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Article

A System to Predict Diameter Distribution in Pure Even-aged Hinoki (*Chamaecyparis obtusa* Sieb.) Plantations (I) - Diameter Distribution Prediction System -

Takao Hayashi*, Kazukiyo Yamamoto* and Takeo Umemura*

ABSTRACT

In this study, we developed a system to predict the distribution of trees in a pure even-aged Hinoki (*Chamaecyparis obtusa* Sieb.) plantation, mainly using measurement data obtained from two experimental forests in the Tokai district of Japan and published data of the Forestry and Forest Products Research Institute of Japan (FFPRI) in Kinki, Shikoku and Kyushu districts. The system consists of a model to predict stand basal area, a model to estimate maximum density, and a model to predict diameter distribution succession. The system can predict the diameter distribution at the end of a growth period by the diameter distribution at the beginning of the growth period without tree height data. To validate the system, we compared the prediction and observation of stand variables (stand density and stand basal area) and statistics of diameter distribution (mean and standard deviation of diameter at breast height) using data from experimental forests in the Kanto district. We also compared the accuracy of the predictions of the system with those of an existing system that required tree height data. The results indicated that our system predicted stand variables and diameter distribution as precisely as the existing system, but without the need for tree height data. We conclude that our system would operate accurately in other districts to predict stand growth.

Keywords: diameter distribution succession, pure even-aged Hinoki plantation, applicable in other districts

INTRODUCTION

Yield tables, both conventional and empirical, are used for the management of plantations in Japan to estimate stand growth for specific tree species under a specific management regime. However, many plantation managers recently have not been following the fixed management plans assumed by the yield tables (MATSUMOTO, 1997).

KONOHIRA (1992) developed 'system yield tables' comprising various prediction methods based on growth models that are suitable for various management plans. The system yield tables are basically computer programs with algorithm to estimate future growth processes of forest stands under various types of management, under various conditions (KONOHIRA, 1995).

Most of existing system yield tables need data such as diameter at breast height (DBH), diameter distribution, tree height, and stand density (e.g. FUKUSHIMA, 1991; YAMAMOTO, 1991). It takes a lot of time and effort to measure the height of sample trees. It is also time consuming to collect stand measurement data and re-estimate the parameters to apply a system yield table to another area. A system yield table that did not need tree height data would greatly reduce the time and effort to apply the system yield table.

A diameter distribution prediction system is important to a system yield table that did not need tree height data. If site index were available, we would be able to predict stand volume without tree height data in according to various thinning regimes by combining the system and the site index curve and the existing volume function.

In this study, we developed a diameter distribution prediction system as a base model of system yield table that can predict stand growth without tree height data. The system could predict stand density, stand basal area (we call them 'stand variables') and diameter distribution without tree height data. To validate the accuracy of this system, we compared the prediction and observation of stand variables and diameter

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distribution. Furthermore, we compared the accuracy of our system with that of the existing system yield table, called 'SHIRAKANBA' (YAMAMOTO, 1991).

DATA

In this study, we used data from Hinoki (*Chamaecyparis obtusa*) plantations in the Tokai, Kinki, Shikoku and Kyushu districts of Japan. Other data from the Kanto district of Japan were used to verify that our system was valid and widely applicable (Table 1).

The main measurement data we used to develop the system were obtained from two experimental forests located at Owase City of the Mie Prefecture in the Tokai district (34° 03'

Table1 The outline of the data.

site	No.of plot	area [ha]	measurment [times]	Initial conditions (average): age [year]	density [trees/ha]	stand basal area [m^2/ha]	meanDBH [cm]	reference
Akinaga experimental stand								
	2	0.30	15	24.0	784.5	32.62	12.53	
Owase research stands								
A	10	0.02	3	22.2	4,610.0	27.94	9.20	
B	3	0.02	3	21.7	5,516.7	26.33	8.18	
C	2	0.02	3	22.0	6,350.0	31.75	7.77	
D	4	0.02	3	22.5	4,575.0	33.26	11.03	
E	3	0.02	3	29.7	4,733.3	26.49	9.06	
F	7	0.02	3	19.9	4,478.6	31.27	10.50	
G	7	0.02	3	23.4	3,042.9	32.80	12.14	
H	6	0.02	3	32.8	3,216.7	38.22	12.77	
published data of FFPRI								
akasawa	2	No data	5	8.0	3,474.5	1.85	2.45	HARA and UENO (1984)
aoidake	1	No data	1	67.0	1,375.0	70.03	24.80	MORITA *et al.* (1982)
asakihara	3	No data	2	26.0	2,766.7	53.00	15.15	SATAKE *et al.* (1982)
experiment	6	No data	2	51.0	888.3	37.78	22.85	HONDA *et al.* (1975), HONDA *et al.* (1980)
hontano	1	No data	2	65.0	961.0	70.14	30.15	HONDA *et al.* (1978), MORITA *et al.*(1983)
kirishima	1	No data	2	63.0	1,256.0	60.31	24.20	HONDA *et al.* (1978), MORITA *et al.*(1983)
kishin	2	No data	2	22.0	2,537.5	35.72	13.35	HONDA *et al.* (1978), MORITA *et al.*(1983)
koshisashi	2	No data	3	63.0	1,116.0	60.95	25.95	HONDA *et al.* (1975), MORITA *et al.*(1980), MORITA *et al.* (1985)
koyasan	2	0.22	10	32.5	2,442.0	29.59	13.10	UENO and HASEGAWA (1976), IEHARA and HASEGAWA (1986), HOSODA (1996)
kudaru-kawayama	3	0.16	4	6.7	3,182.0	No data	No data	SATAKE *et al.* (1982)
kuma-yokoyama	1	No data	1	48.0	909.0	56.61	27.80	HONDA *et al.* (1980), MORITA *et al.*(1985)
manzen	4	No data	3	63.0	1,837.5	67.23	21.50	HONDA *et al.* (1975), HONDA *et al.*(1979), HONDA *et al.* (1980), MORITA *et al.* (1984, 1985)
maruyama	2	No data	2	64.0	1,344.5	51.02	21.70	HONDA *et al.* (1978), MORITA *et al.*(1983)
motoshiro	1	No data	2	64.0	862.0	71.00	31.90	HONDA *et al.* (1977), MORITA *et al.*(1982)
myogabuchi	1	No data	6	10.0	2,850.0	4.13	4.10	IEHARA (1987, 1992)
namerayama	3	No data	2	68.0	1,066.3	55.64	26.43	UENO and HASEGAWA (1975), HASEGAWA (1985)
natsuki	1	No data	1	68.0	1,023.0	64.08	27.90	MORITA *et al.* (1982)
nikawa	4	No data	2	48.0	1,509.5	59.35	22.08	HONDA *et al.* (1979), MORITA *et al.*(1984)
obetoyama	1	No data	8	29.0	1,470.0	27.00	15.30	HASEGAWA (1985)
ohmata	1	No data	4	10.0	2,850.0	4.13	4.10	UENO and HASEGAWA (1977)
ohtaki	1	No data	7	27.0	1,885.0	24.90	12.60	HARA (1986)
osuzu	1	No data	1	68.0	1,091.0	48.50	23.30	HONDA *et al.* (1979)
ran	1	No data	7	23.0	1,914.0	27.40	13.30	HARA and UENO (1985)
saigo-onsen	2	No data	3	27.0	1,807.5	47.80	18.15	HONDA *et al.* (1979), MORITA *et al.*(1984), MORITA (1989)
shin-shigeyama	2	0.20	9	37.5	2,780.0	42.73	13.35	HOSODA and IEHARA (1995)
standard	2	0.20	5	4.0	3,220.0	No data	No data	MIYAMOTO and TAKAHASHI (1988)
sugisaki	1	No data	2	63.0	1,000.0	60.70	27.30	HONDA *et al.* (1977), MORITA *et al.*(1982)
takatoriyama	2	No data	2	83.0	685.0	43.66	28.50	UENO and HASEGAWA (1981), IEHARA (1991)
tankaino	1	No data	1	70.0	1,902.0	79.50	22.70	HONDA *et al.* (1980)
yatsuosan	1	No data	1	73.0	513.0	33.63	28.90	UENO and HASEGAWA (1981)
measurement data at Funyu								
H	2	0.50	3	31.0	1,724.0	53.45	19.39	NAITO (1984, 1988, 1994) FUJIWARA (1977), NAITO and
L	4	0.26	5	67.0	842.3	44.56	26.13	FUJIWARA (1982), FUJIWARA and NAITO (1987, 1993),
S	5	0.09	3	33.4	2,006.4	39.36	16.09	NAITO (1982, 1987, 1994), NAITO *et al.* (1996)

N, 136° 10' E). One of the experimental forests (we call it the 'Akinaga experimental stand') was established in 1932. It consists of two plots (plots #09 and #10) adjacent to each other. Each plot is 0.3ha. These two plots were planted in 1908 at density of 10,000 trees/ha. The difference between the two plots is thinning treatments. DBH of all live trees was recorded from 1932 to 1985, when stand age was 24, 27, 29, 32, 35, 43, 56, 58, 60, 61, 62, 64, 65, 67 and 77 years. Other experimental forests (we call them 'Owase research stands') were established in 1962. They consist of eight sites (A to H); each contains several plots. The area of these plots is 0.02ha. Planted density, stand age and site index of these plots were different from each other. The DBH of all live trees in all plots were measured from 1962 to 1966 every 2 years.

Other data used in developing the system were from the Forestry and Forest Products Research Institute of Japan (FFPRI), were obtained from 27 experimental forests located in the Kinki, Shikoku and Kyushu districts of Japan. The data consist of stand density, mean DBH, mean tree height, stand basal area, and stand age. In this study, we used stand age, stand density and stand basal area.

Measurement data for verifying the system come from experimental forests at Funyu in the Utsunomiya University forest in Tochigi Prefecture (36°47′N, 139°51′E, e.g. FUJIWARA, 1977). The experimental forests consist of three sites (we called them sites H, L and S) and each of them contains several plots. Site index, planted density, plot area and treatment regime of these sites were different from each other. In all plots, DBH and tree height of all live trees were measured.

METHOD

Outline of the System

The system presented in this study consists of three component models as follows.

(a) Stand basal area prediction model
(b) Maximum density estimation model
(c) Diameter distribution succession model

Fig.1 shows the outline of the prediction process in the system presented in this study.

Compornent Models

(a) Stand basal area prediction model

PIENAAR *et al.* (1990) presented the equation to estimate stand basal area ($G(t)$: m^2/ha) from stand age (t:year), dominant height (H_D: m) and stand density ($\rho(t)$: trees/ha) for slash pine (*Pinus elliotti*) plantation as follows:

$$\ln G(t) = a_0 + a_1 \frac{1}{t} + a_2 \ln H_D(t) + a_3 \ln \rho(t) \qquad (1)$$

where a_j is an empirical parameter (j=0 to 3). Eq. (1) can be converted to a stand basal area algebraic difference form with the same coefficients (GADOW and HUI, 1999):

$$\ln G(t+1) - \ln G(t) = a_1\left(\frac{1}{t+1} - \frac{1}{t}\right) + a_2\left(\ln H_D(t+1) - \ln H_D(t)\right) + a_3\left(\ln \rho(t+1) - \ln \rho(t)\right) \qquad (2)$$

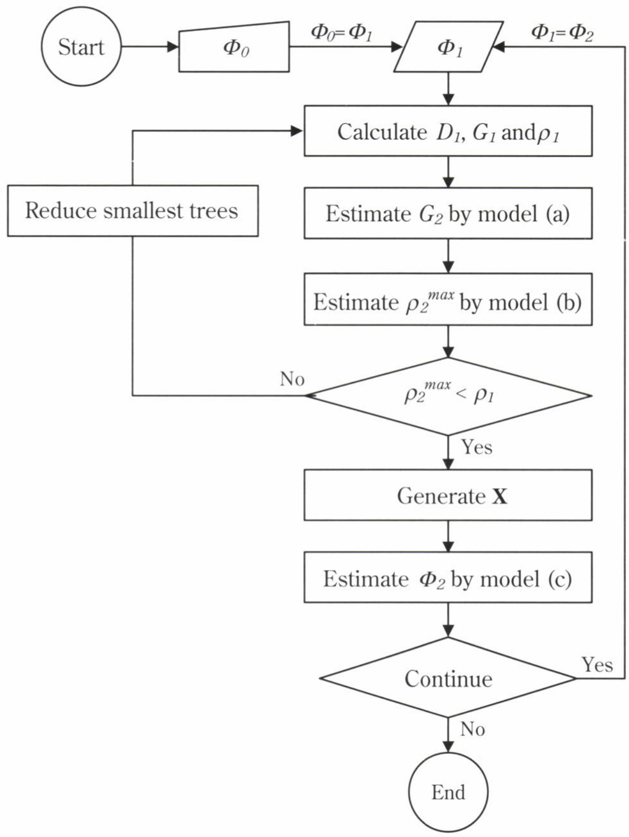

Fig.1 The outline of the prediction process in the system

Note
Φ:diameter distribution
D:mean DBH
G:stand basal area
ρ:stand density
ρ^{max}:maximum stand density
X:diameter distribution succession matrix
subscription
0:initial
1:at the begin of the growth period
2:at the end of the growth period
Model
(a) Stand basal area prediction model
(b) Maximum density estimation model
(c) Diameter distribution succession model

Since dominant height increases with stand age t, we replaced $H_D(t)$ and $H_D(t+1)$ in eq. (2) with t and $(t+1)$.

$$\ln G(t+1)-\ln G(t) = a_1'\left(\frac{1}{t+1}-\frac{1}{t}\right)+a_2'\ln\frac{t+1}{t}+a_3'\ln\frac{\rho(t+1)}{\rho(t)} \quad (3)$$

Then, we obtained following stand basal area prediction model

$$G(t+1)=G(t)\cdot\exp\left[a_1'\left(\frac{1}{t+1}-\frac{1}{t}\right)\right]\cdot\left(\frac{t+1}{t}\right)^{a_2'}\cdot\left(\frac{\rho(t+1)}{\rho(t)}\right)^{a_3'} \quad (4)$$

We estimated the parameters of the stand basal area prediction model by multivariate analysis of eq. (3) on the data for developing the system.

(b) Maximum density estimation model

TANG *et al.* (1994) presented a self-thinning model to describe the relationships between mean DBH and stand density:

$$\ln\rho(t)=\ln b_0+\frac{1}{b_2}\ln\left[\left(\frac{D_{ave}(t)}{b_3}\right)^{b_1 b_2}+b_4\right] \quad (5)$$

where $D_{ave}(t)$ was mean DBH (cm) at stand age t and b_j was the parameter (j=0,1,2,3,4). Parameter b_1 in eq. (5) is slope of maximum density line (i.e. self-thinning rate of fully stocked stand). In this study, we obtained maximum density estimation model by replacing $D_{ave}(t)$ in eq. (5) with stand basal area:

$$\ln\rho(t)=\ln b_0'+\frac{1}{b_2'}\ln\left[\left(\frac{G(t)}{b_3'}\right)^{b_1' b_2'}+b_4'\right] \quad (6)$$

PUETTMANN *et al.* (1993) found that a line connecting the points at which density-dependent mortality starts was parallel to the maximum density line for the pure even-aged stands of red alder (*Alnus rubura* Bang.) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco.). Based on their findings, we estimated the parameter b'_1 of the maximum density estimation model as the slope of the line that connected two points at which density-dependent mortality was thought to start. Parameters b'_0, b'_2 and b'_3 of eq. (6) were determined by use of nonlinear regression for the data of an unthinned stand (HOSODA and IEHARA, 1995). Parameter b'_4 of eq. (6) was determined for each plot. We assumed that the stand density was equivalent to the planted density when basal area was close to zero limitlessly. Then, b'_4 is calculated in each plot as follows;

$$b_4'=\left(\frac{b_0}{\rho_0}\right)^{b_2'} \quad (7)$$

where ρ_0 is planted density (trees/ha). When thinning was performed during the prediction period, we recalculated the parameter b'_4 by replacing planted density with planted density minus number of thinned trees per hectare.

