Ann. For. Res. 55(1): 105-111, 2012

ANNALS OF FOREST RESEARCH
www.e-afr.org

Estimating basic wood density and its uncertainty for *Pinus densiflora* in the Republic of Korea

J.K. Pyo, Y.M. Son, K.H. Lee, Y.J. Lee

Pyo J.K., Son Y.M., Lee K.H., Lee Y.J., 2012. Estimating basic wood density and its uncertainty for *Pinus densiflora* in the Republic of Korea. Ann. For. Res. 55(1): 105-111, 2012.

Abstract. According to the Intergovernmental Panel on Climate Change (IPCC) guidelines, uncertainty assessment is an important aspect of a greenhouse gas inventory, and effort should be made to incorporate it into the reporting. The goal of this study was to estimate basic wood density (BWD) and its uncertainty for *Pinus densiflora* (Siebold & Zucc.) in Korea. In this study, *P. densiflora* forests throughout the country were divided into two regional variants, which were the Gangwon region variant, distributed on the northeastern part of the country, and the central region variant. A total of 36 representative sampling plots were selected in both regions to collect sample trees for destructive sampling. The trees were selected considering the distributions of tree age and diameter at breast height. Hypothesis testing was carried out to test the BWD differences between two age groups, i.e. age ≥ 20 and < 20, and differences between the two regions. The test suggested that there was no statistically significant difference between the two age classes. On the other hand, it is suggested a strong evidence of a statistically significant difference between regions. The BWD and its uncertainty were 0.418 g/cm^3 and 11.9% for the Gangwon region, whereas they were 0.471g/cm3 and 3.8% for the central region. As a result, the estimated BWD for *P. densiflora* was more precise than the value provided by the IPCC guidelines.
Keywords tree biomass, greenhouse gas inventory, emission factors, uncertainty analysis.

Authors. Jung Kee Pyo, Yeong Mo Son, Kyeong Hak Lee (freerider@kongju.ac.kr) - Division of Forest Management, Korea Forest Research Institute, Seoul 130-712, Korea, Young Jin Lee - Department of Forest Resources, Kongju National University, Yesan, Chungnam, Korea.
Manuscript received September 19, 2011; revised January 18, 2012; accepted January 24, 2012; online first April 2, 2012.

Introduction

International efforts have been made to address the issue of climate change, and actions are taken across all sectors and corporations to reduce greenhouse gas emissions at national level (IPCC 2006a, Lauenroth et al. 2006). To effectively reduce the emission, identifying important types of gases and accurately determining their emission levels are needed. In forestry sector, estimating carbon emission level and current carbon stock in forest area are the primary focuses (Macfarlane et al. 2000, Woodlley et al. 2007). The simple and more direct estimation process involves converting forest stand-level volume estimate into carbon stock, with the aid of various emission factors (IPCC 2006a).

One of the important emission factors is the basic wood density (BWD) defined as the ratio between oven dry mass and BWD is the ratio between dry mass and fresh stem wood volume without bark (IPCC 2006a). The measurement of BWD is one of the core studies of wood properties. It is used to convert individual stem volume to biomass. Many studies have found that BWD was affected by stand age, species composition, and stand structure (Johnson & Sharpe 1983, Kauppi et al. 1992, Lehtonen et al. 2004).

Even for the same tree species, the BWD exhibits a range of values possibly due to regions and ages. Consequently, IPCC recommended developed separate BWDs that reflected the influence of regions and ages (IPCC 2006b).

Continuous improvement on the emission factors will produce better estimate of emission level and carbon stock. Uncertainty analysis of emission factors could assist us in managing and improving the factors. The purposes of uncertainty analysis is to evaluate the model and to enhance the accuracy of the inventory system (Monte et al. 1996, Kangas & Kangas 2004). Uncertainty arises from a variety of sources, e.g. lack of data, lack of representativeness, statistical sampling error, measurement error, and laboratory estimation error (IPCC 2006a). For some sources of uncertainty, it is more complicated to determine its value quantitatively, e.g. potential uncertainty arising from models (IPCC 2006a, Peltoniemi et al. 2006, Refsgaard et al. 2007). IPCC guidelines (2006a) recommended two approaches to uncertainty analysis: (1) The first error propagation and (2) Monte Carlo simulation approach 1 should be applied when there is no significant correlation among various parameters and estimates and the uncertainties are relatively small. The second can be used to overcome the limitations related to the correlation between different parameters, and estimates at different period (IPCC 2006a). Therefore, estimating uncertainty of BWD is equally as important as estimating its value for calculating emission level.

