ISSN 1341-562X

JOURNAL OF FOREST PLANNING

Vol. 16 No. 1

September, 2010

Japan Society of Forest Planning

JOURNAL OF FOREST PLANNING

Submission of Manuscripts

Manuscripts should be submitted to following Editorial Office.

Dr. Satoshi TSUYUKI
JOURNAL OF FOREST PLANNING
Lab. of Global Forest Environmental Science,
Department of Global Agricultural Science,
Graduate School of Agricultural and Life Sciences,
The University of Tokyo
1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan
Phone: +81-3-5841-7509, Fax: +81-3-5841-5235
E-mail: tsuyuki@fr.a.u-tokyo.ac.jp

Subscription Information

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

Toho Shoten
343 Yamabuki-cho
Shinjuku-ku, Tokyo 162-0801, Japan
Phone: +81-3-3269-2131, Fax: +81-3-3269-8655
http://www.toho-shoten.co.jp

JOURNAL OF FOREST PLANNING is published by
Japan Society of Forest Planning
University Forests, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan

JOURNAL OF

FOREST PLANNING

Vol.16, No.1 September, 2010

Japan Society of Forest Planning

CONTENTS

Articles

Short Communication

Article

Fourier Transform Analysis of Very High Resolution Remote Sensed Imagery Shows Potential for Estimating Stand Density of Regular-spaced Planted Forests

Tetsuji Ota*[1], Nobuya Mizoue*[2] and Shigejiro Yoshida*[2]

ABSTRACT

An increase in the area of unthinned planted forests is a major issue in Japan, and incomplete record-keeping means that a method for detecting unthinned stands is required. An important indicator of unthinned stands is stand density. In this study, we compared two stand density estimation methods, the discrete Fourier transform method and the local maximum (LM) filtering method, using simulated very high resolution satellite imagery. Even-aged Japanese cedar (*Cryptomeria japonica*) stands were modeled. Trees were positioned as though planted in a lattice pattern typical of these forests in Japan. The discrete Fourier transform method was more accurate than LM filtering and was stable over a range of stand densities, whereas the accuracy of LM filtering was sensitive to stand density and calculation conditions. Hence, the discrete Fourier transform was superior to LM filtering to estimate even-aged coniferous stand density.

Keywords: stand density, Fourier transform, local maximum filtering method

INTRODUCTION

Forest areas account for about two-thirds of the land in Japan, and 41% of forest areas in Japan are planted forests (Forest Agency Of Japan, 2008). An essential management practice for planted forests is thinning of the stand at appropriate intervals (Sakaguchi, 1961). However, cheap imported timber has in recent years lowered the price of domestic timber to the point where the return from thinning operations does not cover the costs (Sakai, 1999). Prices have remained stagnant for several decades (Forest Agency Of Japan, 2008). As a result, thinning is now commonly delayed, and the area of unthinned planted forests in Japan has been steadily increasing (Sakai, 1997). Inadequate thinning can negatively affect the multiple functions of forests by causing a decline in timber quality, increasing the susceptibility of trees to disease, and degrading habitat value. Japan's forest law divests the management of public forests to the municipality level and obliges each municipality to document the location and extent of all stands for which thinning has been delayed in their forest management plans. Private forests in Japan have been managed using a resource database, but the resource database is not correct. The resource database is the result of a calculation from the ground up of past planting, and does not accurately express the current state of private forests. Hence, an efficient method for detecting unthinned stands is required. An important indicator of unthinned stands is stand density. Therefore, techniques for estimating stand density need to be developed.

There has been considerable research interest in recent years in locating individual trees or estimating stand density using very high-resolution imagery (VHRI) of sub-meter spatial resolution (e.g. Pouliot *et al.*, 2002; Wulder *et al.*, 2000; Kayitakire *et al.*, 2006; Leckie *et al.*, 2003; Leckie *et al.*, 2005). VHRI can be collected by either satellite or aircraft using a range of sensor types, but the increasing availability and reduced cost of satellite-borne VHRI makes it attractive for use in forestry applications.

