

Crown Fuel Characteristics and Allometric Equations of *Pinus densiflora* in Gyeongbuk Province, Korea



ABSTRACT

The crown fuel characteristics of the most dominant coniferous species in Korea, *Pinus densiflora*, were investigated in Gyeongbuk province, Korea. Allometric equations using DBH as independent variable were also developed for the estimation of crown fuel load (needles, branches: <0.5 cm, 0.5-1 cm, 1-2 cm, and 2-4 cm in diameter), crown volume, and aboveground biomass. The average crown bulk density in Youngju and Bonghwa was 0.47 kg m^{-3} , while in Daegu, it was 0.29 kg m^{-3} . The crown bulk density of needles and branches with a diameter of <1 cm was 0.21 kg m^{-3} in Youngju, 0.27 kg m^{-3} in Bonghwa, and 0.13 kg m^{-3} in Daegu. The average crown base height was 5.10 m in Youngju, 5.20 m in Daegu, and 3.60 m in Bonghwa. Overall, the *Pinus densiflora* stand in Bonghwa is more hazardous if crown fire occurs compared to the other study sites based on different crown fuel characteristics. The allometric models developed were able to explain at least 79% of the observed variation in the biomass and crown volume. For the aboveground biomass, Daegu had the highest mean tree biomass with 103.54 kg, followed by Youngju (67.35 kg) and then Bonghwa (37.72 kg).

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INTRODUCTION

The Republic of Korea (South Korea) has a total of 6.37 million ha of forest land covering approximately 64% of the total land area which is dominated by 2.67 million ha of coniferous forest land or approximately 42% of the total forested land (Korea Forest Service 2012). The *Pinus densiflora* stands have the widest distribution of forests in Korea, covering 1.48 million ha or 54.90% of the total coniferous forested land, followed by the *Larix kaempferi* and *Pinus rigida* comprising 0.46 million ha (17.20%) and 0.41 million ha (15.20%), respectively (Lee 2010). However, the *Pinus densiflora* forests are declining (Korea Forest Service 2009) due to climate change, blight, and forest fires. The *Pinus densiflora* forests are characterized by

very dense stands brought by the lack of thinning and other silvicultural practices which make these forests more prone to forest fires. Furthermore, few studies have been conducted to estimate the crown fuel characteristics of *Pinus densiflora* in Korea. Therefore, there is an urgent need to conduct studies that will characterize the crown fuel of *Pinus densiflora*.

Crown fuels are the main fuel layer that support crown fire spread (Cruz et al. 2003, Kucuk et al. 2007, Mitsopoulos and Dimitrakopoulos 2007a, Kucuk et al. 2008). Reinhardt et al. (2006) stated that crown fuel characteristics are important factors that affect crown fire occurrence and behavior. As stated by Mitsopoulos

and Dimitrakopoulos (2007a), several studies identify crown fuel load or CFL (Kucuk et al. 2007), crown bulk density or CBD (Cruz et al. 2005, Kucuk et al. 2007), moisture content or MC (Cruz et al. 2004), and crown base height or CBH (Alexander 1988, Kucuk et al. 2007) as important crown fuel characteristics which affect incidences and behaviors of crown fire (Reinhardt et al. 2000, Reinhardt et al. 2006, Koo et al. 2010). The term crown fuel is used to refer to fuels at the individual tree level while the term canopy fuel is used to estimate the fuels at the stand or landscape level (Cruz et al. 2003, Baysal et al. 2019). These crown fuel characteristics are also considered as essential parameters for fire management planning (Keane et al. 2001, Kucuk et al. 2007). Furthermore, estimates of these crown fuel characteristics are required in most of the fire-modeling systems (Reinhardt et al. 2006, Mitsopoulos and Dimitrakopoulos 2007b). CFL is important to be estimated because it represents the potential source of energy that can be released during a crown fire (Mitsopoulos and Dimitrakopoulos 2007a). It is an essential factor in the assessment of crown fire intensity and flame length (Thomas 1963), fuel consumption during a crown fire (Stocks et al. 2004), crown fire severity (Pollet and Omi 2002), and estimation of carbon emission from crown fire (Amiro 2001). Allometric equations which employ diameter at breast height (DBH) as an independent variable are commonly used to predict crown fuel load (Kucuk et al. 2007, Mitsopoulos and Dimitrakopoulos 2007a). DBH is highly correlated with tree biomass and can be easily obtained with little cost and time (Mitsopoulos and Dimitrakopoulos 2007a).