After reviewing research on uncertainty of BWD, Food and Agriculture Organization (2006) provided a range of uncertainty for BWD (10 to 40%). In Finland, the estimated uncertainties of BWD for pine, spruce, and birch tree are below 20% (IPCC 2006b). In Republic of Korea, research on BWD and other emission factors for a wide variety of species and regions are expanding, but research on uncertainty analysis of these factors is limited.

The *P. densiflora* forests account for approximately 26% of total forest area in the country (Korea Forest Service 2011). The tree species is important for its economic and cultural value. Recently, the tree species is the subject for sustainable forest management.

Therefore, the goal of this study was estimating BWD and its uncertainty for *Pinus densiflora* (Siebold & Zucc.) forests in the Republic of Korea.

Materials and methods

Study area and date

Republic of Korea has a total land area of about 10 million ha, and approximately 64% of this is covered by forests (Korea Forest Service 2011). The temperature ranges from 6.4~16.2 ˚C, with annual an average of 12.2 ˚C. The average annual precipitation is approximately 1,302 mm during the last three decade.

The study sites were located throughout of the country, concentrated from the central to northern part of the country (Figure 1). The BWD of *P. densiflora* might be influenced by regions and ages. Firstly, the comparison was carried out for the two regions and then for the two age classes. Estimated BWD of the 36 sample plots were divided into two regional groups, one set of BWD was from plots in Gangwon region and the other set was from plots in the central region. The number of plots for the two regions was 8 and 28 respectively. The reason for the difference in the number of plots is geographic location whereby survey plots in Gangwon region were located in the mountainous areas and survey plots in the central region were spread throughout a larger region.

A total of 36 sample plots were established in representative *P. densiflora* forest stands. For each plot, all *P. densiflora* trees that fell inside the plot were measured for their diameter at breast height (dbh). Five trees per plot were selected according to the plot dbh distribu-

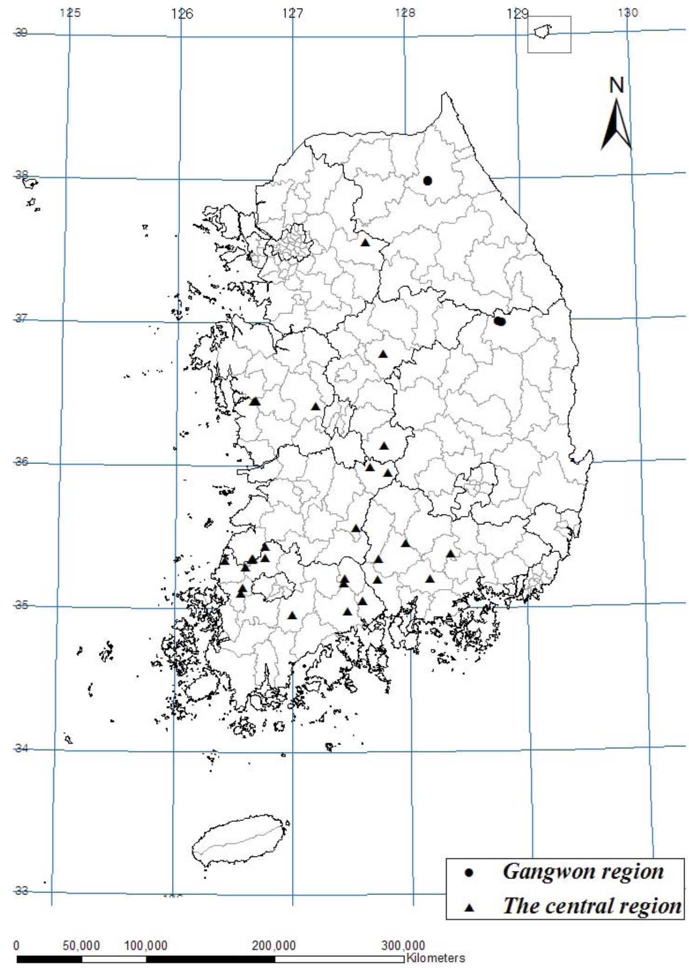

Figure 1 Geographical location of 36 sample plots for *Pinus densiflora* in Korea

tion. This was to ensure that the selected trees were representative of the plot structure. The selected trees did not include suppressed trees and trees with damaged tops. The five selected trees were fell at 0.2 m above ground and were used for the destructive sampling of above-ground biomass, which was outside the scope of this paper. Out of the selected five trees, one of them, having the average dbh, was specifically sampled for BWD estimation. For that tree, a cross-sectional disk was obtained from 1.3 m above the ground, one cross-sectional disk being sampled for BWD estimation per site.

