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Estimation of diameter growth parameters for *Cryptomeria* plantations in Taiwan using the Local Yield Table Construction System

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ABSTRACT

We applied the Local Yield Table Construction System (LYCS), a computer program that estimates stand growth as a function of various density control strategies, to *Cryptomeria* plantations in Taiwan. Parameters of the growth model were estimated from permanent plot data on *Cryptomeria* stands stored in a database at the Experimental Forest of National Taiwan University. The diameter at breast height (DBH) and the number of trees measured in permanent plots were used as parameters to estimate the curve of the DBH growth rate, the effects of stand density on diameter growth, growth in terms of DBH, and diameter distribution. The estimated stand growth could be adapted to the observed values in the permanent plots. Based on these results, yield tables for various stand density control strategies can now be constructed for *Cryptomeria* stands in Taiwan.

Keywords: *Cryptomeria* plantations, Local Yield Table Construction System, stand density, stand growth

INTRODUCTION

The control of stand density by thinning is a main strategy of forest management, and thus to predict stand growth, it is important to consider the various thinning strategies. The Local Yield Table Construction System (LYCS), developed at Tokyo University Forest in Chiba (Konohira, 1995), is a computer program that predicts timber harvest based on various thinning plans (Shiraishi, 1986; Matsumoto, 2005) by using a growth model. Using a parameter estimation methodology (Matsumoto, 1997), LYCS has been applied to Japanese sugi, hinoki, and larch plantations (Tanaka *et al*., 2004; Nakajima *et al*., 2007a, b), and has also been used to develop forest management strategies (Nakajima and Shiraishi, 2007). However, no study had applied the system to *Cryptomeria* forests in other countries. The Experimental Forest of National Taiwan University has data stand volume, height curve parameters, and other aspects of *Cryptomeria* stands (Yang *et al*., 1995), but a growth model for estimating diameter growth as a function of density control in these stands had not yet been devised. Thus, we developed a model to estimate the growth parameters of *Cryptomeria* plantations in Taiwan and evaluated the applicability of the estimated parameters to permanent plot data.

MATERIALS AND METHODS

Data source

The data used for parameter estimation were derived from permanent plot data of *Cryptomeria* stands in the Experimental Forest of National Taiwan University. The data set includes thinning age, number of dominant trees and thinned trees per hectare, mean diameter at breast height (DBH), and mean tree height, all of which were measured approximately every 5 years between 1920 and 1990 at this site. Table 1 summarizes the permanent plots.

Table 1. Permanent plot data (1990)

Plot	Area (ha)	Altitude (m)	Stand density (stems/ha)
Shichuan	0.135	1000	563
Mentyan	0.153	1100	503
Shitourhwu	0.147	1200	565
Sanchianju	0.126	1200	611
Shianjin	0.116	990	802
Anyntuku	0.118	920	517

The plots were 0.116–0.153 ha in area, and located at 920–1200 m elevation. Around 1990, the permanent plots had a density of 503 to 802 trees/ha, and were about 70–80 years old.

Procedures

We estimated the growth parameters by applying relational expressions in the LYCS to the aforementioned data sources using the parameter estimation method (Shiraishi, 1986). The relational expressions are summarized below.

Relationship between stand density and mean DBH:

$$\log N + a \log D = K, \quad (1)$$

where D is the DBH in cm and a and K are parameters.

Increment rate of mean DBH:

$$r = m \exp(-n\, t), \quad (2)$$

where r is the increment rate of the mean DBH (%/year), m and n are parameters, and t is stand age.

Growth model for diameter increment using the results from formulas (1) and (2):

$$r = m \exp(-n\, t) + p\,(K - \log N - a \log D), \quad (3)$$

where p is the parameter.

Formula (1) was estimated by applying a linear curve to log–log scale plotting of the stem number per hectare and mean DBH. Formula (2) was estimated by applying the growth rate curve of the annual growth rate (%/year) of the DBH, sorted by stand age, to Gompertz functions. Formula (3) shows the growth model for the diameter increment using the results from (1) and (2). In formula (3), parameter p represents the influence of stand density on DBH growth, and all parameters (p, m, and n) were estimated by applying the nonlinear least-squares method to DBH growth in permanent plots using the methods developed for Japanese sugi and hinoki plantations (Shiraishi, 1986). We used the quasi-Newton method because it is applicable to high nonlinearity (Nakagawa and Koyanagi, 1982).