(c) Diameter distribution succession model

We defined the interval of the DBH class as 2cm and the DBH of i-th DBH class as $2i$. The number of trees in the i-th DBH class at t was $n(i;t)$. Diameter distribution at $(t+1)$ was expressed as the product of a vector of diameter distribution at t and the diameter distribution succession matrix ($\mathbf{X}(t)$) (UMEMURA and SUZUKI, 1974). To express the effect of tree size (diameter), the components of matrix $\mathbf{X}(t)$ were a function of size class i and stand age t.

To develop the model, we assumed that the trees of i-th DBH class at t could either move to $(i+1)$-th DBH class or stay in the same class at $(t+1)$. According to this assumption, $\mathbf{X}(t)$ consisted of two components: the probability that survivor trees of the i-th DBH class at t were remaining the same size at $(t+1)$ ($p(i,i;t)$) and the probability that survivor trees of the i-th DBH class at t moved to the $(i+1)$-th class ($p(i,i+1;t)$). Using these two probabilities, the periodic diameter increment of the i-th DBH class at t ($\Delta D(i,t)$: cm/year), was expressed as follows:

$$\Delta D(i;t)=2\cdot p(i,i+1;t)+0\cdot p(i,i;t)=2\cdot p(i,i+1;t)$$

Then,

$$\begin{cases} p(i,i+1;t)=\Delta D(i;t)/2 \\ p(i,i;t)=1-p(i,i+1;t) \end{cases} \quad (8)$$

The periodic diameter increment of the i-th DBH class at t was also expressed from the periodic basal area increment of class i at t ($\Delta g(i;t)$: m^2/ha/year) as

$$\Delta D(i;t)=-2i+\sqrt{(2i)^2+40000\Delta g(i;t)/\pi n(i;t)} \quad (9)$$

Periodic mean basal area increment of the i-th DBH class was estimated by allocating the periodic stand basal area increment at t ($\Delta G(t)$: m^2/ha/year) to each individual tree, according to the product of the square of DBH and the number of trees per hectare in the i-th DBH class:

$$\Delta g(i;t)=\Delta G\cdot\frac{(2i)^2 n(i;t)}{\sum_{j=1}^{k}(2j)^2 n(j;t)} \quad (10)$$

where k was the number of the DBH class. Then, the periodic diameter increment of the i-th DBH class was expressed as follows:

$$\Delta D(i:t) = -2i + \sqrt{(2i)^2 + \frac{40000\Delta G(2i)^2}{\pi \sum_{j=1}^{k} (2i)^2 n(j;t)}} \qquad (11)$$

Finally, $\mathbf{X}(t)$ was expressed as follows:

$$X(t) = \begin{pmatrix} \rho(1,1;t) & \rho(1,2;t) & & & \\ & \rho(2,2;t) & \rho(2,3;t) & & \\ & & \ddots & \ddots & \\ & & & \rho(k-1,k-1;t) & \rho(k-1,k;t) \\ & & & & \rho(k,k;t) \end{pmatrix} \qquad (12)$$

where

$$\begin{cases} \rho(i,i+1;t) = \frac{1}{2}\left[-2i + \sqrt{(2i)^2 + \frac{40000\Delta G(2i)^2}{\pi \sum_{j=1}^{k} (2i)^2 n(j;t)}}\right] & (i = 1,\ldots,k) \\ \rho(i,i;t) = 1 - \rho(i,i+1;t) \end{cases}$$

Validation of the System

To evaluate the prediction accuracy of our stand growth system, we applied it to DBH measurement data of experimental forests at Funyu. Then, we compared the prediction and observation of stand variables (stand density and stand basal area) and diameter distribution. In addition, we applied existing system yield tables, called 'SHIRAKANBA' (YAMAMOTO, 1991) to the DBH and tree height measurement data of experimental forests at Funyu and compared the accuracy of our system's prediction with that of the 'SHIRAKANBA' system. Both systems use similar prediction procedures. The main difference is that data on mean tree height of the focal stand is essential to the 'SHIRAKANBA' system, whereas our system does not need any height data.

To compare the accuracy in prediction of stand variables and statistics of diameter distribution, we calculated means and variances of prediction for prediction periods of 5, 10 and 15 years. We used the *F*-test and Student's *t*-test to examine whether the means and variances of the predictions were significantly different from those observed. The experimental plots in site S (see Table 1) were re-measured after 5, 9, and 14 years from plot establishment, but we treated second and third re-measurement data as after 10 and 15 years prediction.

To examine the difference between observation and prediction of stand variables and the statistics of diameter distribution, we calculated mean absolute error (MAE) and mean relative error (MRE) of predicted stand variables. Both indices are expressed as follows

$$\mathrm{MAE} = \frac{1}{m}\sum_{i=1}^{m}\left|x_{(0)i} - x_{(\rho)i}\right| \qquad (13)$$

$$\mathrm{MRE} = \frac{1}{m}\sum_{i=1}^{m}\frac{\left|x_{(0)i} - x_{(\rho)i}\right|}{x_{(0)i}} \qquad (14)$$

where $x_{(o)i}$ and $x_{(p)i}$ represent the observation and prediction of stand variables of *i*-th plot, *m* stands for number of validation plots, respectively.

To compare the prediction and observation of tree number of each DBH class, we calculated the root mean squared error (RMSE)

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{k}\left(n_{(0)i} - n_{(\rho)i}\right)^2}{k}} \qquad (15)$$

where $n_{(o)i}$ and $n_{(p)i}$ are observed and predicted tree number of the *i*-th DBH class, respectively.

Results

The models of stand basal area prediction and maximum density estimation were obtained from data as follows:

$$G(t+1) = G(t)\cdot \exp\left[38.308\left(\frac{1}{t+1} - \frac{1}{t}\right)\right]\cdot\left(\frac{t+1}{t}\right)^{0.0289}\cdot\left(\frac{\rho(t+1)}{\rho(t)}\right)^{0.595} \qquad (16)$$

$$\ln\rho(t) = \ln 1585.790 + \frac{1}{2.582}\ln\left[\left(\frac{G(t)}{0.376}\right)^{-3.31\cdot 2.582} + b_4'\right] \qquad (17)$$

Means and variances of the predicted stand variables and statistics of diameter distribution for each of the prediction period length are presented in Table 2. The *F*-test showed that predictions of stand variables were not significantly different (at the 5% level) from those observed. The *t*-test showed that the means of predictions by our system were not significantly different from those observed when the length of the prediction period was less than 10 years. That test also showed that mean of stand density and mean DBH predicted by the 'SHIRAKANBA' system were significantly different at the 5% level from those observed, even when the length of the prediction period was 5 years (Table 2).

The MAE and MRE of stand variables and statistics of diameter distribution for each of the lengths of prediction period are presented in Table 3. *F*-tests and *t*-tests showed that

Table 2 Means and variances of stand variables for each of the length of prediction period.

prediction period	variables	No. of data	Observation		the system presented in this study		SHIRAKANBA	
			mean	variance	mean	variance	mean	variance
5	Density	11	1,471.7	464,485.1	1,493.7	481,953.4	1,510.2*	500,236.3
	BA		49.513	50.887	50.127	64.678	49.249	68.99
	mean DBH		21.672	27.562	21.585	25.253	21.317*	26.928
	stdev DBH		4.399	0.975	4.525	0.485	4.481	0.806
10	Density	11	1,323.1	347,979.3	1,408.5	487,763.5	1,425.1	568,628.8
	BA		51.624	68.404	52.696	111.444	51.08	99.821
	mean DBH		23.482	30.94	22.966	27.517	22.636*	30.543
	stdev DBH		4.464	0.769	4.657	0.3	4.641	0.497
15	Density	9	1,211.4	397,372.1	1,308.2*	500,846.7	1,282.3	449,742.6
	BA		52.46	38.095	51.547	82.923	49.427	54.669
	mean DBH		25.164	40.533	23.878*	31.52	23.592**	34.066
	stdev DBH		4.519	0.831	4.746	0.289	4.767	0.348

Note: mean DBH and stdev DBH mean average and standard deviation of diameter distribution, respectively. (*) and (**) means this value is significantly different from observation at 5% and 1% level, respectively

Table 3 Mean absolute error (MAE) and mean relative error (MRE) of stand variables for each of the length of prediction period.

prediction period	variables	No. of data	the system presented in this study		SHIRAKANBA	
			MAE	MRE	MAE	MRE
5	density	11	39.03	2.4%	39.09	2.3%
	BA		2.15	4.3%	1.67	3.2%
	mean DBH		0.53	2.5%	0.50	2.4%
	stdev DBH		0.31	8.2%	0.25	5.7%
10	density	11	121.15	7.3%	138.26	8.0%
	BA		4.31	8.6%	3.12	6.3%
	mean DBH		0.98	4.1%	1.19	5.3%
	stdev DBH		0.39	10.0%	0.32	7.7%
15	density	9	97.05	6.7%	88.79	6.6%
	BA		5.37	10.6%	4.08	8.1%
	mean DBH		1.43	5.4%	1.58	6.0%
	stdev DBH		0.53	12.9%	0.51	12.0%

Note: mean DBH and stdev DBH mean average and standard deviation of diameter distribution, respectively.

the means and variances of the MRE values calculated by eq. (14) for the both systems were not significantly different from each other. Therefore, the accuracy in prediction of stand variables was not significantly different between two systems.

The RMSE of diameter distribution for each of the lengths of prediction period and plots is presented in Table 4. *F*-tests and *t*-tests showed that the means and variances of the RMSE values calculated by eq. (15) for the both systems were not significantly different from each other. Therefore, the accuracy in prediction of diameter distribution was not significantly different between two systems. Fig. 2 presents examples of predicted and observed diameter distribution. When initial stand age was old, our system tended to overestimate the numbers of trees of lower DBH class and underestimate that of the higher DBH class. In other cases, there was little difference between prediction and observation.

Discussion

The results indicate that the system we have developed can predict stand variables and statistics of diameter distribution as accurately as the existing system yield table (Tables 2 and 3). The results also indicate that our system can predict tree number of each DBH class as well as the existing

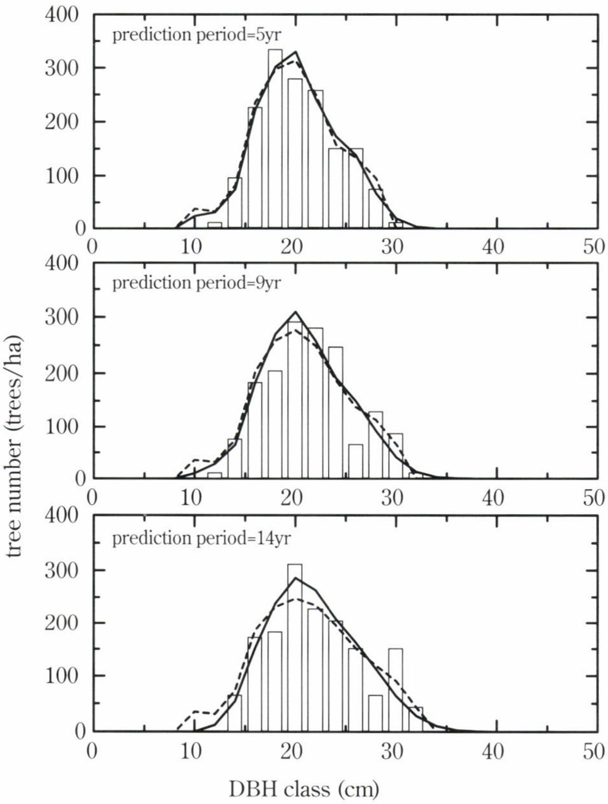

Fig. 2 Predicted and observed DBH distributions (site: S5).

▯ : Observation

—— : Prediction by the system presented in this study

----- : Prediction by 'SHIRAKANBA' system

Table 4 Root mean squared error (RMSE) of predicted tree number of each DBH class.

prediction period	plot	stand age	the system presented in this study	SHIRAKANBA
	H1	36	13.4	22.5
	H2	36	16.8	18.2
	L1-1	72	15.2	17.5
	L1-2	72	10.2	11.8
	L2-1	72	6.8	7.3
5	L2-2	72	7.3	7.6
	S1	40	42.1	30.1
	S2	35	28.4	34.9
	S3	25	72.2	61.5
	S4	46	20.9	26.4
	S5	46	20.6	22.5
	H1	41	14.2	25.0
	H2	41	23.8	18.8
	L1-1	77	20.9	29.4
	L1-2	77	14.7	18.4
	L2-1	77	10.3	12.8
10	L2-2	77	13.9	15.8
	S1	44	55.4	44.8
	S2	39	32.3	42.3
	S3	29	112.9	151.8
	S4	50	19.9	26.7
	S5	50	32.7	36.3
	L1-1	82	26.5	35.0
	L1-2	82	19.2	25.0
	L2-1	82	8.8	11.3
	L2-2	82	10.5	13.0
15	S1	49	47.8	43.1
	S2	44	38.9	55.4
	S3	34	66.2	136.0
	S4	55	19.3	30.7
	S5	55	27.0	36.2

system yield table (Table 4, Fig. 2). Consequently, the system we present can predict stand growth as well as the existing system yield table. Although we did not use tree height measurement data to develop the system and predict stand growth, many of the existing yield tables use that data. Considering this fact, the result indicates that our system would be useful when it is difficult to collect tree height measurement data. Our system was developed mainly using measurement data of experimental plots in the Tokai district and was able to predict diameter distribution of 11 stands in the Kanto district without re-estimating the parameters as precisely as the existing system yield table. Considering this fact, we conclude that our system would operate accurately in other districts to predict stand growth.

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Article

Relationship between Self-thinning Exponent and Relative Spacing Index for *Cryptomeria japonica* and *Chamaecyparis obtusa* Stands

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ABSTRACT

The relative spacing index of a stand is expressed as a function of the average distance between trees and mean tree height. In the self-thinning law, mean and total plant weights are expressed as negative exponential functions of plant density in overcrowded pure stands. In this study, we analyzed the relationship between the self-thinning exponent and the relative spacing index for overcrowded pure stands of two species, *Cryptomeria japonica* D. Don and *Chamaecyparis obtusa* Endl. An allometric model that explains the difference in the self-thinning exponent among species was proposed based on allometric relationships between mean tree height and average distance between trees, and between mean tree height and mean stem volume. The resulting self-thinning exponent for total stem volume, obtained from the proposed model, was -0.938 for *C. japonica* and -0.560 for *C. obtusa*. These values were statistically identical to the exponents obtained from regressions of the relationships between stand density and total stem volume for the two species. Therefore, the proposed model was applicable to *C. japonica* and *C. obtusa* stands. The characteristics related to stem slenderness and relative spacing index determines self-thinning exponent based on the proposed model. The difference in allometric exponents of mean tree height to average distance between trees was found between the two species, but no difference in the exponents of mean tree height to mean stem volume was found. The results indicate that the difference in self-thinning exponents between two species is produced by characteristics related to relative spacing index, rather than by characteristics related to stem slenderness.