Based on the United Nations Framework Convention on Climate Change (UNFCCC), different countries are required to accurately assess the carbon stocks available in their forests and regularly report their forest resource status (Basuki et al. 2009, Kim et al. 2011) and can be used to provide funding in the greenhouse gas reduction (Sakici et al. 2018). Because of this and the important role of forests in global climate change, biomass and carbon stock estimations in forests have become a major research interest (Watson et al. 2000, Lehtonen et al. 2004, Tobin and Nieuwenhuis 2007, Bollandas et al. 2009, Teobaldelli et al. 2009, Li et al. 2010, Won et al. 2012). Carbon stored in forest ecosystems is mostly held in the form of the vegetative biomass of trees such as stem, branches, and leaves (Pajtik et al. 2008, Sharma et al. 2010, Sakici et al. 2018). Furthermore, it is well-known that forests are significant in storing atmospheric carbon dioxide (CO₂) in terrestrial ecosystems (Peichl and Arain 2007); therefore, accurately estimating the biomass of forests is crucial in the assessment of carbon

stored of a forest (Xiao and Ceulemans 2004, Fehrmann et al. 2008, Chung et al. 2009, Hosoda and Iehara 2010). The development of allometric equation is an important method that will estimate the different tree biomass components and total tree biomass. Thus, the objectives of this study were to analyze crown fuel characteristics (MC, CBH, CBD, and CFL) and to develop allometric equations for the estimation of the CFL, crown volume (CV), and aboveground biomass of *Pinus densiflora* stands in Gyeongbuk province, Korea.

MATERIALS AND METHODS

Study sites

Gyeongbuk province has a total land area of 1.90 million ha and 1.34 million ha or 70.56% of the total land area has a forest cover. Furthermore, Gyeongbuk province has the highest *Pinus densiflora* forestland with 419,986 ha as compared to the other provinces in Korea (Korea Forest Service 2012). The mean annual temperature of the province is 12.25°C with a minimum and maximum mean annual temperature of 7.05°C and 18.17°C, respectively. In addition, its mean annual precipitation is 1,126.74 mm (Korea Meteorological Administration 2012). The study sites are located in Youngju, Bonghwa, and Daegu, Gyeongbuk in Korea (Figure 1). This province was chosen because of the high density of *Pinus densiflora* stands and the high frequency of forest fire occurrence in this area. The Korea Forest Service (2012) reported that a total of 1,173 ha of forestlands were burnt annually from 2002 to 2011 in Korea and most of the forest fire damages were observed in Gyeongbuk province with 743 ha year⁻¹. The Gyeongbuk province has an average of 74 forest fire occurrences and 160 ha of damage annually over the past decade making this province the second most vulnerable area in forest fire among the 17 metropolitan cities and province in Korea (Korea Forest Service 2020).

