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Article

Estimating Canopy Information in *Cryptomeria japonica* and *Chamaecyparis obtusa* Stands using Airborne LiDAR Data

Tohru Nakajima[*1], Yasumasa Hirata[*2], Naoyuki Furuya[*3], Katsutoshi Takezoe[*1], Makoto Suzuki[*4] and Satoshi Tatsuhara[*1]

ABSTRACT

Crown density control is one of the main activities in forest management. For the prediction of tree growth, it is important to consider the crown length, leaf biomass, and other canopy parameters as a photosynthetic organ. We estimated the lengths of canopies on the basis of a Digital Surface Model (DSM) and Digital Elevation Model (DEM) obtained from airborne Light Detection and Ranging (LiDAR) data and examined the accuracy of the estimates in even-aged stands. *Cryptomeria japonica* and *Chamaecyparis obtusa* stands were selected for analysis. The study site was the University Forest in Chiba, Japan, which is managed by the University of Tokyo and has stand densities between 350 and 4,000 trees ha^{-1}. First, we calculated the DSM and DEM for the University Forest in Chiba for the analysis of canopy information. We established 12 circular sample plots in *Cryptomeria japonica* and *Chamaecyparis obtusa* stands and measured the crown length of the dominant trees in each plot. Second, we estimated the crown length of the dominant trees in each plot using the DSM and DEM obtained from airborne LiDAR data. Finally, we compared crown lengths obtained from airborne LiDAR data with crown lengths obtained from ground surveys and checked the accuracy of this methodology. The crown lengths obtained from airborne LiDAR data were highly correlated with those obtained from ground surveys (coefficient of determination = 0.95; root mean square error (RMSE) = 0.67). Thus, airborne LiDAR accurately measured crown length, regardless of stand density.

Keywords: canopy, digital elevation model (DEM), digital surface model (DSM), even-aged stands, airborne LiDAR, stand density

INTRODUCTION

Variations in thinning intensity have made plantation forests more diverse (Ito *et al.*, 2005; Nakajima *et al.*, 2006a; Nakajima *et al.*, 2006b). For the management of forests with different stand densities, it is important to develop a growth model adapted for many different types of stands such as multi-storied forests, semi-natural forests, and other forest types. In Japan, the growth model Local Yield Table Construction System (LYCS; Shiraishi, 1986) was applied to *Cryptomeria japonica* ("sugi"), *Chamaecyparis obtusa* ("hinoki"), and *Larix leptolepis* ("karamatsu") stands throughout Japan (Matsumoto, 1997; Tanaka *et al.*, 2004; Nakajima and Shiraishi, 2007; Nakajima *et al.*, 2007a; Nakajima *et al.*, 2007b). The LYCS allows the estimation of forest resources in plantation forests managed under standard density control. However, the original growth model developed for the University Forest in Chiba, Japan, of the University of Tokyo (Shiraishi, 1986) has not been applied to low- and high-density stands that diverge

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from a standard-density. KAJIHARA (1985) and TATSUHARA (1993) estimated the relationship between stand growth and canopy information, whereas SHIRAISHI (2005) and NAKAJIMA *et al.* (2006c) suggested that it is important that the canopy information be modeled to apply the growth model to both low- and high-density stands, although the LYCS has rarely been applied to such stand types.

To introduce canopy information into the growth model, it is necessary to measure mean crown length, depth, width, and volume. It is physically difficult to obtain this information by ground survey because mature tree crowns are tall and overlap the crowns of neighboring trees. Airborne Light Detection and Ranging (LiDAR), a measurement technique that uses laser pulses from aircraft to measure the distance to the ground, could be useful to estimate the canopy structure of standing trees (HIRATA *et al.*, 2003; HALL *et al.*, 2005).

A number of previous studies have used canopy information obtained from airborne LiDAR data. HYYPPÄ and HALLIKAINEN (1996) estimated stem volume from basal area and tree height and derived canopy information from airborne LiDAR data at the stand level. ANDERSEN *et al.* (2005) used airborne LiDAR data to estimate the canopy fuel weight from data such as crown basal area and tree height. In Japan, the crown area and tree height of single trees were surveyed using an airborne LiDAR system in broadleaved forests (TSAI *et al.*, 2006). MATSUE *et al.* (2006) estimated crown cover and stem volume from airborne LiDAR data in sugi and hinoki stands. However, few studies have used airborne LiDAR to estimate the crown length of sugi or hinoki stands of different stand densities or ages.

Our objective was to compare crown length estimates in stands of various densities obtained from airborne LiDAR data with crown lengths obtained from ground surveys. A linear regression between the crown lengths obtained from ground surveys and the crown lengths obtained from airborne LiDAR was carried out. We then discuss the accuracy of the derived crown length measurements.

METHODS

Study Site

The University Forest in Chiba was established in 1892 and is the oldest university forest in Japan. The forest belongs to the University of Tokyo and is located in the cities of Kamogawa and Kimitsu, Chiba Prefecture, Japan, between 50 and 370m above sea level. The terrain is undulating with steep slopes, and most soils are of the brown forest type. The forest is located in a warm-temperate zone, with an average annual temperature of 14°C, a warmth index of 108.7°C and a coldness index of −0.8°C. The average rainfall is 2182mm year^{-1}. The total forest area is 2216ha, 824ha (37%) of which is sugi and hinoki stands, 949ha (43%) is natural hardwood forest, and 387ha (17%) is natural conifer forest. The remaining 57ha (3%) is demonstration forest. Stand age varies from approximately 10 to 100 years.

Sample Plot

We established sample plots in the study area to check the accuracy of crown length measurements obtained from airborne LiDAR. For ground surveys, 12 circular sample plots 22.6m in diameter (0.04ha) were established in sugi and hinoki stands of various stand densities. Diameter at breast height (DBH) was measured on all standing trees in each plot. Tree heights were measured on more than 40% of all trees and estimated for other trees using a NÄSLUND height-diameter curve. The central coordinates of each plot were measured using differential global positioning system (DGPS) receivers (ProMark2, Ashtech and Pathfinder ProXR, Trimble Navigation). The four tallest trees in each plot were selected as the dominant trees, equivalent to the 100 stems ha^{-1} selected as the dominant trees in previous studies (ISHIBASHI *et al.*, 2006). In calculating the observed crown length, the heights to the base of the crown were subtracted from the heights of the

Table 1 The sample plots for the ground survey

Plot	Compartment	Subcompartment	Species	Stand age	Stand density (stems ha^{-1})
Plot 1	11	C1	Hinoki	68	450
Plot 2	11	C1	Sugi	99	350
Plot 7	10	C4	Sugi	90	575
Plot 10	20	C1	Hinoki	27	3,925
Plot 11	20	C1	Hinoki	27	2,350
Plot 13	11	C2	Sugi	40	1,700
Plot 14	4	C1	Hinoki	44	2,025
Plot 18	10	C1	Sugi	102	500
Plot 20	11	D2	Hinoki	55	775
Plot 21	11	D2	Hinoki	55	700
Plot 22	11	D2	Hinoki	55	700
Plot 23	11	D2	Hinoki	55	1,475

dominant trees in each plot. The heights to the base of the crown and the total heights of the trees were measured using VERTEXIII (Haglöf).

The stand examined had a density between 350 and 3925 trees ha^{-1} and ranged in age between 27 and 102 years (Table 1). Stand density decreased with age because thinning had been performed during the development of the stands.

Airborne LiDAR Data

The ALMAPS-G4 (Asahi Laser Mapping System), which consists of the ALTM 3100 laser scanning system produced by Optech, Canada, GPS airborne and ground receivers, and an inertia measurement unit (IMU) that measures the helicopter's roll, pitch, and heading were used to acquire airborne LiDAR data. The laser scanner system transmits laser pulses at 1064 nm (near-infrared) and receives the first and last echoes of each pulse. The elapsed time between transmittance and reception is measured to calculate the distance between the system and the measured object.

Airborne LiDAR data were acquired on 14 August 2005. The flight altitude of the helicopter above the ground was about 500 m and the average flight speed was approximately 19.4m s^{-1}. The pulse repetition frequency of airborne LiDAR was 70kHz and the scan frequency was 27Hz. The maximum scan angle (off nadir) was 18°. The beam divergence was 1.2 mrad. Therefore, the footprint diameter was approximately 60 cm. The interval between footprints was about 25cm. Both first pulse and last pulse were acquired to identify forest canopy and topography data in rugged terrain.

Data from a region of interest (ROI) 200-m wide and 1700-m long were selected for this study. A DEM and a DSM (Fig. 1) for the study area were prepared from the airborne LiDAR data, with a 25-cm cell size. Data for the digital canopy model, which delineates canopy height from the ground, were calculated by subtracting the DEM from the DSM.

Data Analysis

The crown lengths of dominant trees were estimated from airborne LiDAR data using the TNTmips ver. 6.6 (MICROIMAGES, 2001) software of the GIS and image processing system. First, the dominant trees were selected using the DEM and DSM. Tree height can be obtained from the Digital Canopy Model (DCM) showing the canopy surface height from the ground height, and was calculated by subtracting the DEM, *i.e.*, the height above sea level, from the DSM, showing the surface of canopy. When the plot was magnified, airborne LiDAR could identify the canopy of each individual tree as a DCM (Fig. 2). The tree height was defined as the height of the

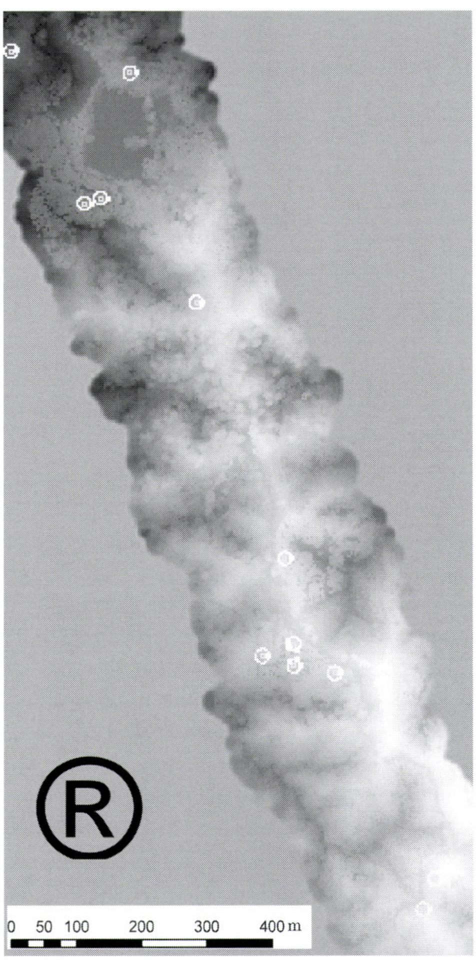

Fig. 1 The Digital Surface Model (DSM) measured by airborne LiDAR
The white circles indicate sample plots.

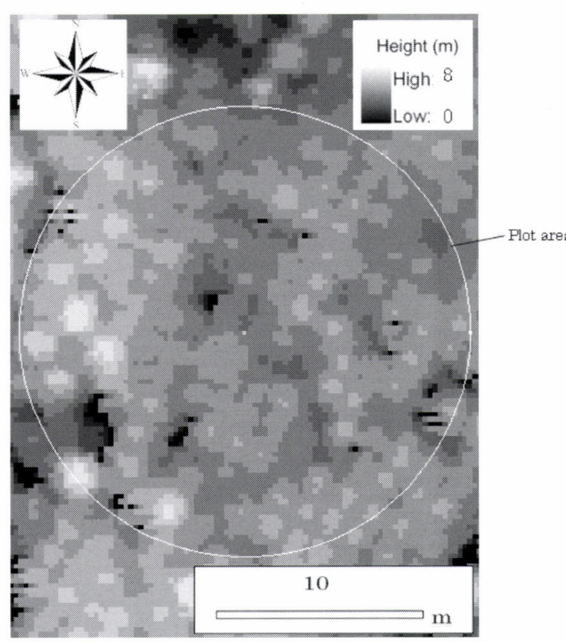

Fig. 2 Enlarged view of Plot 10 measured by airborne LiDAR

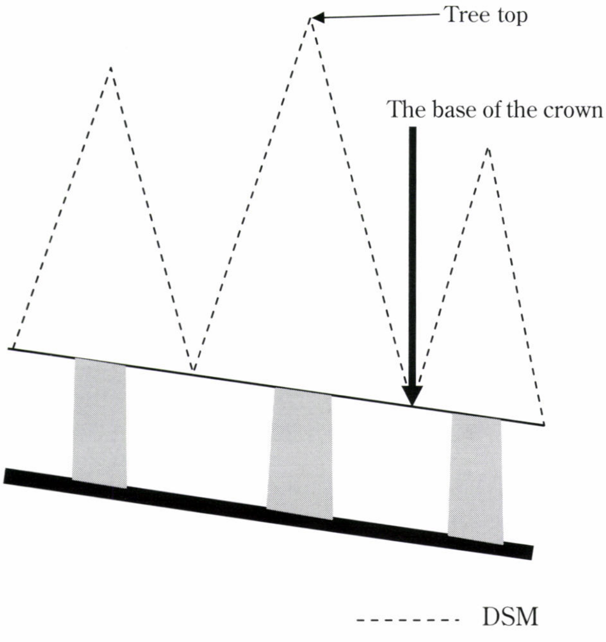

Fig. 3 The position at which tree height was measured to determine the base of the crown
The base of the crown is indicated by a bold arrow.

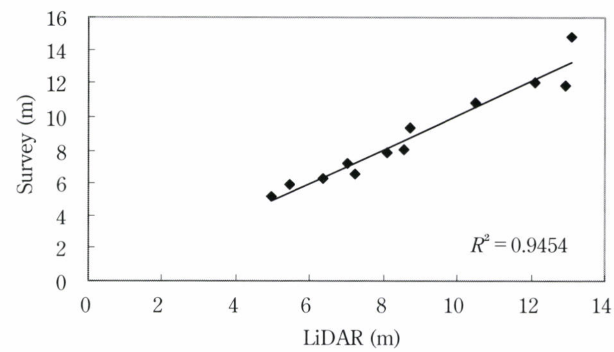

Fig. 4 The crown lengths estimated by airborne LiDAR versus those measured by field survey

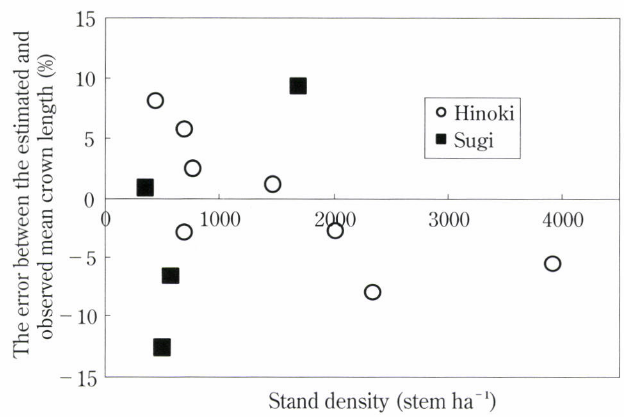

Fig. 5 The error between the estimated and observed mean crown lengths

top of the tree derived from the DCM. Using the local maximum filter of the DCM, we selected the four highest points as the four dominant trees in each plot.