Keywords: self-thinning exponent, relative spacing index, allometric model, stem slenderness

INTRODUCTION

The self-thinning law, or the 3/2 power law of self-thinning (Yoda *et al.*, 1963), describes an increase in mean plant weight w with decreasing plant density N in overcrowded pure stands as follows:

$$w = KN^{\alpha}, \quad (1)$$

where K and α are constants and are referred to as the self-thinning coefficient and self-thinning exponent, respectively. Eq. (1) is defined throughout this paper as a self-thinning boundary line (Weller, 1990; Osawa and Allen, 1993), which is the upper boundary of the w-N combinations, and is estimated by the collection of overcrowded stands. Since the mean stem volume v is isometrically related to mean plant weight, i.e. $w \propto v$ (e.g. White, 1981), the law has been applied to the relationship between mean stem volume and plant density (e.g. Ando, 1968; Xue *et al.*, 1999)

$$v = KN^{\alpha}. \quad (2)$$

The value of the self-thinning exponent is close to -3/2 regardless of species, age, or site conditions (Yoda *et al.*, 1963). The relationship is accepted as a rule or law that applies across the plant kingdom (Yoda *et al.*, 1963; White and Harper, 1970; White, 1981) and has been called the only law of plant ecology (Hutchings, 1983). However, many studies have shown that the self-thinning exponent can differ from -3/2

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(e.g., KIRA and YODA, 1957; ANDO, 1968; ZEIDE, 1987; WELLER, 1987a; OSAWA and ALLEN, 1993; XUE *et al.* 1999). WELLER (1987a) re-examined the evidence for the 3/2 power law and found that many data sets do support a power relationship of the form of eq. (1), but the self-thinning exponent can differ from -3/2. Furthermore, WELLER (1987b) proposed an allometric model that predicts that the self-thinning exponent varies with plant shape and biomass density (the mass per unit occupied space). OSAWA and ALLEN (1993) analyzed the self-thinning exponent in *Northofagus solandri* and *Pinus densiflora* stands based on the allometric relationships between mean stem diameter and mean foliage mass, and between mean stem diameter and mean plant mass. Their results indicated that species-specific differences in the self-thinning exponent may be produced by characteristics related to crowns, rather than by characteristics related to stem form and size (OSAWA, 1995). NISHIZONO *et al.* (2002) analyzed the self-thinning exponent in *Cryptomeria japonica* D. Don and *Chamaecyparis obtusa* Endl. stands based on WELLER's (1987b) allometric model. They found that the characteristics related to stem slenderness could explain only a small part of the difference in the self-thinning exponents between the two species.

The relative spacing index *Sr* is proposed as an index which gives a quantitative criterion for thinning (HUMMEL, 1953), and is given by the usual forest inventory data, i.e., the average distance between trees (or stand density) and mean tree height. NISHIZAWA (1972) and KONDO *et al.* (2001; 2002) reported that the index tended to be a constant in overcrowded stands based on experimental data. Assuming that the self-thinning exponent was -3/2, NOGAMI *et al.* (1995) derived the constancy of *Sr* using dimensional analysis (AMATEIS and MCDILL, 1989). SHIDEI (1963) also concluded that H is proportional to $N^{-1/2}$, which explains the constancy of Sr, based on YODA *et al.*'s (1963) isometric model predicts that the self-thinning exponent is -3/2. However, there has been no report of the relationship between the self-thinning exponent and *Sr* based on an allometric model in which the self-thinning exponent can differ from -3/2.

The objectives of the present study were (1) to propose an allometric model that explains the difference in self-thinning exponents among species based on the relative spacing index; (2) to apply the model to *Cryptomeria japonica* D. Don and *Chamaecyparis obtusa* Endl. stands; (3) to discuss the relationship between the self-thinning exponent and the relative spacing index; and (4) to compare the proposed allometric model with previous ones.

DERIVATION OF ALLOMETRIC MODEL

Let y be the total stem volume (m^3/ha). A relationship to eq. (2) also exits between y and N. Since $y=vN$, eq. (2) can be rewritten as

$$y = KN^{\beta}, \tag{3}$$

where β is a constant, i.e., $\alpha + 1$, and is referred to as the self-thinning exponent. The relative spacing index (HUMMEL, 1953) *Sr* is expressed as a function of the mean tree height H (m) and the average distance between trees D (m), or as a function of H and stand density N (trees/ha)

$$Sr = D/H = 100/H\sqrt{N}. \tag{4}$$

Now suppose that there is an allometric power relationship between D and H

$$D = aH^{b}, \tag{5}$$

where a and b are constants. Eq. (5) is equivalent to

$$Sr = aH^{b-1}. \tag{6}$$

Assuming that b is equal to unity in eq. (6), the relative spacing index is equal to a, i.e., it is a constant.

Based on WELLER's (1987b) allometric model, we assume that there is also an allometric power relationship between H and v

$$H = cv^{d}, \tag{7}$$

where c and d are constants. Eqs. (4), (5) and (7) yield the following self-thinning boundary lines

$$v = (100/(ac^{b}))^{(1/bd)}N^{-1/(2bd)}, \tag{8}$$

$$y = (100/(ac^{b}))^{(1/bd)}N^{-1/(2bd)+1}. \tag{9}$$

Eqs. (8) and (9) allow the self-thinning exponents α and β of eqs. (2) and (3) to be estimated from the allometric exponents b and d

$$\alpha = -1/(2bd), \tag{10}$$

$$\beta = -1/(2bd)+1. \tag{11}$$

The allometric model in which the self-thinning exponent is estimated by eq. (10) or eq. (11) will hereafter be called the "*Sr* model".

MATERIALS AND METHODS

Data

We used the data sets compiled for the Kanto and Chubu districts by the JAPAN FORESTRY AGENCY (1978; 1979; 1980; 1981a; 1981b; 1981c; 1983) in the present study. These data sets were collected by the JAPAN FORESTRY AGENCY to prepare stand density control diagrams (ANDO, 1968). The data for *C. japonica* and *C. obtusa* were gathered from 1,577 and 1,573 stands, respectively. The data set for each stand included mean tree height, total stem volume per hectare, and stand density, and other data.

Stand Selection

The data used in this study were collected by anonymous data collectors, such as the staff of the Japan Forestry Agency. Unfortunately, they did not indicate which data were obtained from overcrowded stands. Therefore, our first task was to determine which stands were overcrowded from an examination of the data. We then used the equivalent yield index curves for all districts of Japan calculated by ANDO (1968) in order to select overcrowded stands. The yield index *Ry* is the ratio of the total stem volume in a given stand to the maximum total stem volume in an overcrowded stand in which the dominant tree height is the same as that in the given stand (ANDO, 1968). The stands that were over the equivalent yield index (Ry=0.95) curve on the relationships between stand density and total stem volume were selected as the overcrowded stands.

Fig. 1 shows the relationships between stand density and total stem volume for *C. japonica* and *C. obtusa*. We recognized two stands of *C. obtusa*, that appeared to be outliers. That is, the total stem volumes and mean tree height in these stands were unusually large for the stand densities. We judged these outliers as a sampling problem and they were dropped from the following analysis. The resulting numbers of overcrowded *C. japonica* and *C. obtusa* stands were 21 and 33.

Analysis Method

The overcrowded stand data were fitted to eqs. (3), (5) and (7) with the reduced major axis (RMA) regression techniques after log-transformation (e.g., LEDUC, 1987; NIKLAS, 1994). The standard error of the ordinary least-squares (OLS) regression was used to approximate the standard error of the RMA regression as recommended by SOKAL and ROHLF (1995). Student's t-test was used to test for significant differences among the slopes or the intercepts between two species, and to compare the self-thinning exponents estimated by the Sr model (eq. (11)) with those obtained by the RMA regression of eq. (3). P values < 0.20 for the former t-test and < 0.05 for the latter t-test were considered to indicate significant differences as recommended by OKUNO (1978).

RESULTS AND DISCUSSION

Application of *Sr* Model

As shown in Fig.1, the total stem volume significantly decreased with increasing stand density for overcrowded *C. japonica* and *C. obtusa* stands (r^2=0.929 for *C. japonica*, r^2=0.928 for *C. obtusa*; p<0.01 for both). The self-thinning exponent β was obtained by an RMA regression of eq.(3). β was calculated to be -0.956 (95% confidence interval -1.078, -0.833) for *C. japonica* and -0.573 (-0.630, -0.517) for *C. obtusa*. The exponents were statistically identical to the slope of the equivalent yield index curves, 0.918 for *C. japonica* and 0.587 for *C. obtusa* (p>0.05 for both).

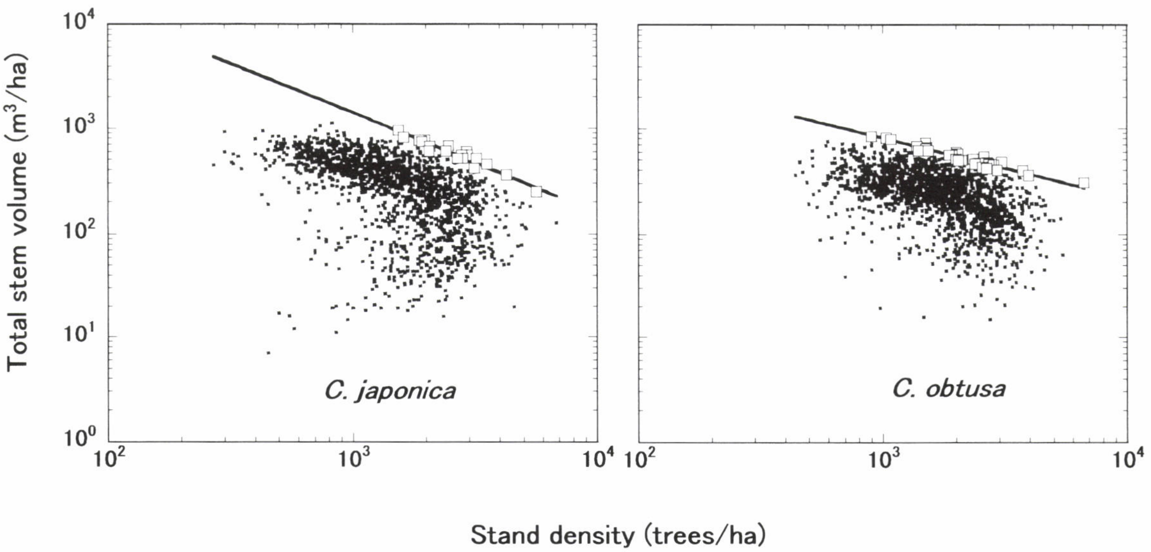

Fig.1 Relationships between total stem volume and stem density with fitted RMA (reduced major axis) regression lines

Note: Open symbols indicate stands that are assumed to represent the uppermost limit of the total stem volume-stand density relationship. Closed symbols indicate stands that lie below the self-thinning boundary line.

The average distance between trees significantly increased with increasing mean tree height for both species (r^2=0.829 for *C. japonica*, r^2=0.898 for *C. obtusa*; p<0.01 for both) (Fig. 2). The values of the allometric exponent b were 0.716 (0.574, 0.858) for *C. japonica* and 0.841 (0.743, 0.940) for *C. obtusa*.

The mean tree height significantly increased with increasing mean stem volume for both species (r^2=0.866 for *C. japonica*, r^2=0.896 for *C. obtusa*; p<0.01 for both) (Fig. 3). The values of the allometric exponent d were 0.360 (0.297, 0.423) for *C. japonica* and 0.381 (0.336, 0.426) for *C. obtusa*.

The constants in eqs. (5) and (7) obtained from RMA regressions and the *Sr* model (eq. (11)) lead to the estimated self-thinning exponent of $-1/(2bd)+1$= -0.938 for *C. japonica* and -0.560 for *C. obtusa* (Table 1). These estimated self-thinning exponents were statistically identical to the exponents obtained by RMA regression of eq. (3) for *C. japonica* and *C. obtusa* (p>0.05 for both), indicating that the self-thinning exponent estimated by the *Sr* model is valid.

Relationship between Self-thinning Exponent and Relative Spacing Index

The relative spacing index decreased with increasing mean tree height (Fig. 4). This was expected from eq. (6) because the value of b is less than unity for *C. japonica* and *C.*

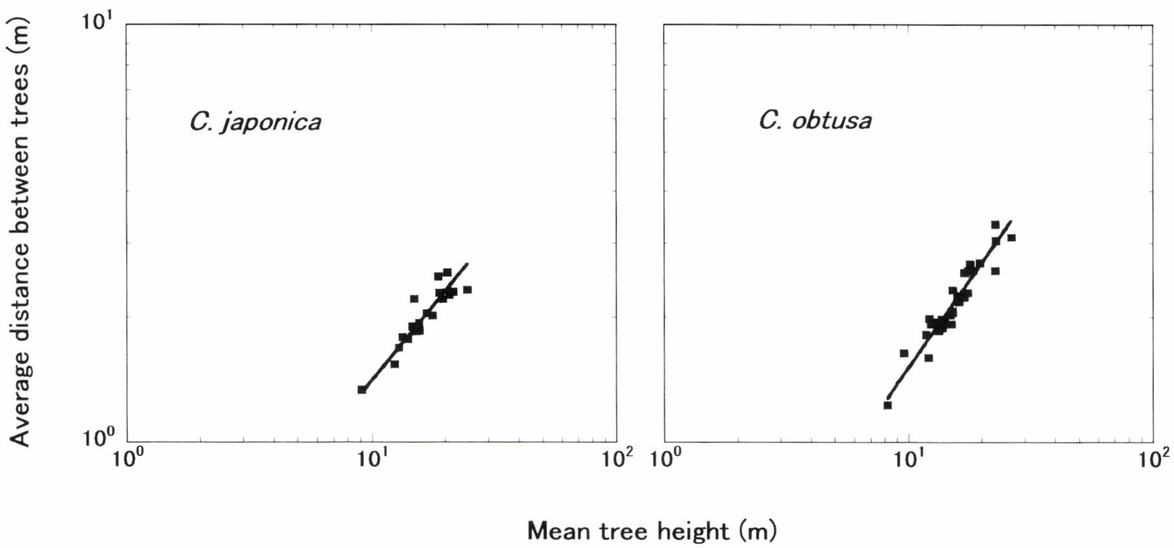

Fig.2 Relationships between average distance between trees and mean tree height with fitted RMA regression lines