Data collection

A 20 m by 20 m plot was established in each study site. A total of 10 representative sample trees in each study site were harvested for the analysis of the crown fuel characteristics of *Pinus densiflora*. The selected trees represented the different DBH classes in the three stands. Trees which have extremely lopsided crowns, which are heavily defoliated, or which have broken tops were excluded. Trees were cut 0.20 m above the ground. Tree total height, DBH, CBH, crown width, crown length, and age were also determined. The tree biomass was partitioned into stems, needles, and branches. Branches were further classified

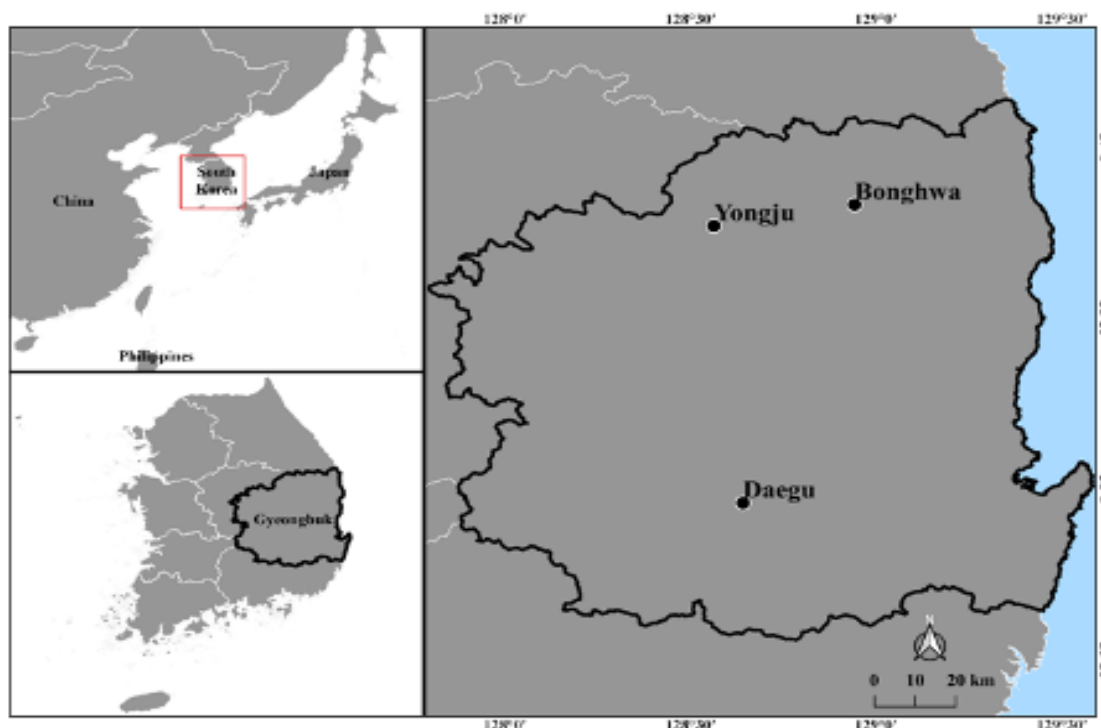


Figure 1. Location of study sites in Gyeongbuk province, Korea.

based on their diameter (<0.5 cm, 0.5-1 cm, 1-2 cm, 2-4 cm, and >4 cm). A disc of 5 cm thickness was collected from every 1 m section of the trunk. After collecting the discs, the remaining trunks were measured to get their fresh weight. The green weight of the other biomass was also determined. In addition, at least 350 g sample of each biomass component was collected. The discs and samples of each biomass component were dried at a constant temperature of 95°C until constant weight was reached.

The stand density was 745 tree ha⁻¹ for Youngju, 2,400 tree ha⁻¹ for Bonghwa, and 2,100 tree ha⁻¹ for Daegu. The mean ages of the trees were 41 years in Youngju, 36 years in Bonghwa, and 30 years in Daegu. Daegu has the highest mean DBH and total height at 18.50 cm and 10.74 m while Bonghwa has the lowest mean DBH and total height at 9.50 cm and 6.80 m, respectively (**Table 1**).