Because trees in Japanese planted forests are planted in a regular lattice pattern, the spatial pattern of trees is likely to contain periodicity. Frequency analysis based on discrete Fourier transform is an efficient method of characterizing the

Corresponding author: Tetsuji Ota
*[1] Graduate School of Bioresource and Bioenvironmental Science, Kyushu University, 6-10-1, Hakozaki, Higashiku, Fukuoka 812-8581, Japan
E-mail: t_ohta@ffp.kyushu-u.ac.jp
*[2] Faculty of Agriculture, Kyushu University, 6-10-1, Hakozaki, Higashiku, Fukuoka 812-8581, Japan

natural periodicity of regularly spaced vegetation (DELENNE *et al.*, 2008; WASSENAAR *et al.*, 2002; COUTERON *et al.*, 2005; PROISY *et al.*, 2007). DELENNE *et al.* (2008) investigated the use of the discrete Fourier transform to detect and characterize inter-row width and row orientation of vineyards and achieved less than 3% error. The inter-row width and tree-spacing within rows in planted forests have similarities with the regular arrangement of vineyards. Hence, analysis using the discrete Fourier transform may be useful for gaining accurate estimates of stand density in Japanese planted forests. To our knowledge, no previous studies have evaluated the accuracy of the discrete Fourier transform in planted forests using VHRI. However, unlike in vineyards, the trees in a planted forest, while planted in a regular pattern, are not necessarily positioned with high accuracy. In addition, the inter-row spacing of a forest stand will be more difficult to detect than that of a vineyard, especially after crown closure. We set out to assess the potential for the discrete Fourier transform method to estimate stand density in planted forests in Japan. We compared the accuracy of the discrete Fourier transform method (DELENNE *et al.*, 2008) and the local maximum filtering method (LM filtering; POULIOT *et al.*, 2002; WULDER *et al.*, 2000; NELSON *et al.*, 2005), a technique for identifying individual trees from remotely sensed data.

If variables within the imagery can be controlled, specific factors of interest may be investigated with increased confidence (RANSON *et al.*, 1986). For the current study, the ideal situation would have been to use imagery of forest stands with different stand density while other conditions, such as stand age, slope, and aspect, were held constant. However, we could not locate any real imagery that meets such conditions. Therefore, we adopted a model-based approach, which is a unique and powerful alternative to using real imagery (BRUNIQUEL-PINEL and GASTELLU-ETCHEGORRY, 1998). This method enables the parameter of interest, i.e. tree density, to be changed, while keeping other parameters constant.

METHODS

Data

In this study, even-aged Japanese cedar (*Cryptomeria japonica*) stands were modeled. The outline of the crown profile of *C. japonica* is parabolic in shape (TAKESHITA, 1985), and was used to create trees in the model. We used the data from a plant density experiment of *C. japonica* (FUKUCHI *et al.*, 2006), which was used to select tree spacing, tree height, and crown shape to generate the model forest images. The data were acquired from a Nelder density plot (NELDER, 1962) established in a national forest in Miyazaki prefecture, Japan (FUKUCHI *et al.*, 2006). The trees in this experiment were planted in 1973 at 10 different densities from 376 trees ha^{-1} to 10,000 trees ha^{-1} and the stand had never been thinned. We used data obtained when the stand was 32 years old and only used density classes from 376 to 3,326 trees ha^{-1} (i.e. <4,000 trees ha^{-1}) because the planted density in Japanese planted forests is approximately 3,000 trees ha^{-1}. The average values of spacing, diameter of breast height (DBH), crown size, and tree height of each stand density were used (Table 1).

