ISSN 1341-562X

JOURNAL OF FOREST PLANNING

Vol. 12 No. 1

June, 2006

Japan Society of Forest Planning

JOURNAL OF FOREST PLANNING

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Subscription Information

JOURNAL OF FOREST PLANNING is pubished halfyearly. The subscription for 2003 is 5,000 yen and the single issue price is 2,500 yen. Subscription orders can be sent to following office.

Toho Shoten
343 Yamabuki-cho
Shinjuku-ku, Tokyo 162-0801, Japan
Phone: +81-3-3269-2131, Fax: +81-3-3269-8655
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JOURNAL OF FOREST PLANNING **is published by**
Japan Society of Forest Planning
Iwate University, 3-18-8 Ueda, Morioka, Iwate 020-8550, Japan

JOURNAL OF

FOREST PLANNING

Vol.12, No.1 June, 2006

Japan Society of Forest Planning

CONTENTS

Articles

Short Communication

Article

A System to Predict Diameter Distribution in Pure Even-aged Hinoki (*Chamaecyparis Obtusa* Sieb.) Plantations (III) -Extension to Stand Volume Prediction-

Takao Hayashi[*1] and Kazukiyo Yamamoto[*1*2]

ABSTRACT

We developed a height-diameter curve estimation model for even-aged hinoki (*Chamaecyparis obtusa* Sieb.) plantations to develop a height-diameter curve that could be applied to any stands at any stand age using diameter distribution and stand characteristics. We used generalized allometric equation for the height-diameter curve equation and assumed that allometric coefficient was equal to 1 (constant) and that maximum height was the upper-asymptote of the site index curve. We performed stepwise multiple regression analysis to derive the remaining parameter related to the slope of curves (referred to here as the 'shape parameter'). For the multiple regression analysis, we used stand age, density, mean basal area and site index as explanatory variables. To validate the model, we estimated the mean tree height of each DBH class and compared the predicted and observed heights. Furthermore, we predicted stand volume by combining the height-diameter curve estimation model and a diameter distribution prediction system developed in a previous study, and compared the predicted and observed data. From the regression analysis, we obtained a linear equation for the shape parameter as a function of stand age, density and mean basal area. The results of model validation indicate that the height-diameter curve estimation model is capable of estimating mean tree height for DBH classes with less bias, and would be useful for diameter distribution-based stand volume prediction. The results of stand volume prediction indicated that when initial stand age was greater than 30 years, the prediction error of both basal area and stand volume were small, while they were over-predicted when initial stand age was less than 30. These results suggest that the predictive error for stand volume was dependent upon the diameter distribution prediction system.

Keywords: Height-diameter curve, pure even-aged hinoki (*Chamaecyparis obtusa* Sieb.) plantation, Stand variables, applicability to wide region.

INTRODUCTION

In a previous study, we developed a diameter distribution prediction system, or the "DDPS", for even-aged hinoki (*Chamaecyparis obtusa* Sieb.) plantations, and validated the system using longitudinal data that were independent of the data used for model development (Hayashi *et al*., 2002). DDPS predicts the number of trees for each DBH class in every year according to any treatment regime. We also estimated parameters of the DDPS for even-aged sugi (*Cryptomeria japonica* D. Don) plantations and found that the DDPS could be applied to sugi plantations located in various regions (Hayashi and Yamamoto, 2006). To predict stand volume based on DDPS, the mean height of each DBH class was required. Once obtained, the mean stem volume for each DBH class could be estimated using an existing two-parameter stem volume function (The Forestry Agency Planning Department, 1970a, 1970b).

While the height-diameter curve has been used for estimating the tree height from DBH, the height-diameter curves in even-aged plantations have been observed to shift to upper right and produce more even curves as the stands grow (Oosumi, 1987; Nagumo and Minowa, 1990; Tanaka, 1992). Some researchers have also investigated the relationships between the slope of the height-diameter curve and stand

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characteristics. KUNISAKI *et al.* (1996) found that the slope of height-diameter curves was decreased as mean DBH increased for most growth stages. KUNISAKI *et al.* (1999) also found that the slope of height-diameter curves varied according to stand density control management. Conversely, INOUE (2000) developed a simple model to describe the slopes of height-diameter curves for even-aged sugi and hinoki plantations, finding that the slope of height-diameter curves were proportional to the mean dimension quotient. Height-diameter curves thus change according to growing stage (stand age) and/or stand characteristics.

In this study we developed a "height-diameter curve estimation model" for even-aged hinoki that could relate the change in the height-diameter relationship to growing stage (stand age) and/or stand characteristics. We also attempted to predict stand volume by combining the height-diameter curve estimation model with both DDPS and an existing two-parameter stem volume function (THE FORESTRY AGENCY PLANNING DEPARTMENT, 1970a, 1970b), and discussed the utility of this method to predict stand volume.

DATA

In this study, we used re-measurement data of permanent sample plots from in hinoki plantations located in the Utsunomiya University Forests at Funyu (Shioya-gun, Tochigi prefecture, 36° 47' N, 139° 51' N) and private forests in Owase City, Mie Prefecture (34° 03' N, 136° 10' E) (Fig. 1). Assessed tree characteristics were DBH (cm) and height (m) of all living trees.

In the Utsunomiya University Forests at Funyu, a total of 21 plots were established in hinoki plantations: two permanent plots, which were re-measured four times after plot establishment (NAITO, 1984, 1988, 1994, 1998; NAITO and MATSUE, 2003a), four long rotation forests, which were re-measured three times after plot establishment (FUJIWARA, 1977; NAITO and FUJIWARA, 1982; FUJIWARA and NAITO, 1987; FUJIWARA *et al.*, 1993), eight growth experimental plots, which were re-measured three times after plot establishment (NAITO, 1982, 1987, 1994; NAITO *et al.*, 1996), and seven permanent plots on spacing effect (NAITO and MATSUE, 2003b). The planting

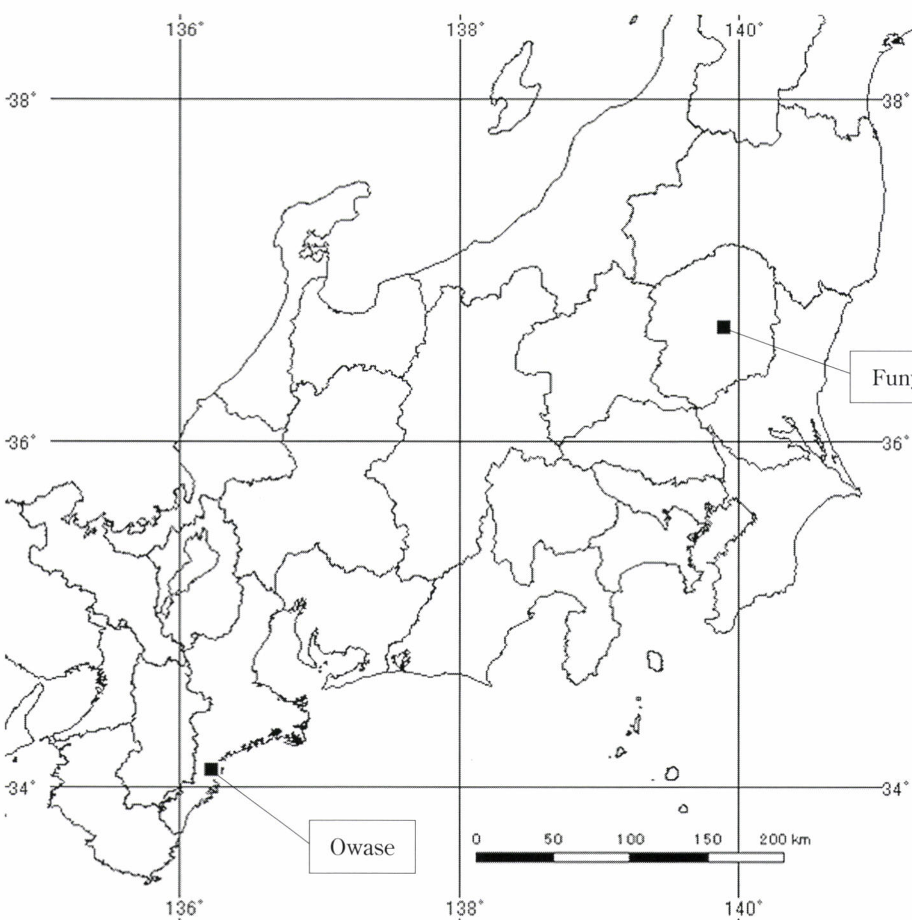

Fig. 1 Distribution of permanent sample plots

density and site index for all of these plots were unknown. The area of the plots, stand age, timing and intensity of thinning, and treatment regime are varied between plots.

In 1962, a total of 43 sample plots were established in private forests located in Owase City that were re-measured twice every two years. The area of all plots was 0.02ha, but the planting density, treatment regime and site index for all of the plots were unknown. Stand age varied between plots.

We divided these plots into those for modeling and those for testing. A summary of the dataset is shown in Table 1. Since the site indexes for all of the plots were unknown, site index for each plot was estimated from stand age and dominant height of initial measurements using local site index curve equations (MIE PREFECTURE AGRICULTURE, FORESTRY and FISHERIES DEPARTMENT FOREST INDUSTRY SECRETARIAT FOREST POLITICS SECTION, 1983; TOCHIGI PREFECTURE FORESTRY and TOURISM DEPARTMENT, 1984). First, we adjusted the site index curve for each plot by changing the upper-asymptote to pass through the data from initial measurement. In this study, dominant height was calculated as the arithmetic means of tree heights of the 100 largest DBH trees per hectare (e.g. EERIKÄINEN, 2003). We then estimated site index (base age was 40 years) from the 'adjusted' site index curve. We also estimated stand volume from observed DBH and tree height using two-parameter stem volume equations (THE FORESTRY AGENCY PLANNING DEPARTMENT, 1970a, 1970b).

METHODS

Model Development

We used a generalized allometric equation (OGAWA, 1980) to model the height-diameter curves:

$$\frac{1}{H}=\frac{1}{aD^b}+\frac{1}{H^*} \qquad (1)$$

where H is the mean height of each DBH class (m), D is DBH (cm) and a, b and H^* are parameters. Parameter a is the ratio of H to D in the limit when D approaches zero (YAMAKURA, 1985) and relates to the slope of the height-diameter curves. Parameter b, which refers to the 'allometric coefficient', is the proportionality constant between height growth ratio and diameter growth ratio (YODA, 1971). Parameter H^*, which refers to 'maximum height', means the tree height when DBH approaches to infinity (YODA, 1971; OGAWA, 1980).

In this study, we made several assumptions regarding these three parameters. It has been empirically demonstrated that the value of the allometric coefficient is nearly equal to 1 in the relationship between tree height and diameter of many shade-tolerant tree species (e.g. YODA, 1971) and well-managed plantation forests (RESEARCH GROUP on FOREST PRODUCTIVITY, 1966). In this study, we assumed that parameter b was always equal to 1.

Parameter a relates to the slope of the height-diameter

Table 1 Basic characteristics of the two data sets

Data set	Number of plots		Measurement times	Plot area(ha)	Initial condition SI	t	N	BA	$\bar{D}$	$\bar{H}$	H_D
Funyu	12	Mean	2.6	0.1316	18.7	34.1	2529	43.5	17.0	14.5	16.1
Modeling		S.D.	1.8	0.1557	2.0	18.9	1938	7.5	6.0	4.8	5.2
		Min	1	0.0144	15.6	15	694	29.7	8.0	9.5	10.3
		Max	5	0.5	21.4	67	7706	56.0	29.8	24.1	25.8
Funyu	9	Mean	3.3	0.1385	19.2	34.7	2769	41.0	16.4	14.7	16.4
Test		S.D.	1.8	0.1554	2.1	20.3	2312	6.9	6.6	5.2	5.2
		Min	1	0.0133	16.9	16	755	31.3	7.5	9.3	10.8
		Max	5	0.5	23.2	67	8120	50.9	28.2	23.1	24.8
Owase	22	Mean	2.9	0.02	15.1	25.3	4050	30.3	10.4	8.5	10.2
Modeling		S.D.	0.3	0	3.2	12.9	2041	11.5	4.1	3.1	3.1
		Min	2		9.5	9	1750	6.2	2.7	2.9	4.9
		Max	3		21.9	59	9600	49.1	18.4	16.1	16.9
Owase	21	Mean	3.0	0.02	14.9	22.4	4655	32.4	9.6	8.0	9.7
Test		S.D.	0	0	3	8.4	2082	8	3.6	2.9	2.9
		Min			9.6	7	1750	15.4	4.7	3.5	4.8
		Max			21	40	8950	52.3	17.6	13.3	15.4

Note t: stand age (years), SI: site index (m), N: stand density (trees/ha), BA: basal area (m^2/ha), $\bar{D}$: mean DBH (cm), $\bar{H}$: mean height (m), H_D: dominant height (m) curves. The impact of the change in parameter a (hereafter, referred to as the "shape parameter") on the slope of the height-diameter curve was dependent upon diameter. When D was smaller than $(H^*/a)^{1/b}$, the slope of the height-diameter curves would increase as the parameter a increases, and vice versa. Given that slope of the height-diameter relationship depends on the growth stage (OSUMI, 1987; NAGUMO and MINOWA, 1990; TANAKA, 1992) and stand characteristics (KUNISAKI *et al*., 1996, 1999; INOUE, 2000), we assumed that shape parameter a varied between stand and occasion.

As stated above, maximum height H^* refers to the tree height when DBH approaches to infinity (YODA, 1971; OGAWA, 1980). Since the dominant height refers to the mean height of the largest trees in one stand at a given time, the upper-asymptote of the dominant height growth curve (i.e. site index curve) can be taken as the largest tree height for the entire growing period. Thus, the upper-asymptote of the site index curve can be interpreted as being maximum height H^*. In this study, we assumed that parameter H^* was plot-specific and that its value was equal to upper-asymptote (H_{max}) of the site index curve that was adjusted for each stand.

Consequently, we were thus able to formulate the height-diameter curve estimation model as follows:

$$\frac{1}{H}=\frac{1}{a_{j,t}D}+\frac{1}{H_{\max j}} \quad (2)$$

where $a_{j,t}$ is a stand-specific and time-variant shape parameter and $H_{\max j}$ is the stand-specific upper-asymptote of site index curve.

To explain the fluctuations in the shape parameter $a_{j,t}$ between stands and occasions, we developed a linear equation using stepwise multiple regression analysis. Since the slope of the height-diameter curves relates to stand characteristics such as growing stage, density and diameter (OOSUMI, 1987; NAGUMO and MINOWA, 1990; TANAKA, 1992; KUNISAKI *et al*, 1996, 1999; INOUE, 2000), we used stand age (t_j), density ($N_{j,t}$) and mean basal area ($\bar{g}_{j,t}$) as explanatory variables. We also used site index (SI_j) as explanatory variables to reflect the differences in productivity among stands. The value of objective variable (shape parameter) was obtained analytically. By solving equation (2), the shape parameter can be expressed as a function of D, H and $H_{\max j}$:

$$a_{j,t}=\frac{H_{\max j}\cdot H}{D(H_{\max j}-H)} \quad (3)$$

We assumed that this relationship applied to all DBH classes. Then, parameter $a_{j,t}$ of the k-th DBH class can be calculate in the same way as equation (3):

$$a_{j,t(k)}=\frac{H_{\max j}\cdot H_{(k)}}{D_{(k)}(H_{\max j}-H_{(k)})} \quad (4)$$

where $D_{(k)}$ and $H_{(k)}$ are DBH and mean tree height of the k-th DBH class. In the multiple regression analysis, we used the weighted mean of shape parameter ($\bar{a}_{j,t}$) as the objective variable, where the weight was the number of trees per DBH class. To detect multicollinearity, we calculated variance inflation factor (VIF_j):

$$VIF_j=1/(1-R_j^2) \quad (5)$$

where R_j is the multiple correlation coefficient for the j-th explanatory variable regressed on all other explanatory variables. As R_j tends towards 1 indicating the presence of a linear relationship in the explanatory variables, the VIF_j for the estimated coefficient of the j-th explanatory variable tends to infinity. It is suggested that a VIF_j in excess of 10 is indicative of the model containing multicollinearity (CHATTERJEE and PRICE, 1977). In this study, we deleted the explanatory variables with large VIF_j (>10). Statistical analyses were performed by R 2.2.0 (R DEVELOPMENT CORE TEAM, 2005).