Crown fuel characteristics

Available CFL is defined as the total aerial fuels that were consumed during crown fire incidents (*Mitsopoulos and Dimitrakopoulos 2007a*). In this study, the available CFL (kg) for the *Pinus densiflora* are the needles and branches with 1 cm diameter or less (*Koo et al. 2010*). On the other hand, crown volume (CV) was determined using the equation suggested by *Koo et al. (2010)* for *Pinus densiflora* in Korea:

$$CV (m^3) = \sum_{i=1}^n \left\{ \frac{\pi \times LCW_i^2 (1 + RH_i)}{3} - \frac{\pi \times SCW_i^2 (RH_i)}{3} \right\}$$

$$RH = \frac{LCW - SCW}{SCW}$$

Where: RH is the ratio height (m)

Table 1. Characteristics of *Pinus densiflora* stands in the three study sites in Gyeongbuk province, Korea.

Components	Study sites		
	Youngju (n=10)	Bonghwa (n=10)	Daegu (n=10)
Location	36° 46' 38"N 128° 33' 46"E	36° 50' 22"N 128° 56' 31"E	35° 58' 01"N 128° 38' 30"E
Stand density (tree ha ⁻¹)	745	2400	2100
Stand age (years)	41	36	30
Mean DBH with range (cm)	18.30 (12.30-27.30)	9.50 (6.00-20.40)	18.50 (6.00-35.00)
Mean Height with range (m)	9.90 (7.40-12.90)	6.80 (5.40-11.20)	10.74 (7.08-13.72)

LCW is the long crown width (m)

SCW is the short crown width (m)

μ is the ratio of the circumference of a circle to its diameter

Scott and Reinhardt (2001) reported that CBD is the dry weight of the available CFL per unit of CV and is measured in kg m⁻³. For the moisture content (MC), the equation is:

$$MC(\%) = \frac{\text{green weight (g)} - \text{oven dry weight (g)}}{\text{oven dry weight (g)}} \times 100$$

Crown base height was determined as the distance from the forest floor to the live crown base (Cruz *et al.* 2004).

Allometric Equations

Using the combined data from the three study sites, the relationships of the different crown fuel loads (needles, branches: <0.5 cm, 0.5-1 cm, 1-2 cm, and 2-4 cm in diameter) to the DBH were analyzed. Furthermore, the relationships of stem biomass, total crown biomass, total aboveground biomass, and CV to the DBH were also investigated. The model form used was:

$$\log Y = \beta_0 + \beta_1 \log X + \epsilon,$$

Where: Y is the dependent variable (CV or biomass)

X is the DBH (cm)

β_0, β_1 are the estimated parameters

log is the natural logarithm

ϵ is the random error

This model form was used in this study as recommended by the Korea Forest Research Institute (2006) for the Korean tree species and was previously used to develop biomass equations for Korean tree species (Son *et al.* 2001) and crown fuel load equation (Lee *et al.* 2012). To correct the bias in log-transformed allometric equations, Sprugel correction factors (Sprugel 1983) were used. The collected data were statistically analyzed using SAS 9.2 (SAS Institute Inc. 2004). In order to evaluate the models, adjusted multiple coefficient of determination (R^2_{adj}), root mean square error (RMSE), and standard error of the estimate (SEE) were determined. These were calculated as:

$$R^2_{adj} = 1 - \frac{\sum_{i=1}^n (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^n (Y_i - \bar{Y})^2}$$