Model

We used the method developed by (KUZUOKA and ARAI, 2002) to simulate very high resolution satellite imagery at different stand densities. This is a very simple method using ray-tracing that expands on the geometric optical model (LI and STRAHLER, 1992). There are four reflectance states represented in this model, as in other geometric optical models: directly sunlit crowns, directly sunlit stand floor, shaded crown, and shaded stand floor. These states are dependent on the reflectance ratio of each object (i.e. the reflectance ratio of tree crowns and stand floor), the intensity and source of direct light, the intensity of ambient light, the

Table 1 Stand attributes from an experimental Nelder density plot used as inputs to a model to generate simulated imagery of even-aged planted forest

Density (trees ha^{-1})	Tree spacing (m)	DBH (m)	Crown diameter (m)	Crown length (m)	Height (m)
376	5.16	34.7	3.7	7.42	17.11
541	4.30	33.1	3.3	9.38	16.88
779	3.58	29.1	2.7	11.24	16.52
1122	2.99	26.7	2.4	12.31	16.53
1615	2.49	22.3	2.1	12.81	15.91
2326	2.07	19.5	1.7	12.81	15.10
3349	1.73	18.2	1.6	12.54	14.84

Table 2 List of parameter values used in the model to generate simulated imagery of even-aged planted forest

Parameter	Value	Reference
The intensity of direct light	1.00	KUZUOKA and ARAI (2002)
Reflectance ratio of the crown	0.12	OTA *et al.* (2007)
Reflectance ratio of the stand floor	0.20	OTA *et al.* (2007)
The intensity of ambient light on the crown	0.20	KUZUOKA and ARAI (2002)
The intensity of ambient light on the stand floor	0.02	OTA *et al.* (2007)
The fraction of direct light diffusely reflected	0.60	KUZUOKA and ARAI (2002)
Solar zenith angle	56.00	OTA *et al.* (2007)
Solar azimuth angle	167.00	OTA *et al.* (2007)
The slope of the regression to approximate satellite imagery	5.93	OTA *et al.* (2007)
The intercept of the regression to approximate satellite imagery	63.00	OTA *et al.* (2007)

fraction of diffusely reflected direct light, and the direction of the surface normal vector at the point of incidence. The image output by this model is not in accordance with the digital number because the image output is the brightness of each pixel. Hence, the output image was transformed using linear regression to approximate satellite imagery. Table 2 shows the parameters used in the modeling and transformation of the image data. These parameter values were obtained from KUZUOKA and ARAI (2002) or OTA *et al.* (2007). Two other values not shown in Table 2 were needed to generate the model image, the satellite position, and spatial resolution. The satellite position was defined as 200km above the simulated stand and the spatial resolution of the model image was determined as 0.6m. Additionally, the shape of crown was approximated as parabolic.

Scene Simulation

The simulated trees were arranged in a lattice pattern to represent the general planting pattern in Japan (Fig. 1). However, trees are not always planted at the exact points of the lattice intersects. Hence, we simulated conditions with trees planted in the correct positions and with two different levels of random error in the positions. To introduce random error into the planting positions, we applied a random distance from the correct position. The random distances for the two different levels of error were selected from normal distributions with standard deviations of 10 and 30cm, respectively. In both cases, we also randomly selected the direction of the misalignment error. The simulation was repeated 50 times for each stand density and each standard deviation. The size of imagery for the final output was set at 32 pixels, as (DELENNE *et al.*, 2008) found this to be a suitable size in a similar study on vineyards. We simulated images larger than 32 pixels and selected only the inner portion to avoid edge effects.

Discrete Fourier Transform

The discrete Fourier transform converts the original image from a spatial domain to a frequency domain. The