Then we examined the estimated values using these parameters and the data on *Cryptomeria* stands in permanent plot in Sanchianju. The plot was established when the stand was 6 years old, and has been measured more than 30 times since then. The latest measurement was taken when the stand was 72 years old. Data on the decreasing number of trees due to thinning or self-thinning have been recorded since the permanent plot was established. We set the observed values of the diameter distribution at stand age 36 as the initial value, and used the data on stand density in LYCS. We compared the estimated values of mean DBH and diameter distribution to the observed values.

Finally, we used an example to predict DBH growth under three stand density control strategies: low (30% of trees thinned at age 15, and 40% at ages 25 and 35), intermediate (20% thinned at age 15, and 30% at ages 25 and 35), and high (20% thinned at age 15, and 30% at age 25).

RESULTS AND DISCUSSION

Growth parameters and adaptability to the permanent plot

Table 2 shows the estimated parameters. Parameter p for our study site was 2.3, the same value as that estimated for *Cryptomeria* at Tokyo University Forest in Chiba (Shiraishi, 1986). This result indicates that the effects of thinning on the diameter growth of *Cryptomeria* are the same in Japan and Taiwan. Thus, our findings support Nakajima and Shiraishi's (2007) suggestion that once p is evaluated in one area, it can be used for the same tree species in other areas.

Table 2. The estimated parameters for *Cryptomeria* plantations in Taiwan

The relationship between stand density and mean DBH		Increment rate of mean DBH	
$\log N + d \log D = K$		$r = m \exp(-n\,t)$	
d	K	m	n
1.025	4.455	4.746	0.033

Figure 1 shows the observed and estimated data for the mean DBH, with an error rate of 8.3% on average (maximum 12.6%). The mean DBH was slightly overestimated, with an 8.3% error rate on average.

A period of 30 years, which is a relatively long prediction period, typically has an error rate of about 10% on average. Our error rate falls within this rate, indicating that our method is accurate and can be used for practical prediction of forest resources. In the future, we will work to improve the prediction accuracy by incorporating more elaborate data analyses.

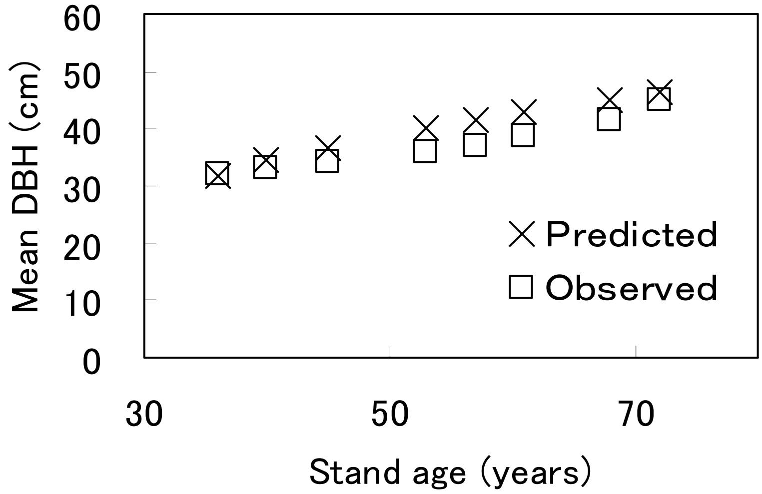


Fig. 1. Mean diameter comparison between the observed and estimated data

Figure 2 compares the estimated and observed diameter distributions. Setting the initial diameter distribution at age 36, we predicted the diameter distribution of the stand at age 68. The distribution at age 36 is shown in the figure as a solid line, while the predicted and observed values at age 68 are represented by a dotted line and thick line, respectively. Even though the curves at 24 to 30 cm DBH did not match, the prediction was accurate, and goodness of fit was observed between the predicted and observed diameter distributions.

Example of a density control plan

We used an example to predict DBH growth under the various stand density controls shown in Fig. 3. At age 60, the densities at the final cutting of low-, intermediate-, and high-density stands were 504, 784, and 1120 stems/ha, respectively, and their mean DBHs were 41.3, 34.9, and 30.7 cm, respectively. In summary, stands of higher densities had smaller mean DBHs. This result is logically consistent and matches current forest management assumptions. Predicting DBH as a function of various types of density control strategies using the parameters described above will help develop a thinning plan for *Cryptomeria* timber production.