Second, the crown lengths of dominant trees were estimated by subtracting the height to the base of the crown from the total tree height. The height to the base of the crown was measured from the height to the rebound point on the DSM cross-sectional surface (Fig. 3). The direction of the DSM cross-sectional surface was estimated from the average slope aspect derived from the DEM in each plot, because there is normally more space for branch and leaf expansion on the slope side of trees. That is why we assumed that the height to the base of the crown could be obtained from the slope aspect.

Third, the average crown length of the dominant trees for each plot was calculated. The estimates of average crown length from airborne LiDAR data were then compared with the manually measured data from the plots. The crown lengths obtained from ground surveys were regressed against the crown lengths obtained from airborne LiDAR. We then calculated the coefficient of determination and the root mean square error (RMSE).

RESULTS AND DISCUSSION

The crown lengths estimated by airborne LiDAR were plotted against those measured in the ground surveys (Fig. 4). The constant term and slope of the regression line were 0.573 and 0.927, respectively. The coefficient of determination was 0.95. The RMSE was 0.67. This results show that airborne LiDAR was able to accurately measure tree crown length.

The absolute value of the error between the airborne LiDAR estimates and the survey observations was within 10%, regardless of stand density, except in one plot (Fig. 5). In this result, there were few differences between the error observed in sugi and hinoki stands, indicating that airborne LiDAR is capable of precisely estimating crown length in both low- and high-density stands (Fig. 5). The first pulse of the airborne LiDAR captured canopy shape correctly, because the distance between neighboring footprints was relatively narrow. A cause of the underestimation in the high-density stands (more than 2,000 stems ha^{-1}) could be that airborne LiDAR did not include the length of the shaded canopy. We verified the outcomes discussed above in the following way. In high-density stands, where branches shade other trees, we measured not only the sunlit canopy, but also the shaded canopy, and included these data in the ground survey data, because the shaded canopy was not completely dead. In other words, the length of the canopy in the survey is the sum of the sunlit and shaded canopies. However, the measurements included only the sunlit canopy, because the DSM measured by airborne LiDAR was obtained primarily from the first pulse, a laser which does not reach the shaded canopy. Additionally, the first pulse likely caught sunlit canopy information correctly, because the distance between neighboring footprints was relatively narrow. Therefore, differences between the crown lengths obtained from airborne LiDAR and ground surveys in high-density stands would be caused by an underestimation in airborne LiDAR, as airborne LiDAR did not include the length of the shaded canopy. However, this would not be significant for predicting stand growth. KAJIHARA *et al.* (1989) compared the distribution of stem volume in sunlit and shaded canopies and found that a shaded canopy has no influence on the stem growth of sugi and hinoki. In other words, the surface area of the sunlit canopy per unit area has more impact on growth than that of the shaded canopy. KAJIHARA (1985) showed that the surface area of the sunlit canopy plays an essential role in the growth of sugi.

Little bias in estimating crown length was observed in the relatively lower density stand of less than 2,000 stems ha^{-1}, although three possible sources of error were considered. First, one reason for the underestimation of crown length is that the first pulse did not reach the shaded canopy. Second, the main reason for the overestimation of crown length would be differences between the ground survey and airborne LiDAR in the measuring point of branches. In the ground survey, we measured the height to the base of the crown as the base of a branch. With airborne LiDAR, on the other hand, we measured the height to the base of the crown from the top of a branch. When the crown is wide, the top of a branch will sometimes droop because of its weight, positioning the branch lower than its root. In this case, the height to the base of the crown measured by airborne LiDAR is lower than that measured in the ground survey. Third, in this study, we assumed that the height to the base of the crown could be observed on the average slope aspect. However, in some cases the base of the crown may not be identical to the average slope aspect, and may be influenced by the size of neighboring trees. In these situations, airborne LiDAR measures branches other than the largest spreading branch that makes up the height to the base of the crown. This is a further reason for the underestimation or overestimation of crown length.

Our results show that the crown lengths of both sugi and hinoki stands can be estimated with airborne LiDAR in stands of different densities and ages. MATSUE *et al.* (2006) used a similar method to estimate the crown-covered area of high-density sugi and hinoki stands (approximately 1,000 stems ha^{-1}). The accuracy of estimating crown information with airborne LiDAR increased with decreasing stand density because individual trees were identified more easily in the DSM and DEM.

Using the DSM derived from airborne LiDAR data, we measured the base of the crown using the average slope estimated from the DEM. The fact that such accurate estimates of crown length could be made using this methodology implies the adequacy of the assumption that the base of the crown is usually easily located on the slope. This case study shows that using airborne LiDAR data we can estimate crown length in Japanese mountain forests, where the terrain is complex and the slope is relatively steep.

We only estimated the average crown length of the dominant trees. To develop stand growth models from canopy information, it would be better to estimate the average crown length of all trees in the stand (Chiba, 2005; Nakajima *et al.*, 2007c). ISHIBASHI *et al.* (2006) showed that the relationship between the average height of the dominant trees and the average height of all trees in a stand can be calculated. Therefore, it may be possible to calculate the average height of all trees in a stand from the average height of the dominant trees by taking the average tree height of the dominant trees estimated using airborne LiDAR data and extrapolating to the average height of all trees in the stand. TANAKA (1993) found no difference between the base of the crown of dominant trees and the base of the crown of all other trees in a stand. Therefore, if the crown length of the dominant trees can be estimated using airborne LiDAR data, the average crown length of all trees in a stand can be estimated and applied to the stand growth model.

If the growth of stands can be estimated by introducing canopy data derived from airborne LiDAR into a growth model regardless of stand density, then crown length, which would otherwise be difficult to measure at ground level, can be precisely measured with airborne LiDAR. The growth model loaded with canopy information or parameters obtained from airborne LiDAR data may enable predictions of regional forest resources. Therefore, the next challenge is to further develop the growth model using additional crown length data derived from airborne LiDAR measurements.

CONCLUSION

We estimated the average lengths of tree crowns based on the DSM and DEM obtained from airborne LiDAR data and examined the accuracy of this method. Airborne LiDAR succeeded in precisely measuring crown lengths in both low- and high-density stands of sugi and hinoki. Using the DEM and DSM derived from airborne LiDAR, we accurately estimated crown length while taking into account both differences in slope and height above sea level. This case study estimated crown length in Japanese mountain forests, where the terrain is complex and slopes are relatively steep. The results indicate that it is realistic to develop growth models based on crown lengths derived from airborne LiDAR data.

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Article

Spatial Heterogeneity of Colonizing Tree Communities in Relation to Slope Characteristics and Stand Structure of a *Cryptomeria japonica* Plantation in Northern Japan

Takashi Kunisaki[*1] and Kanoko Kunisaki[*2]

ABSTRACT

The objective of this study was to infer the most important gradients influencing species composition and abundance of colonizing native trees (CNT) in an unthinned Japanese cedar (*Cryptomeria japonica* D. Don) plantation in northern Japan. A 0.84-ha (60 × 140m) plot was established in the stand and was subdivided into a total of 42 subplots (20 × 10m each). For each tree >3cm in diameter at breast height (DBH) in each subplot, we recorded the species and DBH. Path analysis with structural equation modeling was performed to analyze the correlation and causal relationships between slope characteristics, soil properties and vegetation attributes of the set of subplots. Species composition of CNT was strongly affected by site conditions along relatively short gradients of slope aspect and soil water content, but stand height had little effect on species composition. In contrast, the abundance of CNT was strongly affected by site conditions along relatively short gradients of slope aspect and soil water content, and stand height also significantly affected abundance. The contrasting patterns of variation between species composition and abundance of the CNT may reflect the fact that the mortality rate of CNT at the adult tree stage varies according to vertical stand structure rather than to interspecific differences in survival patterns. In conclusion, recruitment patterns from the juvenile tree stage for each species were related principally to species composition and abundance of CNT, and site-specific mortality at the adult stage was also significantly related to the abundance of CNT.

Keywords: abundance, colonizing native tree, path analysis, plantation, species composition

INTRODUCTION

The conservation of biodiversity has become one of the most important principles in sustainable forest management (Cannell *et al.*, 1992; Hunter, 1999; Kerr, 1999). In Japan, a particular focus is the 10.4 million ha of productive conifer forest currently covering about one-quarter of Japan's total land area. Conifer plantations are usually considered poor subjects for conserving biodiversity; therefore, increasing colonization of native trees (CNT) within plantations has been the focus of sustainable forest management in Japan (Nagaike, 2002; Ito *et al.*, 2003). However, silvicultural systems of mixed-species stands originating from plantations are still not developed in Japan (Masaki *et al.*, 2004). Therefore, the mechanism of tree species coexistence in mixed-species stands has been investigated for various planted coniferous species (Kunisaki and Mitsuishi, 2003; Nagaike *et al.*, 2006; Utsugi *et al.*, 2006).

It is often assumed that the competitive effects of overstory trees determine the distribution and abundance of understory trees in forests (McKenzie *et al.*, 2000). Since weeding and improvement cutting are carried out several years after planting in almost all plantations in Japan, most planted conifers become overstory trees, and the competition for light becomes asymmetric. Several studies have pointed out that species richness and abundance of CNT are negatively correlated with structural variables of planted conifer stands (Kunisaki and Kawamura, 2000; Masaki *et al.*, 2004; Utsugi *et al.*, 2006).

Slope characteristics (i.e., aspect, position, and steepness) within forests also play a critical role in the local variation of

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composition and abundance of understory trees, causing light intensity, moisture, and nutrients to vary (ENOKI *et al.*, 1996; CLARK *et al.*, 1998; TATENO and TAKEDA, 2003; ITO *et al.*, 2006). Slope-mediated gradients regulate the distribution of tree species and may enhance species diversity in montane forests (CLARK *et al.*, 1998; ENOKI and ABE, 2004).

However, stand structural variables and environmental variables covary (ENOKI and ABE, 2004; KUBOTA *et al.*, 2004; GARCIA *et al.*, 2007), and it is difficult to identify which variables are most critical. For example, topographic attributes strongly affect the survival and growth of planted conifer trees (KAWAMURA and KUNISAKI, 2000). Additionally, in the northern hemisphere, south-facing slopes generally experience higher temperature, greater light intensity, and lower moisture availability than north-facing slopes (STAGE, 1976; OHTA, 1991; BARNES *et al.*, 1997). The covariation makes it difficult to identify individual gradients that influence the composition and abundance of CNT, unless experimental manipulations are carried out, because of methodological limitations in applying traditional statistical techniques (NORTH *et al.*, 2005). In general, relationships between the composition of CNT and influencing attributes (i.e., environmental and stand structural variables) can be analyzed using canonical correspondence analysis or a combination of ordination methods (i.e., principal component analysis) and correlation analysis (MCCUNE and GRACE, 2002; LEPŠ and ŠMILAUER, 2003); however, canonical correspondence analysis and correlation analyses cannot identify confounding factors among predictor variables. In addition, relationships between the abundance of CNT and influencing attributes can be analyzed using multiple regression analysis, but multiple regression analysis does not allow multicollinearity of predictor variables.

Structural equation modeling (SEM) is considered to be a major component of applied multivariate analyses and is one of the more comprehensive approaches enabling researchers to analyze interrelationships among variables in multidimensional data, including path model analysis (MCCUNE and GRACE, 2002; PUGESEK *et al.*, 2003). Several studies of natural forests have attempted to relate understory tree species richness and abundance to stand structural attributes and environmental factors using SEM (WEIHER, 2003; KUBOTA *et al.*, 2004; LAUGHLIN *et al.*, 2007), but there have been no comparable studies of conifer plantations.

The objective of this study was to infer the most important gradients influencing species composition and abundance of CNT in an unthinned Japanese cedar (*Cryptomeria japonica* D. DON) plantation in northern Japan by examining relationships among stand structure, slope characteristics, and composition and abundance of CNT using an ordination analysis and SEM.

STUDY SITE

The study was conducted in the Omyojin Experimental Forest of Iwate University in Iwate Prefecture, northern Japan (39°40'N, 140°55'E; Fig. 1). Altitude of the study site ranged from 380 to 460m a.s.l. The slope inclination of the study site ranged from 17 to 42 degrees with a mean slope inclination of 30 degrees. According to meteorological data collected at the Omyojin Experimental Forest between 1990 and 2002, the mean annual precipitation was 1,706mm, and the mean annual temperature was 9.2°C at an elevation of 230m. The annual maximum snow depth was 82cm at an elevation of 240m between 1977 and 1985. Aerial photographs of the Omyojin Experimental Forest taken in 1959 indicated that the past vegetation of the study site was a natural mixed-species stand of the evergreen conifer *Thujopsis dolabrata* var. *hondai* and deciduous broadleaved trees.

In 1964, 4,500 *C. japonica* trees per hectare were planted after the natural stand was harvested. Weeding was carried out

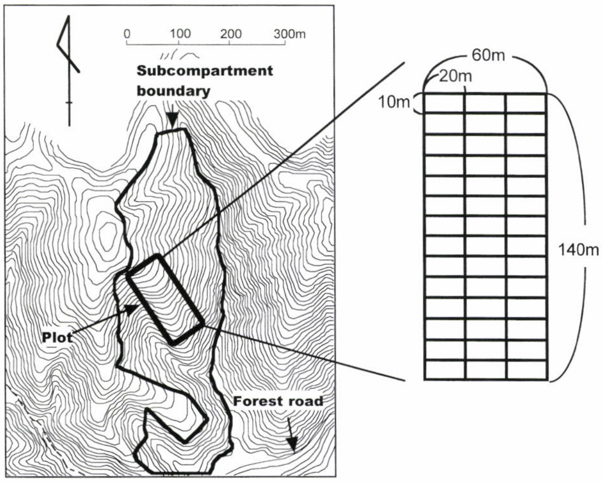

Fig. 1 Location of plot and topographical feature of study site

Table 1 General description of a plot stand

	Stem density (no./ha)	Basal area (m^2/ha)	Mean DBH (cm)	Stand height of subplot (m) Min.	Mean	Max.
Cryptomeria japonica	2,620	39.5	12.7	11.4	14.2	17.5
Colonizing native tree species*	1,810	7.9	6.7	—	—	—
Total	4,430	47.4	10.2			

*Trees ≥ 3-cm diameter at breast height (DBH) were measured.

