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Estimation of Height Growth Patterns and Site Index Curves for Japanese Red Cedar(*Cryptomeria japonica* D. Don) Stands planted in Southern Regions, Korea

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ABSTRACT: The purpose of this study is to estimate height growth patterns and site index curves (base index age 50 years) for Japanese red cedar trees(*Cryptomeria japonica* D. Don) grown in southern regions of Korea. The Chapman-Richards growth function was selected for stand height prediction using on the results of stem analysis data sets. Anamorphic base age invariant site index curves were presented based on this height prediction equation. The resulting site index prediction equation can provide an indication of the productivity of the site quality based on Japanese red cedar trees plantation ages planted in southern regions of Korea.

Key words: *Cryptomeria japonica* D. Don, The Chapman-Richards growth function, Anamorphic site index curves

INTRODUCTION

Japanese red cedar tree(*Cryptomeria japonica* D. Don) is one of the most important tree species in terms of high-value wood products in Japan and Southern Korea. The majority of this species was widely planted for commercial plantations in the 1920s throughout the southern regions of South Korea (Forestry Administration of Korea 1999). Therefore, Japanese red cedar stands are even-aged and intensively managed. However, reliable height growth and site index prediction equations to estimate the growth and volume of Japanese red cedar trees are currently unavailable in the southern regions of Korea (Lee *et al.* 2001).

Site index is a practical and commonly used methods for quantifying site quality for even-aged or pure forest stands and an essential component in growth and yield models. Site index is an expression of forest site productivity defined as the average height of the dominant (or co-dominant) trees in pure even-aged stands at an arbitrarily chosen index age. Typically this base index age is set at 25, 50, or 100 years. According to the Goelz and Burk (1992), the base index age is specified somewhat less than rotation age. Therefore, we decided the base index age as 50 years for Japanese red cedar trees after considering rotation ages published in Forestry Administration of Korea (1999). Several researchers (Pienaar and Shiver 1980, Avery and Burkhart 1994, Lee and Hong 1998) have been published several site index prediction equations for pine plantations grown under different conditions in various geographic locations in the southern United State.

An evaluation of a variety of site index models by Cao (1993) using remeasurement data sets showed that the Chapman-Richards model was more suitable than Schumacher model (1939). However, reliable height growth and site index prediction equations to estimate the height growth patterns of Japanese red cedar trees are currently unavailable in the southern regions of Korea. Therefore, the objective of this study is to develop anamorphic base age invariant site index prediction equations to estimate site index and height growth patterns for Japanese red cedar trees grown in southern regions of Korea.

MATERIALS AND METHODS

Study areas and data sources

Data were collected from Japanese red cedar plantations established during the 1920s throughout the southern regions in South Korea. A total of 32 representative temporary 0.04 hectare sample plots (dimensions: 20m x 20m) were installed in even-aged stands throughout the six different southern regions (Gangjin, Jangheung, Jangseong, Namhae, Suncheon and Yangsan) of South Korea (Table 1). The diameter outside bark at breast height (dbh, nearest 0.1 cm) and the total height (nearest 0.1 meter) of all trees were measured in each sample plot. One dominant standard tree was selected and carefully felled for stem analysis from each sample plot. Outside and inside diameter measurements (nearest 0.1 cm) were made on each felled

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Table 1. Summary of observed statistics for Japanese red cedar plantations in southern regions of Korea

Regions	Stand age (years)	Height (m)
Gangjin	71 (24~85)	16.0 (13.4~17.7)
Jangheung	36 (33~39)	19.6 (17.5~21.5)
Jangseong	53 (33~84)	18.9 (15.5~21.7)
Namhae	37 (36~38)	15.7 (13.4~16.9)
Suncheon	34 (31~39)	16.5 (15.2~18.2)
Yangsan	26 (24~27)	10.9 (9.1~12.0)

Note: Values are average means with ranges in parentheses.

tree. The character and nature of the observed Japanese red cedar stand data sets is shown in Table 1.

The Chapman-Richards growth function

The basic growth function employed was the Chapman-Richards function (Richards 1959, Chapman 1961), which was extension of Von Bertalanffy' s(1957) quantitative laws on the growth of organism. The Chapman-Richards growth function can take the following form:

$$y = b_1(1\text{-}\exp(\text{-}b_2 t))^{b_3}, \qquad (1)$$

where: y=total living biomass, t=time, b_1 = the asymptote, b_2 = the rate parameter, and b_3 = the shape parameter. The total living biomass (y) can refer to size or weight in animal growth, volume, diameter and height in tree growth.

Because of its sigmoidal flexibility in shape and biological and statistical properties, equation (1) has been used extensively in growth and yield studies in biology and forestry for describing site index curves, height-age, diameter-age, basal area-age, and growth rate-age relationships (Pienaar and Turnbull 1973, Clutter *et al.* 1983, Somers and Farrar 1991, Payandeh and Wang 1994).