Validation of the Model

To validate the model, we estimated the mean tree height of each DBH class and compared these to observed values. In reliability tests of the height-diameter curve estimation model, the means (Bias, m; $\text{Bias}_{\%}$, %) and standard deviations (RMSE, m; $\text{RMSE}_{\%}$, %) of residuals (estimated - observed), and the estimates of the standard errors of the residual means (S.E., m) were calculated using the following formulas:

$$\text{Bias}=\frac{1}{n}\sum_{i=1}^{n}(H_i-\hat{H}_i) \quad (6)$$

$$\text{Bias}_{\%}=100\times\frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_i-\hat{H}_i}{H_i}\right) \quad (7)$$

$$\text{RMSE}=\frac{1}{n}\sqrt{\sum_{i=1}^{n}(H_i-\hat{H}_i)^2} \quad (8)$$

$$\text{RMSE}_{\%}=100\times\frac{1}{n}\sqrt{\sum_{i=1}^{n}\left(\frac{H_i-\hat{H}_i}{H_i}\right)^2} \quad (9)$$

$$\text{S.E.}=\sqrt{\frac{\sum_{i=1}^{n}(H_i-\hat{H}_i)^2}{n^2-n}} \quad (10)$$

where H_i and $\hat{H}_i$ are the observed and estimated mean tree height of the i-th DBH class (m) and n is the number of data.

We also predicted stand volume by combining the DDPS (HAYASHI *et al*., 2002) and the height-diameter curve estimation model, and compared predicted and observed values. To predict stand volume, we predicted diameter distribution by DDPS (HAYASHI *et al*., 2002) and calculated stand variables (explanatory variables of the multiple regression for $\bar{a}_{j,t}$) from the predicted diameter distribution. Next, we identified a height-diameter curve for the predicted diameter distribution using height-diameter curve estimation model and calculated the mean tree height of each DBH class using the identified height-diameter curve. We then estimated the mean stem volume of each DBH class by two-parameter volume equations

(The Forestry Agency Planning Department, 1970a, 1970b) and calculated stand volume by summing the products of the mean individual stem volume and tree number of each DBH class.

Since DDPS predicts the diameter distribution for every year (Hayashi *et al.*, 2002), longer-term predictions were based on predicted diameter distributions that contained prediction errors. Consequently, the prediction accuracy for both diameter distribution and stand volume will decrease as the length of prediction period increases. For validating predicted stand volumes, we classified the predictions into several groups according to the length of prediction period (Δt) and analyzed the relationship between prediction error and the length of the prediction period. The categories for the length of the different prediction periods are as follows: (a) Δt = 2yrs, (b) Δt = 4, 5yrs, (c) Δt = 9, 10yrs, (d) Δt = 14, 15yrs. A description of these groups is shown in Table 2. In the reliability tests for stand volume prediction, the means (Bias, m^3/ha; Bias$_{\%}$, %) and standard deviations (RMSE, m^3/ha; RMSE$_{\%}$, %) of residuals, as well as the estimates of the standard errors of residual means (S.E., m^3/ha) were calculated in the same way as mean tree height for DBH class.

RESULTS

The results of the stepwise multiple regression analysis could be expressed as follows:

$$\overline{a}_{j,t} = -0.7331 + 0.01676t_j + 0.0002181N_{j,t} + 0.6708\overline{g}_{j,t} \quad (11)$$

The regression was significant ($p < 0.05$, $R^2 > 0.87$) and the coefficients of all of the selected variables were significant ($p < 0.05$). The largest *VIF* was < 4.00, indicating that multicollinearity among the explanatory variables was not problematic in the model.

We estimated mean height of each DBH class using the model and calculated Bias, RMSE and S.E. for all observation in the modeling and test data. Absolute and relative biases were 0.44m (2.7%) for modeling data and 0.04m (0.0%) for test data. The RMSEs were 2.02m (17.6%) for modeling data and 1.60m (14.8%) for test data. The S.E. was 9.74 × 10^{-5}m for modeling data and 8.69 × 10^{-5}m for test data. These results indicate that height-diameter curve model can be used to estimate the mean tree height for each DBH class accurately, although the variance of the estimates is large.

The means (Bias) and standard deviations (RMSE) of residuals and the ratio of residuals to observations for the height-diameter curve estimation model were calculated for 2 cm DBH classes in the modeling and test data (Fig. 2). For modeling data, the height-diameter curve estimation model tended to underestimate the mean height of larger DBH classes. The magnitude of Bias was larger than 1.50m in DBH class larger than 48cm. When DBH class was between 6cm and 48cm, the magnitude of Bias and Bias$_{\%}$ were small in both data sets. In the modeling and test data, Bias and Bias$_{\%}$ of all DBH class between 6 and 48cm were less than ±1.6m and ±11%, respectively.

Moreover, we predicted stand volume and calculated Bias, RMSE and S.E. for all observation in the modeling and test data. Absolute and relative biases were 49.2m^3/ha (27.9%) for the modeling data and 44.7m^3/ha (27.7%) for the test data. The RMSEs were 112.3m^3/ha (54.7%) for the modeling data and 102.0m^3/ha (59.7%) for the test data. The S.E. was 0.25m^3/ha for the modeling data and 0.22m^3/ha for the test data. The means (Bias) and standard deviation (RMSE) of residuals and the ratio of residuals to observations were calculated for the length of the prediction period for modeling and test data (Table 3). In both datasets, Bias and Bias$_{\%}$ for short-term prediction ($\Delta t \le 5$ years) were larger than those of long-term prediction ($\Delta t \le 10$ years). Since prediction errors in stand variables determined by DDPS varied according to initial stand age, t_0 (Hayashi and Yamamoto, 2006), the prediction error of basal area is likely to affect stand volume prediction. We investigated the relationships between predicted and observed stand variables in relation to initial stand age (Fig. 3). These

Table 2 Means of initial stand variables, the length of prediction period (Δt), and number of data predictions (n)

	Modeling data								Test data							
	Δt=2		Δt=4 - 5		Δt=9 - 10		Δt=14 - 15		Δt=2		Δt=4 - 5		Δt=9 - 10		Δt=14 -15	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
t_0	27.3	12.9	36.0	16.2	56.8	18.9	61.8	18.9	24.4	8.4	31.3	14.9	53.0	19.8	58.0	19.8
Δt	2	0	4.2	0.4	9.6	0.6	14.6	0.6	2.0	0	4.2	0.4	9.5	0.5	14.5	0.5
N	3998	2014	2969	1532	1301	569	1234	538	4579	2114	3855	2277	1325	648	1288	6657
$\overline{D}$	11.0	3.8	14.4	5.8	24.2	6.2	25.6	6.4	10.2	3.4	12.9	5.9	23.0	5.4	24.3	5.7
$\overline{H}$	9.3	3.1	12.3	4.9	20.5	4.3	21.4	4.0	8.7	2.6	11.3	5.0	20.5	3.7	21.6	3.3
BA	33.5	9.7	40.0	10.0	54.3	8.6	57.6	9.4	32.9	7.3	37.8	9.0	49.4	8.1	53.4	8.5
V	267	145	353	162	533	187	587	192	243	117	314	147	518	129	587	118
n	22		26		5		5		21		27		6		6	

Note t_0: initial stand age (years), Δt: prediction period (years), N: stand density (trees/ha), BA: basal area (m^2/ha), $\overline{D}$: mean DBH (cm), $\overline{H}$: mean height (m), V: stand volume (m^3/ha), n: number of plot

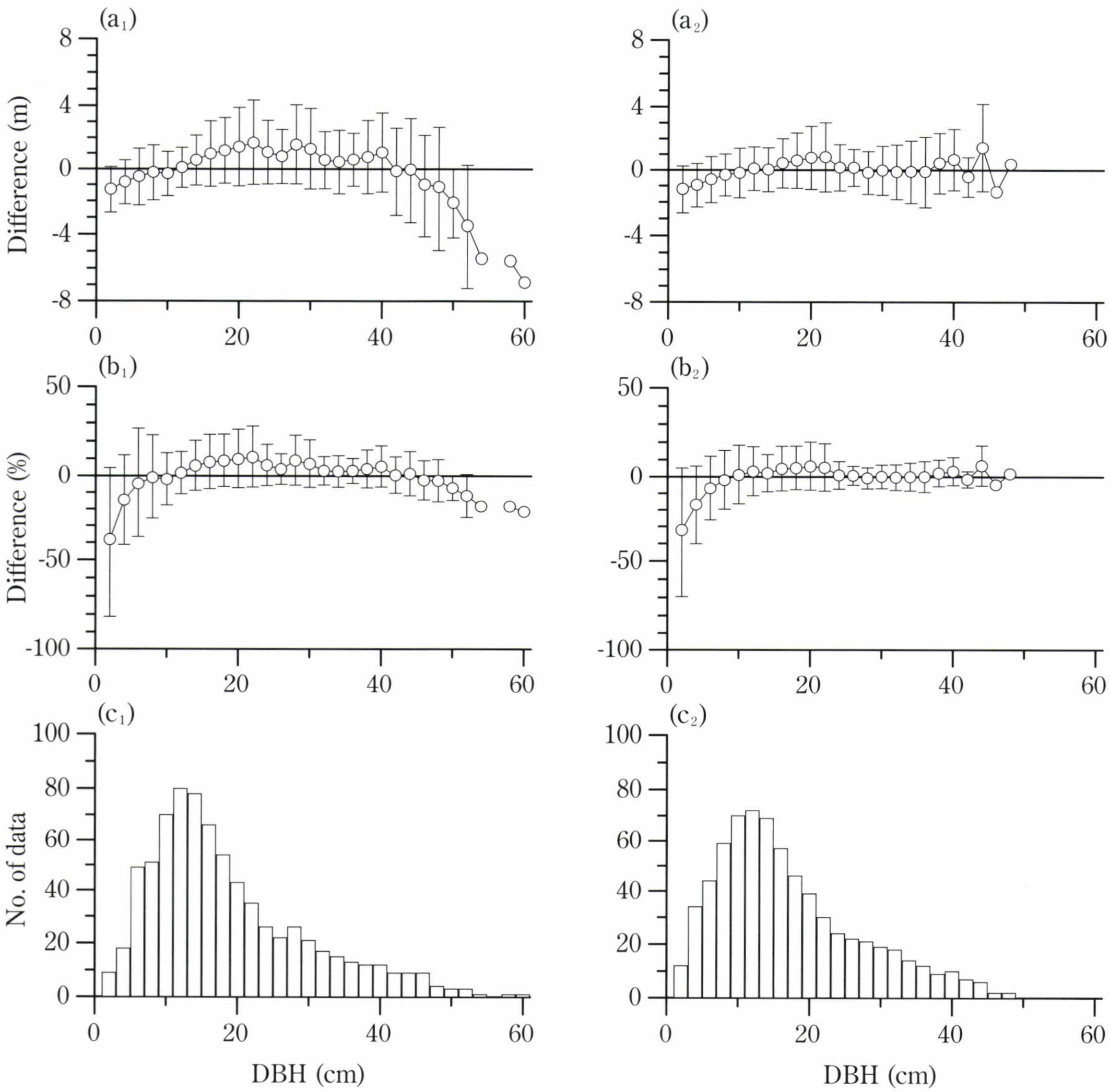

Fig. 2 Means and deviation of residuals (a_1, a_2) and the ratio of residuals to observation (b_1, b_2) of mean height of diameter class and number of plots (c_1, c_2) for modeling (a_1, b_1, c_1) and test (a_2, b_2, c_2) data relative to diameter class (cm)

Table 3 Means (Bias) and deviation (RMSE) of absolute and relative residuals of stand volume prediction and the number of plots for modeling and test data relative to prediction period (years). Relative residuals were determined as the ratio of residual to observed values

Prediction	Modeling data					Test data				
Period	Bias		RMSE		No.of	Bias		RMSE		No.of
(years)	(m^3/ha)	(%)	(m^3/ha)	(%)	plot	(m^3/ha)	(%)	(m^3/ha)	(%)	plot
2	50.9	34.6	79.0	55.4	22	40.9	29.7	60.2	52.3	21
5	72.0	35.2	136. 2	64.0	26	62.9	39.3	103.3	75.4	27
10	-16.2	-4.0	84.6	13.4	5	-13.2	-3.5	91.0	15.5	6
15	-34.9	-6.4	109.8	15.8	5	-19.9	-4.6	118.3	18.6	6

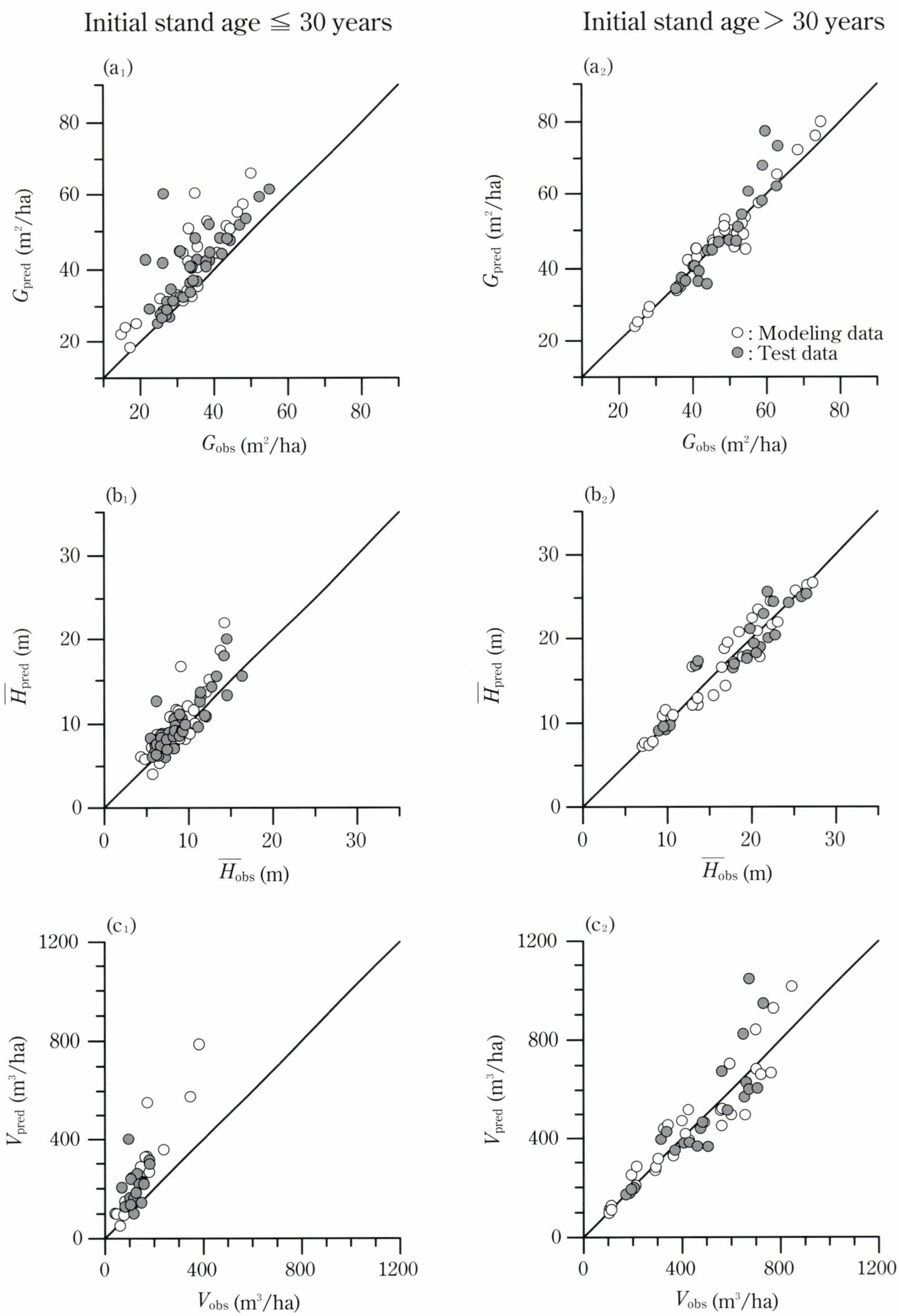

Fig. 3 Scatter plots of observed and predicted basal area (a_1, a_2), mean tree height (b_1, b_2) and stand volume (c_1, c_2) in the modeling (a_1, b_1, c_1) and test (a_2, b_2, c_2) data. In these figures, open and closed circles refer to modeling and test data, respectively

Table 4 Means (Bias) and deviation (RMSE) of absolute and relative residuals of stand volume prediction and the number of plots in the modeling and test data (initial stand age was greater than or equal to 30) with respect to prediction period (years). Relative residuals were determined as the ratio of residual to observed values

Prediction	Modeling data					Test data				
Period	Bias		RMSE		No.of	Bias		RMSE		No.of
(years)	(m^3/ha)	(%)	(m^3/ha)	(%)	Data	(m^3/ha)	(%)	(m^3/ha)	(%)	Data
2	32.2	10.9	55.8	18.9	7	23.1	6.5	47.1	15.2	3
5	32.2	7.5	66.3	17.1	12	10.1	2.2	55.8	12.9	8
10	-11.0	-2.5	92.7	14.1	4	-17.1	-4.5	99.6	16.9	5
15	-34.4	-5.9	121.4	17.2	4	-28.6	-6.5	129.2	20.2	5

figures showed that when initial stand age was less than 30 years, basal area and stand volume were over-predicted. Conversely, when t_0 was greater than 30 years, the magnitude of over-prediction was reduced. We excluded all data with small t_0 (< 30 years) and re-calculated Bias, RMSE and S.E. Absolute and relative bias were 16.3m^3/ha (5.5%) for the modeling data and 13.3m^3/ha (1.7%) for the test data. The RMSEs were 83.6m^3/ha (17.3%) for the modeling data and 117.1m^3/ha (19.7%) for the test data. The Bias and RMSE for the length of prediction period in modeling and test data were re-calculated (Table 4). By excluding the data with small t0, both Bias and RMSE associated with short-term prediction were decreased.