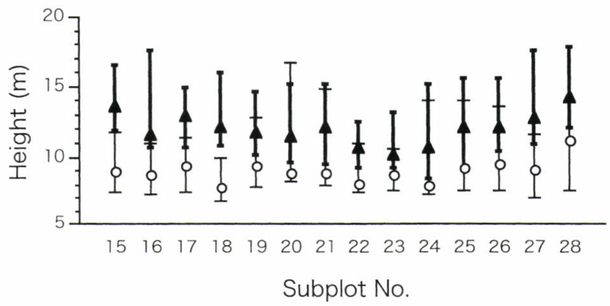

Fig. 2 Height distributions for *Cryptomeria japonica* and colonizing native tree species for subplots on SE-facing block

▲, Upper quartile height of *Cryptomeria japonica* ;○, Upper quartile height of colonizing native tree species. Upper and lower vertical bars show maximum and median heights, respectively.

annually until the stand was 5 years old, and light improvement cutting was implemented between 1975 and 1977. Thinning was not carried out prior to our study. At the time of data collection (in 2000), the relative basal area of *C. japonica* was 83% (Table 1). This species dominated the stand (Fig. 2) and formed a closed canopy. See KUNISAKI and KUNISAKI (2004) for further details regarding the stratification process in this stand.

METHODS

Vegetation Surveys

In 2000, when the stand was 37 years old, a 0.84-ha (60×140m) plot was established containing small ridge in the stand (Fig. 1). This plot was subdivided into three blocks (20×140m each) and a total of 42 subplots (20×10m each). For each tree >3cm in diameter at breast height (DBH) in each subplot, we recorded the species and DBH. Basal area for *C. japonica* (BA_{CJ}) trees in each subplot was used as a measure of *C. japonica* biomass. Stem density of CNT (D_{CNT}) in each subplot was used as a measure of CNT abundance.

Stand height (H_{CJ}) was defined as the mean of the ten largest *C. japonica* trees in each subplot, and was used as a measure of vertical stand structure (i.e., shading effect of dominant *C. japonica* trees on CNT). We measured tree height of *C. japonica* for ten of the largest trees by DBH, except for trees with a bent stem or broken apex, in each subplot. Canopy closure was assumed to increase beneath progressively taller trees as more of the sky hemisphere is obscured (JENNINGS *et al.*, 1999; COMEAU and HEINENAN, 2003).

Topographic and Edaphic Surveys

Slope aspect and steepness in each subplot (A_{SL} and S_{SL}, respectively) were measured using a clinometer. Each block was assigned to ESE-facing (90-115°), SE-facing (115-140°), and SSE-facing (140-180°) block. These three categories of slope aspect were coded as ESE- block=1, SE- block=2, and SSE-block=3. Slope position in each subplot (P_{SL}) was ordered from 1 to 14, increasing downslope within each block.

Mean volumetric soil water content (SWC) was defined as the mean of 20 values measured in each subplot, and we used mean SWC measured by time domain reflectometry (TDR) as a measure of soil water availability. We selected 20 points from the whole area of each subplot and measured SWC of the topsoil (0-12cm) using a TDR probe (CS-620, Campbell Scientific Inc.) with a rod length of 12 cm (KUNISAKI *et al.*, 2005). The probe was inserted perpendicular to the soil layer after removing the organic layer. To minimize the effects of rain, measurements were made on fair days in August at least 2 days after a rainfall event. The SWC of topsoil measured by TDR has a strongly-positive correlation with the SWC of soil samples at 30 cm depth measured by oven-drying (KUNISAKI *et al.*, 2005). Most fine roots of trees in Japan are distributed near the soil surface to a depth of 30 cm (KARIZUMI, 1987).

The mean soil depth of the A-horizon in each subplot (SDA) was defined as the mean of the three values measured in each subplot, and was used as a measure of soil fertility. Three soil pits were dug to a depth of 30-40cm in each subplot, and A-horizon thickness (soil depth of A-horizon after removing the organic layer) was measured using a measuring rod.

Statistical Analysis

Two-way indicator species analysis (TWINSPAN; HILL, 1979b) was performed to find indicator species and to divide the 42 subplots into several groups with similar species composition. TWINSPAN is one of the most popular classification methods used in vegetation science. Relative basal area values of all 40 species (Appendix A) were used in this analysis.

Detrended correspondence analysis (DCA; HILL, 1979a) was performed to determine the ordination axes of species composition for all 42 subplots. The relative basal area values of all 40 species (Appendix A) were used in this analysis. DCA is one of the most popular ordination methods used in vegetation science. The quality of ordination results in DCA axes was evaluated by the coefficient of determination between distances in ordination space and distances in original space (MCCUNE and GRACE, 2002). Relative Euclidean distance (MCCUNE and GRACE, 2002) was used as a measure in original space. In general, eigenvalues of ordination axes have been used as a criterion for evaluating the quality of ordination results (MCCUNE and GRACE, 2002). However, DCA eigenvalues cannot be used for this purpose because of the detrending effect (MCCUNE and GRACE, 2002). TWINSPAN and DCA were performed using PC-ORD version 4 (MjM Software Design).

To clarify covariation among CNT variables, stand structural attributes and environmental variables, Spearman's rank correlation analysis was performed on the data from all 42 subplots.

Path analysis with SEM was performed to analyze the correlation and causal relationships between slope characteristics, soil properties and vegetation attributes of the set of subplots. The DCA axis with the highest coefficient of determination was used as a measure of species composition of the CNT, and stem density of the CNT (D_{CNT}) was used as a measure of the abundance of CNT. A bootstrapping procedure (ARBUCKLE and WOTHKE, 1995) was used to estimate parameters (i.e., the means and standard errors of path coefficients) of the path models, since the assumption of multivariate normality was unreasonable for the dataset. Bootstrapping was run 2,000 times to generate the empirical sampling distribution of parameter estimates for each path model examined. Significance of each standardized path coefficient, representing the strength of the direct effect of one variable on another, was tested with the bias-corrected percentile method (MANLY, 1997). The significance of the correlation between exogenous variables, acting only as predictors for other variables in the model, was also tested using the bias-corrected percentile method.

To infer the most important environmental gradients influencing composition and abundance of the CNT, model selection (JOHNSON and OSLAND, 2004) was applied to 90 path models constructed from an ecological viewpoint for each predicted variable (the DCA axis and D_{CNT}). Model selection is suitable for making inferences from observational data, especially when inferring historical scenarios for which several different competing hypotheses can be proposed. Under the model selection approach, many path models, each representing one hypothesis, are simultaneously evaluated in terms of support by observed data. Path models can be ranked and assigned weights, providing a quantitative measure of relative support for each hypothesis (JOHNSON and OSLAND, 2004). The bootstrapping approach to model selection (ARBUCKLE and WOTHKE, 1995) can be summarized as follows. First, bootstrapping was performed and parameters were estimated for 90 path models. Second, the *P*-value of the Bollen-Stine bootstrap was checked to test the null hypothesis that the implied covariances of the models examined and sample covariances did not differ for each path model; only path models with a *P*-value greater than 0.05 were selected as suitable models. Third, the mean discrepancy between the implied moments obtained from the bootstrap sample and moments of the bootstrap population was calculated for the path models selected in the second step, and the model with the smallest mean discrepancy was chosen as the best model.

We calculated total effects, which indicated the total sum of the strengths of all direct and indirect pathways from predictor variables to a predicted variable (the DCA axis or D_{CNT}). Indirect effects indicated the total sum of the products of all path coefficients from a predictor to the predicted variable. SEM was performed using Amos version 5.0 (SmallWalters).

RESULTS

Two stand groups with similar species composition were discerned by TWINSPAN, and the indicator species were *Cornus controversa*, *Styrax obassia*, *Salix bakko* and *Stachyurus praecox* for stand group A and *Quercus mongolica* var. *grosseserrata* for stand group B (Table 2). The habitat type of the indicator species was based on soil moisture conditions. Stand group A was mesic, except for *Styrax obassia* as an intermediate type, and stand group B was xeric.

Differences in species composition between the stand groups were well represented by the first axis of DCA (Fig. 3). The coefficients of determination between distances in ordination space and distances in original space for the first and second axes of DCA were 0.81 and 0.01, respectively. Therefore, the scores of the first axis (AXIS 1) were used as a measure of CNT species composition in correlation and path analyses.

Correlations between AXIS 1 and other variables indicated that seven of nine variables had significant ($P<0.05$) relationships with AXIS 1 (Table 3). S_{SL} and BA_{CJ} were not correlated with AXIS 1. In contrast, correlations between D_{CNT} and other variables indicated that five of eight variables had significant relationships with D_{CNT} (Table 3). P_{SL}, S_{SL}, and BA_{CJ} were not correlated with D_{CNT}. H_{CJ}, as a measure of vertical stand structure, had significant negative relationships to BA_{CNT}, D_{CNT}, and AXIS 1.

Table 2 Summary of two-way indicator species analysis (TWINSPAN)

Discerned stand group	No. of subplot	Indicator species (IS)	Habitat type of IS*	Eigenvalue
A	30	*Cornus controversa*	Mesic	0.230
		Styrax obassia	Intermediate	
		Salix bakko	Mesic	
		Stachyurus praecox	Mesic	
B	12	*Quercus mongolica* var. *grosseserrata*	Xeric	

*Classifying habitat type with soil moisture condition follows Forest Development Technological Institute (1985).

Only one of the 90 models explaining AXIS 1 was selected as a suitable model, and this model was chosen as the best model by our model selection approach (Fig. 4). In the path diagram, one-headed arrows represent direct effects of one variable on another. This model explained 74% of the variation in AXIS 1, and A_{SL}, P_{SL}, and SWC directly affected AXIS 1. Standardized total effects indicated that A_{SL} and SWC strongly influenced AXIS 1 (Table 4).

In contrast, three of the 90models explaining D_{CNT} were selected as suitable models, and Model 3 was chosen as the best model by our model selection approach (Fig. 5, Table 5). Model 3 explained 57% of the variation in D_{CNT}, and A_{SL}, P_{SL}, and SWC directly affected D_{CNT}. Standardized total effects indicated that A_{SL} and SWC strongly influenced D_{CNT} (Table 6). The

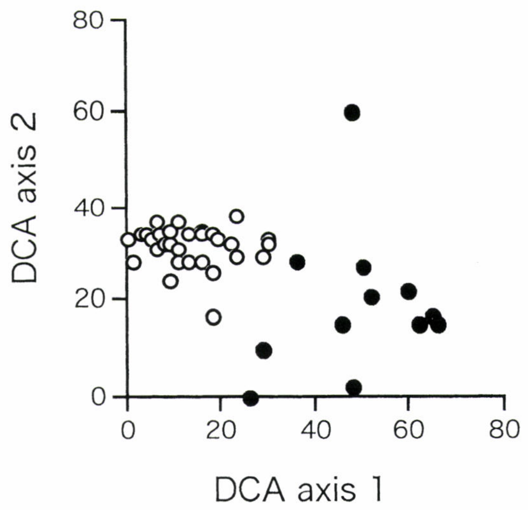

Fig. 3 Ordination diagram of stands using scores for the first and second axes of detrended correspondence analysis (DCA)

○, stand group A; ●, stand group B.

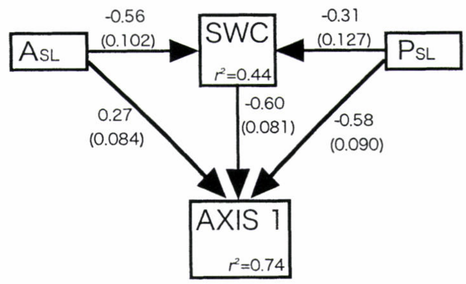

Fig. 4 Best model for explaining the scores of DCA axis 1 (AXIS 1)

The *P*-value of the Bollen-Stine bootstrap is 1.00 (D.F. = 1), and mean discrepancy is 15.77. Numerals near arrows indicate standardized path coeficients (*P*<0.05 based on bias-corrected percentile method), and parentheses indicate standard error estimates obtained from 2000 bootstrap replication. The r^2 values in boxes represent the variance explained for those variables. Error variables are not represented in this figure.

Table 3 Spearman's rank correlation coefficients among variables

	A_{SL}	P_{SL}	S_{SL}	SWC	SDA	H_{CJ}	BA_{CJ}	BA_{CNT}	D_{CNT}
P_{SL}	0.06								
S_{SL}	−0.02	0.71**							
SWC	−0.49**	−0.27	−0.20						
SDA	−0.44**	0.55**	0.37*	0.36*					
H_{CJ}	−0.05	0.08	0.12	0.29	0.14				
BA_{CJ}	0.29	−0.11	−0.10	0.09	−0.19	0.42**			
BA_{CNT}	0.63**	−0.22	−0.13	−0.60**	−0.49**	−0.50**	−0.26		
D_{CNT}	0.60**	−0.22	−0.17	−0.52**	−0.50**	−0.56**	−0.21	0.79**	
AXIS 1	0.58**	−0.43**	−0.30	−0.53**	−0.69**	−0.46**	−0.09	0.71**	0.85**

A_{SL}, Slope aspect; P_{SL}, Slope position; S_{SL}, Slope steepness; SWC, Soil water content; SDA, Soil depth for A-layer; H_{CJ}, The stand height of *C. japonica*; BA_{CJ}, The basal area of *C. japonica*; BA_{CNT}, The basal area of colonizing native tree species; D_{CNT}, The tree density of colonizing native tree species; AXIS 1, DCA axis 1. **P*<0.05; ***P*<0.01.

Table 4 Standardized total effects of predictor variables on predicted variables for best model in Fig. 4

	A_{SL}	P_{SL}	SWC
SWC	−0.56	−0.31	
AXIS 1	0.61	−0.39	−0.60

Total effects include both direct and indirect effects of the attributes and indicate the sum of the strengths of all pathways between two variables.