$$RMSE = \sqrt{\sum_{i=1}^n (Y_i - \hat{Y}_i)^2 / n}$$

$$SEE = \left[\frac{\sum_{i=1}^n (Y_i - \hat{Y}_i)^2}{n - m - 1} \right]^{0.5}$$

Where: Y_i is the observed dependent variable for the i th tree

\hat{Y}_i is the predicted dependent variable for the i th tree

\bar{Y} is the observed mean of the dependent variable

n is the sample size

m is the number of independent variable

RESULTS AND DISCUSSION

Crown fuel characteristics

The crown fuel characteristics of *Pinus densiflora* were observed in the three study sites in Gyeongbuk province, Korea (Table 2). In Youngju, the highest CFL was in the branches (2-4 cm diameter class) at 6.00 kg (29.20%) followed by the needles at 4.10 kg (19.70%) and branches (1-2 cm diameter class) at 3.60 kg (17.50%). For Bonghwa, the largest CFL was in the needles at 3.60 kg (24%) followed by branches of 2-4 cm diameter class at 3.20 kg (21.30%) and branches of 1-2 cm diameter class at 2.90 kg (19.60%). For Daegu, branches (2-4 cm diameter class) have the largest CFL at 9.10 kg (25.60%) followed by needles at 7.80 kg (21.90%) and branches (>4 cm diameter class) at 6.20 kg (17.50%). The available CFL (needles and branches with 1 cm diameter or less) in Youngju was 44% of the total CFL. In Bonghwa, the available CFL represents 57% of the total crown biomass while in Daegu, it represents 45%. In comparison with other studies, the available CFL of *Pinus densiflora* in Mt. Palgong in Korea was 55% of the total crown biomass (Lee *et al.* 2012) which is similar to the results of this study. On the other hand, Mitsopoulos and Dimitrakopoulos (2007a) reported that the available CFL (needles and branches with a diameter of 0.63 cm or less) of *Pinus halepensis* (Aleppo pine) in Greece is 29.3% of the total crown biomass which is lower compared to *Pinus densiflora* in Korea. Stocks *et al.* (2004) reported that available CFL is usually consumed during crown fires. A higher available CFL indicates that a tree is more hazardous specifically during the occurrence of crown fire. The *Pinus densiflora* stands in Bonghwa can be more hazardous during the occurrence of crown fire due to their higher available CFL percentage compared to the two study sites.

Table 2. The average crown fuel characteristics of *Pinus densiflora* in Gyeongbuk province, Korea.

Study sites	Components	MC (%)	CFL (kg)	CFL distribution (%)	CBD (kg m ⁻³)	CBH (m)	CV (m ³)
Youngju	Total	105.30	20.70	100.00	0.47	5.10	43.90
	Needles	119.00	4.10	19.70	0.09		
	Branch(<0.5 cm)	99.00	2.60	12.50	0.06		
	Branch(0.5-1 cm)	92.70	2.50	12.10	0.06		
	Branch(1-2 cm)	105.20	3.60	17.50	0.08		
	Branch(2-4 cm)	105.90	6.00	29.20	0.14		
	Branch(>4 cm)	109.80	1.90	9.10	0.04		
Bonghwa	Total	111.20	14.80	100.00	0.47	3.60	31.60
	Needles	115.70	3.60	24.00	0.11		
	Branch(<0.5 cm)	96.40	2.70	18.40	0.09		
	Branch(0.5-1 cm)	113.00	2.10	14.20	0.07		
	Branch(1-2 cm)	115.70	2.90	19.60	0.09		
	Branch(2-4 cm)	115.10	3.20	21.30	0.10		
	Branch(>4 cm)	-	0.40	2.40	0.01		
Daegu	Total	127.90	35.40	100.00	0.29	5.20	123.90
	Needles	161.10	7.80	21.90	0.06		
	Branch(<0.5 cm)	128.00	3.90	11.10	0.03		
	Branch(0.5-1 cm)	124.00	4.20	11.70	0.03		
	Branch(1-2 cm)	138.90	4.30	12.20	0.03		
	Branch(2-4 cm)	109.90	9.10	25.60	0.07		
	Branch(>4 cm)	105.60	6.20	17.50	0.05		

Note: MC is moisture content, CFL is crown fuel load, CBD is crown bulk density, CBH is crown base height, and CV is crown volume.