DISCUSSION

To validate the height-diameter curve estimation model, we compared estimated and observed mean tree height for several DBH classes. The result of the validation indicated that the mean residual was less than ±1.0m for both data sets. In most DBH classes (between 6cm and 46cm), mean residuals were less than ±1.6m (Fig. 2-a_1, -a_2). These results suggest that the height-diameter curve estimation model can be applied to the estimation of mean tree height for DBH classes with less bias and that the model would be useful for diameter distribution-based stand volume prediction. In predicting the modeling and test data, we did not spread a data series for one plot between both data sets. This was done to ensure that both data sets were independent of each other. Since test data and modeling data were thus independent of each other, this model would be applicable to those stands that were not used in the development of the model.

The results of the validation component of this study indicated that the height-diameter curve estimation model tended to underestimate the mean height of DBH classes larger than 46cm (Fig. 2-a_1), which was probably attributed to an insufficient number of observations from old stands (Fig. 2-c_1). The results of the validation also indicated that the height-diameter curve estimation model tended to underestimate mean height for smaller DBH classes (Fig. 2-a_1, -a_2). However, for stand volume prediction, this would be constitute a minor consideration because trees with diameter less than 8cm are very scare in mature stands. These results suggest that the height-diameter curve estimation model would be able to predict mean tree height of DBH class for mature stands even if the predicted diameter distribution was accurate.

In this study, we tried to predict stand volume by combining DDPS, the height-diameter curve estimation model and existing stem volume function. The result of the validation indicated that stand volume was slightly over-predicted in both data sets and that, due to the characteristics of DDPS, this bias decreased by eliminating the data for younger stands (t_0 < 30 years). Generally, in prediction procedures like ours, the predicted value of stand volume usually contains, (i) a predictive error in predicted diameter distribution, (ii) an estimation error in mean tree height for DBH classes estimated using height-diameter curves based on observed diameter distribution, and, (iii) an error in the estimated mean tree height of DBH classes using height-diameter curves based on predicted diameter distribution, which contains a predictive error. If the predictive error in DDPS decreased, error (iii) would decrease and stand volume prediction would be improved. The predictive error of DDPS is important for stand volume prediction. In our previous study, we found that there were significant differences between predictions and observations when $t_0 \leq 30$ years and that DDPS would perform accurately when $t_0 > 30$ years (HAYASHI and YAMAMOTO, 2006). In this study, basal area was slightly over-predicted in younger stands (Fig. 3-a_1), which affects the estimation of mean tree height for DBH class. Conversely, when initial stand age was greater than 30 years, basal area could be accurately predicted (Fig. 3-a_2), which would then permit accurate estimation of mean tree height for DBH classes and accurate prediction of stand volume (Fig. 3-c_2). It is suggested that the prediction error of stand volume was dependent upon the predictive ability of DDPS.

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*: The titles are tentative translations from original Japanese translated by the authors of this paper.

(Received 7 February 2006)
(Accepted 16 March 2006)

Article

Classifying Plantation Forests in a Snowy Region According to Cutting Age using GIS: A Case Study of Private Forests in Sanpoku Town, Niigata Prefecture

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ABSTRACT

Forest stands must be evaluated before making zoning or harvest plans. This paper evaluated the net income of managed sugi (Japanese cedar, *Cryptomeria japonica* D. DON) plantations in private forests in a snowy region and classified sugi plantations according to the probability of harvesting, using a geographic information system (GIS), in a case study of private forests in Sanpoku Town, Niigata Prefecture. The town includes both low coastal and mountainous inland areas and the snow depth varies markedly. Two transfer points were assumed: a timber market and a local wood-related complex. First, log production was predicted according to site quality, using an existing stand density management diagram, as well as height growth curves to obtain log volumes according to log length and top diameter class. Gross income was estimated from log prices and the predicted log production according to site quality. Then, the total cost from planting through to logging was estimated for standard conditions of productivity, necessary workforce and wages, using four factors: site quality, yarding distance, the deepest snow depth and slope angle. The cost of plantation forest management included the regeneration cost for establishing new plantations and the logging cost for final cutting. Forest net income was evaluated for three cutting ages: short, intermediate and long rotation. Finally, sugi plantations were classified according to the probability of harvest and the area of each class was obtained using GIS on the assumption of present, 10% higher and 10% lower log prices. Site quality was the more important factor in sugi plantation management; it was more important than yarding distance or the deepest snow depth. Prices 10% lower than present prices on the Niigata Timber Market were the minimum necessary to maintain timber production from sugi plantations in private forests, given present costs and subsidies.

Keywords: cutting age, net income, site quality, snow depth, sugi, yarding distance

INTRODUCTION

Many of the plantation forests in Japan were established after 1950, when natural hardwood forests were converted into coniferous plantations. The cutting area of these coniferous plantations is expected to increase in the near future. However, low timber prices, increased wages and the reduction and aging of the forestry workforce have decreased the cutting area of coniferous plantations, especially in private forests. The final cutting of many coniferous plantations has been postponed. Simultaneously, high-performance forestry machines have been introduced to increase productivity and reduce harvest costs. Therefore, plantation forests should be classified according to management goals and harvests should be scheduled. Moreover, each stand should be evaluated before making decisions with regard to zoning and the scheduling of harvest, for example. Usually site quality and yarding distance are used to classify production forests.

IEHARA and KUROKAWA (1990) compared the profitability of hinoki cypress (*Chamaecyparis obtusa* (SIEB. et ZUCC.) ENDL.)) reforestation for different site qualities, and HASEGAWA (2000) evaluated the profitability of sugi (Japanese cedar, *Cryptomeria*

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japonica D. DON) plantations, taking into account the effect of site quality. IEHARA (1993) evaluated the profitability of long-rotation management of a hinoki cypress plantation. The economic evaluation of plantation forests using site quality and rotation-length can be simulated using existing growth models. However, it is relatively difficult to evaluate the differences between yarding distance classes, because the productivity of reforestation and harvest operations are difficult to model using yarding distance classes. Moreover, it is not clear how snow depth affects the profitability of sugi plantations in a snowy region.

Geographic information systems (GIS) have been used to make or simulate forest plans; these systems consider not only the sustainability of forest resources, but also the spatial distribution of forests. GIS plays an important role in spatial decision support systems (SDSS). For example, KILGOUR (1992) developed a computer-based information system for recording and retrieving data on plantation resources, predicting growth and yield and forecasting the future availability of sawlogs and roundwood. NÆSSET (1997) developed an SDSS for long-term forest management planning that coupled GIS and linear programming.

The objectives of this study were to evaluate the net income of sugi plantations in private forests in a snowy region and to classify sugi plantations according to the probability of harvest, using GIS, in a case study of private forests in Sanpoku Town, Niigata Prefecture. Site quality, yarding distance, slope angle and the deepest snow depth were considered. First, log production was predicted by simulating growth to obtain log volumes, according to log length and top diameter class. Gross income was estimated from the predicted log production and log prices. Then, the total cost from planting through to logging was estimated using standard conditions for productivity, labour and wages. Net income was evaluated for three cutting ages: short, intermediate and long rotation. Finally, sugi plantations were classified according to the probability of harvest and the area of each class was obtained using GIS.

STUDY AREA AND DATA

Study Area

The study area consisted of private forests in Sanpoku Town, Iwafune County, Niigata Prefecture (38° 21-33' N, 139° 27-43' E). Fig. 1 shows the location of Sanpoku Town in northernmost Niigata Prefecture, Japan. The total area of private forest is 23,175ha, which is 82% of the total area of the town. The main forest type in this area is sugi plantation, which covers 7,368ha. The elevation varies less than 1,000 m, as shown in Fig. 2. The average deepest snow depth between 1971 and 2000 ranges from less than 1m near the coast to up to 2m inland (JAPAN METEOROLOGICAL AGENCY, 2002), as shown in Fig. 3.

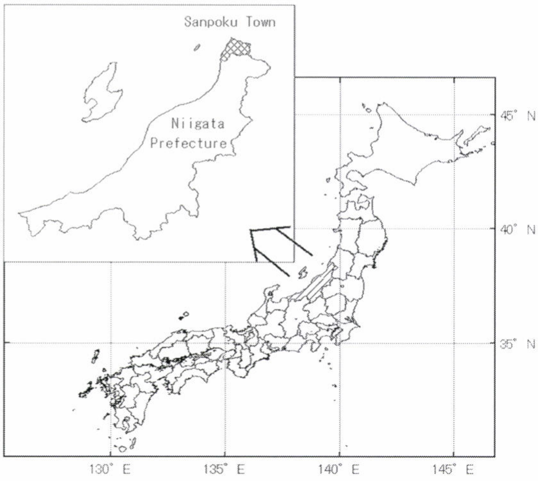

Fig. 1 Location of the study area

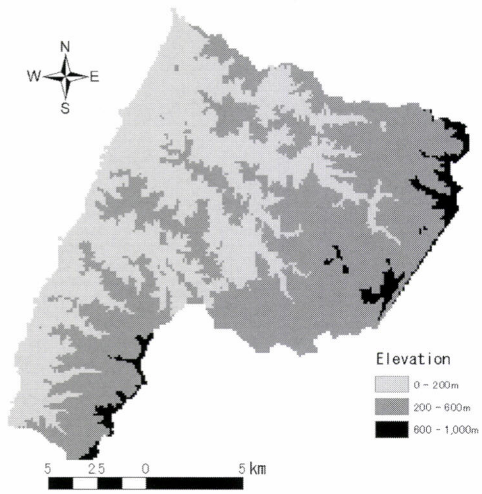

Fig. 2 Elevation of the study area

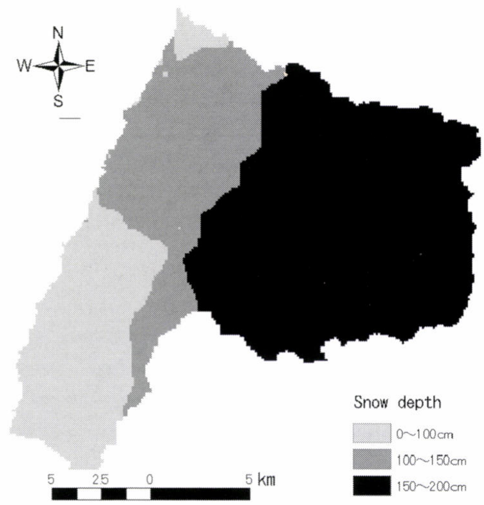

Fig. 3 The average deepest snow depth between 1971 and 2000 in the study area

Timber produced in private forests is sold in timber markets, especially the Niigata Timber Market in Niigata City, or to local sawmills. Recently, forest owners and timber dealers constructed *Sugitopia Iwafune*, a complex of sawmills, a laminated wood factory and wood products factories in Sanpoku Town, to produce standardized timber from sugi in this region. This study evaluated two cases: logs transported to Niigata Timber Market or to *Sugitopia Iwafune*.

GIS Data

ArcGIS 8.1.2 (ESRI, 2001b), including ArcInfo Workstation 8.1.2 (ESRI, 2001a), was used as the GIS for this study. Twenty-three 1:5,000 scale forest maps were input into the GIS by digitizing the boundaries of compartments, subcompartments, contours and roads. Attribute data, which were written in a forest book, were stored in a database table for each subcompartment. The attribute table included the area, forest conditions (*e.g.,* species and stand age) and site conditions (*e.g.,* soil type and surface geology). A digital elevation model (DEM) was created for the study area from the contours and the spot heights of mountaintops. The spatial resolution of the DEM was set at 5×5m, because many forest owners have small stands. The deepest snow depth was interpolated from the "Mesh Climatic Data 2000" produced by JAPAN METEOROLOGICAL AGENCY (2002).

METHODS

Silvicultural Systems

Site index based on an index age of 40 years was classified into three categories: site quality 1 (good), ≥19.4m; site quality 2 (medium), 15.7-19.4m; and site quality 3 (poor), <15.7m. Yarding distance was classified into five categories at 200m intervals: 0-200, 200-400, 400-600, 600-800 and 800-1,000m. The deepest snow depth was classified into three categories: 0-1, 1-1.5 and 1.5-2m. Slope angle was classified into four categories: 0-15, 16-25, 26-35 and 36+ degrees.

Density at planting was set at 2,500 trees/ha for site quality 1 and 3,000 trees/ha for site quality 2 and 3. The regenelation operations shown in Table 1 were assumed. In the study area, snowfall bends stems in winter and the stems need to be straightened by tying them up with rope. Forest managers should perform this operation until the average tree height exceeds two and half times the deepest snow depth

Table 1 Standard amount of labour (mandays/ha) required for each regeneration operation

		Site quality		
Stand age	Operation	1	2	3
1	Site preparation	28.5	28.5	28.5
	Planting	35.1	42.0	42.0
2	Reinforcement planting	1.7	2.0	2.0
	Releasing	8.7	8.7	8.7
3	Releasing	11.5	11.5	11.5
	Straightening stems	15.5*	18.3*	18.3*
4	Releasing	11.5	11.5	11.5
	Straightening stems	15.5*	18.3*	18.3*
5	Releasing	11.5	11.5	11.5
	Straightening stems	15.5*	18.3*	18.3*
6	Releasing	11.5	11.5	11.5
	Straightening stems	18.8**	22.6*	22.6*
7	Releasing			11.5
	Straightening stems	18.8**	22.6**	22.6*
8	Straightening stems		22.6**	22.6*
9	Straightening stems		22.6**	22.6**
10	Straightening stems			22.6**
11	Straightening stems			22.6**
12	Veining	10.0	10.0	10.0
13	Cleaning	14.0	14.0	14.0
	Pruning	17.0	17.0	17.0
17	Pruning	25.4	25.4	25.4

Note: *, operations for the deepest snow depth ≥ 1m
**, operations for the deepest snow depth ≥ 1.5m

(NOOMOTE, 1988; 1989). The intermediate-grade thinning system was assumed for the thinning schedule and intensity. The thinning ratio was 25% in terms of density and thinning was carried out at the age of 20, 30,40, 50 and 60 years.

Predicting Log Production and Gross Income

Log production was predicted by site quality to obtain log volumes based on log length and top diameter class (TATSUHARA and MINOWA, 1992). The existing stand density management diagram for sugi on the Japan Sea side of the Tohoku and Hokuriku regions, and height/age curves for sugi in Niigata Prefecture (EROSION CONTROL SECTION, 1980) were used. Gross income was estimated from the predicted log production and log prices. The growth of model stands was simulated according to the thinning system at five-year intervals, beginning at 20 years.

Predicting the average height of dominant and codominant trees

The average height of dominant and codominant trees was obtained from the height/age curve. Mitcherlich's formula was used as the height/age curve as follows:

$$h(t) = 34.789\{1 - 1.0906\exp(-0.0259\,t)\} \text{ for site quality 1,}$$
$$h(t) = 28.873\{1 - 1.0853\exp(-0.0254\,t)\} \text{ for site quality 2,}$$
$$h(t) = 22.732\{1 - 1.0846\exp(-0.0254\,t)\} \text{ for site quality 3,}$$

where t is age in years and $h(t)$ is the mean height in meters.

Site quality 1, 2 and 3 corresponded to site quality 1, 3 and 5, respectively, in the yield tables for Niigata Prefecture (EROSION CONTROL SECTION, 1980). Average height is as important as density, as it is required when using the stand density management diagram.

Predicting diameter distribution

Both mean diameter and the diameter distribution are necessary for predicting log products according to log length and top diameter class. The Weibull distribution was used for the diameter distribution. The mean diameter and quadratic mean diameter were predicted from stand density and average height, using the stand density management diagram. The variance of diameter V was obtained from the mean diameter D and quadratic mean diameter D_q as follows:

$$V = D_q^2 - D^2.$$

The mean and variation coefficient of diameter determined parameters b and c, using GARCIA's (1981) approximation method. Parameter a, which expresses the smallest diameter in the stand, was estimated from age, t, and the number of trees per hectare, n, using the following equation developed by NAGUMO *et al.* (1981):

$$a = p\,t^q\,n^r,$$

where p, q and r are parameters.

Predicting the height curve

The height curve was used to obtain the height from the diameter class. This curve was predicted from the mean height and mean dbh using a dimensionless height curve (NAGUMO *et al.* 1981), in which height h and dbh d are treated as dimensionless quantities divided by the average as follows:

$$\frac{h}{H} = \left(\frac{d}{D}\right)^{0.5594-0.00178t}$$

where t is age, H is the mean height and D is the mean dbh.