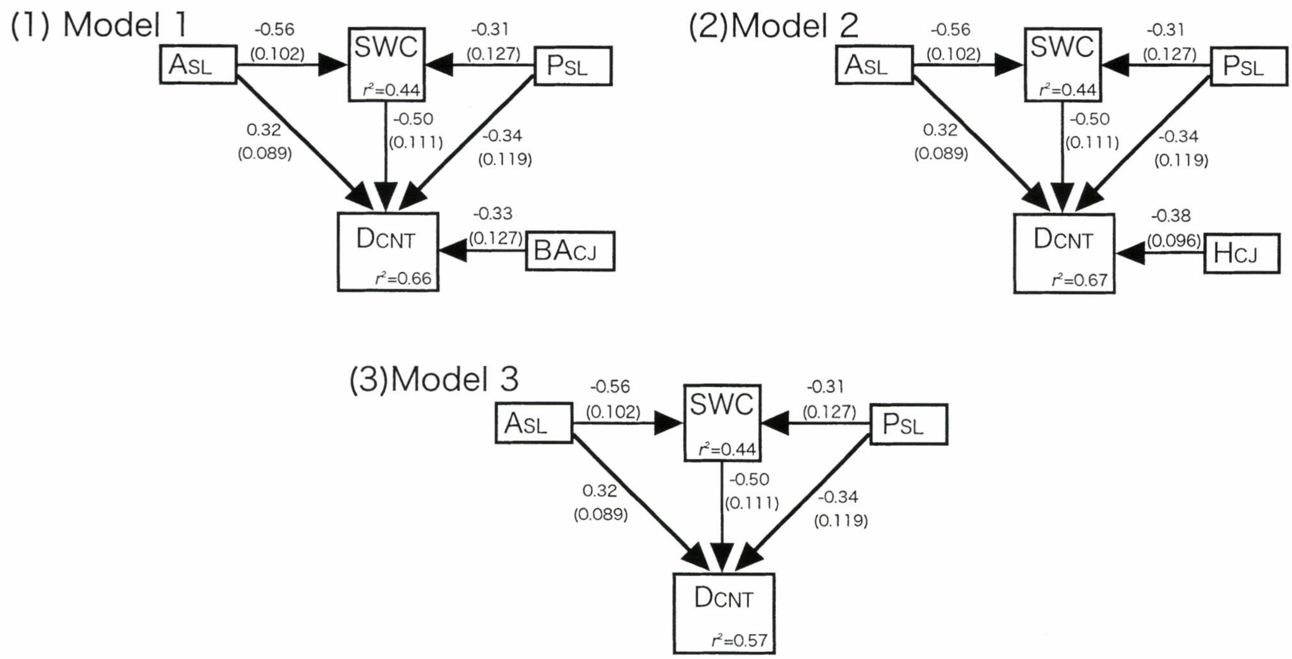

Fig. 5 Three suitable models for explaining stem density of colonizing native tree species (D_{CNT})

Numerals near arrows indicate standardized path coeficients (P<0.05 based on bias-corrected percentile method), and parentheses indicate standard error estimates obtained from 2000 bootstrap replication. The r^2 values in boxes represent the variance explained for those variables. Error variables are not represented in this figure.

Table 5 Summary of path analysis for explaining D_{CNT} shown in Fig. 5

	D.F.	The *P*-value of Bollen-Stine bootstrap	Mean descripancy
Model 1	4	0.413	28.28
Model 2	4	0.425	23.55
Model 3	1	0.998	16.69

D.F., The degree of freedom.

Table 6 Standardized total effects of predictor variables on predicted variables for suitable models in Fig. 5

	A_{SL}	P_{SL}	SWC	H_{CJ}	BA_{CJ}
SWC	−0.56	−0.31			
D_{CNT}	0.60	−0.18	−0.50	−0.38	−0.33

Total effects include both direct and indirect effects of the attributes and indicate the sum of the strengths of all pathways between two variables.

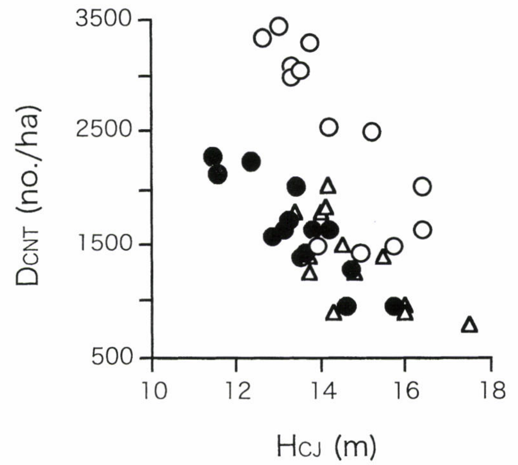

Fig. 6 Relationships between stand height of *Cryptomeria japonica* (H_{CJ}) and the stem density of colonizing native tree species (D_{CNT})

○, SSE-facing block ; ●, SE-facing block; △, ESE-facing block.

standardized total effect of H_{CJ} on D_{CNT} was higher than that of P_{SL} in Model 2, although H_{CJ} was not included in Model 3 (Fig. 5, Table 5). H_{CJ} had a significant negative ($P<0.05$) relationship with D_{CNT} for each category of ASL (Fig. 6).

DISCUSSION

Species Composition of CNT

These results suggest that species composition of CNT in the *C. japonica* plantation was strongly affected by site conditions along relatively short gradients of A_{SL} and SWC. In the northern hemisphere, solar radiation is greatest on SW-facing slopes and least on NE-facing slopes (STAGE, 1976; OHTA, 1991), thereby resulting in aspect-mediated gradients of soil moisture and soil temperature (BARNES *et al.*, 1997). Consequently, the dominance ratio of coniferous to broad-leaved trees varies greatly between SW-facing and NE-facing slopes in boreal forests in Japan (NAMIKAWA *et al.*, 2000), and understory composition shows drastic changes between south-facing and north-facing slopes in temperate forests in Spain (GARCIA *et al.*, 2007). In contrast, although there was slight variation in slope aspect from ESE-facing to SSE-facing blocks in the plantation studied, SSE-facing block had lower SWC than ESE-facing block. In our study, habitat types of indicator species for SSE-facing and ESE-facing blocks could be related to xeric and mesic soil conditions, respectively.

Path analysis suggests that variation in H_{CJ}, as a measure of vertical stand structure, did not affect species composition of the CNT. Using a chronosequence approach that investigates plantations of different ages, FERRIS *et al.* (2000) reported that the species composition of ground vegetation was significantly related to measures of vertical stand structure in conifer plantations in Britain. However, differences in stand age reflect not only variation in stand structural features, but also successional stage (OLIVER and LARSON, 1996), and thereby the species composition of understory vegetation greatly changes through succession with stand age (ITO *et al.*, 2003; 2006). In contrast, successional stage was a negligible factor in our study, because we focused on one even-aged, unthinned plantation of *C. japonica*. Therefore, H_{CJ} does not indicate successional stage, but rather vertical structural features.

Many studies of natural forests have indicated that the proximate factors determining the distribution pattern of adult trees are the recruitment patterns from juvenile tree stage and the survival pattern of adult tree stage for each species among topographic habitats (NAKASHIZUKA, 2001; NAGAMATSU *et al.*, 2002; MASAKI *et al.*, 2005; TSUJINO *et al.*, 2006; YAMADA *et al.*, 2007). The importance of these life-history traits are different according to habitat heterogeneity, and the recruitment patterns from juvenile tree stage and the survival pattern of adult tree stage are particularly important in relation to horizontal heterogeneity (i.e. the distribution of water and nutrients) and vertical heterogeneity (stratification), respectively (NAKASHIZUKA, 2001). However, the variation in H_{CJ} did not affect species composition of the CNT in the plantation studied. Our previous study (KUNISAKI and KUNISAKI, 2004) showed that the mean increment of stem length for the upper CNT was higher than that of the dominant *C. japonica* trees, whereas the recruitment of CNT rarely occurred after canopy closure in the plantation studied. The previous study suggests that the recruitment pattern of CNT is a particularly important determinant of species composition of the CNT, because the upper CNT in the adult tree stage have grown vigorously beneath the dominant *C. japonica* trees. Horizontal heterogeneity in soil water distribution will affect the species composition of CNT strongly through the recruitment pattern from juvenile tree stage.

Abundance of CNT

The abundance of CNT in the *C. japonica* plantation was also strongly affected by site conditions along relatively short gradients of A_{SL} and SWC. In particular, SSE-facing block indicated higher abundance of CNT than ESE-facing and SE-facing blocks. The dominant CNT species on SSE-facing block were *Quercus mongolica* var. *grosseserrata* and *Castanea crenata* (Appendix A), which were densely distributed on xeric soils and have vigorous sprouting characteristics after disturbance in Japanese temperate forests (FOREST DEVELOPMENT TECHNOLOGICAL INSTITUTE, 1985). These results may indicate that regeneration performance of dominant species regulates the abundance of CNT along slope-mediated gradients.

The measure of vertical stand structure (H_{CJ}) also had a significant negative relationship with the abundance of the CNT, although H_{CJ} was not included in the best path model (Model 3). There is a major difference in variation patterns between species composition and abundance of CNT. In general, horizontal heterogeneity in resource distributions promotes tree species coexistence through demographic processes that occur primarily at the juvenile tree stage, whereas the vertical stand structure is important once the tree has become established and has reached the adult tree stage (NAKASHIZUKA, 2001). If mortality rates in the adult tree stage are about the same between major and minor tree species of CNT, species composition of CNT will not change substantially over time. Therefore, the contrasting patterns of variation between species composition and abundance of the CNT may reflect the fact that the mortality rate of CNT at the adult stage varies according to vertical stand structure (i.e., the shading effects of the dominant *C. japonica* trees) rather than to interspecific differences in survival patterns. Vertical heterogeneity in stand structure may also affect the abundance of CNT through the mortality pattern from adult tree stage.

CONCLUSIONS

In this study, we examined relationships among stand structure, slope characteristics, and composition and abundance of CNT in an unthinned *C. japonica* plantation using ordination analysis and SEM. Species composition of CNT was strongly affected by site conditions along relatively short gradients of A_{SL} and SWC, but H_{CJ} had little effect on species composition. In contrast, the abundance of CNT was strongly affected by site conditions along relatively short gradients of A_{SL} and SWC, and H_{CJ} also significantly affected abundance, although the effects of H_{CJ} on abundance were considerably weaker than those of A_{SL} and SWC. In conclusion, recruitment patterns from the juvenile tree stage for each species were related principally to species composition and abundance of CNT, and site-specific mortality at the adult stage was also significantly related to the abundance of CNT.

We suggest that habitat heterogeneity provided by slope characteristics and stand structure can be critical factors in maintaining tree species coexistence in mixed-species stands of *C. japonica* and deciduous broadleaved trees. However, the significance of life-history traits may vary among tree species of different life-history stage and environmental condition. To clarify the mechanisms maintaining tree species coexistence in mixed-species stands, further studies on recruitment pattern for each species along environmental gradients are needed.

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* The title is tentative translation from original Japanese title by the authors of this paper.

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Appendiy A Species composition of colonizing native tree species for each block in study plot

Species name	Life form	SSE-facing block		SE-facing block		ESE-facing block	
		D (no./ha)	BA (m^2/ha)	D (no./ha)	BA (m^2/ha)	D (no./ha)	BA (m^2/ha)
Quercus mongolica var. *grosseserrata*	Tall tree	1,361	6.65	414	2.36	118	0.78
Styrax obassia	Small tree	50	0.11	336	0.60	236	0.41
Castanea crenata	Tall tree	339	2.41	104	1.03	68	1.15
Magnolia obovata	Tall tree	82	0.29	218	0.76	196	0.66
Cornus controversa	Tall tree	68	0.31	164	0.54	225	1.14
Stachyurus praecox	Small tree	7	0.01	50	0.05	229	0.19
Betula maximowicziana	Tall tree	61	0.49	57	0.84	18	0.22
Salix bakko	Tall tree	50	0.31	32	0.19	43	0.30
Prunus grayana	Tall tree	43	0.07	54	0.13	18	0.03
Clethra barbinervis	Small tree	14	0.02	71	0.08	21	0.02
Ilex macropoda	Small tree	39	0.06	18	0.02	7	0.01
Acer mono	Tall tree	25	0.04	7	0.01	21	0.06
Quercus serrata	Tall tree	46	0.35	4	0.01		
Lindera umbellata	Small tree	4	0.01	14	0.01	29	0.02
Morus bombycis	Tall tree	4	0.00	18	0.02	18	0.04
Prunus leveilleana	Tall tree	14	0.02			25	0.04
Acer sieboldianum	Tall tree	7	0.01	7	0.01	25	0.04
Hydrangea paniculata	Shrub	4	0.00	4	0.00	29	0.02
Carpinus laxiflora	Tall tree	29	0.06	7	0.02		
Aralia elata	Small tree	4	0.01	11	0.04	18	0.06
Kalopanax pictus	Tall tree	7	0.03	11	0.04	11	0.01
Fraxinus lanuginosa	Small tree	11	0.03	11	0.02	7	0.02
Rhus trichocarpa	Small tree	25	0.04	4	0.00		
Acer japonicum	Tall tree	21	0.03	4	0.00		
Prunus sargentii	Tall tree	14	0.03	7	0.01	4	0.00
Acer palumatum var. *matsumurae*	Small tree	18	0.03				
Acanthipanax sciadophylloides	Tall tree	7	0.06	4	0.00		
Meliosma myriantha	Tall tree	11	0.03				
Populus sieboldii	Tall tree	4	0.01	4	0.08		
Thujopsis dolabrata var. *hondai*	Tall tree	4	0.00			4	0.00
Rhus javanica	Small tree	4	0.01	4	0.02		
Pinus densiflora	Tall tree	7	0.20				
Fagus crenata	Tall tree	7	0.03				
Acer rufinerve	Tall tree	7	0.04				
Zanthoxylum piperitum	Shrub					7	0.01
Aesculus turbinata	Tall tree			4	0.00		
Carpinus cordata	Tall tree	4	0.00				
Acer micranthum	Small tree	4	0.00				
Corylus sieboldiana	Small tree			4	0.00		
Weigera hortensis	Shrub			4	0.00		

Tree species were arranged in descending order of total stem density for three blocks.
D, Stem density; BA, Basal area

Short communication

Forestry Development and Farmers' Investment Competence in Forestry

Hong-yi Chen[*1], Yasuaki Kurokawa[*2] and Gang-qing Wang[*1]

ABSTRACT

Forest resources are an important part of natural resources and terrestrial ecosystems. With the quick economic development and the national power improvement, China has been increasing the investment in forestry, including many key forest projects, natural reserves and forest parks. However, the lack of adequate and reliable capital input has become a major bottleneck to the development of ecological forestry in China. Although the Chinese government has established the policy to encourage mutual investment in forestry by collectives and individuals to solve the problem, farmers, the subjects of forest management haven't the economic competence to invest in forestry. This has reduced the enthusiasm of farmers' forest management and has been an obstacle of forestry development. For this reason, the countermeasures should be implemented as soon as possible in order to improve farmers' income, and make them play important role in the forestry development.

