Development of Height-Age Model and Site Index Curves for *Pinus rigida* Plantations in South Korea

Yeon Ok Seo[1], Roscinto Ian C. Lumbres[1,2], Young Jin Lee[1]*

[1.] Department of Forest Resources, Kongju National University, Yesan, Chungnam 340-802, South Korea
[2.] College of Forestry- Benguet State University, La Trinidad, Benguet, 2601, Philippines
leeyj@kongju.ac.kr

Abstract: A height-age model, using the Chapman-Richard growth function and site index curves, was developed for *Pinus rigida* in South Korea. The study sites were located in the *Pinus rigida* plantations in Yesan-gun, Muju-gun, Jinan-gun, and Sancheong-gun areas, which are regions in the central and southern parts of South Korea. A total of 15 temporary plots were established and 52 sample trees were harvested for disc collection and stem analysis. In order to evaluate the performance of the developed model, the coefficient of determination (R^2), root mean square error (*RMSE*), bias ($\bar{E}$), mean percent bias (*MPB*), and absolute mean difference (*AMD*) were used as evaluation statistics. It was estimated that the model explained about 98.18% of the variation in the average value of height. The value of $\bar{E}$ was 0.003m, whereas the value of the *AMD* was 1.027m. The computed *RMSE* was 1.381 and the *MPB* was 4.252%. A total of eight site indexes, starting from 8m up to 18m with an interval of 2m, were generated to show the different curves in predicting the productivity of *Pinus rigida* stands in South Korea.

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1. Introduction

The Korea Forest Service (KFS) reported that the Republic of Korea, popularly known as South Korea, has a total of 6.370 million ha of forest land area covering approximately 64% of the total land area. Coniferous forests dominate approximately 42% or 2.672 million ha of the total forested land. The third most widely distributed coniferous in this country is the *Pinus rigida* (pitch pine), with approximately 0.41 million ha or 15.2% of the total coniferous forested land (Lee, 2010). In order to sustainably manage these forests, accurate estimates on forest productivity is essential (Haywood, 2009).

Forest managers can assess forest productivity, such as timber production, through site quality evaluation (Clutter et al., 1983). This evaluation can be a guide in predicting the growth and yield of forests, which are important factors in making critical decisions for forest stands (Spurr, 1952; Spurr and Barnes, 1980). This can also help managers to classify forests based on their productive capability (Lee, 2002). Moreover, the evaluation can also be considered as an important foundation in forest land use planning (Hocker, 1979). Clutter et al. (1983) stated that site evaluation can also serves as a basis in justifying the investment in plantation projects. Most forest managers consider the site index as one of the best measures in evaluating site quality because it is the most direct and widely used index in forestry (Clutter et al., 1983; Dieguez-Aranda et al., 2006; Fonweban et al., 1995; Onyekwelu, 2005). Site index, defined as the total height of the dominant or co-dominant trees in a forest stand at an arbitrary index age, is a method used for quantifying site quality for pure even aged forest stands which is essential in growth and yield modeling (Corral-Rivas et al., 2004; Dieguez-Aranda et al., 2006; Lee, 2002). Akindele (1991) described the site index as the oldest and most satisfactory method, whereas Fonweban et al. (1995) described it as the most efficient and objective tool in evaluating the site productivity of a forest.

The graphical method and the mathematical model are two methods that can be used to evaluate site index. Between these two methods, the mathematical model is more preferred because there are difficulties in conducting statistical tests on the goodness of fit of the curve as well as on the involvement of the element of subjectivity in the graphical method (Akindele, 1991; Onyekwelu, 2005; Onyekwelu and Fuwape, 1998). Mathematical methods utilize different techniques to fit site index curves. These methods could be classified as special cases of three general equation development methods, which are the guide curve, difference equation, and parameter prediction methods (Clutter et al., 1983). Nanang and Nunifum (1999) reported that the guide curve is considered as one of the most popular methods in recent times, particularly on even-aged single species. Furthermore, this technique is very suitable for stands with temporary sampling plots (Akindele, 1991). Site index curves are often based on stem analysis data because it can provide significant information on potential site productivity and moreover, they are more preferred for the development of reasonable and valid height models (Corral-Rivas et al., 2004). Furthermore, the past growth of trees is reconstructed based on the annual growth ring patterns using the stem analysis (Dieguez-Aranda et al., 2006).

Different studies have been conducted in order to develop site index curves for various species in different areas. Site index prediction equations were developed for pine plantations grown under various conditions in the different locations in the southern United States (Avery and Burkhart, 1994; Lee and Hong, 1999; Pienaar and Shiver, 1980). In South Korea, studies were conducted in order to develop site index curves for *Cryptomeria japonica* (Lee, 2002), *Quercus variabilis* (Chung et al., 2002), *Pinus thunbergii* (Shin et al., 2007), *Chamaecyparis obtusa* (Kim et al., 2008), and *Larix kaempferi* and *Pinus densiflora* (Pyo et al., 2009; Shin et al., 2007; Son and Lee, 2003). However, no site index curves have been developed for *Pinus rigida* in South Korea. The development of site index equations as well as studies on the height growth patterns of this species will help forest managers to classify the quality of the different stands of *Pinus rigida* in South Korea. Thus, the objectives of this study is to develop a height-age model using the Chapman-Richards growth function (Chapman, 1961; Richards, 1959) and the anamorphic site index curves for *Pinus rigida* stands.

