Urban Forestry & Urban Greening 18 (2016) 53–58

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Developing the volume models for 5 major species of street trees in Gwangju metropolitan city of Korea

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ARTICLE INFO

Article history:
Received 22 January 2016
Received in revised form 3 May 2016
Accepted 17 May 2016
Available online 18 May 2016

Keywords:
Gwangju metropolitan city
Regression function
Street tree
Urban forestry
Volume model

ABSTRACT

Street trees are one of the most important parts of an urban forest system because they have various functions including environmental conservation, harmony of scenery, traffic safety, and prevention. Moreover, of the analysis factors considered for street trees, volume is mainly used not only for further research on health assessment, environment analysis, carbon storage estimation, and economic analysis, but also for local government management of street trees. For this reason, this study was performed to develop volume models for the 5 major species of street tree of Gwangju metropolitan city in Korea. After selecting the 5 major species – *Ginkgo biloba, Zelkova serrata, Metasequoia glytroboides*, *Prunus serrulata*, and *Platanus occidentalis* – one hundred sample trees of each species were randomly chosen considering diameter at the breast height (DBH), and then diameter at every 2 m height, height, and crown radius were measured. Volume was calculated using the Huber equation. Regression analysis, variance analysis, and descriptive statistical analysis were conducted using the 4 regression equations, and the best volume model was chosen by comparing precision, accuracy, credibility, and normality. From the results, all species showed the same patterns according to model type. That is, models that included diameter and height out-performed models with crown basal area had the highest precision, while model type IV using crown basal area (CBA) as a parameter showed the lowest goodness of fit because CBA can be influenced by volume, planting distance and space, or pollarding. Thus, using DBH and H together should be suitable for designing the volume models for urban-grown trees. However, properly trained experts are very important in order to avoid measurement error. Moreover, a large amount of data on *Platanus ocidentalis* is required to avoid large error in volume due to pollarding treatment. To sum up, model type III was chosen as the best fit models for all species with lowest MSE and highest R^2, and that models can be used to forecast the volume of and making ordinances for street trees in Gwangju metropolitan city, Korea.

1. Introduction

Urban area, which account for about 2% of the world (United Nations, 2012), has increased significantly and is predicted to continue to increase. Several kinds of environmental pollution have been created as by-products of expanding cities owing to concentrated population and industrialization. To address this concern, urban greening has been mentioned as a counteractive measure. In addition, urban forests play important roles in improving the quality of citizen's life by reducing air pollution (Rowntree and Nowak, 1991; Nowak, 1993; Nowak and McPherson, 1993; Akbari, 2002) and noise (Cook, 1978), supplying fresh air (Heisler, 1986; McPherson, 1990; Meier, 1991) and clean water (Sanders, 1986), and providing wildlife habitat (Emlen, 1974; Johnson, 1988; DeGraaf, 2002). The demand by people of urban greening has risen and will continue to rise with increased urban human populations as they recognized how trees are important in a city from the beginning of the 20th century. For these reasons, many large and medium cities have made some projects to plant and take care for urban forestry (Zheng, 2011). Moreover, urban forests are used as a major standard and indicator of carbon-neutral and –offsetting programs at the national or regional levels not only in Korea, but also globally (Seok et al., 2001). Thus, urban forests do not just reduce air pollution, but can preserve and expand ecology resources that improve health and comfort of cities.

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http://dx.doi.org/10.1016/j.ufug.2016.05.004
1618-8667/

Table 1
Current plant statistics in Gwangju.

	Ginkgo biloba	*Zelkova serrata*	*Metasequoia glyptostroboides*	*Prunus serrulata*	*Platanus occidentalis*	other	Total
No. of trees	39,558	18,070	10,472	5712	5004	18,811	97,627
Rate (%)	40.5	18.5	10.7	5.9	5.1	19.3	100.0

Source: Gwanju, 2010.

On the other hand, though the functions of an urban forest are similar to those of a non-urban forest, an urban forest has some special functions such as city environment conservation and prevention, culture and education, city identity, and production. One of the major systems that meets these functions of an urban forest is the street tree. A street tree is a tree planted beside streets in order to produce beautiful landscape, improve living and traffic environments, and maintain connectivity of the natural ecosystem (Regulation of Korea Forest Service). Functions of street trees are classified into environment conservation, harmony of scenery, traffic safety, and prevention. Thus, street trees establish urban identity by not only producing cheerful surroundings, but also by adding landscape elements to monotonous and standardized cities. Furthermore, these trees act as a form of nature in town. Consequently, street trees are very important at a point of conservation.