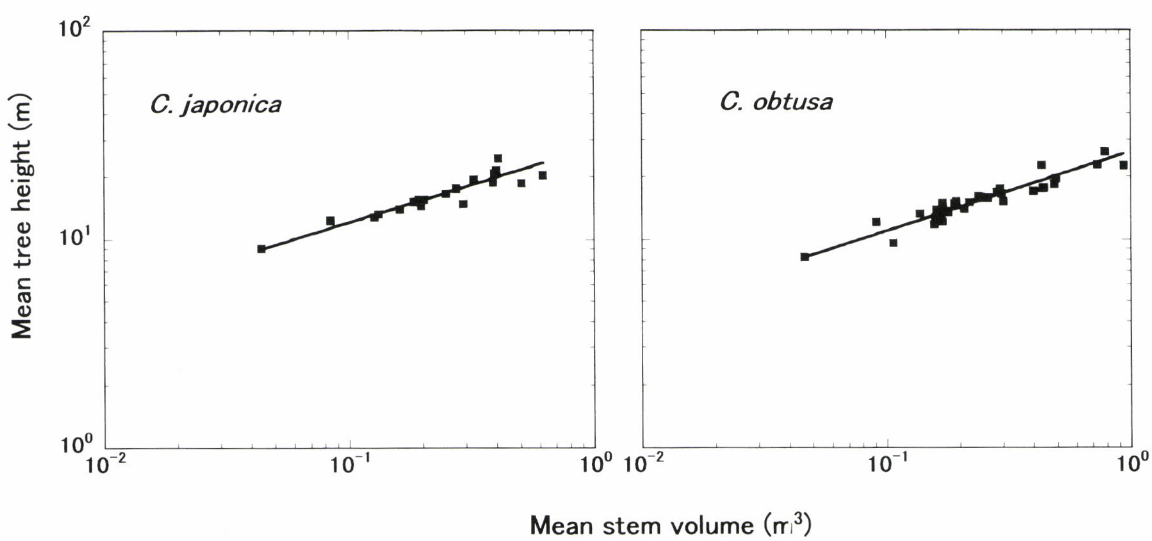

Fig. 3 Relationships between mean stem volume and mean tree height with fitted RMA regression lines

Table 1 Allometric exponents of mean tree height to average distance between trees *b*, and of mean tree height to mean stem volume *d* obtained from RMA regression, and the self-thinning exponent β obtained from RMA regression and the *Sr* model

Species	Regression			*Sr* model
	b	*d*	β	β
Cryptomeria japonica D. Don	0.716(0.574, 0858)	0.360(0.297, 0.424)	-0.956(-1.078, -0.833)	-0.938
Chamaecyparis obtusa Endl.	0.841(0.743, 0940)	0.381(0.336, 0.426)	-0.573(-0.630, -0.517)	-0.560

Note: 95% Confidence intervals are presented in parenthesis.

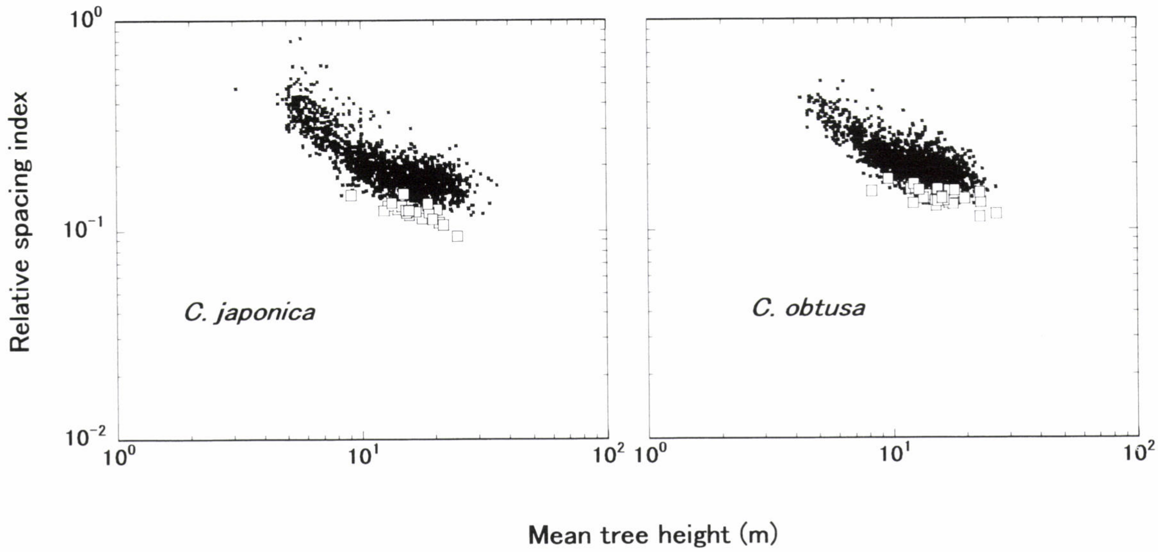

Fig.4 Relationships between relative spacing index and mean tree height
Note: Symbols are the same as in Fig. 1.

obtusa (p<0.05 for both). Assuming that the average tree grows isometrically in overcrowded stands, regardless of the stage of growth (YODA *et al.*, 1963), the relative spacing index in overcrowded pure stands theoretically should be a constant (SHIDEI, 1967; YAMAKURA, 1985). Experimental data collected by NISHIZAWA (1973) and KONDO *et al.* (2001; 2002) were in agreement with this model. However, many studies have questioned the assumption of isometry (WELLER, 1987a, 1987b; OSAWA and ALLEN, 1993; OSAWA, 1996; XUE *et al.*, 1999). In addition, our results show that *d* as well as *b* significantly differed from the predicted value based on the assumption of isometry (p<0.05). Therefore, we reject the assumption of isometry of the average tree and the constancy of the relative spacing index.

The constants *c* and *d* of eq. (7) are related to the stem slenderness (WELLER, 1987b; XUE *et al.*, 1999), and the constants *a* and *b* of eqs. (5) and (6) are related to *Sr* in overcrowded stands. In the *Sr* model, *b* and *d* determine β (eq. (11)). Therefore, characteristics related to stem slenderness and *Sr* determine the self-thinning exponent. However, it is worth noting that even if the characteristics related to stem slenderness or *Sr* differed between the examined species, the differences have little effect on the difference in self-thinning exponents of the two species unless the allometric exponents *b* or *d* differ.

Although the constants related to *Sr* and the self-thinning exponents *b* and β differed significantly (p<0.20), the value of the stem slenderness constant *d* were statistically identical between *C. japonica* and *C. obtusa* (p>0.20). However, the other stem slenderness constant *c* differed significantly between the two species (p<0.20). Thus, even though the stem slenderness differed between the two species, the difference had little effect on the difference in their self-thinning exponents. Therefore, the difference in the self-thinning exponents between *C. japonica* and *C. obtusa* is produced by characteristics related to *Sr*, rather than by characteristics related to stem slenderness.

KANAZAWA *et al.* (1985; 1990) reported that the relative spacing index was closely related to the crown development of even-aged stands of *C. japonica* and *Pinus thunbergii*. VALENTINE *et al.* (1994) also reported that the average crown length was proportional to the average distance between trees in even-aged stands of *Pinus taeda* L. and *Picea sitchensis* Carr. Therefore, our finding that characteristics related to *Sr* affect the self-thinning exponent suggests that the difference in the self-thinning exponent between *C. japonica* and *C. obtusa* is produced by characteristics related to the crown, rather than by characteristics related to stem slenderness. OSAWA and ALLEN (1993) analyzed the self-thinning exponents in *Northofagus solandri* and *Pinus densiflora* stands based on the allometric relationships between mean stem diameter and mean foliage mass, and between mean stem diameter and mean plant mass. They showed that (1) the relationships between mean stem size and mean plant mass are similar for the two tree species examined, but (2) the self-thinning exponents and allometric relationships between mean stem size and mean foliage mass for the two species are quite different. These findings indicate that the species-specific difference in the self-thinning exponent may be produced by characteristics related to the crowns, rather than by characteristics related to stem form and size (OSAWA, 1995). The good agreement between our results and those of OSAWA and ALLEN (1993) supports the validity of the *Sr* model. Therefore, the characteristics related to *Sr* and stem slenderness are sufficient to explain the self-thinning exponent in overcrowded stands.

Comparison of *Sr* Model with Previous Models

WELLER (1987b) also analyzed allometric relationships to obtain a value for the self-thinning exponent. His method is essentially the same as the method presented here, but the specific population variables that he used were different from ours. He first introduced allometric relationships between the mean plant mass w and three other variables: the mean tree height H, the biomass density in the space occupied by a plant B and the radius of the area occupied by a plant R. These relationships were of the form $H \propto w^{\theta}$, $B \propto w^{\delta}$, and $R \propto w^{\varphi}$, where θ, δ, and φ are constants. Then, he formulated a relationship among the constants for self-thinning populations as

$$\varphi = (1-\theta-\delta)/2. \quad (14)$$

Since $\varphi = 1/(2\alpha)$, the self-thinning exponent α and β can be determined from the constants of the allometric relations as

$$\alpha = -1/(1-\theta-\delta) \quad (15)$$

$$\beta = -1/(1-\theta-\delta)+1. \quad (16)$$

Comparing eq. (10) with eq. (15), or eq. (11) with eq. (16), since $\theta = d$, we obtain

$$\delta = 1-d(2b+1). \quad (17)$$

Eq. (17) shows that constant δ is determined by characteristics related to *Sr* and stem slenderness. For lack of reliable data, WELLER (1987b) assumed that the biomass density in the occupied area is a constant value, i.e., δ=0. However, OSAWA and ALLEN (1993) found that the constancy assumption of the biomass density did not hold for *Northofagus solandri*, and XUE *et al.* (1999) found that it did not hold for either *Pinus tabulaeformis* or *Lalix principis-rupprechtii*. Inserting the values of b and d obtained in the present study into eq. (17), we get δ = 0.125 for *C. japonica* and δ = -0.02 for *C. obtusa*. Accordingly, we can predict that the constancy assumption of the biomass density does not hold for *C. japonica*. Actually, NISHIZONO *et al.* (2002), using the same data used in the present study, showed that the value of δ significantly differed from zero for *C. japonica*, although it did not significantly differ from zero for *C. obtusa*. These results confirm our prediction that the constancy assumption of the biomass density does not hold for *C. japonica*, and indicate that the *Sr* model is not inconsistent with WELLER's (1987b) allometric model.

According to the *Sr* model, the self-thinning exponent, i.e. $-1/(2bd)+1$, can be derived from commonly measured stand dimensions, such as tree height, stem diameter at breast height, and stand density. Thus, we can estimate the self-thinning exponent and analyze the mechanism generating the self-thinning exponent using easily available inventory data. In contrast, the allometric model of OSAWA and ALLEN (1993) requires rarely measured stand dimensions, such as foliage mass. Therefore, the *Sr* model can be considered one of the most practical models for estimating the self-thinning boundary line.

CONCLUSIONS

In the present study, we proposed an allometric model (the *Sr* model) that explains the difference in the self-thinning exponent among species based on the relative spacing index, and applied this model to overcrowded pure stands of *C. japonica* and *C. obtusa*. The results indicated that the difference in the self-thinning exponent between *C. japonica* and *C. obtusa* is produced by characteristics related to *Sr*, rather than by characteristics related to stem slenderness. The *Sr* model can be considered one of the most practical models for estimating the self-thinning boundary line.

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Article

Community Forestry Planning and Implementation in Cambodia - A Case Study of Baccod Village -

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ABSTRACT

Through the community forestry pilot projects, the Government of Cambodia has been working with various non-governmental organizations to conserve forest resources and improve the local economy. While understanding of community forestry in the world has grown in the last decade, there are still uncertainties about the extent, potential and conditions of community forestry development in Cambodia. This study examined the planning process of a community forestry project and evaluated its implementation based on the project participants' points of view. It was revealed that even if the project can be considered a success there remained some challenges and problems, which came as a result of unfavorable planning process. For future community forestry development, particularly on degraded forest areas, the study proposed a more promising framework of the planning process. This proposed planning process emphasizes the importance of extension work and monitoring and features a more self-reliant style of community forestry development. Currently, there are million hectares of forest areas where community forestry development should be carried out. To successfully expand community forestry in these areas through the proposed planning process, more foresters at all levels should be trained in community forestry, particularly in respect to facilitation skills needed to work with local communities.

Keywords: Cambodia, community forestry, local level planning, participatory forest management

INTRODUCTION

Community forestry has become popular in many parts of the world owing to the premise that it encourages local people to manage forests based on local needs and objectives (Arnold, 1991; Pofferberger, 1996; Thomas, 2000). In Cambodia, there is also a growing acceptance of community forestry as a key approach to sustainable forest management (Fox, 1997). This has emerged after a two decade centralized forest management that had brought about uncontrollable deforestation nationwide. In 1997, the total forest cover was 10.6 million ha of which 4.1 million ha were subject to forest concessions for commercial logging (Kim *et al.*, 2001). The rest are most degraded forest areas with less commercial value. The Forestry Department in Phnom Penh is under increasing pressure from NGOs and international organizations to design these areas for community forestry development. The first community forestry pilot project in Cambodia was put into practice in 1994 covering 500 ha of degraded forest lands in Takeo province (Sokh *et al.*, 2000). Through this pilot project, the concepts and ideas of community forestry soon become familiar across the country (Patrick, 2000; Butterfield, 1998). In the late 1990s, community forestry has become one of the hot topics in forest policy debates and planning over time. Policy makers have been trying to establish a national community forestry law (Lao *et al.*, 2000). Nevertheless, up to now all draft laws and guidelines related to community forestry has yet to get approved. The absence of such laws has been frustrating the field practitioners and local communities, hindering efforts in community forestry expansion. One of the main reasons for being unable to establish a national community forestry policy has been the lack of understanding and up-to-date documentation of experiences of community forestry practice.

The principle objectives of this study are to examine the planning process at the local level and to evaluate a community forestry project. It aims at identifying opportunities and

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challenges in community forestry development as well as looking for a more effective approach in community forestry planning. The findings of the study are intended for the improvement of current project implementation and the provision of baseline information for future forest policy debates and planning.

METHODOLOGY

Baccod Village and Its Community Forestry

Baccod village belong to Laybo commune, Takeo province. It has a total area of 236ha comprising of 200ha of rice and crop fields and 36ha of community forest. The population of Baccod increased from 617 in 1981 to 901 in 2000. Those who have a family size ranging from 4 to 9 accounted for 91.7% of the total households. Most of the villagers, 97.1%, are farmers whose livelihoods depend mainly on agriculture as the main income source (Table 1). Besides farming, some villagers make their ends meet with other sources such as forest product collection, livestock, and palm sugar production. Most of the villagers in Baccod participated in the current community forestry project, which also covered 17 other surrounding villages in the area. Started in 1994, the project initially was supported by the Mennonite Central Committee (MCC), a non-government organization based in North America. It was an attempt to find a new approach to forest management in which forest resources are to be sustainably managed and used by the local community. The project objectives were to alleviate fuelwood and timber shortages of the rural poor and improve the family income through increasing agricultural yields and soil fertility by rehabilitating forest resources (UNG, 1996).