Keywords: forestry development, investment system, farmers' income

INTRODUCTION

In recent years, the Chinese government has implemented a series of strategies in the construction of forestry and remarkable progresses have been achieved.

From 1995 to 2000, the investment in capital asserts in forestry totaled 50.169 billion yuan and the investment in forestry infrastructure totaled 44.177 billion yuan, including bond investment, involving 24.523 billion yuan of national investment, including the budget capital of central and regional governments. The actual utilization of the World Bank's loans totaled 0.253 billion dollar (SSBC, 1992).

However, from 1989 to 1991, farmers' real net incomes only increase by 0.7% (SSBC, 1992). This was affected by the trade and the price scissors affection between agricultural and industrial goods prices, and the over-extraction of fees and levies from the farmers. The concept of social forestry as a forestry development strategy has been introduced to China, and the philosophy of social forestry is that the forest users have to be motivated to start reforestation. The philosophy of social forestry proves that the subjects of forestry management, farmers, are not only constructors but also beneficial owners (Cui, 1999). However, at present, farmers haven't enough economic investment competence in forestry and even in some areas farmers are still in poverty. Therefore, how to improve present forestry conditions and forest policies has become an important subject for the sustainable forestry development. This paper gives detailed investigation of forestry investment situation and farmers' real living state. And then the suggestion to solve forestry and agricultural development will be presented.

GOVERNMENT INVESTMENT SITUATION IN FORESTRY

In planned economy period (1949-1978), the Chinese government adopted the highly centralized decision-making and management investment system. Under the system, the government pursued a forest policy characterized by tree planning on barren lands and timber harvesting in major forest regions, while expressing concern about protecting forests (Ministry of Forestry, 1986). Large-scale tree planting of wasteland, especially in the north, began in the mid-1950s. The main task of forestry in this period was timber production. The Big Leap Forward campaign was launched in 1958 to encourage the use of homemade furnaces for steel making, but it led to thousands of inefficient furnaces and massive destruction of forests. The compulsory elevation of millions of

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farmers' cooperatives to People' Communes, along with the failure of the Big Leap Forward, contributed to famine that lasted for three years (1960-1962). And the Culture Revolution (1966-1976) catapulted China into unprecedented political chaos and anarchy. During the period, most forestry programs were discontinued, except rampant timber cutting and highly inefficient afforestation campaigns (Chinese Forestry Development White Book, 2000).

From 1979, economic reform was started and China stepped into the Planned Commodity Economy period (1979-1992). In this period the forest sector supplied under-priced logs to support the national economic development. The sector was seen only as a supplier of cheap raw materials. As a consequence, over one billion cubic meters of timber was supplied, and the country's forest resource base was devastated (RICHARDSON, 2000). In spite of this, since 1978, significant changes have taken place in land-tenure system. The popularity of the household production responsibility system in the countryside at the end of the 1970s exerted pressure on forestry to follow suit. Despite initial resistance to change by the central forestry authorities, the first signs of relaxation in government policies appeared with respect to wastelands in mountainous areas. Farmers showed a strong interest in the policy. The changes in forest tenures have been recognized as a crucial driver in China's forestry reform (LIU, 2001)

The establishment of socialist market economy system (1992-present) has changed the mode of resource allocation fundamentally.

With the quick economic development and improvement of the economic strength, the Chinese government increased the investment in forestry as it shows in Table 1, Fig. 1 and Fig. 2. For the investment from the government, the amount of forest resource has increased greatly, particularly the ecological construction, ecological environment has been improved.

However, Compared with the heavy task of ecological construction, it is still in urgent need of government investment. Forest protection and forestry infrastructure construction are short of steady financial sources. Government investment does not keep up with functions of public finance and it is still short of stable sources. The input for forestry capital construction is unstable. Government investment lacks legal foundations.

In the ten years between 1988 and 1997, fixed capital investment in forestry totaled 41.77768 billion yuan. For instance, during the same period investment from the government in forestry (including key projects, nature reserves and forest parks) totaled only 2.37919 billion yuan, accounting for only 5.7% of total forestry investment. (China Annual Statistics Book, 2000)

Another fact is that 36% or 71.761 million mu are state forests, while the rest 64% or 128.239 million mu are collective-owned (China Annual Statistics Book, 2000). Private and other

Table 1 Forestry investment state in different periods (Unit: 10^4 yuan)

Investment State	Overall Investment	Proportion (%)	Annual Growth Rate (%)	Government Investment	Proportion (%)	Annual Growth Rate (%)
Planned Economy	1,646,986	9.05	8.20	1,253,667	10.02	7.49
Planned Commodity Economy	1,800,394	9.89	3.61	1,035,279	8.27	6.35
Market Economy	14,750,900	81.06	44.45	7,104,048	81.71	32.73

Source: China Annual Statistics Book 2000

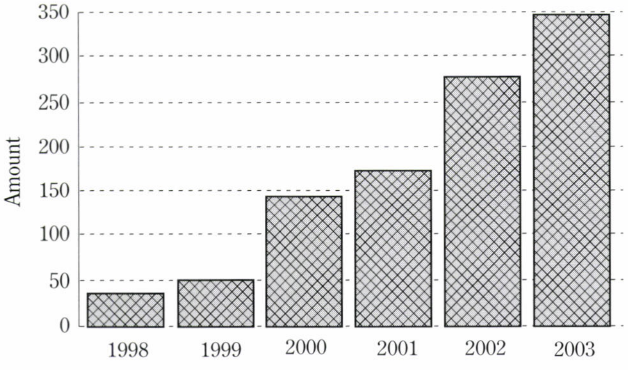

Fig. 1 The amount of government investment (1998-2003) (Unit: 105 yuan)
Source: China Annual Statistics Book 2003

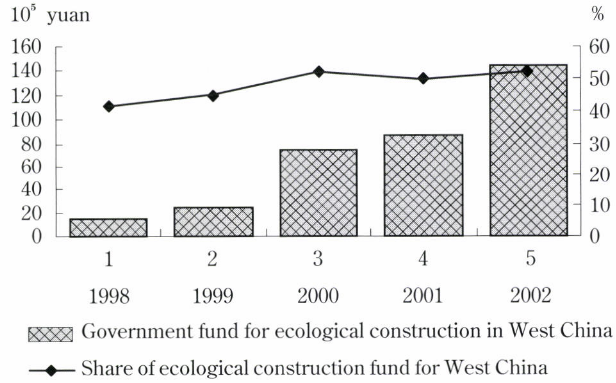

Fig. 2 Trends of government investment in ecological construction
Source: China Annual Statistics Book 2003

ownership forests accounted for nil. In the 42,762 forest management units being subsidized, 1,456 units or 3% are state-owned, the rest 97% or 41,306 are collective-owned. In the state units, most are state forestry farms and nature reserves, accounting for 74% and 19%, respectively. In the collective forests, collective-owned forestry farms accounted for only 6% of total collective pilot forests. That is to say, the majority of collective forests being subsided are household managed forests (China Statistical Yearbook, 2000).

However, landholders particularly farmers have very limited investment competence to their forests, and even in some areas, they live in the poverty.

INVESTIGATION AND ANALYSIS

Economic State of Rural Residents

China has four geographically distinct forest regions (southeast and south; north; northeast; southwest) and two different land ownership categories (state-owned and collective-owned). The northeast and southwest are dominated by state-ownership and natural forests. The other regions are dominated by collective ownership (Gong, 1999). In this study, we focus on rural forestry, which is mainly located in the southeast and south and north areas. In the two regions, approximately 90% of forestry land is managed by rural farmers, under various collective or house-hold management arrangements with the general framework of collective forestry land ownership (Gong, 1999).

Comparing the net income of a farmer to his basic needs of life, and identifying the basic standard of nutrition and the other basic level of necessities, China adopted the criterion of absolute poverty in rural areas. The poverty line defined by the National Bureau of Statistics in 1986 was 204 yuan, and the standard was raised to 580 yuan in 1996 (Nexus, 2000).

The figures of rural poor and their percentage to total rural population are presented in Table 2, and it was estimated by the World Bank and the Chinese Government.

The counties where the level of per capital income of rural residents is below the poverty line are designated as poor counties. The distribution of the rural poor according to the counties is given in Table 4. From 1995 to 2000 the number and proportion of poverty counties and poverty dramatically decreased in the east area, compared with the middle-west area, especially the west area.

At present, the rural labor force is around 440 million people, of whom 75% are employed in the primary industry (agriculture, livestock and fisheries); 54.56 million people or 12.4% are employed in the secondary industry and 55.44% million people or 12.6% are employed in the third industry (Sun, 2000).

Employment pressure is very severe in rural areas, and there is a sharp contradiction between the numbers of people and the limited land resources available. Linqin county in Shanxi province is one of the most important forest districts in China, and the Chinese first forestry reform experiment was in this county. The farmers are richer than those in other forestry districts. But they can't get enough income from agriculture and forestry (See Fig. 3). Therefore a number of rural labors who are willing to transfer to other employment have reached hundred millions. There is only about 13.3 million hectares of arable-land, which can be operated by a maximum of 200

Table 2 Urban and rural population living in poverty (1995-2001)

Year	Poverty line (Yuan)	Population in urban (million)	Percentage	Population in rural (million)	Percentage
1995	752	14.15	5.8	218	33
1996	837	11.65	4.5	194	27
1997	993	13.20	5.1	123	24
1998	1,300	15.26	5.7	96	15
1999	1,547	12.42	4.4	86	12
2000	1,671	17.16	4.2	97	12
2001	1,700	11.68	4.1	70	8

Source: China Annual Statistics Book 2001

Table 3 Distribution of poor counties and poverty population among the east, middle and west regions (2000)

(Unit: 10^5 persons)

Indicator	East region	Middle region	West region	Whole
Number of counties	105	180	307	592
Proportion of counties	17.7	30.4	51.9	100.0
Number of poor people	13,846	20,301	35,907	70,054
Proportion of poor people	19.8	29.0	51.3	100.0

Source: China Annual Statistics Book 2000

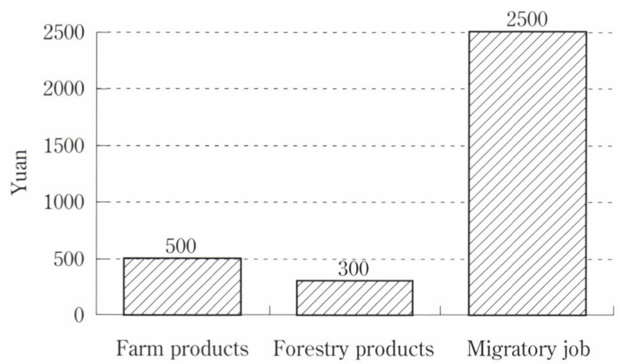

Fig. 3 Main farmers' revenue (Forest farmers in Linqin County, Shanxi Province)

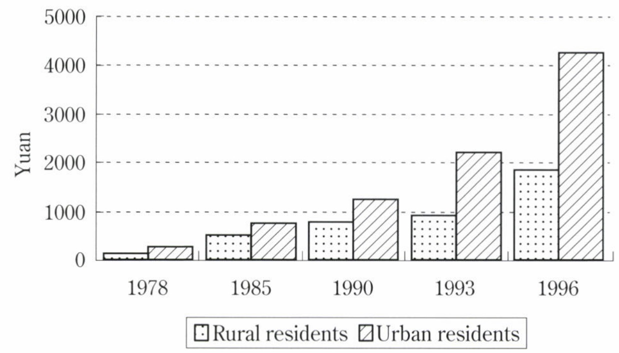

Fig. 5 Income of rural residents and urban residents
Source: China Annual Statistics Book 1996

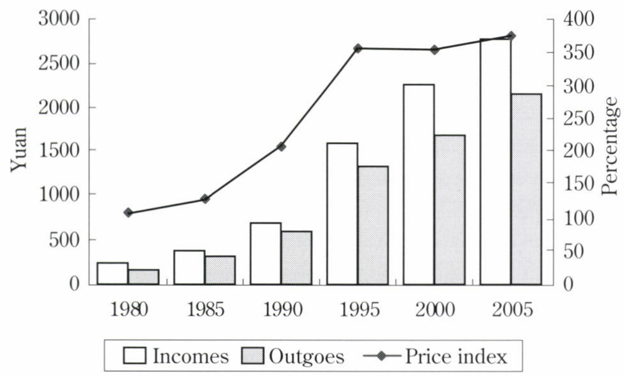

Fig. 4 Variation of incomes and outgoes of rural residents

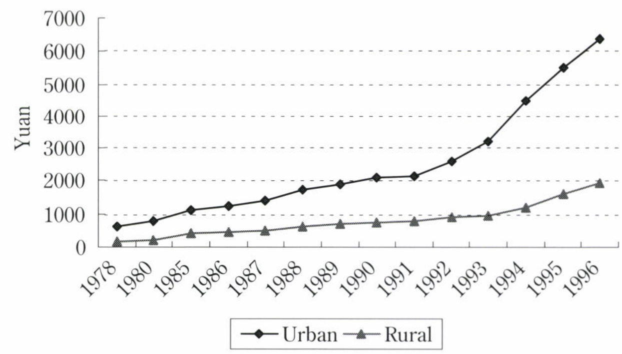

Fig. 6 Gap in wage income between the rural and urban residents
Source: China Statistical Year Book 2000

million farmers. After accounting for those who are now employed in the township enterprises, this still leaves more than 100 million able-bodied workers who are underemployed. By the end of 2000, the size of the surplus labor force in rural areas was estimated to be about 200 million people. Per capita arable land area is only about 0.08 hectares, and per capita possession of other resources is also limited and will decrease in the future (Sun, 2000).

For the decrease of the farmers' income, most farmers have lost initiative to the management of agriculture and forestry, even in some place, for the income can't support their lives, some farmers destroy collective-owned forest to get enough money to support their lives (See Fig. 4). In some poverty areas, it occurred that the government invested to plant trees while farmers destroy the forest. Therefore, the gap of rural and urban incomes has become an important factor that will prevent farmers from the management of forestry, delay the construction of social forestry system and reduce the effects of the government's investment to forestry.

General Overview on Income Disparity

Urban-rural income inequality

Economic reforms since 1978 have made substantial improvements beginning from the living standards of rural residents. Many farmers have boosted their incomes by engaging in specialized agricultural activities such as animal husbandry, agriculture, and orchard production, in addition to raising traditional crops. Furthermore, township and village enterprises have accounted for the bulk of increased wage income earned by the rural resident. The income distribution among rural residents has had remarkable improvements since the early 1980s. The share of poverty-stricken population has decreased from over 90% in 1980 to less than 10% in 1996. Furthermore, we can see a significant improved balance among difficult income groups of rural residents since the early 1990s. However, the rise income or rural residents is distinctly small when compared to that of urban areas. The rural incomes in China are only 40% of urban incomes when in most countries rural incomes are 66% or more of urban income in 1995 (Zheng, 1996). The gap of income between the rural and urban residents has expanded from 1978 to 1994. In fact, such disparity has been the biggest contributor to the problem of equity in China followed by the inter-regional disparity (see Fig. 3).