2. Material and Methods

Study sites

This study was conducted in the *Pinus rigida* plantations in Yesan-gun (92,000ha), Muju-gun, Jinan-gun (60,000ha), and Sancheong-gun (25,000ha) areas, which are located in the central and southern parts of South Korea. Data collection was conducted from 2006 to 2011. The mean annual precipitation in Muju-gun and Jinan-gun was 1,442.1mm, whereas in Yesan-gun and Sancheong-gun, it was 1,228.9mm and 1,479.1mm, respectively. On the other hand, the recorded mean annual temperature in Yesan-gun was 11.6^{o}C. In Muju-gun and Jinan-gun, the mean annual temperature was 10.4^{o}C, whereas in Sancheong-gun, the recorded mean annual temperature was 12.7 ^{o}C (based on the years from 1971-2000) (Korea Meteorological Administration, 2010).

Data collection and analysis

A total of 15 temporary plots were established; eight plots were located in Yesan-gun with a size of 10m × 10m plot, while seven plots with a size of 20m × 20m were established in the regions of Muju-gun, Jinan-gun, and Sancheong-gun. A total of 52 trees were felled from 0.2m above the ground, and discs with a thickness of 5cm were collected for every 2m log section (for example, 1.2m, 3.2m, 5.2m, etc.). Yet, the first and the last disc were collected from the first and the last 1m of the log. These discs were used for the stem analysis. The age at each section height was determined at the laboratory. The height values were estimated at five year increments from the 2006-2008 data, whereas the height values were estimated at one year increments from the 2009-2011 data using DTRS-2000. The average age of the sampled trees was 21y and the average height was 9m (Table 1).

Table 1. Summary of the observed statistics for the height and age of *Pinus rigida* in South Korea

Variables	*n*	Mean	SD	Minimum	Maximum
Age (year)	1,056	21	11	3	44
Height (m)	1,056	8.9	5.2	0.3	19

The Chapman-Richards growth function was used in this study (Chapman, 1961; Richards, 1959), which is the extension of Von Bertalanffy's (1957) quantitative laws of the growth of organism. The form of this function is:

$$H = b_1(1 - exp(-b_2 A))^{b_3}$$

where: H =total height of the tree; (in meter)
A = age; (in year)
b_1= the asymptote;
b_2= the rate parameter; and
b_3= the shape parameter.

This growth function has been widely used because it defines sigmoid curves as having three parameters that characterize the different growth stages, which are influenced by biological processes and behaviors (Peng et al., 2001). Furthermore, this equation has been extensively used in the growth and yield studies of forestry in order to characterize site index curves, height-age, diameter-age, basal area-age, and growth rate-age relationships (Clutter et al., 1983; Payandeh and Wang, 1994; Pienaar and Turnbull, 1973; Somers and Farrar, 1991). To evaluate the model, the following evaluation criteria were utilized: coefficient of determination (R^2), root mean square error (*RMSE*), bias ($\overline{E}$), absolute mean difference (*AMD*), and mean percent bias (*MPB*).

3. Results and Discussion

Model fitting

Using the PROC NLIN procedure in SAS (SAS Institute Inc., 2004), a non-linear regression was applied to fit the height-age data using the Chapman-Richards height growth function (Figure 1).

The parameter estimates and associated standard errors were shown in Table 2. For each parameter estimate, the results indicated that none of the asymptotic 95% confidence intervals contained a zero. Therefore, it was concluded that the equation parameters are significant.

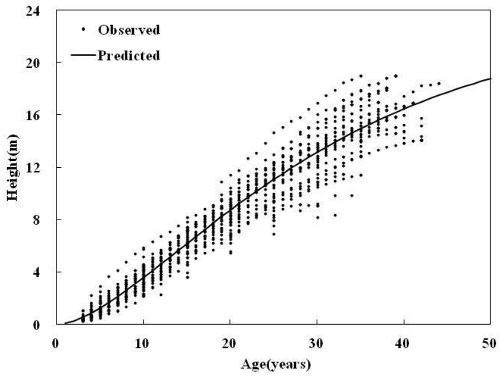

Figure 1. Comparison of the observed and predicted height using the developed height-age model for *Pinus rigida* in South Korea

Table 2. Parameter estimates, approximate standard error, and confidence intervals of the height-age model for *Pinus rigida* in South Korea

Parameter	Estimation	Standard Error	Lower 95% Confidence Level	Upper 95% Confidence Level
b_1	23.6177	1.0943	21.4644	25.7590
b_2	0.0422	0.0036	0.0351	0.0493
b_3	1.7682	0.00869	1.5978	1.9387