Table 1 Characteristics of the respondents

	(N=35) Percentage
Age (years old)	
- 20~60	80
- >60	20
Family size (persons)	
- 1~3	2.7
- 4~9	91.7
- 10~	15.4
Land holdings (ha)	
- Landless	0
- 0.1~1	68.6
- 1.1~	31.4
Main source of income	
- Farming	94.3
- Labor	0
- Business	0
- Others	5.7

Source: Field survey

Activities have been mainly focusing on conservation and protection of the secondary growth forests. Like in its neighboring villages, forest lands of Baccod village were classified into two types of land use. One is the conserved area that is owned communally. This area was designed for natural regeneration where tree cutting is not allowed. Another type of forest lands was designed for upland crop cultivation and tree planting by individual households. Recognition on these family plots is an incentive for the villagers to conserve community forest. Other incentives are that the participants of the project were assured that they would gain almost benefits from the community forests and tree plantings. According to the agreement, the Forestry Department (FD) would only collect revenue as follows: 20% of timber products harvested for sale and 10% of timber products harvested for domestic consumption. Since the project started there has not been any harvest of major forest products as the community forest is still under regeneration.

Data Collection

The data of this study were obtained through field visits and questionnaire surveys conducted in Baccod village. The questionnaire was derived from the Operational Guide for monitoring and evaluation of social forestry in India (SLADE, 1988). The questionnaire was tested in the field and revised by the research team before the actual use to ensure its applicability. One field official of the Community Forestry Unit at the FD and a member of the project who knows the area well were included in the research team to help facilitate the fieldwork. Thirty-six householders or 20% of the total village householders were interviewed by using the tested questionnaire. Households for interview were chosen based on consultation with key informants in the study area as to ensure that project participants from all walks of life were included in the sample, i.e., young and elders, male and female, and small scale land holders (SH) (1ha and smaller) and relatively large scale land holders (LH) (larger than 1ha). As for the selection process, the research team first obtained the list of project participants from the project office in the study area. Since only one third of project participants have land of more than one hectare, it was decided that only one third of all participants in the sample should be those who have more than a hectare of land. Secondly, key informants in the area helped the research team identify locations of selected household on the map. During the field survey, however, some target householders were not at home. In these cases, they were replaced by new householders that had similar characteristics. Consequently, 24 householders belonging to the SH group and 12 householders belonging to the LH group were interviewed. Nevertheless, only 35 finalized questionnaires can be used for data analysis. Before the questionnaire survey, reconnaissance studies were conducted in the targeted village and neighboring villages. The purpose was to get acquainted with the study area and its people, discuss the research proposal with village leaders and organize teams for questionnaire survey that followed.

The data obtained from the field surveys were analyzed and described in Table 2 and Table 3 in terms of percentages for each of the factors, which was used in determining the participants' knowledge and attitude. These included percentages of all participants in the sample, percentages of those who were identified as SH and of those who were identified as LH.

RESULTS

This study firstly identifies the planning process of the Baccod village community forestry project. Secondly it analyzes and evaluates the current implementation based on the participants' point of view.

Project Planning Process

The planning process in setting up the current project can be described as follows. Initially, staff from the MCC and FD visited the community and identified the users of the forest land. Identification of such a group was done on the basis of traditional forest use pattern, accessibility to the forest, formal or informal records, and consultation with senior citizens in the community. At least one member from every family participated in informal discussions regarding forest management, forest protection, planting trees, harvesting, etc. After the discussions, a Forest Protection Committee (FPC) with five members was formed. Its members were from among forest user groups in Baccod village. Once the FPC was formed, various rules and regulations regarding forest protection, management and harvesting were formed. The FPC was registered in the Agriculture Office of Takeo province and the FD. It was then officially recognized. On these grounds, project staff facilitated users in drawing up a simple management plan for the community forest. This plan was a management contract between the local community and the FD. Like regulations of community forest, it was prepared jointly by the project participants and the project staff. The management plan describes the forest vegetation, inventory records, and how the forest would be protected, developed and harvested. The chairman of the FPC on behalf of the users and the FD on the government's behalf signed the plan and the forest was officially handed over to the users (Ung, 1996).

The planning process of the community forestry project in Baccod can, therefore, be briefly described as: 1) Community identification (CI), 2) Discussions (DS), 3) Forest Protection Committee Formation (FPC), 4) Setting of regulations and management plan (R&P) and 5) Implementation (IM) (Fig. 1).

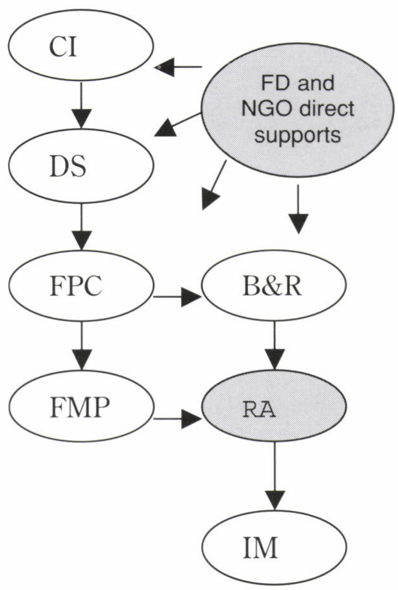

Fig. 1 Schematic structure of planning process of the community forestry project in Baccod village

Note: CI = Community Identification
DS = Discussions
FPC = Forest Protection Committee
B&R = Bylaws and Regulations
RA = Responsible Authorities
IM = Implementation
FD = Forestry Department

Project Implementation

Two important criteria are considered in evaluating the project implementation. These include knowledge of participants about the project and participants'attitude toward the community forestry. Each of these criteria has some factors that were used to identify project participants' knowledge and attitudes. Difference of knowledge and attitude between SH (0.1~1 ha) and LH (1.1~ 3 ha) are also analyzed.

Participants' Knowledge about the Project

According to the project reports, extension work and community mobilization were carried out during earlier stage to provide project participants with information about the establishment of the project. It is observed that all participants in the project are aware of the project establishment. Having asked when they first came to know about the project, most of the participants (65.7%) reported that they knew during the period when it was started. Some 28.6% and 2.9% first knew about the project before and after the project started, respectively. Only a small difference of knowledge between SH and SL could be observed on this factor. For instance, 30.4% of the SH claimed that they knew about the project establishment before it started. Meanwhile, some 25% of the LH was found to have claimed so (Table 2).

Concerning the organization responsible for starting the project, the majority of the participants (54.3%) said that it was the MCC with collaboration with the FD. This is the correct perception. Other participants, 12.3%, believed that the FD solely is responsible for starting the project. Similarly, 20% and 11.4% of villagers believed that the MCC and their village were responsible for starting the project, respectively. The difference of knowledge on this factor between the two groups, SH and SL, seems to be insignificant.

Another important factor under consideration here is the participants' belief about the project objectives. As previously stated, the main objectives of the project were to alleviate fuelwood and timber shortages and to stimulate village development. Without considering the size of land the participants hold, it is revealed that most of all participants, 91.4% and 88.6%, believed that the project objectives were to increase the flow of fuelwood and timber, respectively. There were up to 82.9% of the participants who believed that the objective was to prevent further degradation of the remaining forests. Having considered land size, it revealed that generally SH have better knowledge about the project objectives than SL. For instance, 95.7% and 87% of the SH have correct perception that objectives of the project was to solve fuelwood problem and stimulate village development respectively, compared to 83.3% and 75% of the LH.

Concerning the benefit sharing plan, 17.1% of all participants have a wrong perception that the plan does exist and up to 28.6% said that they don't know. However, the majority of the participants have a correct perception that the plan for sharing valuable products such as timber and poles has yet to be developed. The differences of knowledge between SH and LH found here are that 65.2% of the SH as compared to 33.3% of the LH have correct perception that benefit sharing plan has yet to be developed. In contrast, up to 50% of the LH claimed that they did not know whether plan does exist or not, compared to only 17.4% of the SH.

Table 2 Knowledge of the project and its establishment

Factors	Percentages		
	All	SH	LH
a). Participants' awareness of the project establishment (n=35)			
- Aware	100	100	100
- Not aware	0	0	0
b). Villagers first knew about community forestry project (n=35)			
- Before it started	28.6	30.4	25
- When it started	65.7	65.2	66.7
- Several months later	2.9	4.3	0
- Can't remember	2.9	0	8.3
c). Organization believed responsible for starting the project (n=35)			
- Forest department	14.3	17.4	8.3
- NGO	20	21.7	16.7
- Village	11.4	3.7	16.7
- Others	54.3	52.2	58.3
- Don't know	0	0	0
d). Belief about the purposes of the community forest project* (n=35)			
- For fuelwood	91.4	95.7	83.3
- As land reclamation	20	17.4	25
- For timer and poles	88.6	87	91.7
- To prevent degradation	82.9	87	75
- For income of the village	5.7	4.3	8.3
- Others	2.9	4.3	0
e). Beliefs about plan for the sharing of products (n=35)			
- Plan exists	17.1	17.4	16.7
- No plan exists	54.3	65.2	33.3
- Don't know	28.6	17.4	50

Note: * The percentages may not sum to 100 as responses are not mutually exclusive
All: Percentages of all participants in the sample
SH: Calculated as percentages of those who have small scale land
LH: Calculated as percentages of those who have large scale land
Source: Field survey

Participants' Attitude toward Community Forestry

Five factors were used to examine the participants' attitude toward community forestry in the study area. These include participants' attendance at meetings, opinion regarding land use and species, plantations, product collection, and confidence in the current forest management system (Table 3).

The results from the field survey showed most of the participants claimed that they have attended the meetings related to community forestry. The majority, 68.8%, of those who ever attended the meeting said that they had attended the meeting both before and after the project started. Participants who had attended the meeting only before and only after the project started accounted for 28.1% and 3.1%, respectively. This means that the total participants attended the meetings before the project started is 96.9%. Similarly, the total participants attended the meetings after the project started is 71.9%. By taking land size into consideration, it can be said that more SH (33.3%) participated in the meetings before project started than that of the LH (18.2%). However, SL are found to have higher rate of participation (72.7%) in the meeting both before and after project started than the SH (66.7%).

Concerning land use and species, up to 94.3% and 88% of all participants claimed that they agreed with the current land use and tree species, respectively. Participants who are not satisfied with the current land use accounted for 5.7%. Their idea was that the communal woodlots should be better leased to the poor or used for highland crops. Likewise, participants who were not satisfied with the species, 11.4%, suggested more

Table 3 Participants' attitude toward community forestry

Factors	Percentages		
	All	SH	LH
a). participants attending the meeting (n=32)			
- Before the project started	28.1	33.3	18.2
- After the projected started	3.1	4.8	0
- Both	68.8	66.7	72.7
b). Opinion regarding land use and species* (n=35)			
- Agreed on land use	94.3	95.7	91.7
- Did not agree on land use	5.7	4.3	8.3
- Agreed on species	88.6	82.6	100
- Did not agree on species	11.4	17.4	0
c). Plantation on privately owned land (n=35)			
- Planted seedlings	91.4	95.7	83.3
- Did not plant	8.6	4.3	16.7
d). Villagers collecting products from the community forests (n=35)			
- Grass, leaves and fodder	25.7	26.1	25
- Fuelwoods	40	43.5	33.3
- Timber and poles	5.7	4.3	8.3
- Grazing	20	21.7	16.7
- Others	2.9	4.3	0
e). Belief about village's ability on management (n=35)			
- Capable	74.3	78.3	66.7
- Not capable	20	21.7	16.7
- Don't know	5.7	0	16.7

Note: * The percentages may not sum to 100 as responses are not mutually exclusive
All: Percentages of all participants in the sample
SH: Calculated as percentages of those who have small scale land
LH: Calculated as percentages of those who have large scale land
Source: Field survey

fruit trees be inter-planted in the woodlots to reap tangible benefits. As can be seen from Table 3, 100% of LH agreed on species as compared to 82.6 of the SH. In contrast a higher rate of SH (95.7%) agreed on land use than that of LH (91.7).

At the initial stage, the project provided seedlings free of charge to the villagers. Latter, the seedlings were sold at a very low price so that all villagers could buy if they needed more (NGIM, 1998). The study revealed that 91.4% of the participants have planted trees on their home compounds but not all of them fulfilled the rate agreed upon in the contract. For comparison, 95.7% of SH reported they planted seedlings on their contracted lands while only 83.3 reported to have done so. Since the project started, however, there is not any evidence suggesting that evaluation and monitoring have been carried out to verify the compliance.

Concerning the products collected from the community forests by the participants, 40% of participants collected fuel materials such as leaves, twigs and deadwood. Other products were not available for collection according to the regulations. Nevertheless, as shown in Table 3, some 25.7% of participants are still grazing or collecting fodder. Also, a small number of participants (5.7%) reported that they still have collected timber and poles. The differences in attitude between the SH and LH is not remarkably significant on this factor. MCC, the NGO that initiated the project, has gradually scaled back its supports since 1998. Some participants have become skeptical about the ongoing implementation of the project. The study found that a considerable number of all participants (74.3%) believed that their village is capable of successfully running the current community forestry project. Twenty percent believed that the village would not be able to continue running the project successfully. For this factor, it is observed that more SH (78.3%) than LH (66.7%) believed that their community forestry project would be successful.

DISCUSSIONS

Project Implications

The study found that the project has both weak and strong points. They are believed to have come as a result of unfavorable planning process in which the current project was set up. The study reveals that in addition to having gained basic knowledge, most participants are found to have correct perceptions and positive views on many important factors determining the success of the so-called community-based forest management. For instance, almost all of the participants agreed with the current land use of community forest areas. After two years of natural regeneration, the forest stand in these areas has increased significantly. Even though some participants have not met the required number of trees to be planted on their home compounds, they planted trees as much as they could. As a result, most villagers now have enough fuelwood for cooking and some even have collected poles for domestic use or commercial purposes. Regenerations of degraded forests in the area also contributes to preventing soil erosion and improving soil fertility, which in turn, improve rice and crop productivity. In addition, most of the participants have confidence in their village's ability of the community forest management.

Beside these positive signs, there remained problems and challenges. First of all, the study found that there were a slightly decreasing number of participants attending the meetings regarding community forestry work. This can be an indication of increasing disinterest in the project by participants. One main reason for this seems to be the lack of tangible benefits, particularly benefits from investment in forestry efforts. It is observed that the community forest in Baccod village has been under protection for almost ten years without any specific guideline for pruning or harvesting available products. Taking this into account, therefore, some actions must be taken to reap benefits from forestry activities.

One option is to set up a group of participants responsible for collecting available products. This group can collect products such as fuelwoods, fodder, mushrooms and bamboo shoots for commercial purposes and earn revenue for the village. Another option is that the FD should play an active role in creating an enabling environment in which villagers can access forest product markets. Helping participants in looking for a market for these products would be a good incentive.

Other problems of the project include violations of the community forest law. And some participants are still reluctant to fulfill their obligation of tree plantings on private lands. Thus there is a need to carry out monitoring and promote extension work. It should also be noted that under the current practice there is not benefit sharing plan of forest products among participants. Thus, it is important that this kind of plan be developed to avoid eventual conflicts of interest.

Policy Implications

As mentioned earlier, the project implementation faces some difficulties and challenges. This is believed, in part, to have stemmed from its planning process. In order to have better results in any future community forestry development and expansion, there must be a more favorable planning process. Also in this respect, project planning should be performed in a more self-reliant manner or with less dependence on NGOs. It is believed that the role of non-government and international organizations in community forestry development in Cambodia is crucial but not to the extent that it is essential. Literature review also revealed that many community forestry projects in the world were quite successful even without any input from NGOs (Banerjee, 1996; Carle, 1998). Good planning process is believed to be one of the most important factors determined their success.