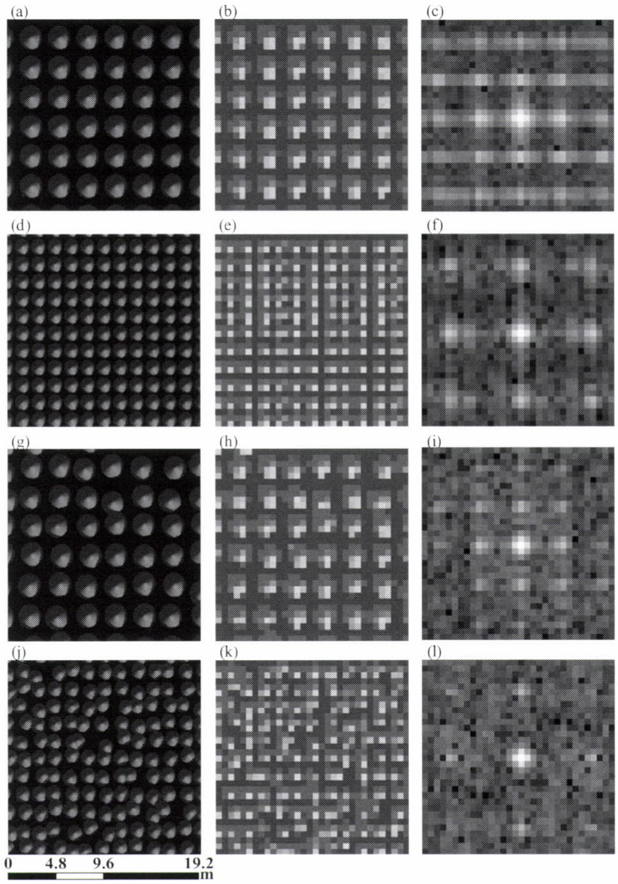

Fig. 1 Images of simulated stands of even-aged planted conifer forest: (a) actual image at 1122 trees ha^{-1} with trees in the correct planting position; (b) the simulated satellite imagery of (a); (c) Fourier image of (b); (d) actual image at 3349 trees ha^{-1} with trees in the correct planting position; (e) the simulated satellite imagery of (d); (f) Fourier image of (e); (g) actual image at 1122 trees ha^{-1} with trees positioned with a 30cm standard deviation from correct planting position; (h) the simulated satellite imagery of (g); (i) Fourier image of (h); (j) actual image at 3349 trees ha^{-1} with a 30cm standard deviation from correct planting position; (k) the simulated satellite imagery of (j); (l) Fourier image of (k)

Fourier amplitude spectrum of the discrete Fourier transform is defined by equation (1):

$$a(u, v) = \left\| \frac{1}{N_x N_y} \sum_{x=0}^{N_x-1} \sum_{y=0}^{N_y-1} f(x, y) \exp\left[-j2\pi \left(\frac{ux}{N_x} + \frac{vy}{N_y} \right) \right] \right\| \tag{1}$$

where N_x and N_y are the size of images, $x = 0, \ldots, N_x$, $y = 0, \ldots, N_y$ are spatial indices in the original image, $f(x, y)$ is the value of the original image, and $u = 0, \ldots, N_x - 1$, $v = 0, \ldots, N_y - 1$ are frequency indices of the discrete Fourier Transform. The result of the discrete Fourier transform is expressed as an image the same size as the original (Fig. 1). However, the Fourier image provides different information from real imagery. The position of pixels in the image produced from the Fourier transform represents spatial frequency. The center of the Fourier image expresses a frequency of zero; the greater the distance from the center, the higher the frequency expressed by the pixel. The direction of pixels from the center represents the direction of the frequency. The pixel value of the Fourier image expresses the amplitude. Fast Fourier transform was used as the discrete Fourier transform. As mentioned, a subset of the larger image was used. Clipping the edge of the image affects the results of the discrete Fourier transform; to reduce this effect the digital number of the original image was multiplied by the Hann window, which is a half cosine wave.