Regional income inequality

Decades of strict central planning has created serious disparities in income in different regions of China. As shown in the following Table 4, per capita annual income of Shanghai was 7,555.89 yuan far ahead of other regions. When we compare the average annual income of high income region such as Jiangsu province, which is located in the eastern region, with that of Guizhou, which has the lowest income level among the western region, the difference is quite enormous. In 1996, per capita annual income of Jiangsu was 2,613.54 yuan while Guizhou had 609.80 yuan, the ratio between two being 4.3 : 1. Similar results could be found when we use different criteria. For instance, in 1996, per capita GDP and the total GDP of the eastern region were 1.9 times and 5.5 times larger respectively than those of the western region.

Major Causes of Income Disparity

China's development policies have created an unbalanced regional development by variations in resource allocation. For this reason, 71.5% of Chinese industry was concentrated in the coastal areas and only 28.5% in inland regions (China Statistical Yearbook, 2000).

Human resources are concentrated in coastal areas but mineral resources are deposited mainly in the interior area. The number of industrial labor force worked and lived in the eastern area (approx. 250million) was almost 49% of the total number in 1996. On the other hand, most of China's minerals, forests and other natural resources are located in northwestern and central China. Only one fourteenth of the nation's coal reserves are located in the coastal regions while more than 92% of its coal deposits are in the interior. About 90% of the nation's forests are in the central and western areas while less than 10% are in its coastal regions (China Statistical Yearbook, 2000).

The coastal regions possess a well-developed financial base and manage a relatively high level of capital accumulation. Over 61% of the total investment in fixed assets was made in the eastern region in 1996. Productivity and living standards in the coastal are higher than that of the interior regions.

Disparities in the technological capabilities between the coast and the interior are significant. The eastern region possesses over 49% of the total number of educational institutions in 1996. The coastal area has a relatively well-developed economy and technological base with better access to capital but is handicapped by over-population which could lead to future problems. By contrast, the interior area is characterized by a vast land area, rich mineral resources, sparse population, and weak technological capabilities. Because of their different resource bases these areas could complement each other (Li, 1993).

CONCLUSION

The data and analysis presented in this paper prove that the construction of forestry and ecological environment can't be fulfilled only by the investment from the government. A new investment system should be enacted. At the same time that the government will increase the investment, the government should encourage enterprises and farmers to invest to forestry. The construction of social forestry is being urged in China, and in social forestry system, farmers are not only the forest constructors, but also beneficial owners. However, at present, farmers haven't investment competence, and even they can't keep their lives. Therefore, the government should take effective measures to improve

Table 4 Per capita annual income by region

Eastern area	Per capital annual income	Central area	Per capital annual income	Western area	Per capital annual income
Hebei	1,442.48	Liaoning	2,099.40	Shanxi	853.27
Tianjin	3,383.85	Heilongjiang	1,541.01	Gansu	1,041.97
Beijing	4,417.85	Jilin	1,456.39	Ningxia	1,020.06
Shandong	1,682.51	In-Mongolia	1,112.49	Sichuan	985.39
Jiangsu	2,613.54	Shanxi	1,186.92	Yunnan	942.46
Shanghai	7,555.89	Henan	1,019.15	Guizhou	609.80
zhejiang	2,443.99	Anhui	1,047.83	Qinghai	1,055.46
Fujian	1,674.75	Hubei	1,341.40	Xinjiang	1,456.63
Guangdong	2,450.21	Hunan	977.06	Xinjiang	1,456.63
Guangxi	842.88	Jiangxi	1,106.78	Tibet	930.86
Hainan	1,753.22				

Source: China Statistical Yearbook (2000) farmers' surroundings and competence.

1. Unique and proper welfare and income redistribution system should be created.

The government should introduce a wide range of policies that are aimed at reducing unemployment and improving the labor forces' competitiveness. Furthermore, the government should reduce differences in education, health services, housing and access to employment and credit between urban and rural areas as well as in different regions. The government should create a system for welfare and redistribution of income that is suitable for the current condition of the Chinese economy. To build a harmonious society, must take its 900 million farmers into the social security system, which is a premise for social stability and can help promote China's advance from an agriculture country to an industrialized country.

2. The regional development should be improved.

At present, there is variation within the south and the north as indicated by the differing effects of de-collectivization and prices for provinces in the south and the north. The results suggest that local-level institutional factors and economic conditions may play a role in land allocation between forestry and agriculture and also in the intensity of harvest.

3. The short-term, medium-term and long-term agricultural development policies and objectives should be enacted quickly.

There are not continued agricultural development policies and definite development objectives in China for a long time. A pressing matter of the moment is to establish the policies including short-term, medium-term and long-term development strategies with the definite development objectives. The policies should contain the effective market system, agricultural fund utilizing system, agricultural technology training system and agricultural basic facility construction pledge system in order to improve rural living and productive surroundings and farmers' income.

When the aforementioned objectives are realized, farmers can have stable income and investment competence and gradually improve their investment initiative. Only farmers as the main force of forestry construction devote themselves into forestry, social forestry system can be build and the forestry sustainable development can be realized.

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Short communication

Stem Volume Equation and Tree Growth For Rubber Trees in Cambodia

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ABSTRACT

Rubber trees (*Hevea brasiliensis*) in Cambodia are important sources for not only natural rubber but also wood products. This study was conducted to set up stem volume equations to estimate the stand volume and the volume increment for rubber trees in Cambodia. Krek Rubber Plantation located in Kompong Cham Province was selected for study area. Sixty trees of the clone PR107 at the age of 36, 44, 45 and 46 were felled and cut into segments of one meter long to formulate the volume equation. The DBH and total height of 450 standing trees (15 plots) at different ages (6-10 and 36- 48) were measured to estimate volume per hectare and the mean annual increment (MAI). This study revealed that the volume equation for standing rubber trees clone PR107 is $V = 0.00018381\ D^{2.23961}\ H^{0.15334}$ or $V = 0.00024884\ D^{2.29535}$ where V is the over bark volume (m³), D is diameter at breast height (cm), H is total height (m). Using the two-variable equation, rubber wood volume at the rotation length of 25-30 years was estimated at about 240 - 270m³ ha⁻¹ with the MAI of 9.33 m³ ha⁻¹ yr⁻¹.

Keywords: rubber trees, volume equation, stem volume, tree growth, mean annual increment (MAI)

INTRODUCTION

Rubber tree (*Hevea brasiliensis*), which is indigenous to the Amazon basin and was named as "white gold" in the earlier twentieth century, has been playing a significant role in sustaining socio-economic base of many countries in the world, especially in South East Asia accounting for about 80% of the total areas under rubber worldwide. The exploitation of rubber trees focused solely on their resin called "Latex" during 25 to 30 years of their life expectancy before being cut down and replanted. Many researchers paid their attention to how to manage the rubber plantations to maximize latex through breeding, cloning or fertilizer application (Shorrock *et al.*, 1965; Colling and Sowching, 1967; Narayanan and Hochai, 1973; Narayanan *et al.*, 1973; Nga and Subramaniam, 1974; Samsuddin *et al.*, 1987). In the past decades, some authors started to pay much attention to rubber wood (Westgarth and Buttery, 1965; Templeton, 1969; Mainstone, 1970; Senghuat, 1981; Sim, 1989; Najib and Othman, 1996) and from the 1980s, there has been growing interest in maximizing the utilization of rubber woods. Further, due to their potentials as a source of raw materials, much attention is being focused on rubber wood as a source of sawn timber to supplement the existing supply (Wanrazali *et al.*, 1983). However, there has been very few information on volume equation and mean annual increment (MAI) of rubber trees. To our knowledge, there is only one paper on volume equation developed by Wanrazali *et al.* (1983) as rubber wood, in the past, was burnt on the spot or mainly used as wood fuel for locomotive engines, brick burning or latex curing (FAO, 2001b).

In Cambodia, the first rubber plantation was established by a French national Mr. Boulliard in 1910 in Prey Nup district, Kompot province, but the establishment of grand rubber plantations for industrial purpose started in 1920 (Tichit, 1981). Since then the share of rubber sector in national economy become more and more vital. In 1964, the exportation of rubber productions increased by 24% of agricultural share in GDP, ranked second after rice production (MAFF, 1965), and in 2004 rubber productions contributed to 4% of 33% of agricultural contribution to GDP, ranked second after forest productions (MAFF, 2004). Now around sixty

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thousands hectares have been occupied by rubber plantations throughout the country. In mid 1990s as the trend of rubber wood processing from foreign countries started in Cambodia, the central government set up a ten-year program of cutting and replanting of rubber trees. Thousands of hectares of old rubber trees per year were felled and sold to rubber wood processing companies. Unfortunately, little information is available concerning either individual tree volumes or mean annual increment (MAI). Therefore, there is an urgent need to develop volume equation and to know the growth rate of rubber trees planted in Cambodia for a better future management.

The objectives of this study were to set up volume equations and to estimate stand volume and the mean annual increment per hectare for the rubber trees in Cambodia. In this study, we investigated the clone PR107, one of the most common clones in Cambodia.

STUDY SITE

The study area is in Krek Rubber Plantation (105°53'38"E-106°00'18"E and 11°46'23"N-11°53'27"N), located in Kompong Cham Province around 190km from Phnom Penh, the capital city (Fig. 1). Large part of the plantation's soil is red basaltic with the average of PH = 4.57 (RRIC, 1968) and the climate is tropical with a bi-annual change of monsoonal systems, the rainy season (May-October) and the dry season (November-April). Mean annual rainfall and temperature have been 1,700mm and 28°C respectively. The total areas under rubber from one to 54 years old in 2005 were 3899.63ha. Due to the civil war during 1970-1990, there are no stands of the age from 15 to 35 years old in 2005.

MATERIALS AND METHODS

To make the volume equations, we used 60 trees from 4 stands at different ages 36, 44, 45 and 46 (Table 1). Before felling, we measured total height and diameter at breast height (DBH at 1.3m) using Vertex III (Haglof, Finland) and diameter tapes, respectively. Then we felled them down, cut into segments of one meter in length (up to 10cm diameter of branches), measured and recorded diameters of both end sides of each segment. Volumes per segment and per tree were calculated by SMALIAN's formula as follows;

$$V_s = \frac{A_1 + A_2}{2} L, \tag{1}$$

where V_s is segment volume (m^3), A_1 and A_2 are cross sectional areas of both end sides of segment (m^2), and L is length of segment (m). We developed the widely used volume equations; one variable formula (2) and SCHUMACHER-HALL's formula (3), and the coefficients were estimated by standard

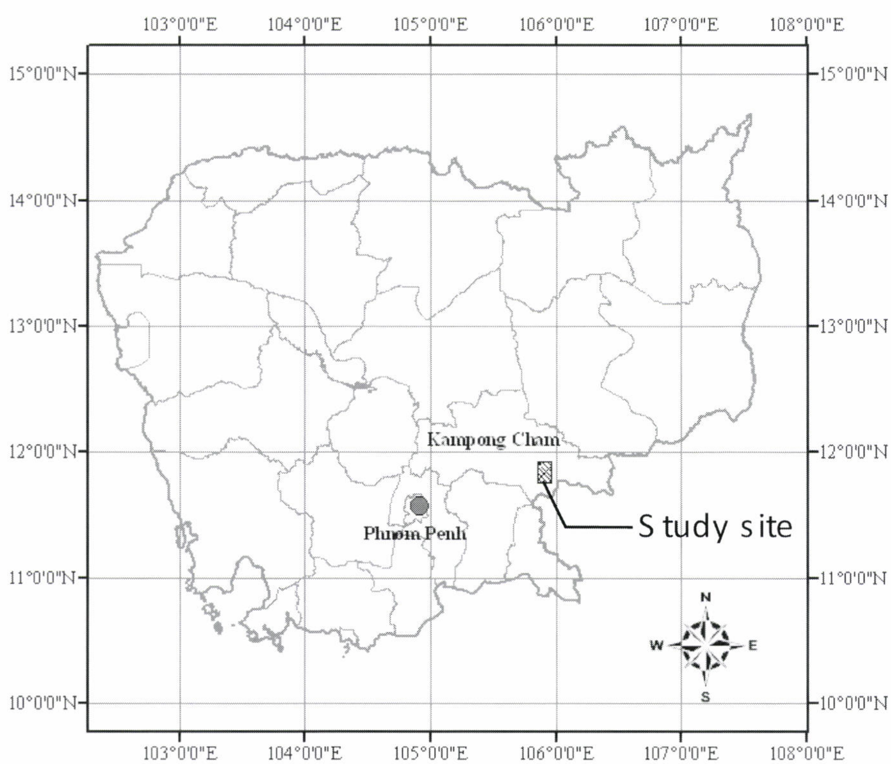

Fig. 1 Location of study site

linear regression methods by applying a logarithmic transformation, the formulae (4) and (5), using the statistic software R;

$$V = a_1 D^{b_1}, \quad (2)$$

$$V = a_2 D^{b_2} H^{c_2}. \quad (3)$$

$$\log V = \log a_1 + b_1 \log D, \quad (4)$$

$$\log V = \log a_2 + b_2 \log D + c_2 \log H, \quad (5)$$

where V is total volume, D is dbh (cm), H is total height (m), and a_1, b_1, a_2, b_2, c_2, are constants.