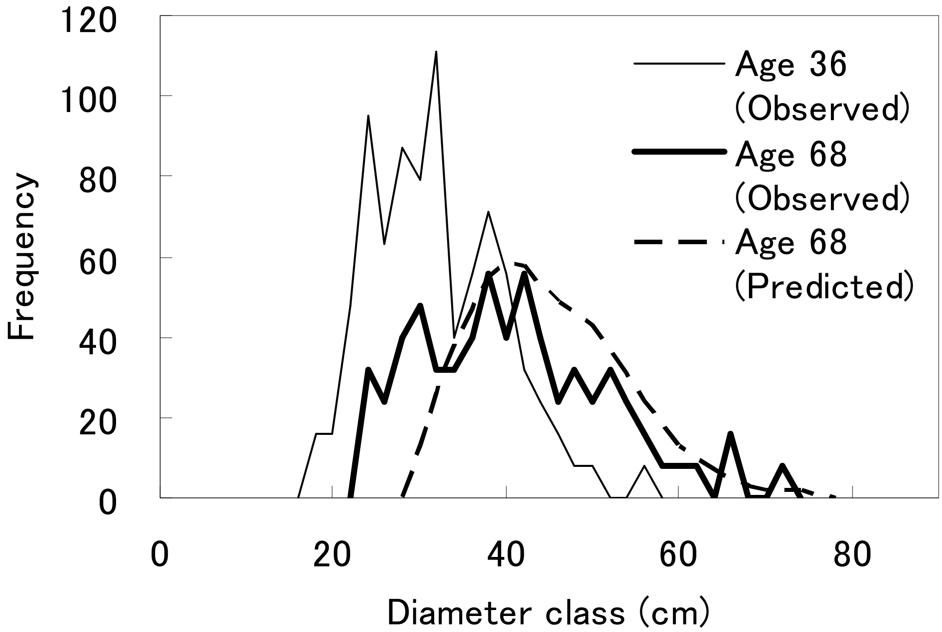
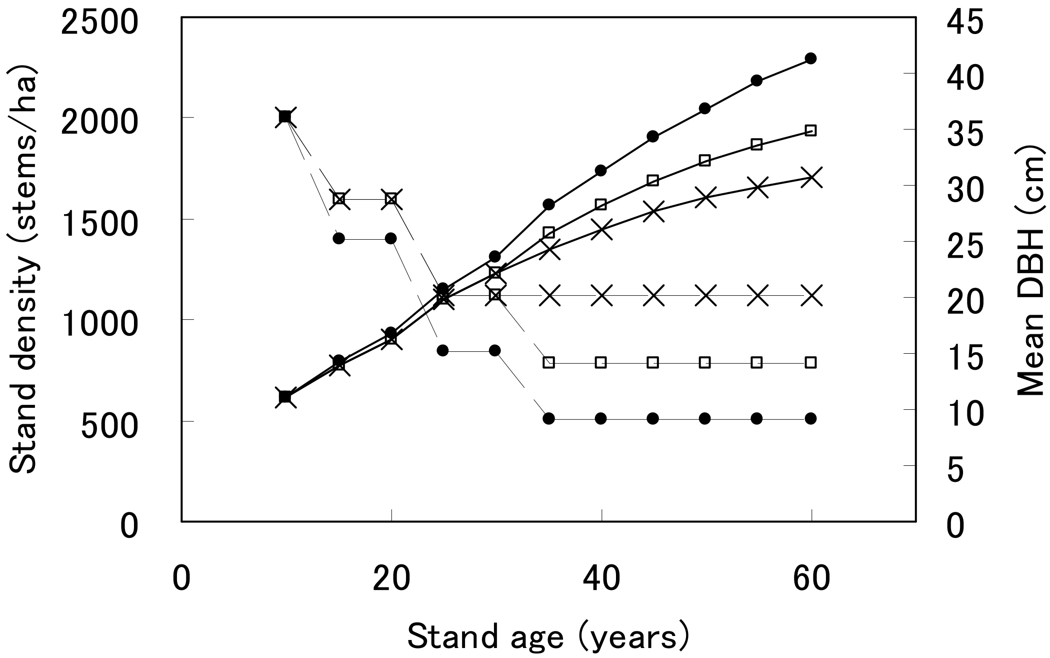


Fig. 2. Distribution comparison between the observed and estimated data



□ Intermediate-density control plan
● Low-density control plan
× High-density control plan

Fig. 3. Comparison of estimated values with a variety of density control plans

CONCLUSIONS

We applied the LYCS to a *Cryptomeria* plantation in Taiwan. The estimated values were adjustable to the observed data in the permanent plots at the Experimental Forest of National Taiwan University, regarding not only mean DBH but also diameter distribution. Thus, we confirmed that these parameters can be used to estimate *Cryptomeria* plantation growth under various types of stand density control strategies.

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