Zero frequency was eliminated because it had no relation to the stand density. Frequencies <2 were also eliminated because the Hann window effect caused excessive amplitudes at low frequencies. We assumed that the peak value of the remaining frequencies expressed the tree spacing, although the larger the misalignment was, the less clear the Fourier image is (Fig. 1c; 1f; 1i; 1l). The tree spacing, S, was expressed as:

$$S = \frac{NR}{r} \tag{2}$$

where r is the distance from the Fourier image center to the pixel or pixels whose value is maximum in the Fourier image,N is the window size (i.e. 32), and R is the spatial resolution (i.e. 0.6m). From tree spacing, the stand density, d, was calculated using equation (3):

$$d = \frac{100^2}{S^2} \tag{3}$$

The accuracy of the estimated density was evaluated by examining the root mean squared error (RMSE). The true number of trees from the original image was calculated from the number of trees whose crown was entirely contained within the analyzed image.

The LM filtering method

LM filtering assumes that the tops of tree crowns show maximum local reflectance. When the center pixel in a moving-window has the largest digital number in the window, that pixel is identified as a tree apex (Pouliot *et al.*, 2002; Wulder *et al.*, 2000; Nelson *et al.*, 2005). Because tree position is determined at the center of the moving-window, the trees at the edge of the image cannot be processed. Hence LM filtering was performed on the larger image before it was clipped to the central 32×32 pixels. The number of trees was estimated using three different sizes of moving window, 3×3, 5×5, and 7×7 pixels. The accuracy of the estimated density was evaluated using RMSE, commission error (false positives), and omission error (false negatives). The true number of trees was calculated from the number of trees whose crown was entirely contained in the analyzed image in the same manner as for the discrete Fourier transform.

RESULTS

Fig. 2 shows relationship between the true and estimated stand density using the discrete Fourier transform. Because same estimates were obtained for each real stand densities, Fig. 2b and 2c shows fewer than the number of estimate. There was a strong linear relationship between the true and estimated density using the discrete Fourier transform for all three positional accuracies, although the estimated values were slightly overestimated (Fig. 2). The RMSE was 314.18 when trees were planted in the correct position, 303.34 when the misalignment (deviation from the correct position) was 10cm, and 166.20 when the misalignment was 30cm. These RMSEs were much lower than the LM filtering method (Fig. 3). In the discrete Fourier transform results, the RMSE did not increase (in fact it decreased) as the misalignment increased, whereas with the LM method the RMSE did not increase from 0cm to 10cm misalignment, but increased substantially as the misalignment increased to 30cm. The discrete Fourier transform method was therefore relatively robust under conditions of incorrect positioning of trees and could estimate stand density accurately for misalignment of up to 30cm. The reason for the overestimation is not clear.

Table 3 shows the average commission and omission errors of the LM filtering. The results for the misalignment cases are average values from 50 simulations for each window size and density. These results indicate that increasing the window size increased the omission error and decreased the commission error, the same result found in other studies (Wulder *et al.*, 2000; Pouliot *et al.*, 2002). However, the commission errors (overestimation) for 3×3 LM filtering were greater than from the real imagery used in the studies of Wulder *et al.* (2000) and Pouliot *et al.* (2002). The reason for this was that in our simulation we had to give the stand floor a fixed reflectance ratio (0.2; Table 1). Thus the highest value and lowest value were equal when all pixels in a window were shaded forest floor, resulting in much misidentification of floor as tree apex.