The total CBD in both Youngju and Bonghwa was 0.47 kg m⁻³ while the total CBD in Daegu was 0.29 kg m⁻³. The crown bulk density of available CFL was 0.21 kg m⁻³ in Youngju, 0.27 kg m⁻³ in Bonghwa, and 0.13 kg m⁻³ in Daegu. Sando and Wick (1972) suggested a minimum CBD value of 0.037 kg m⁻³ to sustain vertical fire propagation in the crown. This means that the CBD of the available CFL is six times higher in Youngju, seven times higher in Bonghwa, and four times higher in Daegu in comparison to the minimum CBD value suggested by Sando and Wick (1972). Agee and Skinner (2005) reported that decreasing the CBD is one of the basic principles in addressing fuel reduction treatments.

In the three study sites, the needles have the highest MC at 119.00% in Youngju, 115.70% in Bonghwa, and 161.00% in Daegu. According to Verbesselt *et al.* (2002), the moisture content of the fuels is important because it affects the different factors of fire behavior such as preheating and ignition of unburned fuels, rate of fire spread, fire intensity and fuel consumption and others. Moreover, Chuvieco *et al.* (2002) stated that a higher MC of fuel will increase the required heat for fuel ignition because some of the energy will be used to evaporate water. On the other hand, the average CBH was 5.10 m in Youngju, 3.60 m in Bonghwa, and 5.20 m in Daegu. Crown base height is crucial in order to determine the susceptibility of the trees to crown fire, and one of the basic principles in fuel reduction treatments is to increase

the distance between the forest ground and the height of the live crown (Agee and Skinner 2005). CBH is also important in the conversion of surface fire to crown fire.

Allometric Equations

Allometric equations that utilize DBH as an independent variable were developed in this study to estimate the different CFLs (needles and branches: <0.5 cm, 0.5-1 cm, 1-2 cm, and 2-4 cm in diameter), stem biomass, total aboveground biomass, and CV of *Pinus densiflora* in Gyeongbuk province in Korea. Models that use other independent variables such as total height, age, CBH, and crown width were excluded in this study. Mitsopoulos and Dimitrakopoulos (2007a) reported that the addition of these variables does not improve the correlation significantly. Moreover, the DBH of all trees are usually measured in most forest inventories. The lowest was found in the branches with 2-4 cm diameter class at 0.79 while the highest R^2_{adj} was found in the crown biomass model at 0.96 (Table 3). The best RMSE was found in the total biomass equation at 0.20 while the equation for the branch of the 2-4 cm diameter class has the poorest at 0.51. The total biomass equation also provides the best SEE at 0.19 while the branch of the 2-4 cm diameter class also has the poorest with 0.48. The correction factor ranges from 1.02 to 1.12. The allometric model for the branch with >4 cm diameter class provides unreasonable estimates which could be due to a lower

Table 3. Parameter estimates and fit statistics of crown fuel load, aboveground biomass, and crown volume equations for *Pinus densiflora* in Gyeongbuk province, Korea.

Variables	β_0	β_1	R^2_{adj}	RMSE	SEE	CF
Needles	-4.016	1.940	0.89	0.30	0.29	1.04
Branch(<0.5 cm)	-4.433	1.942	0.85	0.36	0.34	1.06
Branch(0.5-1 cm)	-3.914	1.728	0.90	0.26	0.25	1.03
Branch(1-2 cm)	-4.916	2.148	0.80	0.46	0.44	1.10
Branch(2-4 cm)	-10.49	4.126	0.79	0.51	0.48	1.12
Crown biomass	-3.721	2.348	0.96	0.22	0.21	1.02
Stem biomass	-1.677	1.892	0.92	0.25	0.24	1.02
Total biomass	-1.637	2.019	0.95	0.20	0.19	1.02
CV(m ³)	-1.739	2.010	0.81	0.48	0.47	1.12

Note: The regression equation form is $\log Y = \beta_0 + \beta_1 \log X$, where X is DBH (cm), Y is dependent variable (CV or biomass), β_0, β_1 are the estimated parameters, R^2_{adj} is adjusted multiple coefficient of determination, RMSE is root mean square error, SEE is standard error of estimate, and CF is correction factor (Sprugel 1983).