According to the report by William, there remains approximately three million hectares of degraded forests in Cambodia where community forestry can be developed (William, 1999). It is estimated that currently only less than 10% of these lands are under community forestry. Most of these community forestry projects developed so far are supported by various NGOs. Cambodia must be able to expand community forestry to the areas that lack support from the NGOs. It is a must because, obviously, NGOs could not provide support to all of the areas but only some, especially, areas with easy access. Community forestry can be developed on both degraded and well forested areas. According to Fox, a expert of community forestry in Southeast Asia, community forestry efforts are not only found on degraded forest lands but also on relatively well forested lands in Indonesia and the Philippines (Fox, 1997). In Cambodia, efforts have been made to develop community forestry on these types of lands, too. However, with present limited capacity, priority should be given to degraded forest lands so as to prevent a complete convert of these lands for agricultural or other uses.

It is expected that community forestry in Cambodia would be expanded at national scale in the near future. To contribute to the expansion of community forestry, this study proposed a new framework of planning process. The proposed planning process comprise of seven progressive steps instead of five as found in the case of community forestry project in Baccod village. Since, in Baccod case, the study found that there is not much different of knowledge and attitude between the small scale land holders and relatively large scale land holders, only a general planning process is proposed. The seven steps in the proposed planning process include 1) Community identification (CI), 2) Local orientation (LO), 3) discussions (DS), 4) Forest Protection Committee formation (FPC), 5) Regulations and management plans (R&P), 6) Implementation and extension (I&E), 7) Evaluation and monitoring (E&M) (Fig. 2). The planning process may take months or years to be finalized, depending on the magnitude of the project and its complexity.

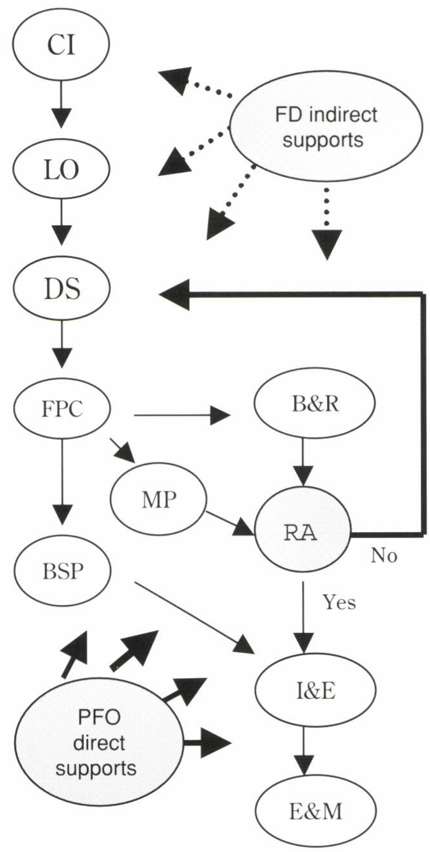

Fig. 2 Schematic structure of the proposed planning process of community forestry

Note: CI = Community Identification
LO = Local Orientation
DS = Discussions
FPC = Forest Protection Committee
B&R = Bylaws and Regulations
BSP = Benefit sharing plan
MP = Management Plan

As mentioned earlier, million hectares of degraded forest lands in Cambodia are in urgent need of community forestry development. It is suggestive that, whether or not there is support from NGOS, the provincial forestry offices provide direct support to the local communities to establish their community forest throughout the planning process. The national Forestry Department, at the same time, is to provide indirect support such as establishing legal framework, policy and related laws and increasing human resources in supporting community forestry development (Fig. 2).

According to the result of the study, some participants in Baccod village did not know well about the project and have negative attitude toward the community forest. It is suggestive that a step called "local orientation" be added into planning process as the second step. This is to help the local communities understand better the idea and concepts of community forestry at the initial stage. Similarly, extension work is added into the sixth step of planning process (Implementation and Extension). Extension work should be planned and carried out during the project implementation to ensure that all project participants are provided with up-to-date information and to improve project implementation.

Another feature of the proposed planning is adding "Evaluation and Monitoring" as the last step in planning process (step 7). In the case of Baccod village, evaluation and monitoring on project implementation have never been properly planned and carried out. Therefore, it has resulted in some crimes against the community forest going unreported as the study has previously revealed. In the proposed planning process, evaluation and monitoring should be conducted by both parties (local community and responsible authorities) to ensure that the minimum requirements in the agreement (between the local community and the responsible authority) are met. It is also to enforce the rules of community forest law and to determine what should be done to improve the project implementation.

In this proposed planning process it is also suggestive that, if regulations and forest management plan (to be formed in step 5) are rejected by the provincial forestry office, the participants return back to discuss again (step 3) and revise previously written regulations and management plan. The forest protection committee can also be terminated or reformed if deemed necessary. A plan for benefit sharing among participants should be formed. It can be also submitted to the provincial forestry office for recognition but not for approval.

CONCLUSIONS

The community forestry project of Baccod village can be considered a promising approach to conserving forest resources in degraded forest areas. It is worth considering in any effort to expand community forestry in Cambodia. An important lesson is to keep in mind that having local community participated in the project with thorough understanding of the project and positive attitude toward the community forest is crucial in any community forestry project. To ensure this, community forestry efforts in Cambodia must be developed through a favorable planning process. To achieve this, the national Forestry Department must make more effort in training staff in community forestry at all levels, particularly in facilitation skills needed to work with local communities.

The proposed planning process of community forestry in this study was designed based on experience of community forestry development in a degraded forest area. More studies, however, are needed to examine and verify whether the proposed planning process is applicable for community forestry development in other types of forest areas such as flooded forests, concession forests and national parks where the local communities also depend on forest resources for subsistent livelihoods.

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Article

Socio-economic Assessment of *Eucalyptus* Plantations in Suixi County, Southern China

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ABSTRACT

A socio-economic assessment of *Eucalyptus* plantations was undertaken in Suixi county, Leizhou Peninsula, P.R.China. Information was collected from officials of the Suixi Forestry Bureau and other agencies, and from interviews in a sample of six villages in the county. *Eucalyptus* plantations have been widely planted on the Leizhou Peninsula. The investigation showed that they play an important role in local environmental improvement, economic development, public infrastructure construction, and domestic energy supplies. But it was found that many plantations have suffered degradation through poor management. Some constraints to sustainable management of plantations, such as those relating to harvesting systems, land security and taxation, were found. Options for removing these constraints need to be further investigated.

Keywords: *Eucalyptus*, socio-economic assessment, county, constraints

INTRODUCTION

Eucalyptus has been regarded as a uniquely promising tree species for matching sites on the Leizhou Peninsula[1)] in southern China, and so has been widely planted since the 1960s. The area of *Eucalyptus* plantations totalled 205,300ha by 1998. Except for Leizhou State Forest Bureau, Suixi county has the largest area of *Eucalyptus* on the peninsula. There are two large woodchip processing plants in Suixi. In recent years woodchips have been exported to Japan, South Korea and Taiwan, bringing greater economic benefits. The annual output value of woodchips reached around 14,500,000 yuan[2)] at its peak in 1997. *Eucalyptus* plantations have become the mainstay of the Suixi forestry sector.

Through more than 40 years of production, with management techniques involving superior trees and clone selection, silviculture has been continually improved to seek higher yield and improved management of the plantations. However, the sustainability of the plantations is questionable as research in some areas has indicated a decline in nutrient status of soil and plantation productivity over continuous rotations. This has been attributed to traditional management techniques involving removal of litter from the site and whole-tree harvesting (Yu, 1999).

Sustainability of plantations is an important subset of the general sustainability issues facing forestry today. Failure to maintain sustainability has negative impacts on the socio-economic health of local communities and future generations. But some of the practical management techniques recommended to promote sustainability also have negative impacts on certain groups in society. Such socio-economic issues need greater attention if we wish to achieve sustainable management of plantations and social sustainability. Without an understanding of these issues, it is difficult to succeed just by applying the best

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1) This study is part of a broader project concerning eucalypts and sustainability, funded by ACIAR (Australian Centre for International Agricultural Research), which is focused on the Leizhou Peninsula. See website at www.eucalypt.net

2) The Chinese currency is the Renminbi (RMB) and the unit of currency is the yuan. The exchange rate is about 8.28 yuan to US$1.

scientific and technical knowledge (Tornqvist, 1997). This paper aims to: (a) assess the socio-economic implications of *Eucalyptus* plantations, which will indicate the importance of sustaining and developing the industry; (b) understand the current management and administrative situation, and (c) identify major socio-economic factors affecting sustainability of the plantations, including barriers to practices promoting sustainability.

METHODOLOGY

Study Area

The study was conducted in Suixi county which is located in the Leizhou Peninsula, in the south of Guangdong province, approximately 16 kilometers east of Zhanjiang (Fig.1). Suixi county has 20 towns and a population of 824,000, in an area of 200,500ha. The area of forested land owned by Suixi county, collectives and farmers (excluding Leizhou Forest Bureau) is 28,229ha, or 14% of the total area. About 76% of the forested land is *Eucalyptus* plantation. The topography is basically flat, and most of the land is 25-45m above sea level. The dominant soils are derived from sedimentary, basaltic and shale parent materials, and are of low fertility. The area has a humid tropical climate. The average annual temperature is 22.8 degrees, and average annual rainfall is 1,678 mm. The major rainy season is from May to September, bringing 76% of total rainfall.

Government agencies

There are forestry agencies in Leizhou at several different levels of China's government – Central, provincial and county.

Suixi Forest Bureau is attached to Suixi county which is in the local government area of Zhanjiang in Guangdong Province. Leizhou State Forest Bureau (LFB) was originally attached to the Forestry Department of Guangdong Province, although in 2000 it was transferred to the State Foreign Economic and Trade Department.

Data Collection

Semi-structured interviews

Semi-structured interviews were conducted with 28 major stakeholders in Suixi County around October 1999. These stakeholders included the leader, former leader and technicians of Suixi Forestry Bureau, retired managers of Suixi Forestry Station, staff of Suixi Forestry Nursery, staff of Suixi Land Administrative Bureau, and leaders and farmers in a sample of 6 surveyed villages.

The surveyed villages cover a range of soil types and locations, plantation ownership patterns, and economic status, but are all villages in which plantations have an important role (Fig.2). Basic information on the surveyed villages, such as soil type, population, number of households, labor force, income and land use, is listed in Table 1. Based on a ranking of households in terms of economic level by the leader of each surveyed village, a total of 15 households were selected for interview, including representatives from each of three categories of rich, poor and medium income. The aim of the category sampling was to try to investigate any differences in their way of managing Eucalyptus plantations and litter collection.

The interviews covered the topics of land utilization patterns, forest distribution, ownership and land tenure patterns, development history and management of *Eucalyptus* plantations, output and revenue of the plantations, current management options and techniques, attitudes toward managing the plantations, problems in managing plantations, positive and negative aspects of plantations, and the primary factors or constraints affecting sustainable management.

Field interviews

Interviews were also conducted in the field with working

Fig. 1 South-east China, showing Leizhou Peninsula and Suixi County

Fig. 2 Location of surveyed towns and villages in Suixi County

Table 1 Basic information for the surveyed villages

Village	Town (District)	Soil type	Number of households	Population	Labor-force	Mean Income (yuan/year)	Total land area (ha)	Proportion of area forested (%)
1. Xinshi	Hetou	Yellow latosolic soil	509	2,865	779	2,450	433	24.7
2. Yanggan	Yanggan	Yellow latosolic soil	680	3,449	2,100	1,800	513	26.0
3. Lemin	Lemin	Yellow latosolic soil	1,156	5,360	2,700	1,500	272	44.1
4. Quanshui	Xialiu	Yellow latosolic soil	1,509	5,700	3,135	1,700	573	46.5
5. Duocun	Fucheng Xiang	Latosol	652	3,107	1,850	2,100	709	52.6
6. Kengwei	Huanglue	Latosol	485	2,800	1,400	1,200	320	52.1
Total or mean in survey			4,991	23,281	11,964	1,792	2,821	41.0

farmers, providing a chance to engage in informal conversations with local farmers on plantation issues. In addition to helping to identify some of the implications and problems of managing *Eucalyptus* plantations, these conversations also help in checking the information provided in home and office interviews.

RESULTS AND DISCUSSION

The Socio-economic Implications of *Eucalyptus* Plantations

Historical Development

Before 1949, the original vegetation in Suixi county had mostly degraded into grass and barren land. The environment was so severe that it was difficult to grow trees, and nobody considered developing tree plantations on open-access degraded land. However, in 1954, the Leizhou Forest Bureau successfully planted *Eucalyptus* plantations on Leizhou Peninsula.

The *Eucalyptus* plantation grown, in particular, in Yangguang town in Suixi county by LFB in 1955 provided a great demonstration for others to follow. After that, *Eucalyptus* was planted along roads and in villages for trials by Suixi Forest Management Department, the fore-runner of the Suixi Forest Bureau. A large range of plantations could not be established by forest farms of each town and community until 1964 due to government restrictions in that special historical phase of China. But local farmers were impressed by the growth of the Bureau's plantations, and became enthusiastic about growing *Eucalyptus*.

Before 1964 forestlands were open access resources. Following demonstrations of successful plantings of *Eucalyptus* tree species in this area, some barren forestlands were privately occupied and reclaimed by local farmers to establish plantations. From 1981 to 1982, following the Central Government's decision on 'reconfirming forest tenure right, dividing freehold hills, and forestry production responsibility system', some villages, including Yanggan and Xinshi, took all forest lands back from private occupiers and redistributed them to households. The aim was to achieve better management of these forests and forestland equality among households.

Land tenure

Three kinds of land tenure relations developed in Suixi county, namely, ownership by:

i) government (national or county),
ii) community (village collectives) and
iii) household (farmer).

The community-owned plantations may be managed by the village collective itself, but in some cases the management of the stands is contracted out to forestry specialists. Table 2 shows the area and tenure of *Eucalyptus* plantations in the 6 surveyed villages. These are all either community or village-owned.

The tenure systems have been subject to several policy changes in recent years. The effect of the tenure systems and their changes on infrastructure and management is discussed further below.

Management techniques

From the 1960s to 1970s, *Eucalyptus* trees were grown from rooted seedlings in small pits with little subsequent management, resulting in annual average yields of only 2.85 m^3 per hectare. From the 1980s to 1990s, management techniques were improved, as the Forest Bureaus adopted techniques such as containerised clonal planting stock produced by tissue culture, machine ploughing and application of inorganic fertilizers. This assisted the development and expansion of fast-growth high-yield *Eucalyptus* plantations with short rotations. The improvements in management techniques led to an increase in average annual yield to 11.25m^3 per hectare over 5 to 6 year rotations. The management and performance of household-owned plantations, however, tends to be much poorer.