The cross-sectional disks collected from the field were used for estimating BWD, using the water displacement method. Each disk was immersed into a vessel fully filled with distilled water causing the water to overflow. The displaced water was collected and measured, in order to determine the green volume of the disk. After the disk was dried at a constant temperature of 85 °C for about 7 to 10 days, until the disk reached a constant weight. Then, the disk was measured for its dry weight.

Statistical analysis

We followed the recommendation by IPCC (2006b) for the threshold for splitting emission factors by age class, i.e., the BWDs were separated into one set with age ≥ 20 years old and one set with age < 20 years old. The number of plots for the two separate age classes was 7 and 29 respectively. Finally, t-test was used to test differences in BWDs between the grouping, i.e., the two null hypotheses stated that there was no difference in BWD between Gangwon and central regions, and that there was no difference between the two age classes. The hypothesis testing was carried out in SAS (2004), and the significance-level was set at 0.05, i.e. $\alpha = 0.05$.

In addition to the hypothesis testing, uncertainty of the BWD was also assessed for each region. The uncertainty of BWD was calculated as follows,

$$uncertainty = \frac{0.5 \cdot (95\% CI_{width})}{\mu} \cdot 100\% \qquad (1)$$

The ratio of half of the width of the 95% confidence interval (95% CI_{width}) to mean (μ) and was expressed in percentage following IPCC (2003) and Fujiwara et al. (2007).

Results

The age of the *P. densiflora* forest in Republic of Korea ranges from 30 to 50 years, and this age class accounts for approximately 80% of the *P. densiflora* stands in the country (Korea Forest service 2011). In our study, the average age of the *P. densiflora* forests in the Gangwon region was estimated to be 26 years old, whereas the average age in the central region was estimated to be 37 years old. Despite that, the forests in Gangwon region is younger than that in the central region, the average dbh and height in the former region is larger (Table 1). According to Park et al (2005), this was due to the growth characteristics of *P. densiflora* stands in the Gangwon region.

The hypothesis testing suggested an evidence that BWD was significantly different between

Table 1 The summary statistics (mean and range) of the sampled stands

Regions	Number of sample plots	Age (years)	DBH (cm)	Height (m)
Gangwon region	8	26.0 (13.0 - 36.0)	19.8 (9.3 - 26.9)	14.6 (3.6- 20.3)
The central region	28	37.0 (11.0 – 57.0)	16.6 (6.1 – 32.7)	11.8 (3.0 – 20.8)

the two regions (p value = 0.0112, Table 2). The estimated average BWD for *P. densiflora* in the Gangwon region was 0.418 g/cm^3 with uncertainty of 11.9%. On the other hand, the average *P. densiflora* in the central region was estimated to be 0.472 g/cm^3 with uncertainty of 3.8% (Table 3).

The other testing failed to reject the hypothesis that there was significant difference between age-class (p value = 0.0927, Table 2). The estimated BWD for trees < 20 years was 0.429 g/cm^3 with uncertainty of 9.0%. On the other hand, the BWD for trees ≥ 20 years was estimated to be 0.467 g/cm^3 with uncertainty of 4.3% (Table 4).

Discussion

The results indicated that BWD for *P. densiflora* forests did not depend on age classes. This suggested that when estimating emission level for the *P. densiflora* forests, one may not need to concern about the age classes of the forest stands. Although an other studies, suggested that BWD depended on stand ages, species and stand structure (Lehtonen et al. 2004), this was not supported by our, which indicated no difference of BWD in age class. One possible reason for our result may be the small sample size for age class < 20 years. To further assess the effect of stand age on the BWD, there is a need to increase the number of young *P. densiflora* stand sampled.

On the other hand, the results indicated a significant difference in BWD between the two regions in Republic of Korea. Similar results were showed by Park et al. (2005). The difference in BWD between the regions might be attributed to different growth rate in the two regions, e. g. the central region showing dense annual ring and a relatively high proportion of heartwood ratio. The results also indicated the higher uncertainty of BWD in the Gangwon region as compared with we central region. This is likely due to smaller sample size for the former region, but could also due to the large range in age classes and site productivity in the Gangwon region (Table 3). Japan reported that the average BWD of *P. densiflora* forests in

Table 2 Age-class and regional comparison of BWD for *Pinus densiflora* forests in Republic of Korea

Variable	Variance	t value	p value
Region	Equal	-2.68	0.0112
Age-class	Equal	-1.73	0.0927