In order to estimate stand volume and its increment, we established 15 sample plots at different ages (6-10 and 36-48). Each sample plot included three planting lines; each has 10 trees as shown in Fig. 2. The planting points were designed regularly equidistant from one stem to one stem and from one line to another line. However, in the sample plots some trees

Table 1 Summary of data for volume equation

Stands		A	B	C	D
Age (years)		36	44	45	46
DBH (cm)					
	mean	34.5	44.8	42.4	39.8
	min	26.0	28.0	29.8	26.5
	max	41.0	62.0	56.4	52.0
Total Height (m)					
	mean	23.5	32.0	28.0	27.8
	min	16.2	25.3	18.4	16.9
	max	25.3	42.1	35.9	47.3
Stem volume (m^3) estimated by Smalian's formular					
	mean	0.90	1.84	1.29	1.22
	min	0.25	0.60	0.65	0.41
	max	1.37	3.41	2.21	2.30

Table 2 Primary data of 450 standing trees in 15 sample Plots

Ages	Plot Areas	No. trees	DBH (cm)			Total Height (m)			Volume	MAI
in 2005	(m^2)	per ha	Max	Min	Mean	Max	Min	Mean	m^3/ha	m^3/ha/year
6	538	558	19.2	15.2	14.3	9	8.2	12.8	61	10.10
8	521	575	24.0	9.9	17.1	18.8	10.5	15.5	98	12.19
9	597	502	22.7	9.0	16.0	19.6	9.0	15.2	74	8.22
10	594	505	23.7	10.9	16.3	18.1	9.0	14.8	78	7.78
37	1,049	286	73.0	19.7	39.1	37.8	15.7	26.6	366	9.88
38	783	383	50.5	17.4	35.2	39.6	16.9	27.7	374	9.85
39	620	484	52.7	19.8	33.6	41.5	14.1	22.9	398	10.20
40	812	369	41.7	20.7	34.4	39.6	23.0	30.6	331	8.26
41	1,120	268	61.1	49.5	38.8	19.2	14.6	26.3	336	8.19
42	817	367	50.8	17.2	35.2	41.7	14.8	27.9	356	8.48
44	945	318	62.3	17.4	41.5	50.4	15.1	31.5	455	10.33
45	699	429	50.5	20.8	37.2	37.2	15.6	25.6	448	9.96
46	971	309	54.6	24.0	40.6	42.2	17.6	31.9	412	8.95
47	851	352	52.0	25.1	38.1	42.5	16.4	31.6	406	8.64
48	740	405	60.2	19.9	37.5	50.1	17.0	33.4	473	9.86

Fig. 2 Lay out of Sample Plots
The circle and cross symbols indicate living and dead or removed trees, respectively.

were dead or removed out and therefore the area of each plot was calculated in the form of three rectangles while each length of every 10 trees was made by the direct measurements, and the width was based on the records of the interval of planting lines which varied from 6m, 7m to 8m. The areas of sample plots varied from 538m² - 971m² (Table 2). DBH and total height of 450 standing trees in 15 sample plots were measured by the diameter tapes and Vertex III tools, respectively. Volume per hectare in each sample plot was calculated by the more reliable set up volume equation.

RESULTS AND DISCUSSION

Volume Equations

Table 1 shows summary of data used for developing volume equations for 4 stands. The range of data is 20-62cm for DBH, 16.7-47.0m for total height, and 0.25 to 3.41m³ for stem volume. Fig. 3 showed the relationship between log V and log D, and the one variable formula was

$$\log V = -3.6041 + 2.2953 \log D \ (R^2 = 0.9233, N = 60), \quad (6)$$

$$\text{or } V = 0.00024884\, D^{2.2953}. \quad (7)$$

SCHUMACHER-HALL's formula was

$$\log V = -3.73563 + 2.23961 \log D + 0.15334 \log H, \quad (R^2 = 0.9245, N = 60), \quad (8)$$

$$\text{or } V = 0.00018381 D^{2.23961} H^{0.15334}. \quad (9)$$

Statistically, the results of the two formulae found no much difference ($R^2 = 0.9233$, $R^2 = 0.9245$), and this may be due to high correlation between D and H. This result indicates that the one variable formula using only DBH is applicable for the studied clone.

To check the applicability of the volume equations

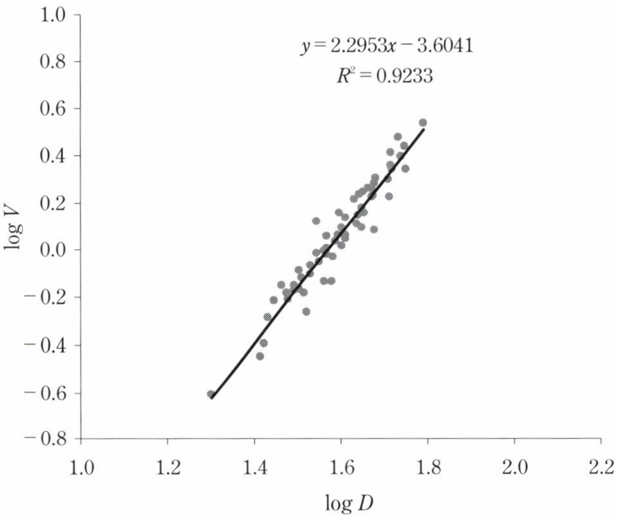

Fig. 3 Volume of 60 felled trees based on DBH

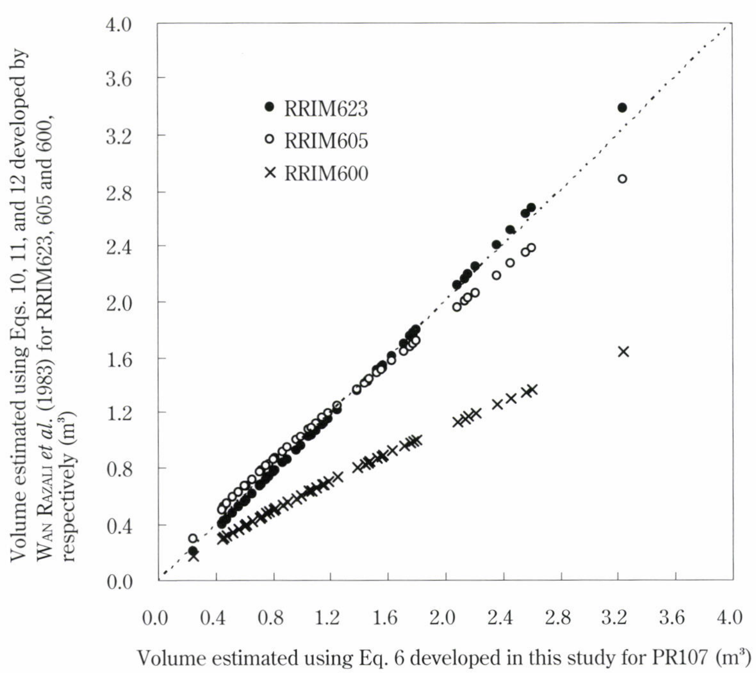

Fig. 4 Comparison of wood volume for the 60 sample trees estimated using the one-variable equations developed for the clone PR107 in this study (Eq. 6) and by WAN RAZALI *et al.* (1983) for the three clones; RRIM623 (Eq.10), RRIM605 (Eq.11) and RRIM600 (Eq. 12)
Note: The broken line indicates 1:1.

developed in this study to other clones, we compared wood volume for the 60 sample trees estimated using the one-variable equations developed for the clone PR107 in this study (Eq.6) and by WANRAZALI *et al.*, (1983) for the three clones; RRIM623 (Eq.10), RRIM605 (Eq.11) and RRIM600 (Eq. 12) as follows;

$$\log V = 2.4627\log D - 3.88570656 \quad (\text{for RRIM623}, R^2 = 0.4280), \qquad (10)$$

$$\log V = 2.01461\log D - 3.151701113 \quad (\text{for RRIM605}, R^2 = 0.5754), \qquad (11)$$

$$\log V = 1.97473\log D - 3.321792547 \quad (\text{for RRIM600}, R^2 = 0.5148). \qquad (12)$$

As shown in Fig. 4, the relationship of the estimated volume between Eq.10 for RRIM623 and Eq.6 for PR107 is very close to the 1:1 line, indicating that the volume equation developed in this study can be applied not only for PR107 but also for RRIM623. However, our PR107-equation tends to slightly underestimate and overestimate the volume from the RRIM605 equation for trees with smaller and larger than about 1.2m^3, respectively, while consistently overestimating the volume estimated from the RRIM600 over all range of tree size (Fig. 4). Due to the existence of more different clones of rubber trees (about 25 clones), we need more comprehensive and intensive research on the volume equations as in AKINDELE and LEMAY (2006) who classified the volume equations for 77 common timber species in the tropical rain forests into 5 species groups.

Tree Growth

Table 2 shows summary for 15 sample plots. Fig. 5a, 5b and 6 indicate the changes in total height, DBH and stand volume in relation to stand age, respectively. The ranges of mean values are 14.3 to 41.6cm for DBH and 12.8 to 33.4m for total height. The stand volume per hectare is from 60.6 to 473.5m^3. Due to no planting during civil war (1970-1990), we can not exactly predict tree size at the age 25-30 years old that is common rotation age. To get rough information at the age 25-30, linear regression lines are indicated in the Fig.5 and 6.

There were not large differences between different stands in the mean annual increment (MAI), which is stand volume at a given age divided by the age (Table 2). The average MAI of all plots was 9.33m^3/ha/yr, which was larger than the value of 7m^3/ha/yr for Indonesia, Malaysia, Thailand and Vietnam reported in the FAO working paper (FAO, 2005). It was described that stand volume of rubber wood is about 250m^3 in Thailand (CHANTUMA *et al.*, 2002) and 207.9m^3 in Malaysia (SURATMAN *et al.*, 2004) at 25-30 year old trees that are common rotation age. Based on the regression line shown in Fig. 6 of our results, the stand volume was estimated to be 240m^3-270m^3 at 25- 30 years old trees, indicating that there are not large differences among those three countries. However, stand volume per hectare depends upon numerous factors such as clones, sites, and management system (FAO, 2001a), so we need more investigation for each clone and site covering wide range of age classes.

Is the growth potential of rubber tree higher than other plantation tree species in tropical forests? The mean annual increment (MAI) of volume/ha for rubber trees in Cambodia was also not remarkably lower if compared to teak plantations (*Tectona grandis*) - a world's premier hardwood timber planted mostly in tropical zones. MAI of teak plantations in Indonesia and Myanmar with 50 year rotation age were found 13.8m^{3}ha^{-1}y^{-1} and 8.7m^{3}ha^{-1}y^{-1} (PANDEY and BROWN, 2000) respectively while *Acacia mangium* has 24m^{3}ha^{-1}y^{-1} of the MAI in Malaysia (FAO, 2005). According to this 2005 FAO working paper, the MAI of *Eucaltyptus robusta* is 21m^{3}ha^{-1}y^{-1} in Malaysia, India and Papua New Guinea, and *Casuarina equisetifolia* in Asia has 7-10m^{3}ha^{-1}y^{-1} of the MAI. Based on these references, the growth potential of rubber tree in

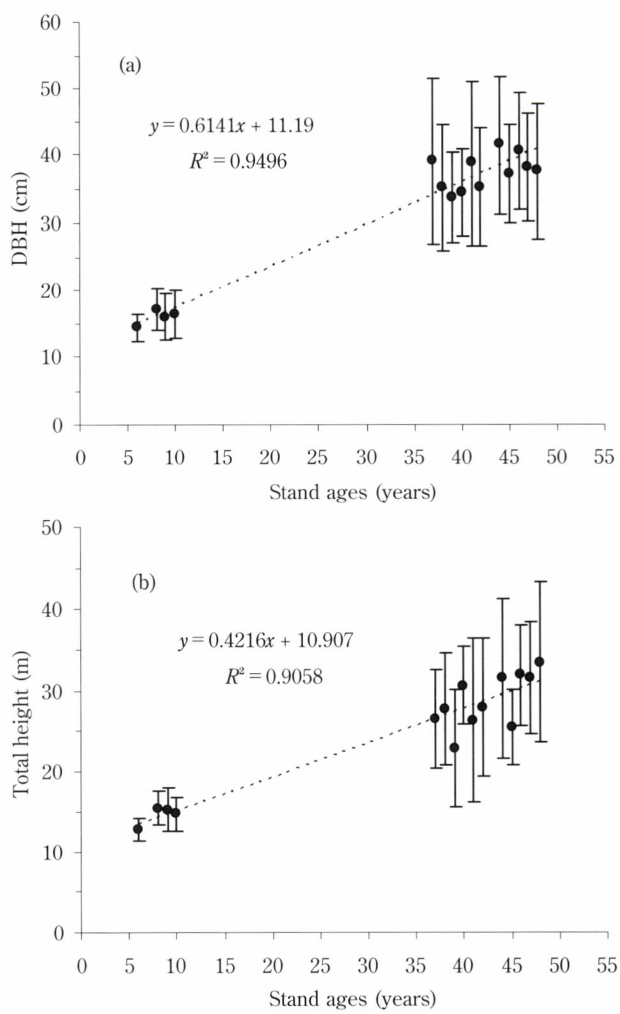

Fig. 5 Relationship between DBH (a), TH (b) and Ages. The dots and error bars indicate mean and standard deviation, respectively.

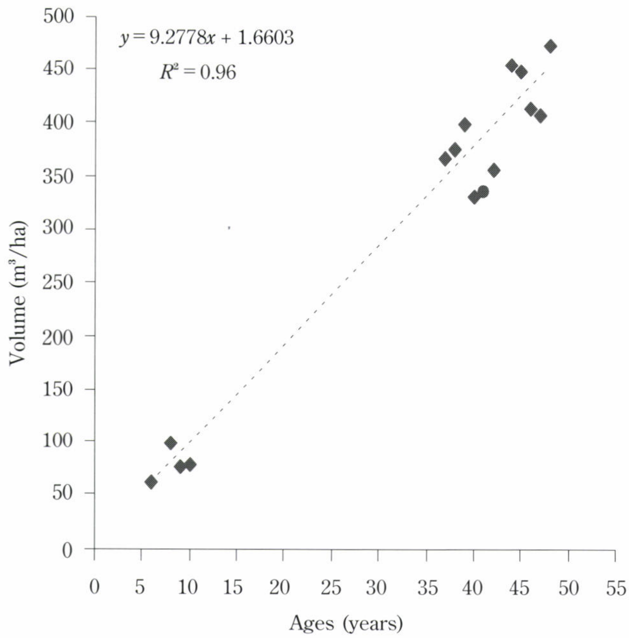

Fig.6 Volume of 15 stands by ages

Cambodia is lower than the fast growing species such as *Acacia mangium* and *Eucaltyptus robusta*, but not so large different from the other species.

CONCLUSIONS

This study is the first trial to develop wood volume equation and growth information of rubber trees in Cambodia, being very essential for better management of rubber forests. Although our samples were lack of the middle ages (15-30 years old) due to internal war, we obtained the following findings;

1) Both of the one - and two - variable volume equations were well-fitted.
2) The developed one-variable equation for the clone PR107 can be used for the clone RRIM623.
3) The MAI was about $9m^3ha^{-1}y^{-1}$, being smaller than the fast-growing species and similar to other species such as Teak.
4) The stand volume estimated for common rotation ages (25-30 years old) may be about 240-270m^3/ha, similar to the value reported in Malaysia and Thailand.

However, our result calls for further research to develop volume equations and predict stand growth for other clones in various regions.