Predicting the stem taper curve

The stem taper curve was used to estimate log volume for log length and top diameter class. The true stem form for the diameter class was predicted from the height and dbh for the relative stem taper curve. KUNZE's formula was used as the stem taper curve.

$$y^2 = p\,x^r,$$

where x is relative height, $(h - m)/h$, y is relative diameter, $d\,/\,d_{0.9}$, h is total height, d is diameter at height m above the ground, $d_{0.9}$ is diameter where relative height x is 0.9, p and q are parameters.

The stand form factor was predicted from the number of trees and mean height of dominant and codominant trees, using the stand density management diagram. Setting breast height form factor at the stand form factor, the parameters of the relative stem taper curve were obtained by solving the equations derived from the relative volume.

Predicting log volume based on log length and top diameter class

After estimating the diameter distribution, average heights for diameter class and stem forms for diameter class, the log cross-cutting strategy makes it possible to predict log numbers and log volumes, according to log length and top diameter class in a stand. First, as many 4-m logs with a minimum top diameter of 30cm as possible were cut from a tree. This was then repeated for 3.65-m logs with a minimum top diameter of 22cm, 3-m logs with a minimum top diameter of 18cm and 4-m logs with a minimum top diameter of 8cm. FLURY's diameter elliptic ratio was assumed to be 4.5%, to estimate the shortest diameter at the top end.

Predicting gross income

Gross income was estimated by multiplying log volume and log price for each log length and top end diameter class and summing these values. Log prices were set at the average log prices for 2002 on the Niigata Timber Market and *Sugitopia Iwafune*, as shown in Table 2. Log prices was declining gradually and the average log prices in 2000, two years before, was 10% higher than those in 2002. Thus log prices were also set at 10% higher and 10% lower than the prices in 2002 as a range of possible fluctuation. The log prices per m^3 vary with log length and top end diameter class. The

Table 2 Log prices (Yen/m^3) by log length and top end diameter class

	Log length	Top end diameter		
		Small	Intermediate	Large
Niigata Timber Market	4 m	10,380		28,880
	3.65 m		14,480	28,880
	3 m	10,380	13,600	
Sugitopia Iwafune	4 m	9,000		17,000
	3.65 m		16,000	17,000
	3 m	9,000	14,500	

Note: Small, intermediate and large top end diameter class include diameters of 6-13, 14-28 and 30+ cm, respectively

Niigata Timber Market charges a commission of 8% on sales, while the *Sugitopia Iwafune* does not.

Estimating Expenses

The cost of plantation forest management includes (1) the regeneration cost for establishing new plantations and (2) the logging cost for thinning and final cutting.

Regeneration cost

The regeneration cost includes costs for planting, releasing, veining, cleaning, pruning and straightening. The planting density was specified as 2,500 trees/ha for site quality 1 and 3,000 trees/ha for site qualities 2 and 3. The reinforcement planting density was assumed to be 5% of the planting density. The seedling price was set at 75 yen for planting and 90 yen for reinforcement planting. We assumed that stems were straightened with rope until the average tree height exceeded two and half times the deepest snow depth. The average height was estimated using the height/age curves for each site quality and the deepest snow depth was estimated from the "Mesh Climatic Data 2000". The price of rope was set at 1,000 yen/roll for 2.5-bu(7.5-mm)-thick rope, which was used in 3- to 5-year-old stands and 900 yen/roll for 3-bu (9-mm)-thick rope, which was used in 5- to 10-year-old stands.

Workers' wages were set at 11,000 yen/day (MHLW, 2003). The ratio of insurance to wages was assumed to be 27.325% (OGURA and OGURA, 1997) and included workmen's accident compensation insurance, health insurance, welfare annuity insurance and unemployment insurance. The standard amount of labour required for each regeneration operation, when calculating silvicultural subsidies, was used. It is summarized by site quality in Table 1. The actual amount of labour was estimated from the standard amount of labour multiplied by a distance coefficient DI (TAKAHASHI *et al.*, 1996). This coefficient was calculated as follows:

$$DI = 0.95858 + 0.01523\,S + 0.00008\,D,$$

where S is the slope class and D is the distance to the nearest road (m). Slope class was 1, 2, 3, or 4 for slope angles of 0-15, 16-25, 26-35, or 36+ degrees, respectively. Miscellaneous expenses were assumed to be 8.7% of wages and were added to the site preparation, releasing and cleaning costs.

Logging cost

Logging costs consist of (a) logging operation costs and (b) common logging costs required to install and remove a yarder and log deck, maintain the logging site and transport workers. Logging and common costs were estimated, mainly, using the methods described by UMEDA *et al.* (1982)

The conventional logging system was used to estimate logging costs because the conventional system is still used in Sanpoku Town. For final cutting, the following system was assumed:

Felling with a chain saw → cable yarding → bucking with a chain saw

For thinning, felling with a chain saw was assumed because thinning does not generate income and thinned trees are left in the forest in most cases.

1. Logging operation cost

The logging operation cost is the sum of the operation costs for felling, yarding and bucking, as well as transportation costs. The operation costs include four costs: the machine rental cost including attachment rental, fuel expenses, personnel expenses and miscellaneous expenses for each operation and are calculated as follows:

Machine rental cost per m^3 = machine price × the rate of depreciation per hour × working hours per day / productivity,

Fuel expenses per m^3 = the amount of fuel per day × fuel price / productivity,

Personnel expenses per m^3 = wage × the number of workers / productivity.

where productivity means log volume produced for a day per person. The wages of loggers were set at 14,000 yen/day.

The ratio of insurance to wage was assumed to be 27.325%. Miscellaneous expenses were assumed to be 10% of the wage.

The transportation cost was estimated as the trucking fare per m^3, dividing the truck fare by the load capacity. The nearest timber market, Niigata Timber Market, is about 110 km from Sanpoku Town, while the distance to *Sugitopia Iwafune* was set at 10 km. We assumed that 6-ton trucks were used and the fares were set at 40,050 and 13,900 yen, as the average fares for 110 and 10km, respectively, according to the Niigata Prefecture Trucking Association. Therefore, the cost was calculated at 6,675 and 2,317 yen/m^3 for the Niigata Timber Market and *Sugitopia Iwafune*, respectively.

The logging operation cost per m^3 without insurance, miscellaneous expenses and transportation cost was estimated from the productivity of felling and bucking, P_1, and the productivity of yarding, P_2, using the following equation:

Logging operation cost per m^3 without insurance, miscellaneous expenses and transportation cost (yen/m^3) = 16,496 / P_1 + 67,708 / P_2 + 737.

Then, the total logging operation cost per m^3, including these costs, was estimated using the following equation:

Total logging operation cost per m^3 (yen/m^3) = 21,722/P_1 + 89,781/P_2 + 4112.

The total logging operation cost was evaluated by multiplying the total logging cost per m^3 by log volume.

The productivity of felling and bucking depends on the volume per harvested tree and harvested volume per ha (UMEDA *et al.*, 1982). The productivity of felling and bucking was modelled from figures drawn by UMEDA *et al.* (1982) as follows:

$P_1 = 12.29472\sqrt{x} - 0.56379$ for final cutting when the harvested volume ≥ 300m^3/ha,

$P_1 = 9.075685\sqrt{x} - 0.53892$ for thinning when the harvested volume is between 50 and 300m^3/ha,

$P_1 = 7.526339\sqrt{x} - 0.42195$ for thinning when the harvested volume is between 30 and 50m^3/ha,

$P_1 = 6.000566\sqrt{x} - 0.35033$ for thinning when the harvested volume < 30m^3/ha.

The productivity of felling and bucking was estimated from the volume per harvested tree, x. Felling was assumed to contribute 30%, in the combination of felling and bucking. If thinning did not pay, bucking was not carried out. Therefore, the productivity was estimated by multiplying the above value by 10/3. The productivity of yarding depends on the volume per harvested tree, yarding distance and engine power (UMEDA *et al.*, 1982). The productivity of yarding was modeled from figures drawn by UMEDA *et al.* (1982) as follows:

$P_2 = 0.95\ (58.273\,x + 7.448)$ for yarding distance class =1,

$P_2 = 0.95\ (50.636\,x + 6.679)$ for yarding distance class =2,

$P_2 = 0.95\ (48.000\,x + 4.100)$ for yarding distance class =3,

$P_2 = 0.95\ (44.636\,x + 3.219)$ for yarding distance class =4,

$P_2 = 0.95\ (40.375\,x + 2.197)$ for yarding distance class =5,

where 0.95 is a modification coefficient for a cable yarder with an intermediate (20-75 horsepower) to powerful engine. The productivity of yarding was estimated from the volume per harvested tree, x, and the yarding distance class, assuming that a cable yarder has a intermediate engine.

Table 3 The amount of labour (mandays) required to install and remove a yarder and log deck

Yarding distance class	1	2	3	4	5
Installing yarder	10	24	38	52	67
Removing yarder	3	4	11	16	20
Installing log deck	16	16	16	16	16
Removing log deck	5	5	5	5	5

Note: class 1, 0-200m; class 2, 200-400m; class 3, 400-600m; class 4, 600-800m; class 5, 800-1,000m

2. Common logging costs

Common logging costs include the costs for installing and removing the yarder and log deck, maintaining the logging site and transporting workers. The amount of labour required to install and remove a yarder and log deck is shown for yarding distance class in Table 3. The amount of labour required to install and remove a yarder increased with the yarding distance, while the amount of labour required to install and remove a log deck is constant, regardless of the yarding distance. The costs of installing and removing a yarder and log deck were estimated as personnel expenses. The wages of loggers and miscellaneous workers were set at 14,000 and 11,000 yen/day, respectively. The ratio of insurance to wages was assumed to be 27.325%. These costs do not depend on the cut area or harvested volume and the costs per m^3 decrease with increasing yield. Other costs were estimated using the method of the Forestry Agency of Japan, as follows:

Cost of maintaining a logging site (yen) = 0.0587 × stand volume × wage,

Cost of transporting workers (yen) = x × (8.1 - 3.4 × log (int(x / 1,000,000)) / 100,

where x is the total cost at a logging site, *i.e.*, the logging cost and costs of installing and removing a yarder and log deck without insurance, miscellaneous expenses and transportation costs.

Subsidies

The central government and Niigata prefectural government subsidize silvicultural operations. Together, the two governments subsidize 40% of the cost of planting, releasing, straightening, thinning and pruning; the prefectural government alone subsidizes another 30% of the cost of releasing, straightening, thinning and pruning. Note that the standard subsidy costs for both governments are higher than those for the prefectural government alone. The net income was calculated after considering subsidies.

GIS Processing

Site quality was estimated for each subcompartment from elevation, slope aspect, slope angle, soil type, sedimentation type, microtopography, surface geology and the deepest snow depth, using the model developed with type I quantification theory by the Niigata Prefectural Government (EROSION CONTROL SECTION, 1978). Elevation, slope aspect and slope angle were estimated from the DEM. Sedimentation type and microtopography were also estimated from the DEM, using the values for specific catchment areas calculated from the water flow direction on the DEM. Soil type and surface geology were obtained from the subcompartment attribute table and the deepest snow depth was from the "Mesh Climatic Data 2000". The site index was estimated for each cell of a raster layer, using the model, and then the average site index for each subcompartment was calculated from the cells on the raster layer using a zonal function of the GIS.

Yarding distance was estimated for each subcompartment from the road data, calculating the straight-line distance to a road. Cable yarding systems were used to carry logs from the stand to a road in the logging system. The horizontal distance to the road was used as an easy index of the yarding distance instead of the true yarding distance, because landing points are not fixed, but are chosen for each logging situation. The yarding distance was estimated for each cell in the raster layer and then the average yarding distance for each subcompartment was calculated from the cells in the raster layer using a zonal function of the GIS.

Larvae of the long-horned beetle (*Anaglyptus subfasciatus* PIC) sometimes bore into the trunk from dead branches and eat dead knots, reducing the value of the trunk because of resulting decay and discolouration. Plantations affected by gales are damaged more easily because more branches in these forests are broken by the wind. In this study area, strong northwesterly winds occur in winter. Therefore, the subcompartments exposed to the northwesterly wind were assigned a higher probability of damage, using the shaded relief function of the GIS. The solar azimuth and altitude were set at 315° and 0°, respectively.

Classifying Stands by Cutting Age using Net Income

Net income was evaluated for stand ages of 50, 60 and 80 years, which correspond to short, middle and long rotations, respectively, by subtracting expenses from the gross income and considering subsidies. The discount rate was set at zero, based on forest rent theory, because most owners have small forests in Japan and tend to base harvest decisions on the net income, which is based, in turn, on harvesting profit and regeneration cost. This varies with site quality, yarding distance, slope class and the deepest snow depth. The subcompartments were classified into four classes: (1) Class A: stands where the net income becomes positive by age 50; these plantations could be harvested using a short rotation, (2) Class B: stands where the net income becomes positive between age 50 and age 60 and have a low probability of damage; these plantations could be harvested using an intermediate rotation, (3) Class C: stands where the net income becomes positive between age 60 and age 80 and have a low probability of damage; these plantations could be harvested using a long rotation and (4) Class D: stands where the net income is still negative at age 80 or where the net income is negative at age 50 and the probability of damage is high due to strong winds in winter; these plantations are not suitable for timber production.

RESULTS AND DISCUSSION

The site index was classified according to the three site qualities, as shown in Fig. 4. Yarding distance was classified according to the five categories, as shown in Fig. 5. The classification of sugi plantations into the four classes is shown in Fig. 6 and the areas of the sugi plantations in each class are shown in Table 4. The figure and table show three cases: (a) present timber prices, (b) 10% higher timber prices and (c) 10% lower timber prices.

For present timber prices, when transporting logs to the Niigata Timber Market, class D occupied about 70% and 30% belonged to classes B and C. The latter two classes are scattered around the southern coastal area, where the deepest snow depth is less than 1m and stands have good site quality. For logs transported to *Sugitopia Iwafune*, profitability was improved. The percentage of class D decreased, while those of the other three classes increased, and class C occupied about 40%. As a result, stands in the coastal area and stands of good quality belonged mainly to classes A and B and inland stands belonged mainly to class C.

For prices 10% higher than the present level, for logs transported to the Niigata Timber Market, the percentage in class D dropped dramatically and 65% belonged to class C. Some stands in the southern coastal area, where the deepest snow depth was less than 1 m, and some stands with good site quality, belonged to classes A and B. For logs transported to *Sugitopia Iwafune*, the percentage of classes C and D decreased and those of classes A and B increased. Class C constituted about half. Stands in the southern coastal area belonged mainly to class A and stands in other areas belonged mainly to class B.