Area of Eucalyptus plantation

Eucalyptus plantations are now widely distributed throughout the county, according to the information from Suixi Forestry Bureau. In 1998, the area of *Eucalyptus* plantation was 21,480 ha, making up 85% of the total plantation area, for which the distribution of soil types is 71% in sediments, 22% in shale,

Table 2 Area and tenure of *Eucalyptus* plantations in surveyed villages, 1998-99

Village	Town	Forest Area (ha)	Area of Eucalyptus (ha)			
			Total Area	Collective-Mananged	Contracted to Specialists	Household-Managed
1. Xinshi	Hetou	107	57	57	0	0
2. Yanggen	Yanggen	133	133	133	0	0
3. Lemin	Lemin	120	120	67	20	33
4. Quanshui	Xialiu	267	267	40	33	193
5. Duocun	Fucheng xiang	373	320	233	67	20
6. Kengwei	Huanglue	167	133	47	67	20
Totals		1,167	1,030	577	187	267

Table 3 Area of *Eucalyptus* plantations in Suixi County*

	1994	1995	1996	1997	1998
1. Total area of Eucalyptus plantation (ha)	24,783	23,571	20,788	22,349	21,480
High-yield Eucalyptus plantation (ha)	11,371	7,942	8,994	7,038	14,602
2. Area of other plantations (ha)	5,780	5,536	4,960	4,398	3,737
3. Eucalyptus plantation as % of total	81	81	81	84	85

*Includes all owned or managed by Suixi Forest Bureau, including its govemmental plantations (one forest farm of SFB and 12 township forest farms) and community plantations. Excludes Leizhou Forest Bureau.

Source: Forest Administration Division of Suixi Forestry Bureau

Table 4 Output value of sectors of Suixi county (yuan $\times 10^6$)

	1994	1995	1996	1997	1998
1. Industry	3,518	3,408	3,297	3,148	3,176
2. Agriculture	894	1,570	1,340	1,694	1,560
3. Forestry	26	46	59	43	48
4. Husbandry	304	472	532	286	346
5. Sidelines	422	850	1,079	1,121	1,225
Total	5,162	6,345	6,308	6,293	6,356

Source: Statistics Bureau of Suixi County

and 7% in basalt (Suixi Forestry Bureau, 1994). Since 1989, high yielding *Eucalyptus* plantations under intensive management have been developed. The area of such intensively managed plantation reached 14,602 ha by 1998, making up 68% of the total area of Eucalyptus plantation (Table 3).

The Leizhou State Forest Bureau occupies 10.6% of the land area and owns approximately 16,750ha of *Eucalyptus* plantations in Suixi county, which are not included in Table 3. 70 percent of villages can gain access to LFB's forests for collecting litter.

Economic contribution

Suixi is a typical agricultural county with 101,005 ha of arable land. Its economic income comes mainly from industry (sugar processing industry), agriculture and sidelines. Forestry's contribution is smaller than other sectors, but its share of total output increased in the 1990s (Table 4). In 1996, the value of output of Forestry reached 59 million yuan, 2.28 times that of 1994.

Eucalyptus has made a significant contribution to Forestry. Table 5 shows the harvested volume and output value for chip wood, timber and fuelwood from 1994 to 1998. The total value of output has fluctuated, falling from a peak of 25.45 million yuan in 1995 to 13.08 million in 1998. The table shows that chipwood contributed 80 per cent of total output of *Eucalyptus*. In recent years, annual average tax on *Eucalyptus* chips paid to Suixi County was 991,200 yuan.

Table 5 Harvest yield and output value of *Eucalyptus* plantations of Suixi County

	1994	1995	1996	1997	1998
1. Harvested volume (m^3)	43,621	63,829	44,122	44,499	36,017
1) Chip wood	30,534	44,680	30,885	3,115	25,212
2) Timber	10,905	15,957	11,030	11,125	9,004
3) Fuelwood	2,181	3,191	2,206	2,225	1,801
2. Output value (yuan × 10^3)	16,099	25,450	17,530	17,816	13,087
1) Chip	12,723	20,280	14,327	14,692	10,645
2) Timber	3,010	4,596	2,912	2,803	2,161
3) Fuelwood	366	574	291	320	281

Source: Forest Administration Division of Suixi Forestry Bureau

Employment

Eucalyptus has played a central role during various stages of Suixi forestry development. It provided immediately available work to relieve periodic unemployment. With the expansion of *Eucalyptus* plantations, 20 forest farms belonging to townships, 2 chip and timber processing plants, and 43 small timber and furniture mills have been established. As of 1995, the number of employees in eucalyptus plantations, nurseries and processing plants had reached 1,090. However, in recent years, it seems that local laborers have been getting fewer employment opportunities as timber middle-men have been using their own wood-harvesting teams employing immigrants from neighboring provinces during the harvesting season.

Public infrastructure improvement

The infrastructure of villages in Suixi has generally been improved since the development of *Eucalyptus* plantations. New schools, irrigation and tap water systems, and electricity power facilities have been built. The extent of improvement in different villages varied, depending on the area and tenure of *Eucalyptus* plantations. Towns and villages with relatively more Eucalyptus plantations owned and managed by collectives have higher incomes from selling *Eucalyptus* products and more funds for improving their infrastructure.

Quanshui village of Xiuliu town has a large area of *Eucalyptus* plantations, but 72.5% are owned by individual households (from Table 2). As a result the Village Administration Committee has less than 30,000 yuan income from *Eucalyptus* plantations yearly, and correspondingly less funds were available for the improvement of infrastructure. On the other hand, villages such as Yanggan and Kengwei, with more collective-managed and contracted plantations, have an annual average income for their Village Administration Committee of 150,000 yuan. From 1994 to 1998, total investment in infrastructure was 840,000 yuan in Yanggan and 750,000 yuan in Kengwei village (Table 6). *Eucalyptus* has indeed made a significant contribution to village development and services for local people.

Table 6 *Eucalyptus'* contribution to infrastructure construction (yuan × 10^3)

Infrastructure	Villages		
	Yanggan	Kengwei	Quanshui
Irrigation system	240	50	20
Roads, bridges	150	450	20
Electricity and tap water	250	150	30
School construction	200	100	30
Total	840	750	100

Supply of fuelwood for farmers

In the 1950s, native forests covered only 3.6 percent of the county, mostly in scattered patches, and large blocks of forest were rare. Farmers who lived on the better sites depended on the forests for fuelwood for cooking, while people who lived in towns on sedimentary soil, such as Leming and Hetou, had to collect grass for fuel. The development of plantations in the 1960s solved the fuelwood shortage problem of local farmers. Fuelwood is usually gathered in the form of litter from 2 to 5 year old plantations. Plantations are not thinned, and all the wood from final harvest is taken by the harvesting teams.

Environmental improvement

In Suixi, the dominant soils are sandy soils, derived from marine sedimentation. Before 1949, the original vegetation had mostly degraded into grass and barren land. Drought, wind-blown sand and tidal water often hit the area. With the wind blowing in from the sea, the sky above the area became yellow with sand, crops were buried and houses collapsed (Shi, 1996). The air was extremely dry and rainfall declined. Local residents suffered great disasters from wind and drought. In 1954, *Eucalyptus* was successfully introduced and planted in Suixi County. Since then, *Eucalyptus* has been widely used to establish shelterbelts protecting crop fields from the 'yellow' wind, and for greening the landscape around roads and living zones.

With the market and economic development in the 1980s, *Eucalyptus* plantations were increasingly managed for production purposes. The area of plantations was progressively increased. With the establishment and development of the plantations, the wind-blown sand disappeared and environmental conditions improved. The *Eucalyptus* plantations reduced wind speed and protected crop fields. The yield of paddy rice increased to twice its previous level. According to the records of Suixi Meteorology Bureau, annual average rainfall was 1401mm from 1913 to 1953, and 1470 mm from 1955 to 1964, but increased to 1802 mm from 1965 to 1995. The local people believed that the increase in annual rainfall was related to the expansion of *Eucalyptus* plantations.

The interviewees of Kengwei and Quanshui village reflected that the flow of surface water was decreasing yearly. In many areas of the world, reductions in water yield have been blamed on high water use by *Eucalyptus* plantations. However, these villagers attributed it to the development of sugarcane in the 1990s, not Eucalyptus. This was the opinion of the villagers rather than a scientific fact. Related scientific research for this project is investigating the water use of different eucalypt species in Leizhou, taking detailed measurements of plantation water use, with concurrent weather and site data.

Main Factors Affecting Sustainable Management of *Eucalyptus* Plantation

The study investigated different possible sources of non-sustainability, including:

i) decline in site fertility, due to removal of nutrients
ii) converting land from plantation to other uses.

Litter collecting by households

In the past, all farmer households collected forest litter because of custom and poverty. Currently, the situation has not changed greatly although their economic status has obviously improved. According to the survey, all households collect dead branches, litter, and residues for fuelwood all year round. Of the 70% of households in the poor category, all totally depended on such wood for fuel. Households in the rich category (10% of total) and medium category (20% of total) used one or two bottles of liquefied petroleum gas per year, but most of the fuel they used was litter collected from plantations. Traditionally, communities living around state or collective forestry plantations have been allowed access to fuelwood in the forest. It appears that some managers of private plantations also allow this practice. There is no special rule limiting collection of fuelwood. In Suixi County, litter seems to be an open access resource. It is hard to find a *Eucalyptus* plantation without litter collecting activities.

Most fuelwood was collected from state or collective-managed *Eucalyptus* plantations as those plantations can produce more litter than the individual-managed plantations because of their better growth and condition. In the 1980s, it was very common for farmers to collect litter not only for their daily use, but also for selling to small mills, such as brick making and lime mills. But in the 1990s, with the bankruptcy of many small mills, the number of farmer households selling litter decreased. Selling fuelwood is not common now, but still exists. Less than 5% of farmer households, just those living in villages in coastal areas near large-scale *Eucalyptus* and pine plantations, collect fuelwood for selling. Such fuelwood is usually bought by farmer households and privately-managed restaurants in the area.

It is women's task to collect fuelwood. Usually, they collect 50 kg each time at 10 to 15 day intervals (Table 7). According to these figures, the annual minimum amount of fuelwood collected is 1,200kg per household.

Scientific research has indicated that the removal of litter, which is rich in nutrients, is a significant factor in the decline in soil fertility in plantations over the long term. Village leaders and most of the farmers interviewed recognize that litter-collecting is a problem for sustainability, but they have not devised solutions to the problem. Because of the relative poverty of many of the villagers, it would have a serious impact on their welfare if they were forced to stop litter-collecting and turn to alternatives such as gas for fuel.

Table 7 Data on fuelwood collecting in the surveyed villages of Suixi

Village/Town	Households using only Fuelwood (%)	Households using LPG and fuelwood (%)	Quantity collected & frequency	Collecting place
Xinshi/Hetou	70%	30%	50kg,2-3 hours/time,/10days.	Anywhere
Yanggan	100%		50kg/time,/3 days	Anywhere
Lemin				Anywhere
Quanshui/Xialiu Waipo	80%	20%	50kg/time,/10-15 days	Anywhere,80-90% coming from plantation of LFB.
Baishuitang	70%	30%	50kg/time,/7days	Anywhere, most from Collective Plantation
Fuchengxiang	85%	15%	150kg, 2 hours/time,/15 days	Anywhere
Huanglue	70%	30%	50-500kg/time,/10-15 days	Anywhere

Even some Forest Bureau managers considered it would be socially unacceptable to prevent villagers collecting litter and that such a policy could be impractical to enforce.

Lack of management skills

Farm household-based *Eucalyptus* plantations in the 6 surveyed villages are poorly managed. Most of their plantations were initially planted in the 1960s, and have now become third or fourth generation coppice plantations. Just a few rich farmers replanted in the 1980s. All interviewed farmers had little knowledge of fast-growth and high-yield management techniques which are widely used by the contracted specialists and applied to some of the collective-managed plantations. The farmers had received no technical training from local forestry authorities. The shortage of management skills directly led to the degradation of their plantations, and hence low yield and benefits. The lack of skilled management is not related to the economic level of households. Almost all households of the rich, medium and poor categories provide no further silviculture for their plantations.

Whole-tree harvesting

Whole-tree harvesting of *Eucalyptus* is common in Suixi Forest Bureau plantations. This means that the stem, branches, bark, stump and roots are all removed from the site and sold or used. After harvest, another rotation of *Eucalyptus* is planted. Compared with harvest techniques taking stems only, there is a considerable loss of nutrients from the site through biomass removal and increased soil erosion. From the viewpoint of sustainable management, greater retention of biomass such as branches and roots on the harvest site would be preferable. From a socio-economic viewpoint, however, such a policy would mean a loss of income to the people who sell or use the branches, bark, stump or roots. In publicly-owned plantations, the sellers are usually the harvesting contractors. They may be able to compensate for their loss by obtaining higher contract payments for harvesting on a stem-only basis.

Land tenure changes

One of the factors affecting the sustainable management of community-based *Eucalyptus* plantations has been the changes of land tenure. The taking back of forest lands from the private occupiers and redistribution to households was described above. The aim was to achieve better management of these forests and forestland equality among households.

However, both the plantations originally established by farmers and those given back to households were badly managed. Currently, more than 90% of plantations are third or fourth rotation coppice with poor appearance and low yield (Suixi Forestry Bureau, 1996). One reason is that farmers lack confidence in the security of their forestland tenure. The interviewed households, of all economic categories, are afraid that the grown trees and forestland will be taken back some day. Fearing the loss of their investment, farmers are reluctant to invest money to maintain and manage the plantations on a sustainable basis.

In order to enhance the yield of plantations, and increase the income of the community for public well-being, the committees of some villages made a decision in 1996 that the committee would take back the tenure of all forest land from households and change to community management of the plantations or contracting out. Up to now, 80% of towns in Suixi county have made the same decision and put it into effect although local farmers are opposed.

The fieldwork for this study found that the growth of new plantations managed by specialists is indeed better than that of the collectives. However, farmers are reluctant to contract out management of their own plantations, as they fear they will lose their right of access for wood use and fuelwood collection, and will receive even lower economic returns derived from lower land rent.

The committees of the 6 villages all encourage local farmers to contract the forestland which has just been taken back to further develop high-yield *Eucalyptus* plantations, but there are no farmers in Xinshi, Yanggan, Doucun or Kengwei village, and just 2 rich farmers in each of Lemin and Quanshui village who have made such a contract. The area contracted is less than 20ha.

Land tenure security is a very important and sensitive issue for community and farm household-based plantations such as in Suixi. The interviews revealed that most farmers had lost confidence in the security of their forestland tenure - a situation which tends to destroy the foundations of sustainable management.

Heavy taxation

Taxation is a fundamental national policy instrument. A rational tax policy encourages investment. By contrast, excessive taxation and fees discourage investment (Wu, 1993). Data on taxes and fees indicate that local governments and forest agencies levied from seven to nine kinds of taxes and fees on timber. Consequently, farmers had to pay 37-40% of their sales revenue in taxes, which is significantly higher than for other agricultural products such as sugar cane. When the costs of tree planting and tending are taken into account, the net income of farmers from *Eucalyptus* timber production is half of sales revenue. High taxation, by reducing the farmers' effective return from tree growing, reduces their incentive to maintain and develop their plantations. It appears that this has been a key factor encouraging farmers to cut the plantations and illegally replace them with cash crops such as sugarcane.