Table 3 Estimated mean and uncertainty of BWD of *P. densiflora* forests by region in Republic of Korea

Region	BWD (g/cm^3)	95% CI_{width}		Uncertainty (%)
		2.5 percentile	97.5 percentile	
Gangwon region	0.418	0.369	0.468	11.9
The central region	0.472	0.453	0.489	3.8

Table 4 Estimated mean and uncertainty of BWD of *P. densiflora* forests by age-class in Republic of Korea

Age-class	BWD (g/cm^3)	95% CI_{width}		Uncertainty (%)
		2.5 percentile	97.5 percentile	
< 20	0.429	0.390	0.468	9.0
≥ 20	0.467	0.447	0.488	4.3

the country was 0.451 g/cm[3] (Fujiwara 2007), similar to study, which could be due to similar ecological and climatic conditions. According to IPCC (2006a), the BWD for *Pinus pinaster*, *Pinus radiata*, *Pinus strobus* and *Pinus sylvestris* were 0.44, 0.38, 0.32 and 0.42, respectively, which were in the range of the BWD for *P. densiflora* in Republic of Korea. Thus, the results of this study were consistent with other literatures. Furthermore, we have obtained country specific BWD values that could be used in estimating emission level in the Republic of Korea.

Food and Agriculture Organization estimated the uncertainty of BWD to be in the range of 10 to 40% (IPCC 2006b). In Finland, the uncertainties of BWD for pine, spruce and birch trees were under 20% (IPCC 2006b). In Japan, estimated uncertainty of the BWD for *P. densiflora* was 7.2% (Fujiwara 2007). The uncertainty estimates found in this study indicated more precise BWD values than the uncertainty recommended by IPCC (2006b). The contribution of the uncertainty to BWD estimates in this study included environmental factors, as growing conditions and measurement errors. However, water displacement method should minimize the error in estimating volume of a disk. Similar method was also applied by Fujiwara (2007) in estimating BWD.

Conclusion

The results obtained in this study, BWD estimates and its uncertainty by regions, are useful in estimating country-level greenhouse gas emission. The BWD, combined with other emission factors and information from forest inventory, will be used to estimate emission level, whereas the uncertainty estimates for estimating uncertainty of emission level through the method of error propagation (IPCC 2006a). IPCC (2006a) also recommended calculating uncertainty for every emission factor which was reported voluntarily and continously by the countries involved. Furthermore, the uncertainty estimate could assist in improving the inventory system, and thus, developing method of reducing uncertainty due to various causes. Therefore, in order to improve on the BWD estimates, more data could be collected, for improving analysis of BWD by age classes, regions and other environmental factors. The results provided fundamental results for estimating carbon sequestration of *P. densiflora* forests in Republic of Korea for greenhouse gas inventory system in the forestry sector.

References

Food and Agriculture Organization, 2006. Global forest resources assessment 2005. Food and Agriculture Organization, Rome, Italy, 153 p.

Fujiwara T., Yamashita K., Kuroda K., 2007. Basic densities as a parameter for estimating the amount of carbon removal by forests and their variation. Bulletin of the Forestry and Forest Products Research Institute 6(4): 215-226.

Intergovernmental Panel on Climate Change (IPCC)., 2003. Good practice guidelines for land-use, land-use change and forestry. IPCC National Greenhouse Gas Inventory Programme. Institute for Global Environmental Strategies. pp. 5.8-5.10.

Intergovernmental Panel on Climate Change (IPCC)., 2006a. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 1. General Guidance and Reporting. IPCC National Greenhouse Gas Inventory Programme. Institute for Global Environmental Strategies. pp. 3.6-3.78.

Intergovernmental Panel on Climate Change (IPCC)., 2006b. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Use. IPCC National Greenhouse Gas Inventory Programme. Institute for Global Environmental Strategies. pp. 4.73.

Johnson W.C., Sharpe D.M., 1983. The ratio of total to merchantable forest biomass and its application to the global carbon budget. Canadian Journal of Forest Research 13: 372-383.

Kangas A.S., Kangas J., 2004. Probability, possibility and evidence: approaches to consider risk and uncertainty in forestry decision analysis. Forest Policy and Economics 6: 169-188.

Kauppi P.E., Miclikeinen K., Kuusela K., 1992. Biomass and carbon budget of European forests, 1971 to 1990. Science 256: 70-74.

Korea Forest Research Institute, 2010. Survey manual for biomass and soil carbon. Korea Forest Research Institute, pp. 7-10.

Korea Forest Service, 2011. Statistical yearbook of forestry. Korea Forest Service, 30 p.