number of samples ($n = 10$). Moreover, the results of the model evaluation show a very poor performance for this model (>4 cm diameter class). Mitsopoulos and Dimitrakopoulos (2007a) reported that the estimation of branches with larger diameter is considered as less important in fire behavior prediction because these crown fuels are rarely consumed during the occurrence of crown fire. Allometric equation for the estimation of crown volume is also developed in this study and the parameters and evaluation statistics were presented (Table 3). This model was able to explain 81% of the observed variation of CV. Furthermore, the RMSE and SEE of the developed model was 0.48 and 0.47, respectively.

The allometric models developed were used to predict the total CFL, available CFL, and CV of the *Pinus densiflora* in the different DBH classes (1 cm interval). Using these estimates, the total and available CBD for the different DBH classes were also determined (Figure 2). Based on these results, the total CBD increases as the DBH increases, while the available CBD decreases. This indicates that *Pinus densiflora* trees with lower DBH are more susceptible to crown fire compared to trees with higher DBH.

Aboveground Biomass

The different biomass components (stem, needles, and branches) of the *Pinus densiflora* in the three study sites were determined (Table 4). The highest mean aboveground biomass was found in Daegu at 103.54 kg which could be attributed to its higher mean DBH and total height compared to the two other study sites. Daegu's biomass was followed by Youngju's (67.35 kg) and then Bonghwa's (37.72 kg). The stem has the highest biomass in the three study sites followed by the branch and then the needle, respectively. On the stand

level, Daegu has also the highest aboveground biomass at 238.13 Mg ha⁻¹. Daegu was followed by Bonghwa at 90.53 Mg ha⁻¹ and Youngju at 50.78 Mg ha⁻¹. The mean aboveground biomass of the trees in Bonghwa was lower compared to Youngju but on the stand level, the aboveground biomass in Bonghwa was higher than in Youngju. This could be attributed to the stand density in Bonghwa which was higher at 2,400 tree ha⁻¹ compared to Youngju at 754 tree ha⁻¹. The allometric models that were developed were used to predict the aboveground biomass in the different DBH classes (Figure 3). All the different biomass components increase as the DBH increases.

The study of Noh *et al.* (2010) showed that the *Pinus densiflora* forests in Gyeongbuk province, Korea has a biomass (aboveground and belowground) ranging from 18.40 Mg ha⁻¹ (10-year-old stand) to 202.80 Mg ha⁻¹ (71-year-old stand). Park and Lee (1990) reported that a 33-year-old stand of *Pinus densiflora* in Gyeongbuk province has a biomass of 108.90 Mg ha⁻¹ (1,030 tree ha⁻¹) while the 70-year-old stand has a biomass of 161.20 Mg ha⁻¹ (400 tree ha⁻¹). In the study of Park *et al.* (2005), the aboveground biomass of *Pinus densiflora* stands in Gyeongbuk ranges from 21.10-204.00 Mg ha⁻¹. In Gangwon province, Korea, the estimated aboveground biomass of *Pinus densiflora* stands ranges from 22.00-308.80 Mg ha⁻¹ (Li *et al.* 2010). Furthermore, Kimmins *et al.* (1985) stated that the pine forests of temperate regions of different countries exhibit total biomass values of 50-300 Mg ha⁻¹ for 20-50 year stands. The results from the previous studies are comparable with the result of this study in terms of biomass. It was also observed that different factors such as age, mean DBH, mean total height, and stand density can greatly affect the biomass of the forest stands.

