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Estimation of Basic Wood Density and its Uncertainty for *Quercus* Species in South Korea

ABSTRACT

Basic wood density is recommended by the Intergovernmental Panel on Climate Change as one of the parameters that can accurately estimate carbon stocks of trees. This study was conducted to estimate the basic wood density of Quercus acutissima, Quercus mongolica, Quercus serrata, and Quercus variabilis in South Korea and to determine their uncertainty. Water displacement method was used to determine the fresh volume of the cubic specimen without bark while the oven-dry weight was determined through oven-drying with a temperature of 85°C until it reached the constant weight. The basic wood density and uncertainty were 0.695 g cm^{-3} and 2.59% for Q. acutissima, 0.663 g cm^{-3} and 3.33% for Q. mongolica, 0.664 g cm^{-3} and 6.60% for Q. serrata and 0.721 g cm^{-3} and 1.66% for Q. variabilis, respectively. Analysis of variance showed that there is a significant difference in terms of the basic wood density of the four Quercus species ($p<0.001$). The results of this study on the basic wood density and uncertainty of the different Quercus species are essential in providing accurate information for estimating the biomass of Quercus forests.

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INTRODUCTION

International efforts have been made to address global warming that leads to climate change, and actions are taken across all sectors and corporations to reduce greenhouse gas (GHG) emissions at national level. Identifying the different types of gas and determining the source of emissions are needed to reduce GHG emission. Forest has an important role in the reduction of GHG particularly the carbon dioxide and because of this, estimation of biomass and carbon stock stored in the forests have become a major research interest (*Watson et al. 2000, Lehtonen et al. 2004, Tobin and Nieuwenhuis 2007, Teobaldelli et al. 2009, Li et al. 2010*). Furthermore, the United Nations Framework Convention on Climate Change (UNFCCC) required different countries to accurately assess carbon stocks in forest ecosystems and regularly report their forest resources status (*Basuki et al. 2009, Kim et al. 2011*). The Intergovernmental Panel on Climate Change (*IPCC 2006*) recommends basic wood density (BWD) as one of the parameters that can accurately estimate current carbon stocks. BWD is needed in the estimation of biomass by multiplying BWD to the biomass expansion factors (BEF) and merchantable growing stock volume of a tree and then converting biomass to carbon.

The estimated BWD can be applied in the 5th National Forest Inventory (NFI) conducted by Korea Forest Service from 2006 up to 2010 with objectives of determining the state of the forests and assessing the biomass and carbon stored in the Korean forests. The result of this inventory showed that broadleaf stands account for approximately 26% of the total forest in South Korea and the *Quercus* species is expected to become South Korea`s climax species (*Korea Forest Service 2010*).

Forest inventories can provide significant information in estimating carbon stocks available in the forests because it is the most practical method of assessing the aboveground biomass (*Lehtonen et al. 2004, Teobaldelli et al. 2009, Behera et al. 2017*). BWD can be used to convert the volume information collected from NFI into total oven-dried biomass of an individual trunk (*Fearnside 1997, Fujiwara et al. 2007*). The *IPCC* (*2003, 2006*) suggested a BWD value for *Quercus* species in Asia, however it is only based on the genus and not on the specific species. *Nogueira et al.* (*2005*) reported that the BWD may vary among species.

Another importance of the measurement of BWD is in forest product utilization. It is a significant factor in forest product manufacture (*Kimberley et al. 2017, Pretzsch et al. 2018*) because of the strong correlation of wood density to the strength properties of wood and chemical composition of the cells (*Nogueira et al. 2005*).

The *IPCC* (*2006*) guideline not only suggested to determine the BWD but also to conduct uncertainty assessment which is very essential in the GHG inventory. Uncertainty is important because it evaluates the estimated emission factors and it enhances the accuracy of the inventory system (*Monte et al. 1996, Kangas and Kangas 2004*). The uncertainty arises from a variety of sources and it is complicated to evaluate especially in terms of the potential uncertainty arising from the model (*IPCC 2006, Peltoniemi et al. 2006, Refsgaard et al. 2007*). Food and Agriculture Organization (FAO) suggested that the value of uncertainty in BWD should be lower than 40% (*FAO 2006*). In South Korea, several studies regarding BWD and biomass expansion factors of different species and from various regions were conducted (*Park et al. 2005, Seo et al. 2006, Li et al. 2010, Kim et al. 2011*), but information regarding the uncertainty of forest carbon emission factor is still insufficient. To date, there are minimal researches regarding the emission factor and its uncertainty. Thus, the purpose of this study was to estimate the BWD of the four major *Quercus* species in South Korea. This study also determined the uncertainty of the estimated BWD of the four *Quercus* species. Furthermore, differences in BWD among the four *Quercus* species were determined using Analysis of Variance (ANOVA).