Market price fluctuation

Suixi is a major Eucalyptus planting county, but the agricultural sector is still much larger than the forestry sector. Approximately 25% of income in Suixi comes from agriculture (Table 4). Sugarcane is the major crop. From the beginning of the 1990s, the increasing market price of sugar resulted in farmers gradually replacing their *Eucalyptus* plantations with sugarcane. Seeking higher and quicker profits, local farmers illegally cut trees to expand their plantings of sugarcane. The total area of *Eucalyptus* plantation in Suixi decreased from 24,783 ha in 1994 to 21,480 ha in 1998. 13% of *Eucalyptus* plantation was converted into sugarcane. In recent years, with the rising price of eucalyptus wood and chips, local farmers have tended to return to replanting *Eucalyptus*. The market price fluctuation of products seems to be one factor affecting the development of *Eucalyptus*.

CONCLUSIONS

The results of interviews and fieldwork indicated that *Eucalyptus* plays a key role in Suixi county in local economic and infrastructure development, environmental improvement, employment and supply of fuelwood for domestic use. The development of the *Eucalyptus* has created more positive socio-economic benefits than other tree species. No negative effects were presented by interviewees. Nevertheless, *Eucalyptus* plantations are facing heavy degradation, particular in the household-based management system. As well as inappropriate harvesting techniques such as whole-tree harvesting and lack of management skills by local farmers, socio-economic factors such as land tenure, litter collection, taxation and market price fluctuations are all contributing to poor and unsustainable management of the plantations.

Through more than 40 years' practice and experiment, and silvicultural techniques dealing with the selection of superior clones and prescription of special fertilizers etc., fast-growth high-yield plantations have been developed and extended by local forestry authorities and Leizhou State Forestry Bureau. High-yield plantations have been gradually replacing the old low-yield coppice plantations owned by Government and local communities. However, these intensive silvicultural and management techniques have not been effectively extended to the household-ownership system. It is suggested that local forestry authorities freely disseminate the techniques to local farmers to promote the sustainable management of plantations at household level.

The interviews showed that there is little difference in management of the household-based plantations between the three categories of rich, poor and medium-income households. Extensive management methods with no tending, no fertilizing and no replanting are typical, even among the rich households.

Farmers interviewed were worried about changes in land tenure. Due to past changes, land tenure has become a sensitive issue to farmers. A stable guaranteed system of land tenure is important to promote sustainable management of crops. On the other hand, taking ownership back from farm households into collective hands may result in better management with a longer-term perspective. Most of the communities are moving to a system of contracting out their plantations to forestry specialists, and the growth of plantations contracted out to specialists was found to be clearly better than that of collectives or farmers. However, farmers are reluctant to contract out management of their own plantations, as they fear they will lose their right of access for wood use and fuelwood collection, and will receive even lower economic returns derived from lower land rent.

Litter collection and whole-tree harvesting are typical in Suixi plantations, but scientific research has suggested that this removal of biomass is a major reason for declining long-term productivity. Management changes such as retaining foliage and roots on the site, and controlling collection of litter, would promote sustainability, but would have adverse effects on some of the poorer members of the rural community who benefit from use or sale of the litter and tree components. Litters and residues are major sources of fuel for the poorer farmers' daily life. When farmers become richer, they tend to stop collecting litter and residues. Under current conditions, it seems to be impossible to control collection. However, just leaving the tree roots in the ground is suggested as a partial solution that would be more feasible. Even in this case, it may be appropriate to compensate harvesting contractors for their loss of income from roots.

Heavy taxation on plantations is bound to reduce plantation owners' expected profits and discourage long-term investment. Taxation of *Eucalyptus* in Suixi is around 37%, which is higher than that for Leizhou State Forestry Bureau. Taxation policy should be adjusted to ensure that plantations are not taxed more heavily than alternative crops and to encourage sustainable management.

Other management options, such as inter-cropping with green manure crops or nitrogen-fixing trees, need to be considered, as they may be able to restore soil nutrients with less adverse socio-economic effects. The costs and benefits of the main technical options for sustainable management are to be evaluated in a later stage of the current project, taking account of the distributional effects on different socio-economic groups.

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Short communication

Estimation of Relative Iilluminance using Digital Hemispherical Photography

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ABSTRACT

The sky factor, which is an estimate of relative illuminance used in the field of architecture, measured from digital hemispherical photography was compared with relative illuminance measured directly by illuminance meters. At fifty sample points selected randomly in ten stands, digital hemispherical photography was taken using a digital camera (Coolpix 900, Nikon) with an exclusive fish-eye lens (Fish-eye converter FC-E8, Nikon), and relative illuminance was simultaneously measured using illuminance maters (T-10, Minolta). The sky factor was significantly higher than relative illuminance ($p<0.001$), with the average and maximum differences being 17.191% and 24.995%, respectively. This suggested that the sky factor measured from digital hemispherical photography could not be directly used as an estimate of relative illuminance. However, there was a high correlation between sky factor (*SF*) and relative illuminance (*RI*) ($r=0.971$, $p<0.001$), and the regression line of *SF* against *RI* was $SF=1.091RI+15.354$ ($r^2=0.953$, $p<0.001$). The regression line between sky factor and relative illuminance could therefore be used in correcting the overestimation. In conclusion, although digital hemispherical photography would be a convenient means for estimating light environment, we should pay attention to the characteristics presented in this study to avoid the overestimation.

Keywords: digital camera, hemispherical photography, light environment, relative illuminance, sky factor

INTRODUCTION

Hemispherical photography is a useful device in estimating light environments (Anderson, 1964). One of the simplest light environment estimates measured from hemispherical photography will be openness grade proposed by Ando (1983). The openness grade is the ratio of the sky area to all area of the hemispherical photography and is often called unweighted openness. Another simple estimate may be sky factor, which has been used widely in the field of architecture (Yamada, 1989). The sky factor is the ratio of sky area weighted by the incident angle of cosine law (Grace, 1971) to all area of hemispherical photography and is called weighted openness. Inoue *et al.* (1996) studied in a *Chamaecyparis obtusa* stand the relationships of relative illuminance to sky factor and openness grade measured from film hemispherical photography, and showed that sky factor was a better estimate of relative iiluminance than openness grade.

Recently, an inexpensive digital camera that can equip with an exclusive fish-eye lens has been on sell from Nikon Co., Ltd. The digital hemispherical photography will be useful in estimating light environments since it enables us to omit the cost, time and labor for film processing and image scanning. Using the digital camera, Englund *et al.* (2000) compared digital and film hemispherical photography, and showed that the light environment estimates were significantly different between two techniques. The light environment estimated from digital hemispherical photography, however, has never been compared with the environment measured directly by light sensors. To assess the usefulness of the digital hemispherical photography, it is necessary to compare

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measured and estimated light environments. The objective of the present study is thus to compare the sky factor measured from digital hemispherical photography with relative illuminance measured directly by illminance meters.

MATERIALS AND METHODS

Study Site

The present study was conducted in the Hiruzen Experimental Forest of Tottori University, western Japan. A circular plot of 0.02ha was established in two *Cryptomeria japonica* (CJ), two *Chamaecyparis obtusa* (CO), two *Pinus densiflora* (PD), two *Larix leptolepis* (LL) and two deciduous broad-leaved stands (BL). BL was dominated by *Quercus serrata*, *Quercus acutissima* and *Castanea crenata*. In each plot, tree height and diameter at breast height (DBH) of all living trees were measured. General description of each plot is shown in Table 1.

Hemispherical Photography

At five sample points selected randomly in each plot, hemispherical photography was taken on still and cloudy conditions using a digital camera (Coolpix 900, Nikon) with an exclusive fish-eye lens (Fish-eye converter FC-E8, Nikon). The camera was mounted at a height of 1.2m above ground level on a tripod and leveled with a bubble level (Teraoka, 1995). An automatic setting for aperture width and shutter speed was used (Englund *et al.*, 2000). On the Coolpix 900, three image qualities (basic, nomal and fine) can be selected. Using Coolpix 950, Englund *et al.* (2000) studied in a tropical wet forest the effect of difference in image quality on the unweighted openness estimate, and concluded that the basic quality image was adequate, because of its small memory, facilitative data collection and storage. Inoue *et al.* (unpublished) also examined the effect of difference in image size (normal and VGA) on sky factor and canopy cover estimates, and showed that no differences in the estimates due to image size were found. The VGA image was only quarter of the size of the normal image. Thus, the basic quality and VGA size image was used in the present study. In LL and BL, all photographs were taken before leaf flushing.

Image Analyses

Lee *et al.* (1983) found that the bule-filtered grayscale image enables us to obtain maximum contrast between tree crown and background among blue, red and green-filtered grayscale images. Mizoue and Inoue (2001) also applied three widely used automatic thresholding algorithms to blue-filtered grayscale tree crown images and showed that the discriminant analysis proposed by Otsu (1979) was the most effective algorithm. Thus, all digital images were converted to binary (black and white pixels) by applying the discriminant analysis to the blue-filtered grayscale histogram of the hemispherical photography. That is to say, the pixels that had a blue-filtered grayscale level higher than the threshold determined by the discriminant analysis and all other pixels were respectively converted to white and black.

The used exclusive fish-eye lens had more than 180° view angle and distortion (Englund *et al.* 2000). Based on the unpublished data provided by the Electric Image Technical Center of Nikon Co., Ltd., a calibrating procedure for the view angle and distortion was developed. By calibrating the view angle and distortion using the developed procedure, the sky factor was measured from obtained binary hemispherical photography. These image analyses were performed using an image-processing program developed by Delphi 5.0J (Inprise Corporation).

Table 1 General description of each plot

Plot	Species	Tree height(m)*	DBH (cm)*	Stand density (stems/ha)
CJ1	*Cryptomeria japonica*	22.6 ± 2.1	41.6 ± 6.5	450
CJ2	*Cryptomeria japonica*	21.1 ± 2.9	32.9 ± 7.5	850
CO1	*Chamaecyparis obtusa*	16.8 ± 0.8	27.0 ± 4.0	750
CO2	*Chamaecyparis obtusa*	14.1 ± 1.0	18.0 ± 3.2	1,550
PD1	*Pinus densiflora*	22.2 ± 1.8	33.0 ± 6.9	500
PD2	*Pinus densiflora*	12.5 ± 1.7	20.0 ± 3.9	1,100
LL1	*Larix leptolepis*	15.0 ± 4.0	18.3 ± 6.5	1,050
LL2	*Larix leptolepis*	13.0 ± 5.4	15.1 ± 8.0	1,050
BL1	broad-leaved species**	12.9 ± 1.8	18.6 ± 5.4	500
BL2	broad-leaved species**	12.8 ± 7.8	15.1 ± 10.3	900

Note: *Average ± S.D.
**The dominant species were *Quercus serrata*, *Quercus acutissima* and *Castanea crenata*.

Comparison with Relative Illuminance

Using illuminance meters (T10, Minolta), relative illuminance at each sample point was repeatedly measured five times just after taking hemispherical photography and averaged. The sky factor at open area was 98.607%, indicating that the open area was fully opened. To compare sky factor with relative illuminance, the paired t-test, correlation analysis and regression analysis were performed. In the paired t-test and correlation analysis, all percent data of sky factor and relative illuminance were transformed by arcsin.

RESULTS

Fig. 1 shows the comparison of sky factor and relative illuminance. The sky factor and relative illuminance ranged from 15.260% to 65.991% and from 1.222% to 46.069%, respectively. The paired t-test indicated that sky factor was significantly higher than relative illuminance (p<0.001), with the average and maximum differences being 17.191% and 24.995%, respectively. However, there was a high correlation between sky factor (*SF*) and relative illuminance (*RI*) (r=0.971, p<0.001), and the regression line of *SF* against *RI* was SF=1.091RI+15.354 (r^2=0.953, p<0.001). The slope of the regression line was significantly different from unity (p<0.05).

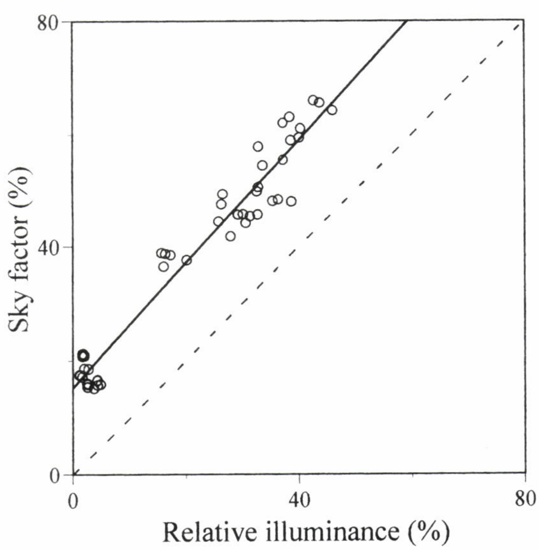

Fig. 1. Comparison of sky factor measured from digital hemispherical photography and relative illuminance measured directly by illuminance meters

Note: The solid and broken lines indicate the regression line of sky factor against relative illuminance and 1:1, respectively. The regression line of sky factor (*SF*) against relative illuminance (*RI*) was SF=1.091RI+15.354 (r^2=0.953, p<0.001).

DISCUSSION

The result of the present study showed that sky factor measured from digital hemispherical photography was significantly higher than relative illuminance measured directly by illuminance meters. By contrast, INOUE *et al.* (1996) compared sky factor measured from film hemispherical photography with relative illuminance, and reported that the difference between sky factor and relative illuminance ranged from -0.96% to 0.98% and tended to be unbiased. The discrepancy in the results between present and previous studies would be introduced by the difference in the used devices, i.e., digital and film camera. ENGLUND *et al.* (2000) compared digital and film hemispherical photography, and showed that the light environment estimates were significantly higher in digital hemispherical photography than film one. They suggested that the digital hemispherical photography all looked much brighter than film one, and the difference in brightness would be the result of difference in the light sensitivity between two techniques (ENGLUND *et al.*, 2000). A manual setting for aperture width (RICH, 1990) might enable us to correct the difference in light sensitivity, but the optimum setting for aperture width will vary with field conditions such as illuminance. To take hemispherical photography efficiently in the field, an automatic setting for aperture width will be useful than the manual one.

The sky factor measured from digital hemispherical photography was highly correlated with relative illuminance measured by illuminance meters. The result presented in this study suggests that the relative illuminance can be estimated by the procedure that substitutes the measured sky factor into the regression line obtained in the present study. This estimation procedure enables us to reduce the average difference between estimated and measured relative illuminances to 0.003%, and would be more practical and effective in correcting the overestimation of sky factor against relative illuminance than the use of the manual setting for aperture width. Thus, the sky factor measured from digital hemispherical photography can not be directly used as an estimate of relative illuminance, but the procedure using the regression line will provide a good estimate of relative illuminance. The regression line might depend upon the used sample data, and therefore further measurements of sky factor and relative illuminance will be required to obtain an accurate and precise regression line.

CONCLUSION

In the present study, the relative illuminance was estimated using a new technique, the digital hemispherical photography. The result suggested that the sky factor measured from digital hemispherical photography could not be directly used as an estimate of relative illuminance, but the procedure using the regression line would provide a good estimate of relative illuminance. In conclusion, although the digital hemispherical photography would be a convenient means for estimating light environment, we should pay attention to the characteristics presented in this study to avoid the overestimation.

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