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Short communication

Increase in Stem Volume per Unit Sunny Crown Dimension for Even-Aged Hinoki Cypress (*Chamaecyparis obtusa*) Stands

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ABSTRACT

To investigate the quantitative relationships between increase in stem volume (SVI) and sunny crown dimensions for Hinoki cypress (*Chamaecyparis obtusa* Endl.), we calculated the SVI per unit sunny crown dimension using three different sunny crown dimensions [i.e., volume (SCV), surface area (SCSA), and volume increase (SCVI)]. Samples were collected from six stands of even-aged Hinoki cypress in Nara Prefecture, Japan. For each SVI per sunny crown dimension, the mean among stands was compared. The SVI/SCV did not vary among the sampled stands, whereas the SVI/SCSA and SVI/SCVI varied with the stage of growth. Although our observed mean SVI/SCV was slightly larger than that in another region, the minimal difference observed between regions suggests that the SVI/SCV can be generally used to estimate the SVI of Hinoki cypress. Thus, SVI/SCV is an appropriate coefficient with which to estimate SVI.

Keywords: sunny crown volume, sunny crown surface area, sunny crown volume increase, stem volume increase, Hinoki cypress

INTRODUCTION

Crown dimensions are useful for predicting the responses of trees to silvicultural treatments (e.g., thinning or pruning) because crowns support foliage, the photosynthetic organ. Crown dimensions are often incorporated into growth and yield models as factors that are used to estimate tree growth (Mitchell, 1975; Shimizu *et al.*, 1984; Takeshita, 1985; Ottorini, 1991; Yoshida, 1991; Cole and Lorimer, 1994; Raulier *et al.*, 1996; Saigusa et al., 1996; Matsue, 2000; Valentine and Mäkelä, 2005). Sunny crown dimensions are particularly effective predictors of stem volume growth. For example, Inose (1982) found that increases in the stem volume (SVI) of Todo fir (*Abies sachalinensis* Mast.) could be predicted by the increase in sunny crown volume. Similarly, Kajihara (1985) used the sunny crown surface area to predict the SVI of Japanese cedar (*Cryptomeria japonica* D. Don). Because sunny crown dimensions can clearly be used as predictors of SVI, it is valuable to thoroughly investigate the quantitative relationships between SVI and sunny crown dimensions.

The simplest expression of the relationship between sunny crown dimensions and SVI is the SVI per unit sunny crown dimension. When the SVI per unit sunny crown dimension of a tree is known, the SVI can be calculated by multiplying the sunny crown dimension by the SVI per unit sunny crown dimension. Therefore, the incorporation of the SVI per unit sunny crown dimension into a sunny crown dynamic model allows the prediction of SVI. However, because of the labor-intensive work required, very few detailed measurements of sunny crown dimensions and SVI have been collected. In particular, these data are lacking for one of the most widely distributed plantation trees in Japan, Hinoki cypress (*Chamaecyparis obtusa* Endl.) (but see Kajihara, 1982; 1996). To generate additional data for the estimation of SVI from sunny crown dimensions, we calculated the SVI per unit sunny crown dimension using three different sunny crown dimensions (i.e., volume, surface area, and volume increase) in stands of even-aged Hinoki cypress.

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MATERIALS AND METHODS

Field Measurements

Samples were collected from six stands of even-aged Hinoki cypress in Nara Prefecture, Japan (Table 1). Stand age ranged from 10 to 72 years, and densities ranged from 1,000 to 5,250 trees/ha. The mean diameter at breast height ranged from 6.8 to 29.1cm, and the mean total height varied from 5.5 to 16.8m.

We randomly selected 112 sample trees in the stands. Prior to felling, the diameter at breast height (DBH) of each tree was measured using calipers. The DBH of the sample trees ranged from 3.6 to 32.5cm. The height of the sunny crown base of each tree was measured on the percentage scale using a Spiegel relascope. A 5-m pole was placed upright against the tree trunk for these measurements. The sunny crown length (SCL) was calculated by subtracting the height of the sunny crown base from the total height (H) of the tree.

After each tree was felled, H was measured using surveyor's tape; H ranged from 4.1 to 18.7m. To measure SVI, disks were removed from the stem 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. To measure the shape and size of the sunny crown, each crown segment was placed vertically on the ground, and the crown radius at the middle of each segment was measured in four directions at right angles using surveyor's tape.

Laboratory Measurements

The removed stem disks were taken to the laboratory, and the annual rings were counted. For each disk, the current- and previous-year radii in four directions at right angles were measured. The current- and previous-year stem cross-sectional areas were calculated using average radius measurements of the stem cross-section, which was assumed to be circular in shape. The current- and previous-year log volumes for each segment were calculated using SMALIAN's formula (OSUMI *et al.*, 1987). Each log volume increase was calculated as the difference between the current- and previous-year log volumes. The SVI for each tree was computed as the sum of the log volume increases.

Calculation of Sunny Crown Dimensions

To obtain sunny crown volume (SCV), surface area (SCSA), and volume increase (SCVI), the sunny crown profile of each tree was represented using the following equation:

$$r = az^b \tag{1}$$

where r is the crown radius at distance z from the apex and a and b are parameters. The parameters were estimated using the non-linear least squares method, minimizing the sum of squared residual (SSR):

$$\mathrm{SSR} = \sum_{i=1}^{n}\sum_{j=1}^{4}(r_{ij} - az_i^b)^2 \tag{2}$$

where r_{ij} is the j-th crown radius ($j=1, 2, 3, 4$) at the i-th distance z_i ($i=1, 2,\cdots, n$) from the apex. SCV and SCSA were calculated by rotating eq. (1) on the trunk axis. Because SCSA cannot be calculated directly, Romberg's integration was used.

The mean leaf longevity of Hinoki cypress was estimated as 4.4 years (INAGAKI *et al.*, 2003); thus, we calculated the SCVI over 4 years. The SCVI was calculated by subtracting the SCV from 4 years prior (above the current-year sunny crown base) from the current-year SCV. Because the shape and size of the sunny crown from 4 years prior were assumed to be the same as those of the current-year sunny crown, the SCVI was calculated as follows:

$$\mathrm{SCVI} = \pi\int_0^{\mathrm{SCL}} r^2\,dz - \pi\int_0^{\mathrm{SCL-HI}} r^2\,dz \tag{3}$$

where HI is the total height increase over 4 years. The HI was calculated by subtracting the H from 4 years prior from the current-year H. The H from 4 years prior was estimated using the ordinary stem analysis technique.

Statistical Analysis

The SVI per unit sunny crown dimension was calculated for each sampled tree. One-way analysis of variance was used to compare the means among stands.

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

RESULTS AND DISCUSSION

Variations in SVI, SCV, SCSA, and SCVI were determined for the stage of growth (Fig. 1). Mean SVI, SCV, and SCSA increased with increasing mean H. Thus, trees with larger SCV or SCSA produce larger SVI. In contrast, mean SCVI decreased in stands > 12 m in mean H, whereas SCVI increased in stands < 12 m in mean H. This pattern emerged because trees in older stands have smaller HI (i.e., thinner SCVI) than younger stands.

The SVI/SCV did not vary with increasing mean H, and there was no significant difference in SVI/SCV among stands ($F = 1.356$, $p > 0.05$; Table 2 and Fig. 2). KAJIHARA (1982) collected data from eight even-aged stands in Kyoto Prefecture, Japan, ranging from 9 to 76 years old and estimated the SVI/SCV for 26 Hinoki cypress trees ranging from 4 to 25m in H and from 5 to 34cm in DBH. Although our observed mean SVI/SCV of all sampled trees (Table 2) was slightly larger than that of KAJIHARA (1982) (mean ± standard deviation = $5.59 \pm 3.00 \times 10^{-4}$ m^3/m^3), this minimal difference observed between regions suggests that the SVI/SCV can be generally used to estimate the SVI of Hinoki cypress.

The SVI/SCSA increased with increasing mean H and differed among stands ($F = 6.257$, $p < 0.05$; Table 2 and Fig. 2). Although KAJIHARA (1996) presented measurements of changes in SVI/SCSA for an even-aged Hinoki cypress stand, ours are the first measurements of changes in SVI/SCSA among Hinoki cypress stands that vary in the stage of growth. KAJIHARA (1996) measured changes in SVI/SCSA for intervals ranging from 14 to 26 years old for an even-aged Hinoki cypress stand. However, no trends in SVI/SCSA were observed because these time intervals were likely too short (KAJIHARA, 1996). In contrast, KAJIHARA (1994) calculated SVI/SCSA for 30 even-aged Japanese cedar stands ranging from 6 to 60 years old, demonstrating that SVI/SCSA decreased with increasing stand age for stands > 30 years old, whereas SVI/SCSA increased in stands < 30 years old. Although the 41-year-old stand (Stand E) exhibited the largest SCV/SCSA among our sampled stands (Table 2), we did not have sufficient data from older stands to observe a trend in the

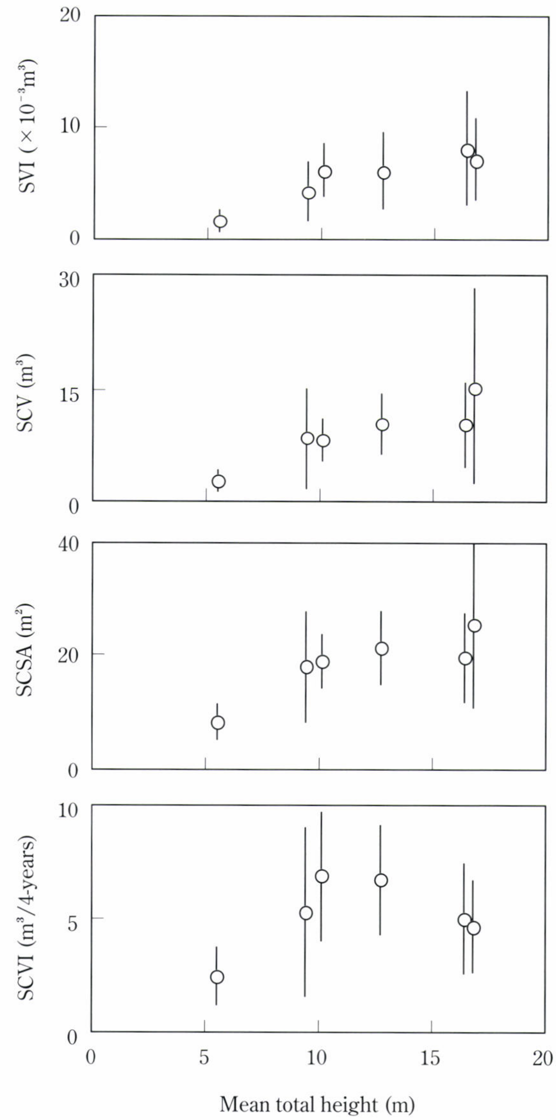

Fig. 1 Means of the increase in stem volume (SVI) and three sunny crown dimensions [volume (SCV), surface area (SCSA), and volume increase (SCVI)] in six Hinoki cypress stands
Vertical bars indicate standard deviations.

Table 2 Means and standard deviations of the increase in stem volume (SVI) per unit sunny crown dimensions [volume (SCV), surface area (SCSA), and volume increase (SCVI)] for each stand sampled and for all stands combined

Stand	SVI/SCV ($\times 10^{-4}$ m^3/m^3)	SVI/SCSA ($\times 10^{-4}$ m^3/m^2)	SVI/SCVI ($\times 10^{-4}$ m^3/m^3/4-years)
A	6.66 ± 2.66	1.96 ± 0.82	6.94 ± 2.70
B	8.02 ± 2.21	3.34 ± 0.93	9.64 ± 2.79
C	7.44 ± 6.35	2.61 ± 1.20	10.31 ± 6.36
D	5.91 ± 2.65	2.81 ± 1.31	8.66 ± 3.31
E	8.48 ± 3.70	4.06 ± 1.65	16.32 ± 6.14
F	6.18 ± 2.95	3.11 ± 1.06	15.97 ± 4.70
all stands	6.99 ± 3.76	2.91 ± 1.31	11.11 ± 5.69

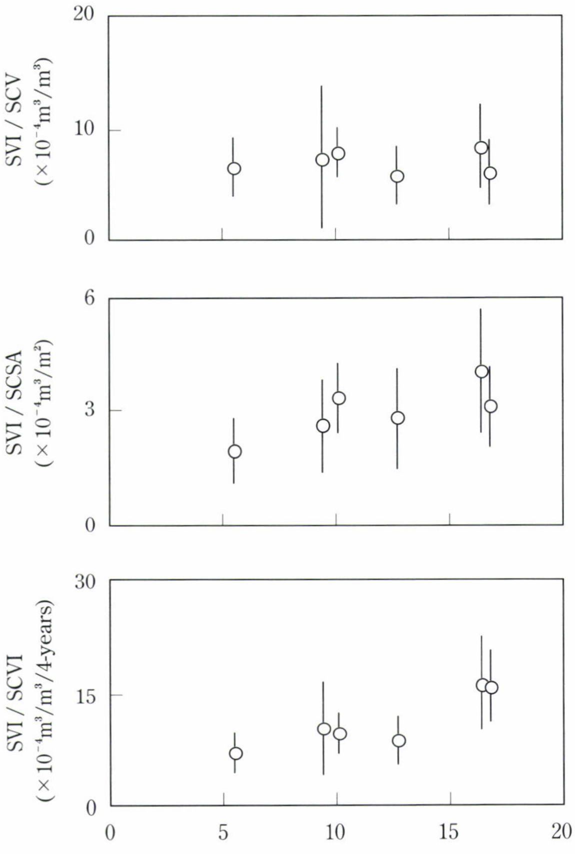

Fig. 2 Mean increase in stem volume (SVI) per unit sunny crown dimensions [volume (SCV), surface area (SCSA), and volume increase (SCVI)] in six Hinoki cypress stands
Vertical bars indicate standard deviations.

changes in SCV/SCSA with stand age.

The SVI/SCVI was very large in older stands (Stand E and F) and differed significantly among stands ($F = 29.194$, $p < 0.05$; Table 2 and Fig. 2). This pattern was caused by the decrease in SCVI as the SVI increased in older stands. These opposing trends in SVI and SCVI suggest that changes in SVI/SCVI are more complex than those in SVI/SCV or SVI/SCSA.

CONCLUSION

We determined the SVI per unit sunny crown dimensions for six even-aged Hinoki cypress stands. The SVI/SCV did not vary among the sampled stands, whereas the SVI/ SCSA and SVI/SCVI varied with the stage of growth. Thus, SVI/SCV is an appropriate coefficient with which to estimate SVI.

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