MATERIALS AND METHODS

Study site

South Korea has a total land area of 9.96 million ha or 45% of the total area of the Korean peninsula. According to the Korea Forest Research Institute (KFRI), the forest covers of this country are approximately 64% of the total land area (*Lee 2010*). The coniferous forests dominated the forest land with 2.67 million ha or about 42%. It is followed by the mixed forests with 1.84 million ha or 29%, broad leaved forests with 1.66 million ha or 26% and other types of forests with 0.18 million ha or 3%, respectively (*Korea Forest Service 2010*). The *Quercus* species and other broadleaf forest trees were reported to have a total land area of 1.54 million ha and have an estimated stock volume of 177.62 million m^3 (*Korea Forest Service 2010*). This country has a temperate climate with four distinct seasons which are winter, spring, summer and autumn. The annual mean temperature is 12-14ºC in the Central region and Southern region while 3-10ºC in the Northern region. The annual mean precipitation of this country ranges from 600-1600 mm (*Lee 2010*).

In this study, a total of 50 plots with a size ranging from 0.01-0.04 ha were established in the different *Quercus* forests of South Korea (**Figure 1**) and in each plot, one representative tree was harvested to collect a sample disc. The age, diameter at breast height (DBH), and height of sampled trees were measured and were considered in the selection of the representative tree. The four *Quercus* species included were *Quercus acutissima*, *Quercus mongolica*, *Quercus serrata* and *Quercus variabilis*.

Data collection

The sampled discs with a thickness of 5 cm were obtained from 1.3 m above the ground in order to determine the BWD of the four *Quercus* species (KFRI 2010). It was concluded that the BWD measured at breast height represents the mean density of the trunk of a tree (*Fujiwara et al. 2004, Fujiwara et al. 2007*). A cubic specimen with a size of at least 250 cm^{-3} was collected in each sampled disc. In addition, water displacement method was used to determine the fresh volume of the cubic specimen without bark (*Nogueira et al. 2005*). The cubic specimen was immersed into a vessel full of distilled water causing it to overflow. Then the excess water was collected and their volume was measured to determine the fresh volume of the cubic specimen. On the other hand, in order to determine the oven-dry weight, the cubic specimens were dried to a temperature of 85°C as recommended in the different studies in Korea (*Seo et al. 2006, KFRI 2010, Seo et al. 2013, Jung et al. 2014*) until it reached the constant weight. Oven-dry weights were determined using a digital weighing balance with a precision of 1/3000F.S. *Fearnside* (*1997*) reported that there are two types of density, the fresh or green density