For prices 10% lower than the present level, for logs transported to the Niigata Timber Market, most stands

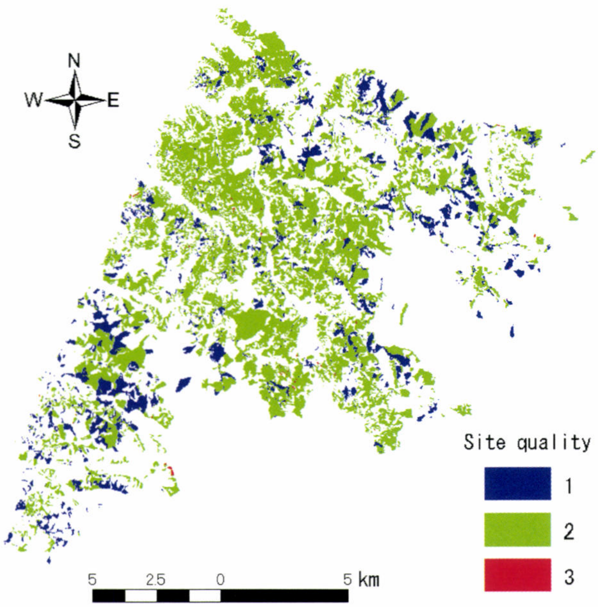

Fig. 4 Site quality in the study area

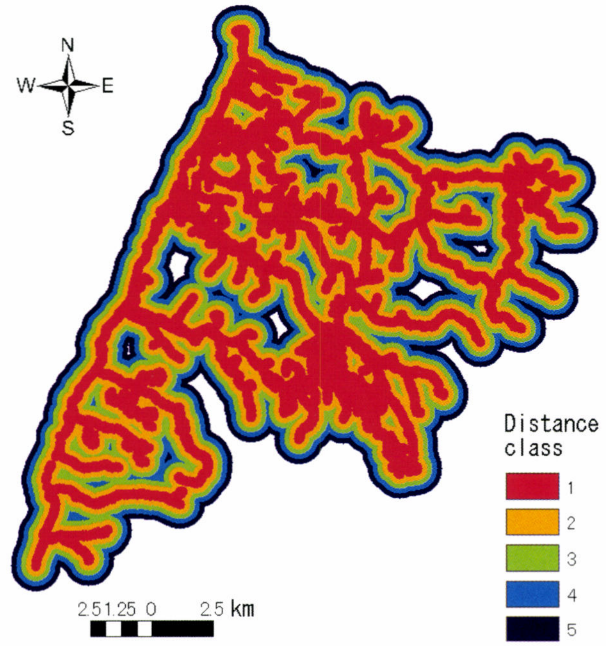

Fig. 5 Yarding distance class in the study area
Note: class 1, 0-200m; class 2, 200-400m; class 3, 400-600m; class 4, 600-800m; class 5, 800-1,000m

Table 4 Area of sugi plantations in the four classes

(a) Present timber prices

Transportation site	Class A		Class B		Class C		Class D	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Niigata Timber Market	77.0	0.8	1286.2	14.1	1498.4	16.4	6258.9	68.6
Sugitopia Iwafune	1626.3	17.8	2120.8	23.3	3866.1	42.4	1507.3	16.5

(b) Timber prices 10% higher

Transportation site	Class A		Class B		Class C		Class D	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Niigata Timber Market	997.4	10.9	581.0	6.4	5903.6	64.7	1638.5	18.0
Sugitopia Iwafune	2651.2	29.1	4866.2	53.4	899.0	9.9	703.9	7.7

(c) Timber prices 10% lower

Transportation site	Class A		Class B		Class C		Class D	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Niigata Timber Market	0.0	0.0	835.9	9.2	594.6	6.5	7690.0	84.3
Sugitopia Iwafune	1282.8	14.1	433.9	4.8	2369.2	26.0	5034.6	55.2

Note: class A, short rotation; class B, intermediate rotation; class C, long rotation; class D, unsuitable for timber production

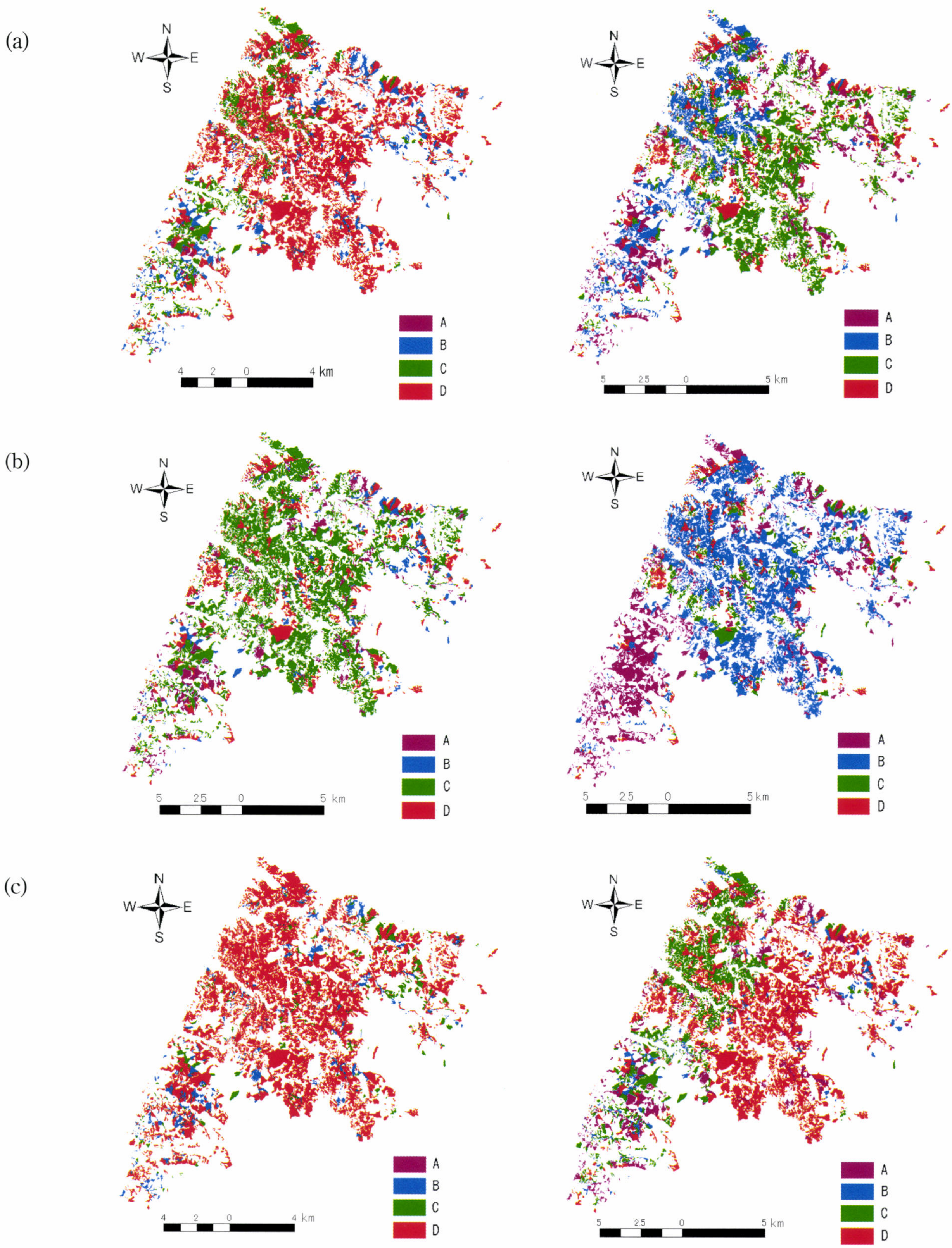

Fig. 6 Classification of sugi plantations into four classes
(a), present timber prices; (b), 10% higher timber prices; (c), 10% lower timber prices
Left, transporting logs to the Niigata Timber Market; Right, transporting logs to *Sugitopia Iwafune*
Note: class A, short rotation; class B, intermediate rotation; class C, long rotation; class D, unsuitable for timber production

belonged to class D. For logs transported to *Sugitopia Iwafune*, the percentage of class D increased to 55% and those of the other three classes decreased. Class B occupied about half. Class A, B and C stands occurred mainly in the coastal area and most inland stands belonged to class D.

Regeneration cost accounts for around half of the total cost. Fig. 7 shows the standard total regeneration cost and subsidies by site quality and snow depth class. The straightening of stems prostrated by snow is necessary in snow depth classes 2 and 3, but not in snow depth class 1. These operations cost 20 to 40% and 30 to 50% of the total regeneration cost for snow depth classes 2 and 3, respectively; the subsidy for this operation occupied a similar percentage of the total regeneration subsidies. If this operation is carried out annually until the average tree height exceeds two and half times the deepest snow depth, it places a large burden on plantation forest management. The simulation showed the disadvantage of the costs of forest management in deep snow areas. Moreover, about two thirds of the total regeneration cost were covered by the central and local governments. The government subsidies improved the profitability of plantation management, although site quality 3 (*i.e.*, poor sites) was still

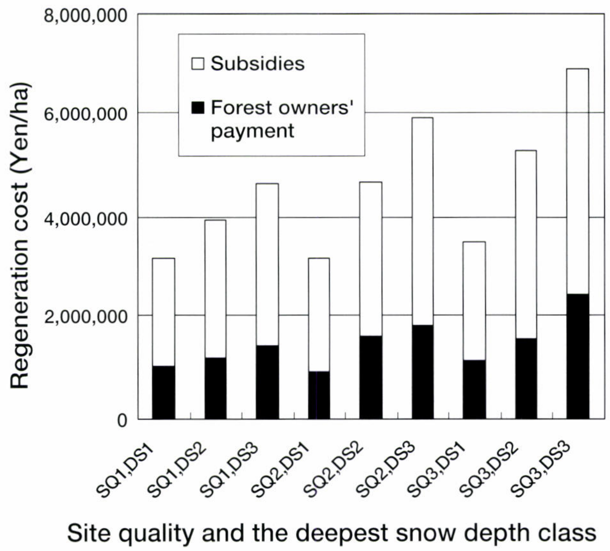

Fig. 7 The standard total regeneration cost and subsidies by site quality and snow depth class
Note: SQ, site quality; DS, the deepest snow depth class.

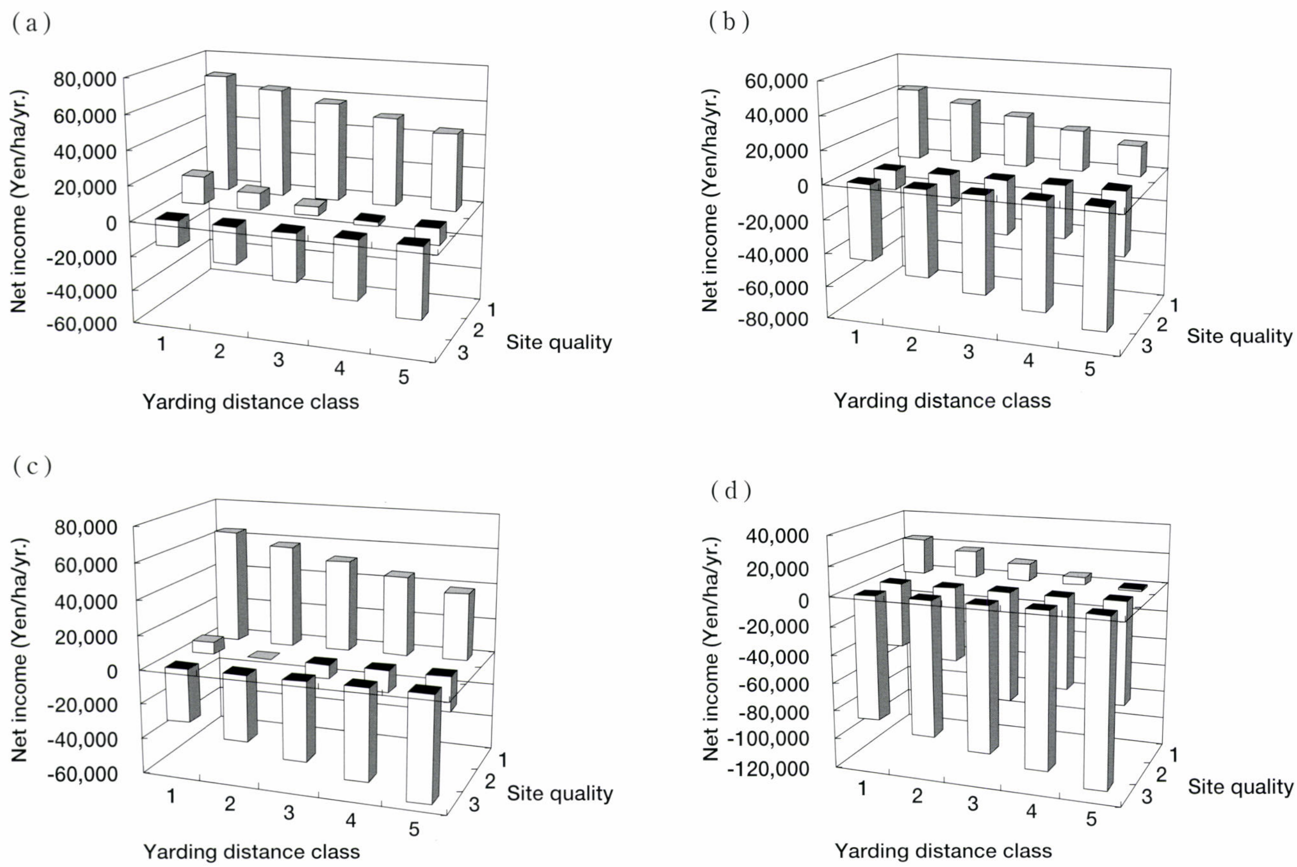

Fig. 8 The net income at the age of 80 years for slope class 2 when logs are transported to the Niigata Timber Market (a), subsidized for snow depth class 1; (b), without subsidies for snow depth class 1; (c), subsidized for snow depth class 3; (d), without subsidies for snow depth class 3

unsuitable when regeneration was subsidized. Forest owners' profitability for different regeneration ages did not change much for site quality 1, because growth was quick; however, it was most affected at the deepest snow depth for site quality 3, because the trees grew slowly.

Fig. 8 shows the net income for stands at age 80 years for snow depth class 1 and 3, for slope class 2 and for logs transported to the Niigata Timber Market. According to this figure, site quality affected the net income more than did the yarding distance class, although the net income changed with both site quality and yarding distance class. Yarding distance class affects the cost of harvesting timber and site quality affects both gross income and the cost of harvesting timber. Fig. 8 (a) and (b) show the case of snow depth class 1, where snowfall does not nearly affect forest management. Timber to be harvested depends on site quality. Thus, in this case, site quality had an even larger effect on gross income than on regeneration cost. Fig. 8 (c) and (d) show the case of snow depth class 3, where the effect of snowfall on forest management appeared sensitively. Comparing with Fig. 8 (b) and (d), the operations of straightening stems increased regeneration cost and this effect became more sensitive for stands with lower site quality, because the operation of straightening stems needs carrying out for longer period. In subsidized cases, Fig. 8 (a) and (c), the effect of snowfall became smaller than that in unsubsidised cases, as shown in Fig. 7. Yarding/skidding distance is one of the two most important variables affecting logging operations (CONWAY, 1982). However, IEHARA and KUROKAWA (1990) showed that site quality greatly affected the profitability of a hinoki cypress plantation and that site quality should have priority when considering reforestation with hinoki cypress, although they considered logging cost, but not yarding distance. Therefore, site quality should take precedence over yarding distance class when choosing sites for plantation forests.

The geographic distribution of the four classes changed with fluctuating timber prices. Fig. 6 (c) showed that prices 10% lower than the present prices in the Niigata Timber Market are the minimum required to maintain timber production from sugi plantations in private forests, given the present costs and subsidies. The geographic distribution changes with fluctuations in wages and timber prices. HASEGAWA (2000) showed that the difference in the profitability of sugi plantations among site qualities increased with wages and that the profitability fell rapidly for stands with low site quality. Sugi plantations on low-quality sites are not profitable at the present wage level.

We assumed that the logs were transported to the Niigata Timber Market or *Sugitopia Iwafune*. It is more profitable to transport logs to *Sugitopia Iwafune* because the transportation costs are lower; in addition, the prices of small and intermediate logs were very similar at the two sites, as shown in Table 2. Fig. 6 shows that constructing *Sugitopia Iwafune* improved the profitability of sugi plantation management in private forests. For large logs, however, the price at the Niigata Timber Market was higher than at *Sugitopia Iwafune*. Therefore, forest owners can sell large logs at the Niigata Timber Market and other logs at *Sugitopia Iwafune*, to maximize profitability. This selective selling improves profitability, especially for 80-year-old stands.

For private forests, the conventional logging system is still most commonly used and high-performance forestry machines are used only for about 30% of stands, although more high-performance forestry machines are being introduced to logging operations in private forests each year (FORESTRY AGENCY, 2003). The following logging system is possible for stands within 400 m of a road and slopes no steeper than 15 degrees.

Felling with a chain saw → yarding with a tower yarder → bucking with a processor

The productivity of logging systems using high-performance machines was 2.8 times that of the conventional logging system and the harvesting cost for the logging system with high-performance machines was 93% of that of the conventional logging system (FOREST POLICY SECTION, 1996). Therefore, it is possible to increase profitability by using high-performance machines for yarding distance classes 1 and 2. However, it is difficult to increase profitability for yarding distance class 3 because only a processor is available for bucking instead of chain saws.

CONCLUSIONS

The silviculture of sugi plantations using clearcutting was analyzed in terms of net income. Site quality proved to be the most important factor for sugi plantation management and was more important than yarding distance and the deepest snow depth. It was more important in a snowy region than other region in Japan because of the operation of straightening stems. The probability of harvesting sugi plantations in private forests in Sanpoku Town was classified. For present timber prices, when transporting logs to the Niigata Timber Market, 70% of sugi plantations, especially plantations affected by snowfall, were unsuitable for timber production and transporting logs to Sugitopia Iwafune proved to improve profitability. The recent decline in timber price decreased profitability of sugi plantation management rapidly in this town. Timber prices 10% lower than present prices at the Niigata Timber Market were the minimum required to maintain timber production from sugi plantations in private forests, given present conditions in terms of costs and subsidies.

Forest owners can base the probability of cutting their stands according to log prices using GIS to plan their harvest schedule and forestry officers can utilize this method to devise a regional forest plan. In addition, the net income included government subsidies, because the management of many plantation forests requires subsidies. This simulation would be useful for assessing the value of subsidies needed.

ACKNOWLEDGMENTS

We would like to thank Erosion Control Section, Department of Agriculture and Forestry, Niigata Prefectural Government for providing GIS data in forest maps and inventory records. We would also like to thank the Niigata Timber Market and *Sugitopia Iwafune* for providing timber price records.