The performance of the developed model was evaluated by using the evaluation criteria, which are shown in Table 3. The R^2 was 0.9818, which means that the model explained about 98.18% of the variation in the estimate of total height. In addition, Peng et al. (2001) stated that a larger R^2 or a value near to one is better, meaning that the result of the created model is well fitted. Moreover, the computed *RMSE* was 1.381, whereas the *MPB* was 4.252%. The value of $\bar{E}$ was 0.003 m, while the value of the *AMD* was 1.027 m. Peng et al. (2001) explained that a negative value of $\bar{E}$ indicates that the developed model gave an over prediction while a positive value gave an under prediction. Moreover, the explanation defines that if the computed $\bar{E}$ value is near to zero, the created model is better. A lower *AMD* value means that the model is more accurate. To further evaluate the developed model, the bias in the different age classes were determined (Figure 2). The results illustrated that the highest under prediction was found in the 36-40 age class with 0.533 m; the highest over prediction was found in the 41-45 age class with 1.096 m.

Table 3. Fit statistics and evaluation statistics of the fitted Chapman-Richards model for *Pinus rigida* in South Korea

R^2	*RMSE*	$\bar{E}$	*AMD*	*MPB*
0.9818	1.3811	0.003 m (p=0.9460)	1.027 m (p=0.0001)	4.252 (p=0.0001)

*Coefficient of determination (R^2), Root Mean Square Error (*RMSE*), bias ($\bar{E}$), Absolute Mean Difference (*AMD*), and Mean Percent Bias (*MPB*)

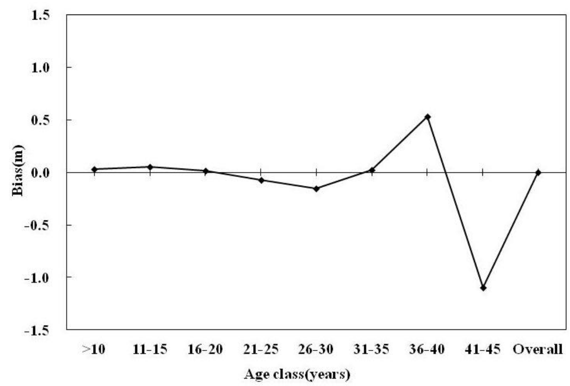

Figure 2. Bias of the developed model in height estimation by age classes for *Pinus rigida* in South Korea

Site index curves

The guide curve method, described by Clutter et al. (1983), was utilized in this study for the development of anamorphic site index prediction equation in order to estimate the site index (*SI*) for any given index age of *Pinus rigida*. The equation for the guide curve is:

$$H = 23.6177(1-\exp(-0.0422A))^{1.7682}$$

The index or base age (*IA*) for *Pinus rigida* used in this study was 30 as recommended by the Korea Forest Service (2009). Furthermore, Goelz and Burk (1992) stated that the index age is commonly selected less than the rotation age. The procedure described by Clutter et al. (1983) was also used to derive the curves for the other site index values. In this method, the rate parameter (b_2) and the shape parameter (b_3) of the equation (2) were constant, whereas the asymptote parameter (b_1) varied in determining the height (*H*) where age (*A*) is equivalent to the index or the base age (*IA*). The equation created to estimate the site index for any given age was:

$$SI = H(\frac{1-exp(-0.0422IA)}{1-exp(-0.0422A)})^{1.7632}$$

Equation (3) can be rearranged algebraically to estimate the *H* at a given site index as follows:

$$H = SI(\frac{1-exp(-0.0422A)}{0.7180})^{1.7632}$$

Site index curves were generated using equation (4) for *Pinus rigida* stands ranging from 3 years to 50 years of age, as shown in Figure 3. A total of six *SI*, starting from 8m to 18m with an interval of 2m, were generated in order to show the different curves in predicting the yield of a forest stand.

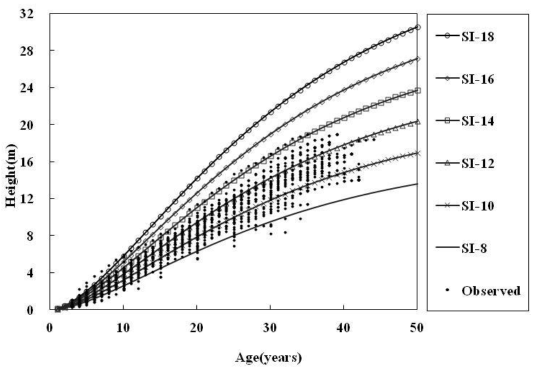

Figure 3. Site index curves developed for *Pinus rigida* in South Korea

4. Conclusion

Site index curves had been developed for the different major species in South Korea except for *Pinus rigida*. The results of this study, in particular, the site index curves, will help forest managers to evaluate and classify pure stands of *Pinus rigida* in South Korea according to their potential productivity. The site index model, which was developed in this study, is a significant management tool in providing simple numerical values that can be easily measured and understood. For future study, it is recommended that site index curves that have more desirable attributes, such as polymorphism and multiple asymptotes, must be developed as suggested by Corral-Rivas et al. (2004).

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Corresponding Author:
Dr. Young Jin Lee
Department of Forest Resources,
Kongju National University,
Yesan, Chungnam 340-802, South Korea
E-mail address: leeyj@kongju.ac.kr

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