass expansion factors in the Korean case, the mean BCEF, BEF and R values for *Q. mongolica* and *Q. variabilis* were calculated based on the default values given by the IPCC to compare the mean values in this study. The mean default BCEF value with forest ages of 21-100 years old was 1.5500 Mg/m^3, which was much higher than the mean value of BCEF for the two species in our study, whereas the mean default values (1.4000 and 0.3500) of BEF and R seemed to be slightly higher than the mean default value of BEF and R in this study. The results of a comparison suggested that the biomass expansion factor values in this case may be more representative estimates of forest biomass in *Q. mongolica* or *Q. variabilis* forests of Korea than those

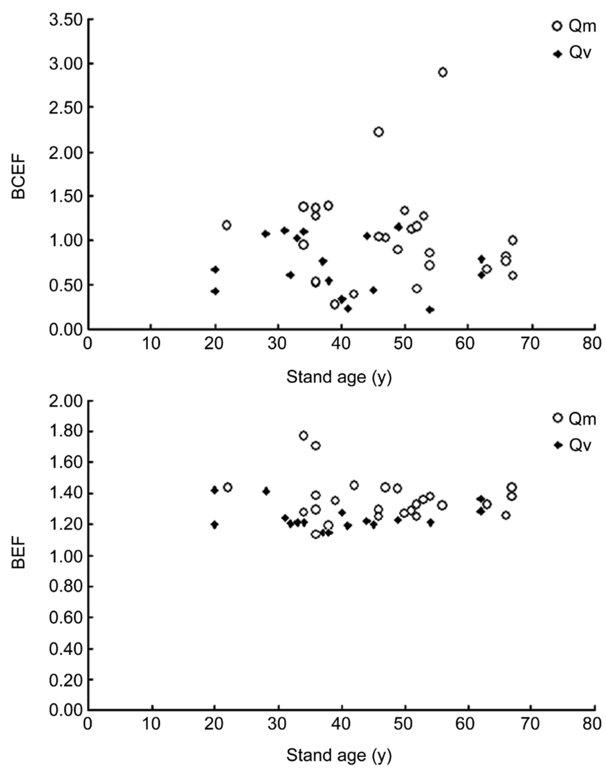

Fig 1. Changes in the biomass conversion and expansion factors (BCEF) and biomass expansion factors (BEF) with stand age for *Quercus mongolica* (Qm) and *Quercus variabilis* (Qv) in Korea.

using the default values.

Recent studies indicate that the relationships between BEF and stand age are heteroscedastic and non-linear. For example, Li et al. (2010c) reported that BEF is expressed as a logarithmic equation of stand age for natural Japanese red pine (*Pinus densiflora*), whereas a exponential equation was used between BCEF and stand age for Finnish birch (*Betula pubescens*) (Lehtonen et al. 2004). However, no significant relationship between BEF and stand age was observed in the present study (Fig. 1). Different results may be due to different tree species and the relatively small scale data in this study. Because the biomass expansion factors of different tree species are sensitive to stem biomass and volume, any change in stem biomass or stem volume may influence the values of the biomass expansion factors. For example, studies on the heartwood of living hardwood trees rotted by microorganisms growing on wood biodegradation with increasing age were more than that of coniferous species (Chi 2001, Chi et al. 2004), suggesting that further evidence for the relationship between BCEF and stand age will take different species into account and require more data from future studies.

Ground vegetation is an important biomass component in oak forest ecosystems. The EBEF was easily defined, and it is believed that the EBEF is a complementary method for estimating the ground vegetation biomass in *Q. mongolica* or *Q. variabilis* forests in Korea.

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