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(Received 8 April 2005)
(Accepted 4 April 2006)

Article

Farmers in Degraded Forest in Thailand: Their Behavior and Socio-economic Conditions

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ABSTRACT

Farmers' behavior and their socio-economic conditions were studied focusing on the agricultural land use patterns and production, as well as their basic needs. An interviewing survey of farmers living in some selected forest village projects was conducted using participatory rural appraisal tools and techniques. Findings showed that field crops was found to be the major agricultural land use in all sizes of landholding, especially in the North and Northeast. On the other hand, most of the farmers were more likely to grow field crops at first thought, regardless of the size of landholding. Unlikely, paddy rice (followed by field crops) was the major agricultural land use in the Central region, whereas rubber plantation was the major one in the South. The difference in agricultural land use by regions can be attributed to the geographical, socio-economic, and environmental characteristics of each region.

The species grown in degraded forests by the farmers were not much different between the North and the Northeast regions, except more fruit trees were planted in the North. Apart from corn and cassava, cotton and sugarcane were found to be the main cash crops in the Central region, and some fast growing tree species like *Eucalyptus sp.* could be generally planted in many areas. In the South, rambutan, coconut and durian were the most popular fruit trees of the region usually grown in areas of small landholding sizes. Regarding the basic needs of farmers, the most wanted ones were income; followed by land and water respectively. However, the three important basic needs mentioned here were together at all times when farmers' need was assessed.

Keywords: degraded forest, land use, land holding, agricultural production, farmers' need assessment

INTRODUCTION

Problem of deforestation in Thailand has been recognized and considered to be one of the most important and urgent government agendas. In the 1960's, forest destruction was high, and rapidly increased to over 0.5 million ha. per year in the middle of the 1970's. Since the 1980's, the rate progressively decreased but is still unacceptably high at about 180,000ha. per year. The average clearance since the first survey in 1961 until the latest in 1998 was approximately 420,000 ha per year (RFD, 1986; 1989; 1995; 1999). The forest land areas decreased dramatically from 53.3% of the total land area in 1961 to 30.52% in 1982, 26.64% in 1991 and recently to 25.28% in 1998 (RFD, 1999).

There are several recent empirical studies that attempt to identify and explain the role of factors causing deforestation on a global and national scale (cf. Allen and Barnes, 1985; Grainger, 1986; Palo *et al.*, 1987; Panayotou and Sungsuwan, 1989; Reis and Margulis, 1990; Bilsborrow and Geores, 1994; Southgate, 1994). However, their results were conflicting and, therefore, inconclusive. For example, Allen and Barnes (1985), Grainger (1986), Panayoutou and Sungsuwan (1989), found that the population increase has a significant positive effect on the annual change in forested areas, while Westoby (1978) emphasized, that taken in isolation, there was no correlation between population variables and deforestation. Despite the fact that government policies prohibiting forest encroachment were later issued, Thai farmers continued the practice of migrating to clear new land when the agricultural

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area in their home communities was exhausted (GREPERUD, 1996). The abundance and wide distribution of forest lands ensured low production costs. It is estimated that there have been more than one million families living and cultivating in degraded forests.

One of the primary purposes of the government is to manage the conflict between national policy on land use and forests on one hand, and the needs of the people for land and forest products on the other. This study is aimed to explore farmers' activities, their socio-economic conditions and needs in relation to land use changes and forest encroachment. The study consists of two main parts - the first part focuses on the agricultural land use patterns and production, and the second part deals with basic needs assessment and the relationship between landholding, income, and needs.

MATERIALS AND METHODS

The collection of data on socio-economic conditions focusing on land use patterns, landholding size, agricultural production including need assessment was done by interviewing farmers living in 30 forest village projects representing all regions of the country (Fig. 1).

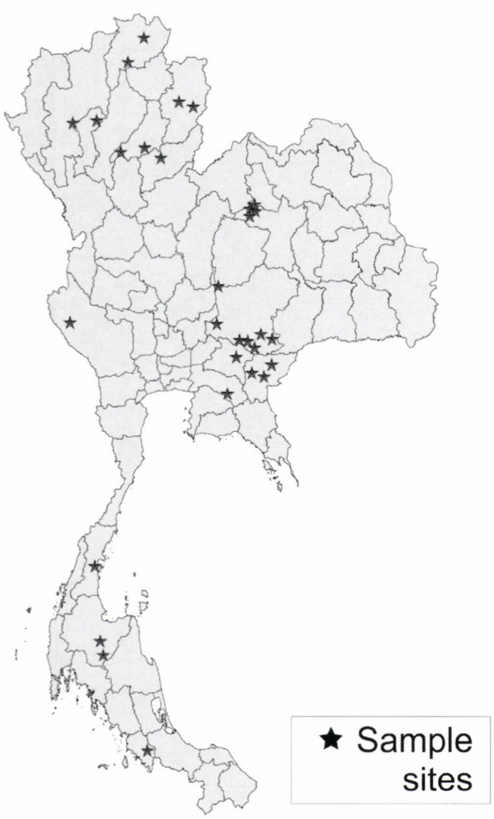

Fig. 1 Map showing sample sites for data collection

About ten forest village members of each project, who know very well about the village, were selected for an interview. The selection of interviewees was made by considering both gender and economic status. In comparison, the interview survey was also carried out with the farmers living in villages surrounding the forest reserved area. A correlation analysis was done to understand the relationship between land use patterns, landholding size, and basic needs of the farmers in each region of the country.

RESULTS

Agricultural Land Uses

In terms of cultivation area for field crops (Table 1), there was only a little difference among three categories of landholding sizes; *small* (0 - 15 rai : *rai is a unit of land area, 6.25 rai = 1 hectare*), *medium* (16 - 50 rai) and *large* (over 50 rai), indicating that farmers mostly think of growing crops as a first choice regardless how large the land they are cultivating. There are several reasons to support their decisions: 1) they have limited funds to invest, 2) they prefer to grow what they can consume with their family, 3) and the market is locally available for them to sell the crops.

Cultivation area of each agricultural land use varies by landholding size (Fig. 2). As a result of an interview survey, it seemed that there was no farmers holding large plots of land in the North, which can be attributed to hilly and mountainous characteristics of the region. Farmers with a small piece of land tended to make use of their land; mostly for field crops (38.5% of total agricultural area). But farmers holding a medium sized plot of land would rather grow field crops (83.6% of the area) than other agricultural land uses (Table 1).

Like in the northern region, major agricultural land use in the Northeast was field crop cultivation, which was (ranging from 60% - 67% of the total agricultural area) among three groups of landholding plot size. Moreover, small landholding farmers seemed to grow a smaller area of paddy rice (only

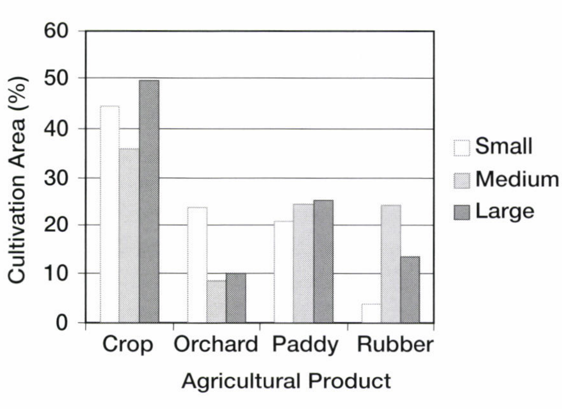

Fig. 2 Cultivation area by agricultural products and landholding size in nationwide

Table 1 Cultivation area (%) by agricultural land use and landholding size

Land Holding Size	Region	Crop	Orchard	Paddy	Rubber	Other
Small (0-15 rai)	North	38.5	30.3	23.5	-	7.7
	Northeast	67.0	18.8	11.8	-	2.4
	Central	33.0	12.5	38.5	4.9	11.1
	South	28.0	34.1	10.6	15.7	11.6
	Nationwide	44.3	23.7	20.8	3.7	7.5
Medium (16-50 rai)	North	83.6	8.2	8.2	-	-
	Northeast	60.2	13.3	21.7	-	4.8
	Central	14.9	10.5	48.3	13.9	12.4
	South	11.5	1.9	13.9	66.4	6.3
	Nationwide	36.0	8.5	24.6	24.3	6.6
Large (over 50 rai)	North	-	-	-	-	-
	Northeast	64.6	15.3	20.1	-	-
	Central	35.0	9.9	43.3	7.1	4.7
	South	35.3	-	-	64.7	-
	Nationwide	49.5	9.9	25.3	13.4	1.9

1 rai=0.16 hectare or 1 hectare=6.25 rai

11.8%) than those holding a larger piece of land.

Agricultural land use in the Central region was different from the two regions mentioned before. It was clear to see that the main agricultural land use was paddy rice, which was observed in all three groups of landholding sizes. Also, it was found that the paddy rice cultivation area in each group of landholding size was not much different. This is due to the fact that the lowland and flat areas in the Central region are most suitable for paddy rice cultivation. It was interesting to observe that field crop cultivation area in large landholding groups (35% of land area of the region) also covered as big area as its in the small landholding group (33% of land area of the region). There could be two reasons: 1) the lands belong to large landholding farmers are not in the lowland close to water resources, or 2) large landholding farmers not only grew paddy rice but also they separated some part of their land for field crop cultivation. Landholding size in the South mainly falls in small and medium groups while very few farmers hold larger plots than 50 rai of land. In small landholding size, orchards cover the largest portion of land use, followed by crops, rubber and paddy. However, in medium landholding size, rubber plantations cover the largest portion of land use type, followed by paddy, crops and orchards.

Agricultural Production

From the interview survey, the farmers grew various species of trees, cash crops and fruit orchards. An overall view; rice (22.99% of the farmers) followed by maize or corn (18.97%) and cassava (14.06%) were the main crops grown by the farmers in forest village projects. Most of them (68.08%) made use of their lands for cash crop production, and only

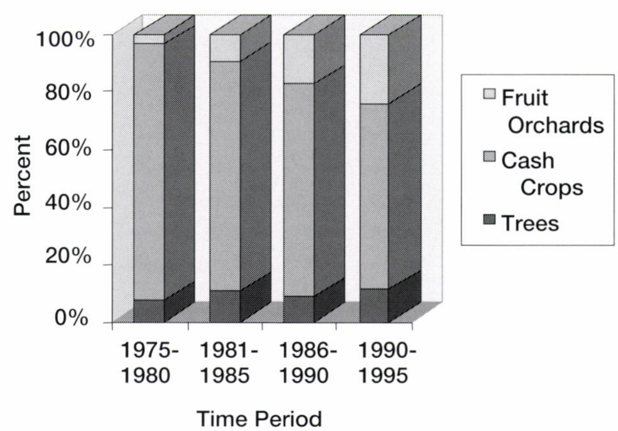

Fig. 3 Agricultural production by times in Nationwide

22.54% for fruit orchards, and 9.38% for tree plantation.

By looking at the agricultural production in different periods of time from 1975 to 1995, it was found that the farmers nationwide tended to decrease the production of cash crops, but increase the production of fruit orchards. In terms of tree planting, the farmers seemed to realize and pay more attention to the important role of forest tree plantation, especially fast growing tree species (Fig. 3).

Shifting cultivation have been widely practiced throughout the Northern region by both minority groups of hill tribes and lowland Thais. As a result of the interview survey, about 64% of the farmers grew cash crops, mainly rice (25.52%), corn (17.71%), and bean (10.94%). Fruit mainly grown in this region were lychee, longan, and mango respectively. About 10% of forest cover was found in the Northeastern region. However, one-third of the country's population live in this region, most of them are relatively poorer than those in other regions. Agricultural productivity is also relatively low due to long dry seasons. Findings revealed that about 92.8% of the northeastern farmers grew cash crops, whereas 7.2% grew fruit orchards. Corn (36.8%), cassava (35.2%) and rice (16.00%) were the main crops grown.

Geographically, areas in the Central region are characterized by flooded lowland. Therefore, about 80% of the farmers grow cash crops, followed by fruit orchards (6.66%), and trees (5.33%). The main crop production was rice, accounting for 42.67% of the farmers, followed by cassava (25.33%) and corn (8.00%). The general characteristics of Southern peninsula are rather different from the other regions. The central part of the South is covered by mountains, while areas in both eastern and western sides face the Gulf of Thailand and Andaman Sea respectively. The average annual rainfall is higher than 2,000 mm., which is suitable for rubber plantation. The results from the interview survey indicated the fact that almost 70% of the farmers preferred to plant rubber trees for their main source of income.

Farmers' Socio-economic Conditions

Migration

Migration or encroachment rate was increasingly high starting in 1965. People continued migrating into the forest illegally until 1975 when the Forest Village Project was started. However, the highest number of farmers that migrated into forest villages was in the period from 1980 to1985, because the farmers (at the beginning of the project) were still not sure and did not understand project implementation. The main reason for farmers to join the forest village project was that they needed more new land for farming (almost 50% before the project started and almost 70% after the project started). The second main reason for joining the project was that they followed their families or relatives. About 10% of them joined the project because they could not cultivate their crop in their old land (due to drought, flooding, etc.). It could be observed that the number of farmers migrating into the project tended to decrease after 1985. This could be attributed to the following three reasons: 1) farmers may migrate to work in the industrial sector, 2) the project may have limited land provided to the farmers, and 3) other land allocation programs have been started such as Land Usufructuary Program (also known as Sor Tor Kor program), and the Land Reform Program. For those who were satisfied with the land and all the facilities provided by the project, they did not move out and at the same time they persuaded outsiders such as their friends and relatives to come and join the project. But those who were not satisfied left the village and returned to their old farms or looked for new land, or they may have kept their houses, but rented their farmlands to others and looked for other non-farm jobs outside the village.

In summary, based on the questionnaire survey, it could be noticed in every region that the farmers moved in and out gradually after the project started resulting in uncertain numbers of the population. Since 1982, the population did not change until 1994 when the government stopped providing support to the forest village projects except maintaining the forest plantations. Many of the farmers were unemployed by the project and were looking for sources of additional income.

Source of Income

Generally, the farmers earned their main income from two sources; sale of goods and as laborers, varying from region to region. Since the farmers usually have not enough income from their on-farm activities, many of them have other sources of income from off-farm activities. It could be, however, noticed that 42% of the farmers' main source of income was laborers wages, whereas 32% come from selling their goods and products (Fig. 4). By comparing the regions, the main sources of income in the Northern, Northeast, and Central regions were similar; laborers wages followed by the sale of goods. This could be explained that the income from agricultural production was not enough to support their living conditions. This might result from the following two reasons:

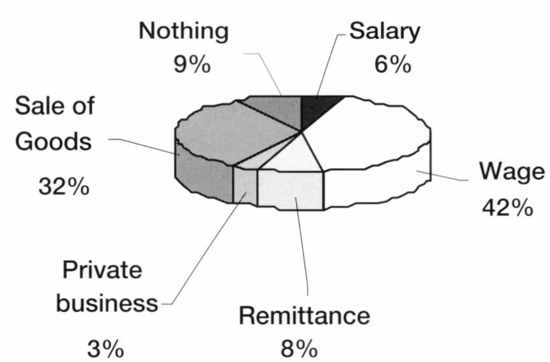

Fig. 4 Sources of income by number of villagers nationwide

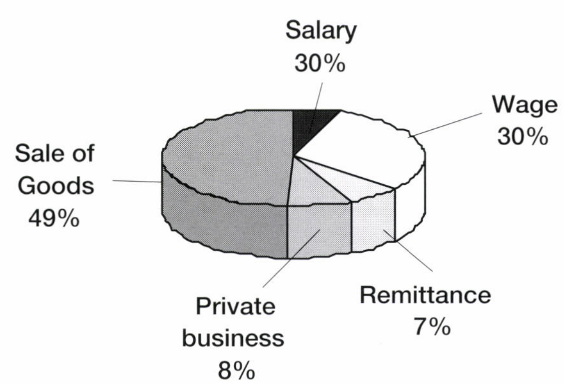

Fig. 5 Sources of income by the amount of income nationwide

1) the land fertility was poor or the size of land was too small resulting in low productivity, 2) and there was not enough labor in the family. Therefore, the farmers worked as a laborer for their main source of income which required no cash investment.

Unlike other regions, the main source of income in the South was from the sale of goods, followed by laborers wages. This could be attributed to the living standard and socio-economic condition of people in the South which is better than those in other regions. Income gained from the rubber tree plantations was very much higher than that gained from the same size of land cultivated with corn or cassava in the Northeastern region. Even though the price of rubber varies by the world market price, it is supported by the government when the price is lower than it should be.

Even though most of the farmers worked as a laborer for their main source of income, the amount of income earned from this wage was less than that earned from the sale of goods (Fig. 5). This could reflect the fact that the farmers work mainly on their farms and worked as a laborer on a part time basis, usually in the summer season. In many cases, the husband may, sometimes, go to work as a laborer inside or outside the village while the wife and, if available, their adult children take care of their farms. It was, therefore, meant that laborers wage was a second source of income.