However, most of the studies conducted previously in Korea regarding street trees tended to be weighted toward specific analysis such as status, carbon inventory, or economic and public value. Study on development of growth models is necessary because growth, especially volume, has been used as the important analysis factor in health assessment, environmental analysis, carbon storage estimation, and economic analysis of street trees (Nowak and Crane, 2002; Maco et al., 2003; Soares et al., 2011; Lee, 2012; Choi, 2015; Park, 2015). For this reason, some studies have recently been carried out on this topic (McHale et al., 2009; Park, 2011); however, the research is still limited because most Korean researchers and citizens mainly focus on the benefits and economic of urban forests or non-urban forests.

Developing volume models is necessary as a reference not only for non-urban forests (West et al., 1999; Jenkins et al., 2003; Zianis and Mencuccini, 2004; Pilli et al., 2006; Muukkonen, 2007), but also for urban forests (Aguaron and McPherson, 2012). However, most of the developed volume models are intended for non-urban forests; those for urban forests are very rare. One volume equation cannot be used for both types of forest because planting and growth environments of an urban forest are really different from those of a non-urban forest. For this reason, independent volume models for an urban forest should be developed based on the data measured from trees planted in a town. Thus, this study was carried out to furnish an important resource needed for management and further research for the major species of street tree in Gwangju, Korea by performing sampling investigation and developing volume models.

2. Materials and methods

2.1. Materials

Gwangju metropolitan city has a 501.2 km^2 area and 1,492,000 population and is the 5th largest city in Korea, located in the southwestern part of country (E 126° 38′ 35″–127° 00′ 34″, N 35° 03′ 13″–35° 15′ 22″). Its annual average temperature and precipitation are 14.3 °C and 1288 mm, respectively.

The most commonly planted species in Gwangju are *Ginkgo biloba* (40.5%), *Zelkova serrata* (18.5%), *Metasequoia glyptostroboides* (10.7%), *Prunus serrulata* (5.9%), and *Platanus occidentalis* (5.1%), of which 100 sample trees were selected, and diameter, height, and crown radius were measured (Table 1). For that, diameter at every 2-m height was measured using a laser dendrometer (Criterion RD 1000, Laser Technology, USA), and the crown radius of each tree was gauged with a laser distance meter (Leica Disto A5, Leica, USA) in 4 directions.

Table 2
Forms of volume regression equations used for this study. (unit: m^3, cm, m, m^2).

Model type	Form of volume regression equation
I[a,b]	$V=\alpha\times DBH^{\beta}$
II[a]	$V=\alpha\times\left(DBH^2\times H\right)^{\beta}$
III[a,b]	$V=\alpha\times DBH^{\beta}\times H^{\gamma}$
IV[b]	$V=\alpha\times CBA^{\beta}$

[a] source: Kim (2011).
[b] source: Yoon et al. (2013).

2.2. Methods

Volume was calculated by sectional measurement using the Huber equation, which has low error. Each sectional length of stem was 2 m, and the end of stem was calculated like a cone shape. Thus, the total volume was estimated by combining all sectional volumes as below.

$$V=[l_0\times A_0]+\left[\sum_{i=1}^{n-1}A_i\times l\right]+\left[A_n\times\frac{1}{3}\times l_n\right]=\left[\frac{\pi}{20}\times d_0^2\right]+\left[\sum_{i=1}^{n-1}\frac{\pi}{2}\times d_i^2\right]+\left[\frac{\pi}{12}\times d_n^2\times l_n\right]$$

where, V is the total aboveground volume, l is sectional length, A is basal area, and d is diameter.

DBH (diameter at breast height) and H (height) are normally used as independent variables for volume models because these factors produce the largest effects on volume and are measured easily and accurately. In addition, some studies on the relationship between CBA (crown basal area) and V (volume) have been conducted (Mayer, 1958; Freist, 1962; Kramer, 1971; Mitscherlich, 1978; Yoon et al., 2013). For this reason, CBA is also used as an independent variable in this study. The basic forms of regression equations are shown in Table 2.

To develop the volume models by street tree species in Gwangju, Korea, the most suitable model was selected within the above 4 regression equations using PROC NLIN, PROC GPLOT, and PROC UNIVARIATE procedures of SAS 9.3 software (SAS Institute Inc, 2012), based on precision, accuracy, credibility, and normality. The chosen criterions were MSE, R^2, standard deviation, dispersion, Shapiro-Wilk test, and residual plot.

3. Results and discussion

The status of street trees in Gwangju was summarized based on the descriptive statistical analysis on the sample data. DBH, H, CBA, and V were used as connection parameters, and mean, minimum, maximum, standard deviation, coefficient of variation, and range were estimated according to species. *Metasequoia glyptroboides* had the largest mean DBH and H at 38.1 cm and 19.2 m, respectively. *Prunus serrulata* had the lowest values at 11.0 cm and 9.4 m, respectively, because it was recently planted, and so is younger than the