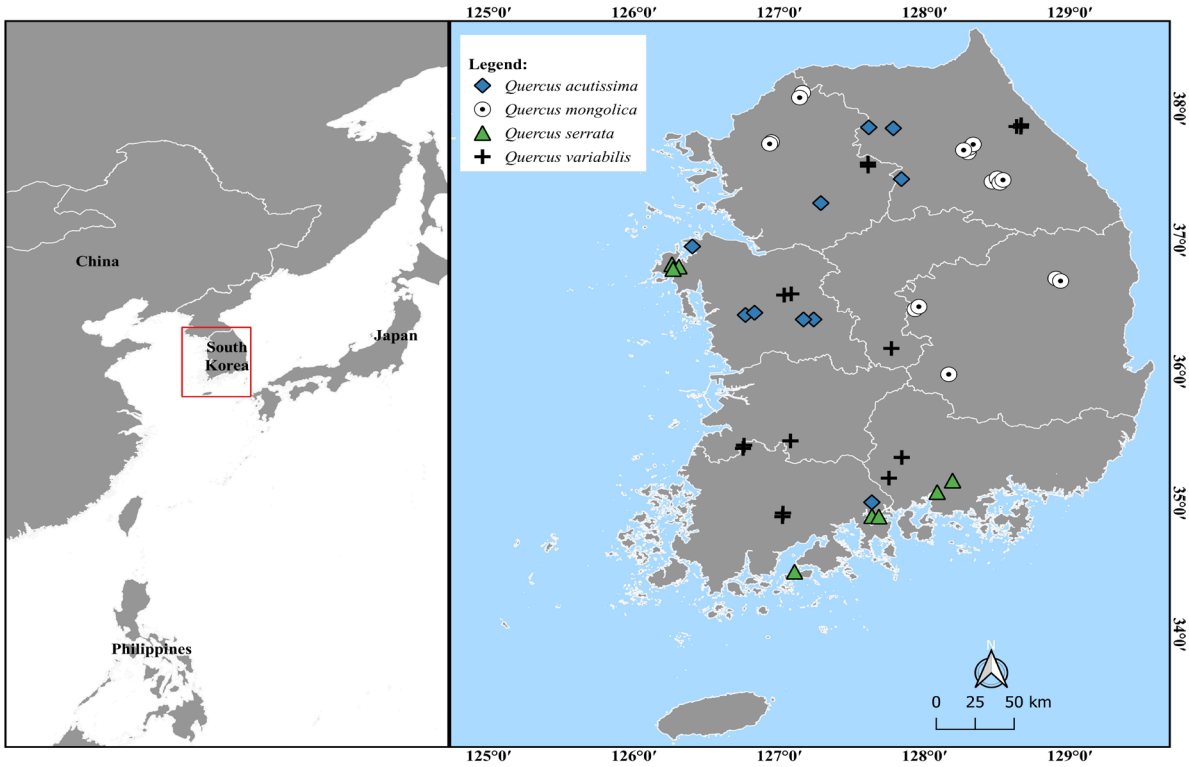

Figure 1. Geographical location of the study sites of four Quercus species in South Korea.

which can be determined by dividing the green volume to the green weight. The other type is the basic density which can be calculated by dividing the oven-dry weight to the wet volume (*Fearnside 1997*) which is needed in estimating the biomass from volume data of a forest.

The average age of the four *Quercus* species ranged from 36 to 50 years. The youngest tree observed was a 20-year-old *Q. acutissima* tree while the oldest was a *Q. mongolica* which was around 85 years old. In terms of mean DBH and mean total height, the *Q. variabilis* had the highest with 20.3 cm and 15.2 m, whereas the *Q. serrata* had the lowest mean DBH and total height with 13.9 cm and 11.8 m, respectively. On the other hand, the highest DBH and total height observed were found in *Q. variabilis* with 30.8 cm and 20.4 m, respectively (**Table 1**).

Table 1. Summary of observed statistics of the four *Quercus* species in South Korea.

Species	No. of observations	Age (years)	DBH (cm)	Height (m)
Quercus acutissima	10	26 20-60	16.18 7.8-23.6	14.2 10.3-18.2
Quercus mongolica	17	50 23-85	16.6 7.9-24.1	12.1 7.9-16.3
Quercus serrata	8	37 22-48	13.9 5.4-19.7	11.8 6.4-17.8
Quercus variabilis	15	50 34-84	20.3 12.5-30.8	15.2 10.5-20.4

Data Analysis

The BWD was calculated as the ratio between dry mass and fresh wood volume without bark (*IPCC 2006*). To determine if there is a significant difference on the BWD among the four *Quercus* species, ANOVA was used and the null hypothesis was tested at a 5% level of significance. A *p*-value lower than 0.05 means that the null hypothesis is rejected. The collected data were subjected to statistical analysis using SAS ANOVA Procedure (*SAS Institute Inc. 2004*). The uncertainty of emission factors is vital in the inventory system of the forestry sector (*MacFarlane et al. 2000, Lauenroth et al. 2006, Woolley et al. 2007*). *IPCC* (*2006*) defined uncertainty as the lack of knowledge of the true value of a variable that can be described as a probability density function (PDF) characterizing the range and likelihood of possible values. In this study, the uncertainty of BWD was determined at 95% confidence interval as suggested by the *IPCC* (*2003*) and used in the study of *Fujiwara et al.* (*2007*). The equation was summarized in equation (1).

$$\text{Uncertainty} = \frac{1/2 \times (95\%\ \ C.I.)}{\mu} \times 100, \quad (1)$$

where, C.I. is confidence interval, μ is average of the emission factor.