Looking at different regions, it was found in the Northern, Northeastern, and Southern regions that the amount of income from the sale of goods was higher than that from a laborers wage. But the amount of income in the Central region was mainly generated from the laborers wages. This could be attributed to the fact that farmers were living in and near an industrial center which required more laborers. Farmers had better access to employment opportunities to generate income by working in factories.

Farmers' Needs Assessment

The main purpose of the Forest Village Project is to slow down the rate of deforestation caused by the people living in the forest areas. The project's principle is to move those people out from watershed and other protected areas, and settle them down in degraded forest areas suitable for agriculture. According to the interview survey, it was found that 85% of the interviewees were satisfied to continue living in the village. Only 6% of them expressed that they were not satisfied, the main reason was that they needed more land.

Although most of the farmers could meet their needs, it did not mean that they did not need more assistance and development from the government. The standard of living was relatively low compared to the villages outside the forests. Basic needs (income, infrastructure, land, water, electricity, health, dwelling, food, and education) assessment was carried out based on 5 degrees of satisfaction ranging from "Very Satisfied" to "Not Satisfied". The results showed that most of the farmers were not satisfied with their income, lands, water supply, and infrastructure. This could reflect the fact that land and water were still their main problems and were the most important basic needs. Particularly, land demand was raised up as the first priority to be discussed among the farmers. Currently, there is no absolute solution or clear policy on forest land management. There is no doubt that forest resources has been continuously encroached upon.

In order to be able to understand the needs of the farmers, all of the interviewed households were questioned about their most important needs and how much they were satisfied with these needs (using 5 percentage scores: 1 = 100% satisfied, 2 = 75% satisfied, 3 = 50% satisfied, 4 = 25% satisfied, and 5 = not satisfied). Items not answered were discarded. Some of the preferences were directly related to individual household requirements (income, land, water, house, food) while others were community oriented (infrastructure, electricity, health or medical services, and education). In order to assess their priorities of need, an index of priority was applied as discussed in Poudyal (1990). The needs identified by the respondents in order of importance were: income, water, land, infrastructure, housing, food, electricity, health, and education (Table 2).

Table 2 Farmers' basic needs assessment

Ranking score	Basic needs								
	Income	**Water**	**Land**	**Infra-structure**	**House**	**Food**	**Electricity**	**Health**	**Education**
1	17	46	68	38	73	50	136	108	126
2	36	51	47	69	78	103	44	77	81
3	89	61	57	84	70	91	16	44	35
4	76	42	42	65	44	36	15	40	35
5	79	95	86	34	28	8	63	18	8
Total Correspondents	297	295	300	290	293	288	274	287	285
Total score	1055	974	931	858	755	713	647	644	573
Mean score	3.6	3.3	3.1	3.0	2.6	2.5	2.4	2.2	2.0
Index of priority	0.89	0.83	0.78	0.74	0.64	0.62	0.59	0.56	0.50

It is not surprising that income is the most important need. This is due to the fact that most of the interviewed farmers have not enough income. Even though they have a small piece of land for farming, they would be satisfied if they could earn enough income either from the sale of produce they can make on those lands or from other sources of income. According to the interview survey, the average annual income (including all sources of income) of the farmers in degraded forest reserves was about 28,000 - 30,000 Baht or US $ 700 - 750 (1 US $ = 40 Baht). In the meantime, about 60% of them had to get a loan from the Bank of Agriculture and Agricultural Cooperatives with an average of 10,000 - 30,000 Baht/year (about 30% of them hold a loan of less than 10,000 Baht, and the rest hold a loan of more than 30,000 Baht).

Water, especially for farming, was one of the most important needs. Although there had been provisions for water wells in the settlements as well as large water reservoirs, there was a lack of water especially in the dry season. The problem of irrigation was found to be the most prominent. Since field crop cultivation was an important source of employment as well as household earnings, owing to the rainfed conditions of the area, it could not contribute efficiently to strengthen the household economy of the farmers. In addition to water for farming, in many cases, they also lacked water for drinking and household consumption.

Land, especially for cultivation was the third most important need. The farmers living in degraded forest reserves will be provided with degraded land they have occupied but not more than 2.4ha (or 15 rai). Even though most of the interviewed farmers had been allocated with land for farming, about 43% of the total number of satisfied farmers awarded land expressed their opinion that this need had not been met as the land owned or allocated was too small.

Transportation and telecommunication are becoming important living factors in the life of the farmers. Due to the fact that most forest villages are located in remote areas, the farmers have limited access to the main road connecting to the city. Therefore, transportation of agricultural products to the market is very difficult resulting in an increased cost of their produce. The project has a small budget to construct and maintain roads. Some roads can not be used all year round. In addition, as information technology is growing very fast, the farmers are now considering the importance of having telephone lines or satellite telecommunication set up in several remote areas.

Other basic needs were electricity, health and education. However, many farmers still need better and permanent housing facilities. It was also noticed that farmers have started to realize the lack of local food which could be previously collected around the villages.

Income and Landholding Size

As mentioned earlier, the average annual income of the farmers living in degraded forests was about 30,000 Baht. However, the results from the interview survey indicated that about 60% of the farmers had an income lower than the average amount (Fig. 6). Moreover, 33.4% of those farmers have annual incomes lower than 10,000 Baht. On the other hand, there was only about 18% of them that could support their families without difficulty.

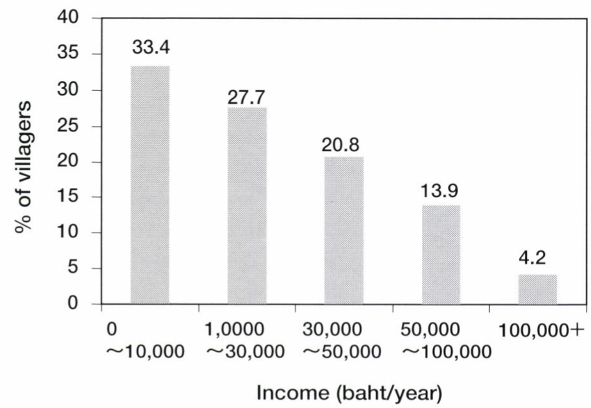

Fig. 6 Number of farmers by income

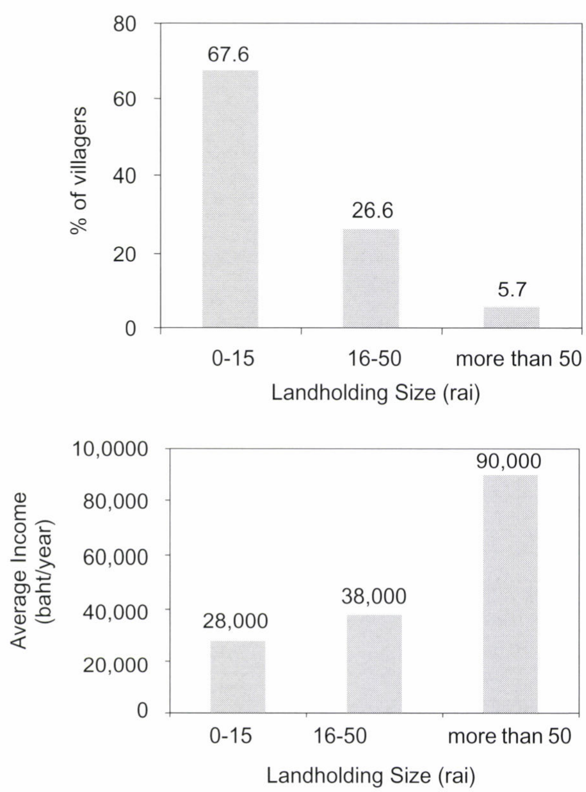

Fig. 7 Number of farmers and amount of income by landholding size

Fig. 7 compared the number of farmers and amount of their income in relation to landholding size. It turned out that the number of farmers and amount of income were in the opposite direction in relation to landholding size. On the other hand, the number of farmers decreased, but the average income increased, as landholding size was bigger. This figure was not uncommon but indicated, to some extent, the existing problems of farmers' poverty with a small piece of farmland. And other related problems could be inevitably linked resulting in more complicated problems.

The results showed that the difference in average annual income of farmers by landholding size in each region of the country. By comparing the average annual income of the farmers in each region, farmers in the South earned the highest annual income (56,000 Baht), followed by those in the Central region (37,000 Baht), the Northeast (35,500 Baht) and the North (24,500 Baht). In the same manner, it was a fact that farmers in the South earned more average annual income when looking at each landholding size.

But it was interesting to observe the difference among farmers in the medium-landholding group of the North, Northeast and Central regions. It was found that farmers in the North could gain higher annual income (66,500 Baht) than those in the Northeast (33,000 Baht) and the Central (25,000 Baht). There can be at least two factors to support this finding, 1) the difference in land uses; fruit trees may be the source of a higher income than cash crops, 2) and the additional source of income from off-farm activities.

Farmers' Need for Land and Landholding Size.

The answers of the farmers towards their needs for land were separated and compared based on the satisfaction ranking scores. Then the average landholding size of the farmers in each ranking score was also calculated. The figures in Table 3 showed the degree of farmers' need for land and their average landholding size. Due to the result from this study, we could only learn extensively the land demanding situation of the farmers at the time being. There were about 37.21% of the farmers who were satisfied with their landholding size (75% satisfied and more), and about 46.51% of those who were not satisfied (25% satisfied and less). Meanwhile, about 16.28% of the farmers were moderately satisfied (50% satisfied). It is rather difficult to say how large exactly of landholding size the farmers would be satisfied as we need to concern with other factors, for example, farmers' potential (in terms of capital, labor, know-how, and so on); land use patterns; site conditions of the land. However, this findings were based on the calculation of overall data collected from the interview survey. The comparison of this relationship was not made in each region of the country, but tended to be not much different.

Table 3 Relationship between farmers' needs and landholding size

Degree of needs	Percent of respondents	Average landholding size (rai)
100% satisfied (score 1)	22.09	25.3
75% satisfied (score 2)	15.12	14.7
50% satisfied (score 3)	16.28	13.7
25% satisfied (score 4)	14.73	10.5
Not satisfied (score 5)	31.78	8.1

Table 4 Relationship between farmers' need and gaining income

Degree of Needs	Average annual income (Baht)
100% satisfied (score 1)	45,500
75% satisfied (score 2)	43,500
50% satisfied (score 3)	40,000
25% satisfied (score 4)	32,000
Not satisfied (score 5)	30,000

Farmers' Need for Income and Gaining Income

As was done in farmers' need for land, the calculation was separately made to compare the average income of farmers in each ranking score of their need for income. It could be implied from the results in Table 4 that the farmers would be 100% satisfied if they could earn more than 45,500 baht annually, or at least, they should be able to earn about 40,000 baht annually, which is higher than the average annual income of farmers who have medium size of landholding. The important points to be addressed here are: 1) whether or not farmers make use of their land efficiently, 2) what can be their additional sources of income, and whether or not the government can provide them with more land.

Table 4 Relationship between farmers' need for income and gaining income.

DISCUSSIONS AND CONCLUSIONS

The results from this study could reflect the farmers' behavior of how they spend their life in degraded forests, in terms of land utilization and agricultural production. In addition, their problems and basic needs could be identified as well in comparison of each region of the country. Lessons learned from this study can be of great benefits for the decision maker to find ways for the solution of farmers' problems and needs. For example, the farmers would be rather satisfied if they could earn more than 45,500 baht annually for their income, but their average annual income was about 28,000 - 30,000 baht. It is meant that the government policy must emphasize on the promotion of off-farm employment for farmers' additional income in local areas in order to meet with their need. This would help improve farmers' living standard and they would no longer move farming lands and encroach more forest lands. Additionally, by doing this, farmers would not be necessary to migrate and work as a labor in the city. In the meantime, the government policy, however, must provide enough support (especially source of water for both consumption and farming) for their subsistence farming so that they could save their expenses of household consumption.

Land is also one of the most wanted needs by farmers in all regions, and is the most critical issue for policy makers due to its complication. Most of farmers living in degraded forests are holding small piece of land (not lager than 15 rai) and need more land for farming. Based on the results of this study, they would be very satisfied if they could be provided with larger piece of land (an average of 25 rai per household approximately). However, the suitable size of land to be allocated to the farmers is a controversial question because land in each region are different in terms of physical and biological conditions. Lacking of land for farming is still one of the major causes of deforestation which is difficult to be overcome by a specific land allocation policy. But helping the farmers improve the efficiency of land utilization process by introducing new suitable technologies could be a possible way to decrease the demand of land and consequently to slow down the degree of deforestation.

Infrastructure, like transportation and telecommunication, is also important and needed since farmers living remotely in degraded forests have less access to main road and communication medias. Agricultural products could not be easily transported to the local available markets resulting the higher cost or lesser income. Expanding local road network to the remote areas could be positive reason for social and economic development. But in the opposite manner, it could be negative or risky to the forest protection measurement as the forest encroacher could have more access to the forests. The establishment of local community cooperatives should be taken into consideration and promoted to help farmers, to some extent, solve their own problems.

Other problems and needs (house, health, electricity and education) seemed to be not serious issues for the farmers because they could be provided with some little difficulty.

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(Received 16 October 2005)
(Accepted 18 April 2006)

Short communication

A Model for Predicting the Vertical Distribution of Cross-sectional Area Increments in Hinoki Cypress Stems

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ABSTRACT

To confirm that the vertical distribution of stem cross-sectional area increment (CSAI) for Hinoki cypress can be described by two straight lines derived from three tree attributes: sunny crown length (CL), stem volume increment (SVI), and CSAI at the base of the sunny crown ($CSAI_{(CL)}$), two model were constructed and compared. One is the unrestricted model for describing the vertical distribution of CSAI by two straight lines ($CSAI_{(z)}=az$ and $CSAI_{(z)}=b+cz$ where $CSAI_{(z)}$ is the CSAI at a distance z from the apex, and a, b, and c are parameters), and the other is the restricted model imposed two restrictions on the unrestricted model: (*i*) the two straight lines intersect at the coordinates (CL, $CSAI_{(CL)}$), (*ii*) the area of the diagram formed from the two straight lines is equal to the SVI. AKAIKE's information criterion (AIC) and root mean square error (RMSE) were used to identify the better model. Data were obtained from 112 sample trees selected in six pure stands of even-aged Hinoki cypress. Parameters in the unrestricted model were estimated from CSAI dataset using least-squares method, and those in the restricted model were calculated from measurements of CL, SVI, and $CSAI_{(CL)}$ for each sample tree. The unrestricted model fit well to CSAI observations, indicating that the vertical distribution of CSAI can be described by two straight lines. The AIC value for the restricted model was smaller than that for the unrestricted model, indicating that the restricted model is superior to the unrestricted model in describing the vertical distribution of CSAI. Although the restricted model returned a larger RMSE value than the unrestricted model did, the difference in RMSE was small. In conclusion, the vertical distribution of CSAI for Hinoki cypress can be described by two straight lines derived from CL, SVI, and $CSAI_{(CL)}$.

Keywords: stem cross-sectional area increment, vertical distribution, predicting model, Hinoki cypress

INTRODUCTION

The ability to predict the stem form of a tree resulting from stand density management decisions is important in forestry because of the economic value of timber quality. The cumulative stem diameter at a particular height depends on the previous-year diameter and the current-year stem cross-sectional area increment (CSAI). Therefore, the ability to predict the vertical distribution of CSAI along the stem allows a prediction of the stem form.

In general, the vertical distribution pattern of CSAI can be divided into two segments: the segment within the crown and the segment below the crown. Within the crown, CSAI increases downward from the apex (ONAKA, 1950; LARSON, 1963). Below the crown, the vertical distribution patterns can be divided into three types based on the crown ratio, which is the proportion of the crown length to the total height of the tree. Type 1 occurs in trees with a large crown ratio, such as isolated trees, in which CSAI increases downward to ground level; type 2 occurs in trees with a medium crown ratio, such as trees that are not suppressed but whose lateral development is restricted, in which CSAI is constant; and type 3 occurs in trees with a small crown ratio, such as suppressed trees, in which the CSAI decreases (ONAKA, 1950). INOSE (1985) postulated that in Todo-fir (*Abies sachalinensis* Mast), the vertical distribution of CSAI can be approximated by two straight lines broken at the base of the crown. His postulate suggests that the vertical distribution of CSAI can be described by a diagram of two simple geometrical figures consisting of a triangle and a quadrilateral, which are divided

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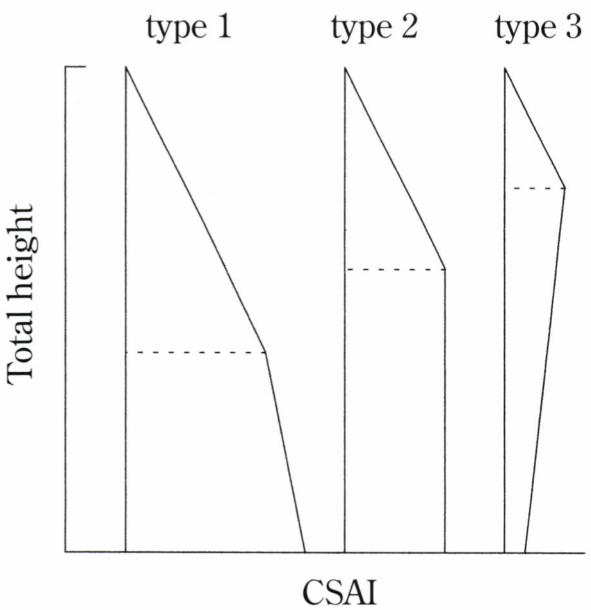

Fig. 1 Schematic diagram of the vertical distribution of the stem cross-sectional area increment (CSAI) described by two straight lines broken at the base of the crown Dotted lines show the positions of the base of the crown.

by the base of the crown (Fig. 1). The vertical distribution shifts from type 1 to type 3 as the crown ratio decreases. When the total height of the tree is known, the shape and size of the diagram for type 2 can be determined by two of three tree attributes: crown length (*i.e.*, distance from the apex to the base of the crown), stem volume increment (*i.e.*, area of the diagram), and CSAI at the base of the crown. Adding the remaining attribute allows the determination of vertical distribution of CSAI for type 1 or type 3 trees. Thus, INOSE's (1985) postulate is convenient and effective in predicting the vertical distribution of CSAI.