Validation

The statistical measures used in this study for model validation were the coefficient of determination (R^2), root mean square error (RMSE), mean percent bias(MPB), mean absolute error(AMD), and a simple linear regression analysis of observed versus predicted height. Percent mean bias is calculated as a percentage of the observed trees height. Also, mean absolute error in terms of overall prediction accuracy was used in this study to further examine the performance of the height prediction models. Average mean differences (MD) is measures of the bias in estimating mean heights, while AMD is measures of precision. The sum of the absolute deviation is a measure of precision in fitting height prediction (Zar 1999).

RESULTS AND DISCUSSION

Height growth of Japanese red cedar stands

The nonlinear regression was used to fit 309 age-height pairs using the PROC NLIN procedure in SAS (SAS Institute Inc. 1989) for the Chapman-Richards height growth function. Multiple starting values for parameters were provided to ensure that the nonlinear least square solution was a global minimum rather than a local minimum. Resulting parameter estimates and associated asymptotic standard errors are indicated in Table 2. None of the asymptotic 95% confidence intervals for each of the parameter estimates contained zero, thus the conclusion was reached that the equation parameters are significant. In addition, it was estimated that the model explained about 64.7 % of the variation in the average value of height (Table 3).

A plotting of residuals against predicted height indicated that a random pattern around zero with no detectable trends. Due to diverse and different environment conditions of plantation regions, it tends to show large height growth variations as trees get old.

The residual mean differences (MD) and the absolute residual mean differences (AMD) were calculated for validation purposes. A paired t-test showed that expected value of the residuals were not significantly different from zero at the 0.05 level of probability (*p*-value = 0.7386). The absolute residual mean differences as a magnitude of error index showed 2.42 meter. The Table 3 indicated fit statistics for average validity tests of the Chapman-

Table 2. Parameter estimates, approximate standard errors, and approximate confidence intervals for the Chapman-Richards growth function

Parameter	Estimate	Standard error	Lower 95% confidence level	Upper 95% confidence level
b_1	13.25755	0.34240	12.58378	13.93132
b_2	0.12549	0.01718	0.09168	0.15930
b_3	4.13816	1.07120	2.03028	6.24605

Table 3. Fit statistics for average validity tests of the Chapman-Richards growth function

RMSE	MD	AMD	MPB	95% C.I. for percent bias	Fitted index (R^2)
3.12990	0.05928 (p=0.7386)	2.42347 (p=0.0001)	7.65924 (p=0.0072)	7.65924 5.54597	0.64661

Note: RMSE= $\sqrt{\sum_{i=1}^{n}(y-\hat{y})^2/n}$, $MD=\sum_{i=1}^{n}\frac{e_i}{n}$, $AMD=\sum_{i=1}^{n}\frac{|e_i|}{n}$,

Mean Percent Bias= $100 * \left(\frac{\hat{y}-y}{y}\right)$, $R^2=1-\sum(y-\hat{y}_i)^2/(y-\hat{y}_i)^2$, other variables are defined as before.

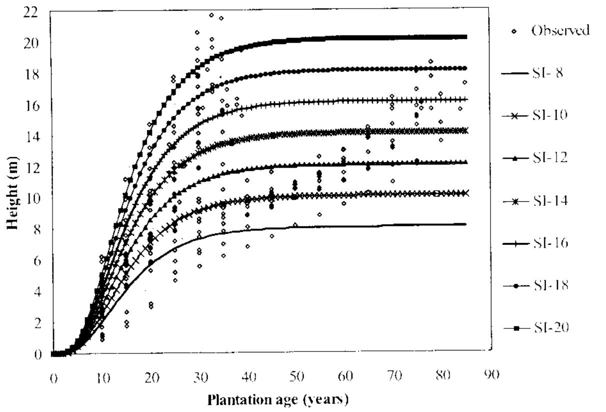

Fig. 1. Site index curves for Japanese red cedar plantation stands in southern Korea (base index age=50 years).

Richards height growth function.

Site index prediction of Japanese red cedar stands

Substitution of the nonlinear regression coefficients in Table 2 into equation (1) gave this Chapman-Richards height prediction equation

$$HT = 13.25755(1-\exp(-0.12549\,AGE))^{4.13816} \qquad (2)$$

Using procedures described by Clutter *et al.* (1983), equation (2) is a guide curve, which can be used to develop an anamorphic site index prediction equation to estimate site index for any given index age.

$$S = HT\left(\frac{1-\exp(-0.12549IA)}{1-\exp(-0.12549AGE)}\right)^{4.13816} \qquad (3)$$

where S is site index (m) for index age (IA).

For an index age 50 years, the above equation (3) can be algebraically rearranged as:

$$HT = SI_{50}\left(\frac{1-\exp(-0.12549AGE)}{0.99812}\right)^{4.13816} \qquad (4)$$

Site index curves generated from equation (4) and illustrated in Figure 1 for Japanese red cedar plantation stands ranging in plantation age from 1 to about 85 years old.

The results of this study show that height growth prediction equation has been developed to predict the height of the Japanese red cedar stands. Guide curve was transformed into an anamorphic site index prediction equation. The resulting site index prediction equation can provide an indication of the productivity of the site quality based on Japanese red cedar plantation ages. However, for plantation ages less than 35 years, the observed height showed very sensitive due to the wide topographical and environmental differences in southern regions. In spite of the some limitations, site index is very useful tool because it provides a simple numerical value that can be easily measured and understood.

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