Lauenroth W.K., Wade A.A., Williamson M.A., Ross B.E., Kumar S., Cariveau D.P., 2006. Uncertainty in calculations of net primary production for grasslands. Ecosystems 9: 843-851.

Lehtonen A., Mäkipää R., Heikkinen J., Sievänen R., Liski J., 2004. Biomass Expansion Factors (BEF_s) for Scots pine, Norway spruce and birch according to stand age for boreal forests. Forest Ecology and Management 188: 211-224.

Macfarlane D.W., Edwin J.G., Harry T.V., 2000. Incorporating uncertainty into the parameters of a forest process model. Ecological Modelling 134: 27-40.

Monte L., Lars H., Ulla B., John B., Rudie H., 1996. Uncertainty analysis and validation of environmental models: the empirically based uncertainty analysis. Ecological Modelling 91: 139-152.

Park I.H., Park M.S., Lee K.H., Son Y.M., Seo J.H., Son Y., Lee Y.J., 2005. Biomass expansion factors for *Pinus densiflora* in relation to ecotype and stand age. Journal of Korean Forest Society 94(6): 441-445.

Peltoniemi M., Palosuo T., Monni S., Mäkipää R., 2006. Factors affecting the uncertainty of sinks and stocks of carbon in Finnish forests soil and vegetation. Forest Ecology and Management 232: 75-85.

Refsgaard J.C., Jeroen P.V.D.S., Anker L.H., Peter A.V., 2007. Uncertainty in the environmental modelling process. A framework and guidance. Environmental Modelling and Software 22: 1543-1556.

SAS Institute Incorporated., 2004. SAS/STAT 9.1 User's Guide. SAS Institute Incorporated Cary, NC. pp. 915-928.

Winiwarter W., Kristin R., 2001. Assessing the uncertainty associated with national greenhouse gas emission inventories a case study for Austria. Atmospheric Environment 35: 5425-5440.

Woodlley T.J., Harmon M.E., O`connell K.B., 2007. Estimating annual bole biomass production using uncertainty analysis. Forest Ecology and Management 253: 202-210.

Note. The current number of the Annals of Forest Research publishes two articles presented at the last XXIII IUFRO Congress: Pyo et al. (2012) and Ishizuka et al. (2012).

The congress took place in Seoul, Korea, between August 22-28, 2010. It was organized in 153 sessions; depending on their importance some plenary (i.e. six of them), some sub-plenary (i.e., 15 sessions), and other technical (i.e., 132 sessions). The sessions were proposed by different IUFRO units/subunits that were competing for one of the almost 150 available spots. Louisiana Tech University, Taiwan National University and Transilvania University succeeded in winning the organization of a technical session at the congress. The technical session, with the title "Biomass and biodiversity conservation of the mixed-species stands considering the climatic uncertainties", focused on the quantitative representation of the mixed species stands. The session was jointly supported by the IUFRO unit 4.03 and sub-unit 1.01.06 (Ecology and silviculture of oak), and enjoyed an unexpected large audience; the hall allocated to the session couldn't seat the entire audience, at least one dozen of scientist standing against the wall to listen the presentations.

The research performed by Pyo et al (2012) focuses on estimating basic wood density of *Pinus densiflora* that grow in the Republic of Korea. The research compares the uncertainties of basic wood densities with the values supplied by the Intergovernmental Panel on Climate Change guidelines and found that they are within the recommended range. The investigation carried by Ishizuka et al (2012) aims at the understanding of the co-existence mechanisms of two beech species growing in Japan, as well as the evaluation of the distributional properties and spatial abundance of seedlings in respect with topography, light, overstory, and grazing. The analysis was executed using a generalized linear model, and found that co-dominance of the species cannot be attributed to the spatial segregation nor are site specific, but most likely is a trade-off between growth and resilience to pasture.

The increasing interest of both practitioners and theoreticians involved in the analysis and assessment of mixed species ecosystem recommends the continuation of this topic to the next IUFRO congress. In eventuality that there are sufficient human and financial resources, at least one conference between congresses should be organized. To this end, the Second IUFRO Conference on Complex Forest Ecosystems, to be held in New Orleans in October 2013, is expected to significantly enhance current knowledge on mixed species stands, by integrating spatiality and remote sensing data acquisition within the scientific investigations focused on mixtures (Bogdan M. Strimbu, School of Forestry, Louisiana Tech University, 1201 Reese Dr. Ruston LA, USA. Tel.: 1-318-257-2168, email: strimbu@latech.edu).