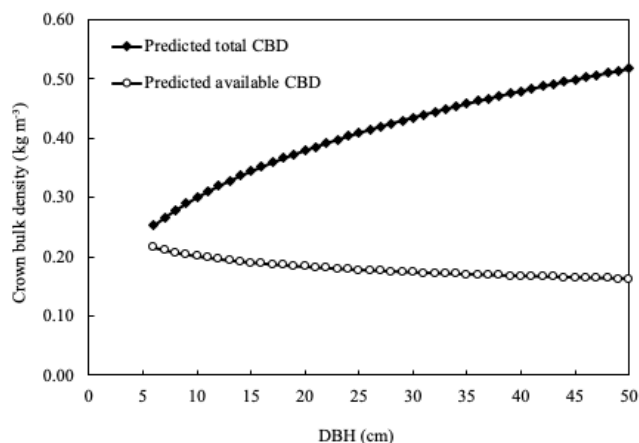


Figure 2. Predicted total and available crown bulk density of *Pinus densiflora* in Gyeongbuk province, Korea.

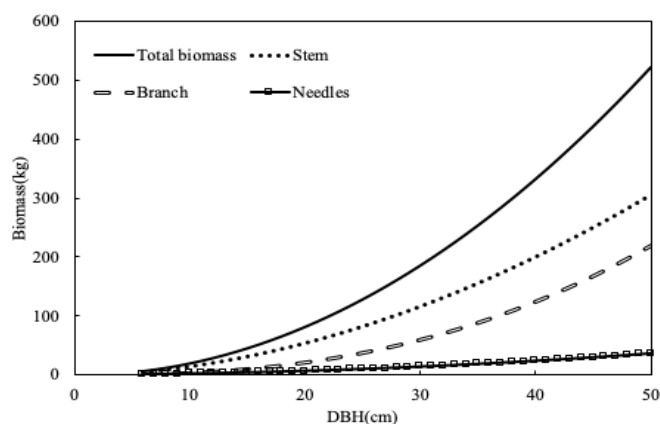


Figure 3. Predicted biomass using the developed allometric equations of *Pinus densiflora* in Gyeongbuk province, Korea.

Table 4. Mean biomass of the different tree components of *Pinus densiflora* in the three study sites in Gyeongbuk province, Korea.

Biomass	Youngju		Bonghwa		Daegu	
	kg tree ⁻¹	Mg ha ⁻¹	kg tree ⁻¹	Mg ha ⁻¹	kg tree ⁻¹	Mg ha ⁻¹
Stem	46.66	35.18	22.91	54.98	69.35	159.50
Needle	4.07	3.07	3.55	8.52	7.77	17.87
Branch	16.62	12.53	11.26	27.03	26.42	60.76
Total	67.35	50.78	37.72	90.53	103.54	238.13

CONCLUSION AND RECOMMENDATION

The crown fuel characteristics and the aboveground biomass of *Pinus densiflora* in Gyeongbuk province, Korea were investigated using destructive sampling. *Pinus densiflora* in this province had a relatively higher CFL and CBD which could indicate that this species in Gyeongbuk province is more hazardous specifically during the occurrence of a crown fire. To help the forest managers in quantifying the crown fuel characteristics and aboveground biomass of this species, allometric equations were developed using DBH as a predicting variable. The results of this study could help forest fire managers in the assessment of crown fire hazard, prediction of crown fire behavior, and estimation of aboveground biomass of *Pinus densiflora* in Korea which are very important in forest fire management and climate change mitigation.

Studies that investigate the relationship of different CFL classes (needles, branches: <0.5 cm, 0.5-1 cm, 1-2 cm, and 2-4 cm in diameter) to DBH are minimal for *Pinus densiflora* in Korea. Thus, the CFL and CV equations developed in this study could be utilized in the estimation of CFL and CV of the different *Pinus densiflora* forests in Korea on a temporary basis. Nonetheless, it is still recommended that future researches be conducted to investigate the effects of stand age class,

topography, and stand characteristics on the relationship of CFL and DBH (Mitsopoulos and Dimitrakopoulos 2007a) of *Pinus densiflora* in Korea.

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