RESULTS AND DISCUSSION

Basic Wood Density

The BWD of the four *Quercus* were 0.695 g cm^{-3} for *Q. acutissima*, 0.663 g cm^{-3} for *Q. mongolica*, 0.664 g cm^{-3} for *Q. serrata* and 0.721 g cm^{-3} for *Q. variabilis* (**Table 2**). The *p*-value (< 0.0001) was lower than 0.05, thus the null hypothesis was rejected. There is a statistically significant difference on BWD among the four *Quercus* species in South Korea.

This study also compared the mean BWD among *Quercus* species using the Duncan`s multiple range test post hoc analysis. Among the four *Quercus* species, the mean BWD of the *Q. mongolica* (0.663 g cm^{-3}) is comparable to the mean BWD of the *Q. serrata* (0.664 g cm^{-3}), whereas the mean BWD of *Q. acutissima* (0.695 g cm^{-3}) is comparable to the mean BWD of *Q. variabilis* (0.721).

The results of this study on the BWD of four major *Quercus* species can be significantly used as an emission factor on the inventory system of the forestry sector. The ANOVA results indicated that there is a significant difference on the mean BWD among the four *Quercus* species. This is highly relevant especially that the *IPCC* (*2006*) only recommended a single BWD value which is 0.7 g cm^{-3} for the *Quercus* species located in Asia. This information will help the forestry sector of South Korea to accurately estimate the carbon stocks available on their forests. In comparison with other studies, the BWD of the *Q. serrata* and *Q. acutissima* in Japan was 0.633 g cm^{-3} and 0.668 g cm^{-3}, respectively (*Fujiwara et al. 2007*) which are comparable with the BWD of the four *Quercus* species which could be attributed to the similar ecological and climatic conditions between these two countries.

Uncertainty of Basic Wood Density

Uncertainty is crucial in forest researches due to varying structure, age, species complexity and regional differences of forests. IPCC (2006) also considered uncertainty estimates as an important element in conducting a complete inventory on the emission and removals of GHG. The uncertainty of BWD for the *Quercus* species was 2.59% for *Q. acutissima*, 3.33% for *Q. mongolica*, 6.60% for *Q. serrata* and 1.66% for *Q. variabilis* (**Table 2**).

FAO provided uncertainty estimates for the BWD of various species and it ranges from 10% to 40%. On the other hand, the estimated uncertainty of the BWD for *Q. serrata* and *Q. acutissima* in Japan were 1.3% and 1.5%, respectively (*Fujiwara et al. 2007*). The uncertainty is calculated from measured data related to emissions and removal factor. However, these parameters are affected by sampling design, method for measuring BWD, expert judgment, among all other factors. In comparison with FAO`s recommendation on the uncertainty of BWD which is below 40%, the uncertainties of the BWD for *Quercus* species of this study were significantly lower.

CONCLUSION AND RECOMMENDATIONS

A significant difference was observed among the BWD of the four *Quercus* species in South Korea. The results also showed that the uncertainty estimated have lower values compared to the recommended value given by *IPCC* (*2006*) and the standard set by FAO which is 40% or lower. Thus, the BWD values for *Quercus* species can be used in accurately converting the volume data into more essential information such as biomass and carbon stocks. The results of this research can be substantial in providing fundamental data for estimating the carbon sequestration of *Quercus* species in South Korea. However, this study did not investigate the influence of age class, stand density, site quality, elevation and region or location on BWD of *Quercus* species. It is recommended to collect more samples from different areas and stand age classes in South Korea to further improve the accuracy of the BWD estimation and consequently the biomass of *Quercus* forest in South Korea.

Table 2. The basic wood density and uncertainty of the *Quercus* species in South Korea.

Species	BWD (g cm^{-3}) (Mean ±S.D.)	95% C.I. limit		Uncertainty (%)
		2.5th percentile	97.5th percentile	
Quercus acutissima	0.695a ±0.025	0.677	0.713	2.59
Quercus mongolica	0.663b ±0.042	0.641	0.685	3.33
Quercus serrata	0.664b ±0.046	0.611	0.697	6.60
Quercus variabilis	0.721a ±0.021	0.7089	0.7328	1.66

Note: Different letters implies that there was a significant difference ($p<0.001$) using the Duncan's Multiple Range Test.

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