The postulate that CSAI increases at a constant rate within the crown and remains constant below it (*i.e.*, type 2) has been used to estimate CSAIs for various heights of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (MITCHELL, 1975), Norway spruce (*Picea abies* (L.) Karst.) (DELEUZE and HOULLIER, 1995), and Japanese cedar (*Cryptomeria japonica* D. Don) (KAJIHARA and UGAI, 1995) trees. However, the CSAI in the lower portion of stems is either underestimated or overestimated when the type 2 postulate is applied to the vertical distribution of CSAI in type 1 or type 3 trees. This systematic bias, which stems from differences in the crown ratio, hampers the prediction of stem forms in stand density management decisions, because the crown ratio is closely related to stand density. Therefore, new models are needed to predict the vertical distribution of CSAI for trees that do not fit the type 2 paradigm.

The objective of our study is to develop a model for predicting the vertical distribution of CSAI for Hinoki cypress (*Chamaecyparis obtusa* Endl.) based on the work of INOSE (1985). To achieve this objective, it is necessary to develop appropriate methods for estimating crown length, stem volume increment, and CSAI at the base of the crown and to confirm that the vertical distribution of CSAI can be described by two straight lines derived from these three attributes. TAKAHARA (1954) and KAJIHARA (1981) determined that the quantity of foliage in the shaded crown bears little relation to the stem volume increment for Japanese cedar and Hinoki cypress. Therefore, this report confirms that the vertical distribution of CSAI for Hinoki cypress can be described by two straight lines derived from measurements of the sunny crown length, the stem volume increment, and the CSAI at the base of the sunny crown.

MATERIALS AND METHODS

Model of CSAI Distribution

Assuming that the vertical distribution of CSAI can be described by a simple diagram formed with a triangle and a quadrilateral (Fig. 1), CSAI (cm²/year) at a distance *z* (m) from the apex within the triangle is expressed as

$$\mathrm{CSAI}_{(z)} = az \quad (1)$$

where *a* is a parameter. In contrast, CSAI within the quadrilateral is expressed as

$$\mathrm{CSAI}_{(z)} = b + cz \quad (2)$$

where *b* and *c* are parameters. A CSAI distribution model obtained by combining eqs. (1) and (2) can be written as

$$\mathrm{CSAI}_{(z)} = azI_1 + (b + cz)I_2 \quad (3)$$

where I_1 and I_2 are dummy variables defined as

$$I_1 = \begin{cases} 1 & \text{If } 0 \le z \le z_B \\ 0 & \text{Otherwise} \end{cases}$$

and

$$I_2 = \begin{cases} 1 & \text{If } z_B < z \le \mathrm{H} \\ 0 & \text{Otherwise} \end{cases}$$

where z_B is the distance from the apex to the base of the triangle on the stem, and H is the total height of the tree. This is the basic model for describing the vertical distribution of CSAI by two straight lines. By imposing the restriction that eqs. (1) and (2) intersect at the coordinates (CL, $\mathrm{CSAI}_{(CL)}$) where CL is the sunny crown length, we can obtain

$$a = \frac{\mathrm{CSAI}_{(CL)}}{\mathrm{CL}}, \quad (4)$$

and

$$b = (a - c)\mathrm{CL}. \quad (5)$$

Adding the further restriction that the area of the diagram is equal to the stem volume increment (SVI), we obtain

$$c = \frac{2SVI - (2H - CL)\,CSAI_{(CL)}}{(H - CL)^2}, \quad (6)$$

Substituting eqs. (4), (5), (6), and CL for parameters a, b, c, and z_B into eq. (3) results in a model to describe the vertical distribution of CSAI by using CL, SVI, and $CSAI_{(CL)}$. Because this model was generated by imposing the two restrictions on the basic model, it is termed the restricted model, while the basic model is called the unrestricted model. If the restricted model is better at estimating CSAIs at various heights than the unrestricted model is, then the efficacy of the two restrictions can be recognized in describing the vertical distribution of CSAI by two straight lines derived from CL, SVI, and $CSAI_{(CL)}$.

Data Collection

Samples were obtained from six pure stands of even-aged Hinoki cypress in Nara Prefecture, Japan. Stand age ranged from 10 to 72years, with densities ranging from 1000 to 5250 trees/ha, mean diameter at breast height measuring 6.8 to 29.1cm, and mean total height varying from 5.5 to 16.8m (Table 1). One hundred and twelve sample trees were selected at random in the stands. The trees ranged from 3.6 to 32.5cm in diameter at breast height and from 4.1 to 18.7m in total height.

To measure SVI and CSAIs at various heights, each sampled tree was felled. Disks were removed from the stems at stump height (0.2m), at intervals of 0.5, 1, or 2m below the lowest live branch, and at intervals of 0.5 or 1m within the crown beginning at stump height. The disks were brought to the lab and measured for the current- and previous-year radii in four directions at right angles. The CSAI for each disk was computed as the difference between the current- and previous-year stem cross-sectional areas, with the stem cross-section assumed to be elliptical in shape. The current- and previous-year volumes of each log segment were calculated using SMALIAN's formula (OSUMI *et al*., 1987). The volume increment of each log segment was calculated as the difference between the current- and previous-year log volumes. The SVI for each sample tree was estimated by summing the volume increments of the log segments.

Table 1 Stand descriptions

Stand	Age (year)	Density (trees/ha)	Mean diameter at breast height (cm)	Mean total height (m)	Number of sample trees
A	10	5,250	6.8	5.5	20
B	16	3,006	11.8	10.1	15
C	19	3,828	11.9	9.4	20
D	29	2,602	12.6	12.7	22
E	41	1,820	18.6	16.4	15
F	72	1,000	29.1	16.8	20

The separation between the sunny and shaded crowns (*i.e.*, the base of the sunny crown) for each tree was averaged visually to find the point representing the average height to the top point of the crown contact in the direction of the contour. The separation height was measured using a wide-scale Spiegel relascope prior to felling the tree. A 5-m pole was placed upright against the tree trunk for the measurements. The CL was calculated as the difference between H and the separation height. The $CSAI_{(CL)}$ was interpolated from CSAIs at the top and bottom of the log where the base of the sunny crown was located.

Model Fitting

To estimate parameters a, b, and c in the unrestricted model, eq. (3) was fitted to the CSAI dataset for each sample tree. For the i-th sample tree (i = 1, 2, … , 112), $CSAI_{ij}$ is the CSAI observation at the j-th distance z_{ij} (j = 1, 2, … , n_i) from the apex. When $CSAI_{ik}$ and $CSAI_{ik+1}$ ($1 \le k \le n_i - 2$) are located within the triangle and the quadrilateral, respectively, the sum-of-squares error is

$$SSE_{ik} = \sum_{j=1}^{k}\left(CSAI_{ij} - a_{ik}z_{ij}\right)^2 + \sum_{j=k+1}^{n_i}\left(CSAI_{ij} - b_{ik} - c_{ik}z_{ij}\right)^2. \quad (7)$$

Parameters a_i, b_i, and c_i in the unrestricted model were estimated using the least-squares method when the minimum SSE_{ik} was attained. For the restricted model, parameters a_i, b_i, and c_i were calculated from eqs. (4), (5), and (6) using three measurements, CL, SVI, and $CSAI_{(CL)}$, for each sample tree.

Model Evaluation

To confirm that the vertical distribution of CSAI can be described by two straight lines, the coefficient of determination R^2 for the overall fit for all sampled trees in the unrestricted model was calculated and tested statistically using F-test. The two models were compared using AKAIKE's information criterion (AIC, SAKAMOTO *et al.* 1986). AIC was calculated as

$$AIC = \sum_{j=1}^{112}\left(n_i \log\hat{\sigma}_i^2 + 2m_i\right) \quad (8)$$

where $\hat{\sigma}_i^2$ and m_i are the estimate of the residual variance and the number of the parameters of the model for the i-th sample tree. The values of m_i in the unrestricted and restricted models were 3 and 0, respectively. When this criterion is used, the model with the smaller AIC is presumed to be the better one. The root mean square error (RMSE) was also used to identify the better model.

RESULTS AND DISCUSSION

The unrestricted model fit well to CSAI observations for Hinoki cypress (Fig. 2, upper panel). Occasionally, CSAI increases dramatically in the vicinity of the butt (ONAKA, 1950; ASSMANN, 1970). Trees with this sort of extreme increase were

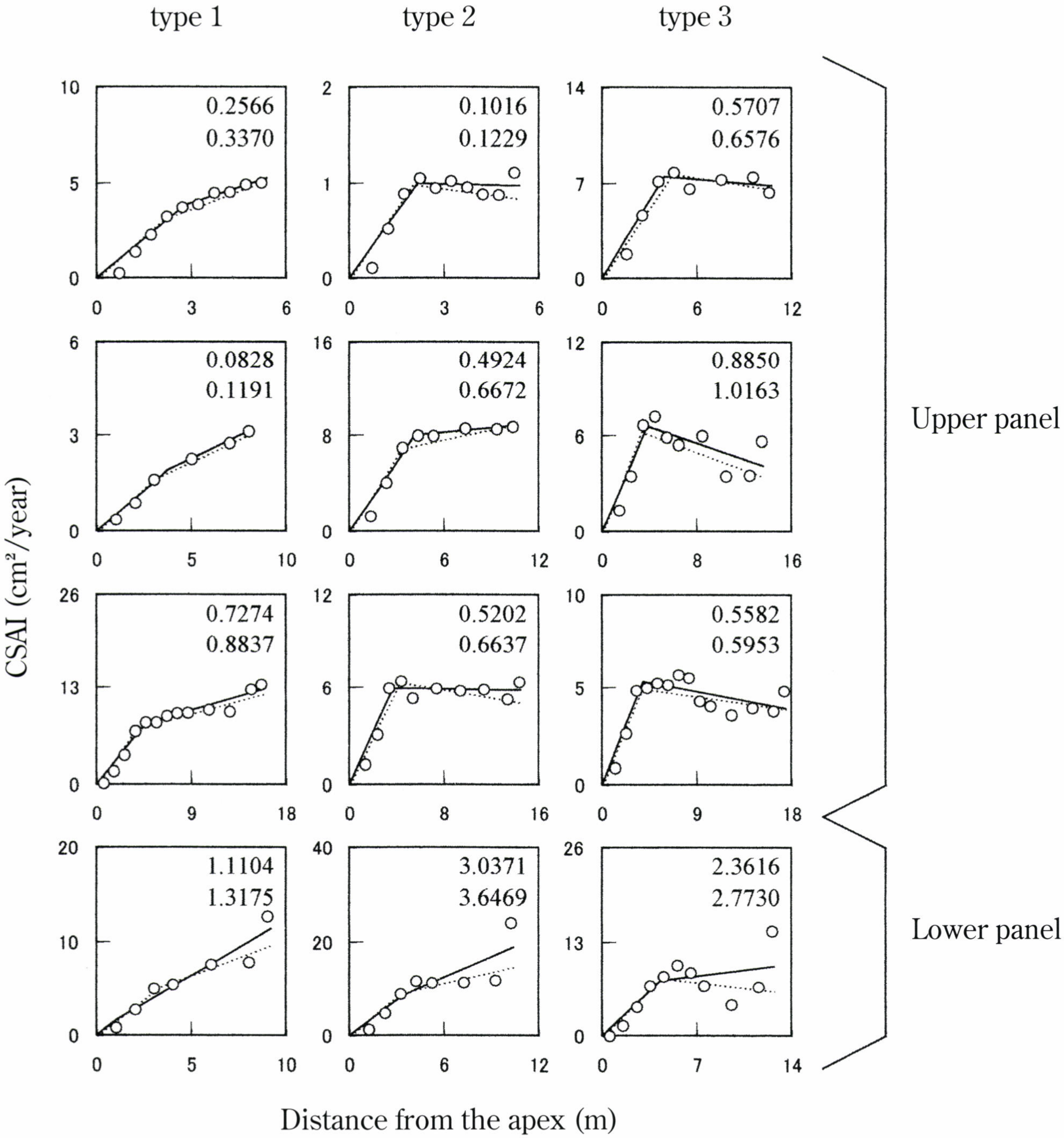

Fig. 2 Examples of the vertical distribution of stem cross-sectional area increments (CSAI)
Upper and lower panels show trees without and with the extreme CSAI increase in the vicinity of the butt. Open circles represent observations. Solid and dotted lines are fitted to the unrestricted and restricted models. Upper and lower values in each graph represent root mean square errors (cm²) for the unrestricted and restricted models.

included among the sampled trees in this study (Fig. 2, lower panel). For these trees, the unrestricted model overestimated CSAI above the butt. Nevertheless, the value of R^2 for overall fit was statistically significant (R^2 = 0.939, F = 34.870, P < 0.001). These results indicate that the vertical distribution of CSAI for Hinoki cypress can be described by two straight lines.

Although imposing the two restrictions on the model increased RMSE (Fig. 3) for each tree, the vertical distribution obtained by the restricted model closely matched that of the unrestricted model (Fig. 2, upper panel). For the sample trees

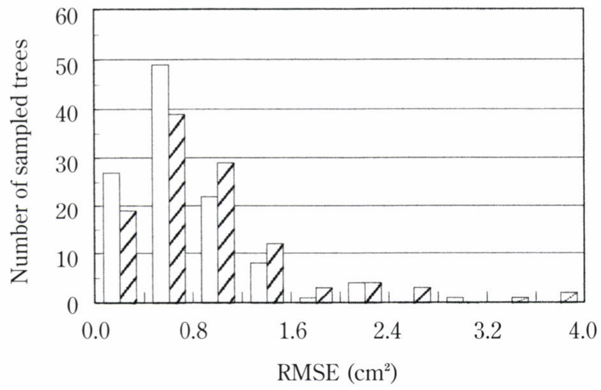

Fig. 3 Distribution of the root mean square error (RMSE) for each sampled tree
Open and striped bars represent numbers of sampled trees for the unrestricted and restricted models, respectively.

with the extreme CSAI increase, the restricted model estimated CSAI below the sunny crown more precisely than the unrestricted model did, except in the vicinity of the butt (Fig. 2, lower panel). This suggests that this limited increase in CSAI has no great influence on estimates obtained using the restricted model.

The AIC value for the restricted model was smaller than that for the unrestricted model (Table 2), indicating that the restricted model is superior to the unrestricted model in describing the vertical distribution of CSAI. For overall fit, although the restricted model returned a larger RMSE value than the unrestricted model did (Table 2), the difference in RMSE was only 0.2729cm². This overestimation of the area of a circle results in slight overestimations of diameter as well; 0.0346cm for a 5-cm diameter circle, 0.0174cm for a 10-cm circle, and 0.0087cm for a 20-cm circle. Therefore, the difference in RMSE between the two models for predicting stem form may be negligible. In conclusion, the vertical

Table 2 AKAIKE's information criterion (AIC) and root mean square errors (RMSE)

Model	AIC	RMSE (cm²)
Unrestricted	-19503	0.8762
Restricted	-19605	1.1491

distribution of CSAI for Hinoki cypress can be described by two straight lines derived from CL, SVI, and $CSAI_{(CL)}$.

The restricted model described here is a convenient and effective tool for predicting the vertical distribution of CSAI for Hinoki cypress, because it requires only three tree attributes: CL, SVI, and $CSAI_{(CL)}$. Integrating the restricted model with models for estimating the three attributes will enable prediction of the distribution. Therefore, the next step is to develop appropriate methods for estimating CL, SVI, and $CSAI_{(CL)}$.

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(Received 11 February 2005)
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