The RMSE in the LM filtering results was much higher

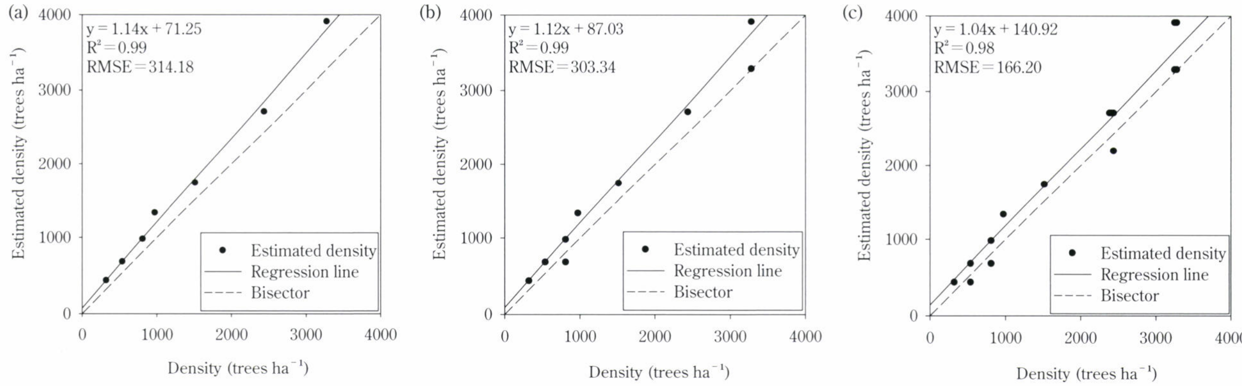

Fig. 2 Estimated versus actual stand density from simulated imagery of forests
Estimated density was determined using discrete Fourier transform with (a) trees in the correct planting position; (b) trees positioned with a 10cm standard deviation from the correct position; and (c) trees positioned with a 30cm standard deviation from the correct position.

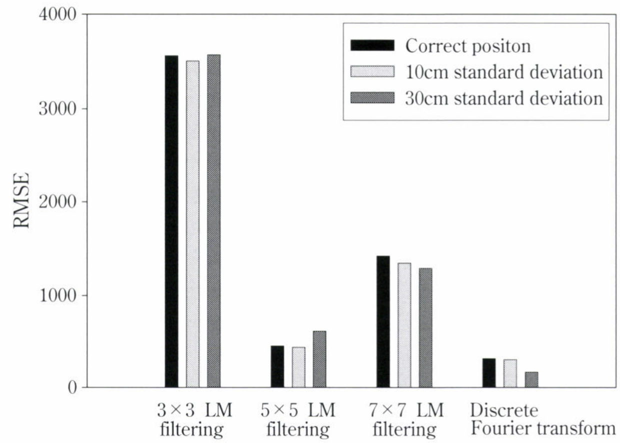

Fig. 3 RMSE for estimates of stand density from simulated imagery of even-age forests using the LM filtering method with three different sized search windows as well as for the discrete Fourier transform method

Table 3 Estimation errors for stand density estimation from simulated imagery of forests using the LM filtering method

standard deviation of misalignment error	Window size	Type of error	Planted density 376	541	779	1122	1615	2326	3349
0cm	3×3	Commission error (%)	96.25	88.30	60.53	40.00	6.67	1.10	0.00
		Omission error (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5×5	Commission error (%)	0.00	0.00	9.09	0.00	0.00	1.10	0.00
		Omission error (%)	0.00	0.00	0.00	0.00	0.00	0.00	36.36
	7×7	Commission error (%)	0.00	0.00	9.09	0.00	0.00	0.00	0.00
		Omission error (%)	0.00	0.00	0.00	0.00	12.50	85.56	95.04
10cm	3×3	Commission error (%)	96.14	88.49	63.77	42.30	7.48	1.07	0.16
		Omission error (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5×5	Commission error (%)	18.63	3.62	6.68	4.56	1.49	0.98	0.03
		Omission error (%)	0.00	0.00	0.00	0.00	0.00	0.31	36.86
	7×7	Commission error (%)	6.16	3.62	6.68	4.56	0.26	0.00	0.00
		Omission error (%)	0.00	0.00	0.00	0.00	19.54	82.93	88.74
30cm	3×3	Commission error (%)	96.08	89.21	70.87	47.14	10.07	1.76	0.84
		Omission error (%)	0.00	0.00	0.00	0.00	0.00	0.18	1.49
	5×5	Commission error (%)	25.51	7.30	5.46	3.38	2.05	0.68	0.15
		Omission error (%)	0.00	0.00	0.00	0.00	0.86	10.74	48.58
	7×7	Commission error (%)	5.65	5.32	5.35	3.12	0.55	0.23	0.00
		Omission error (%)	0.00	0.00	0.00	3.11	34.79	76.22	86.04

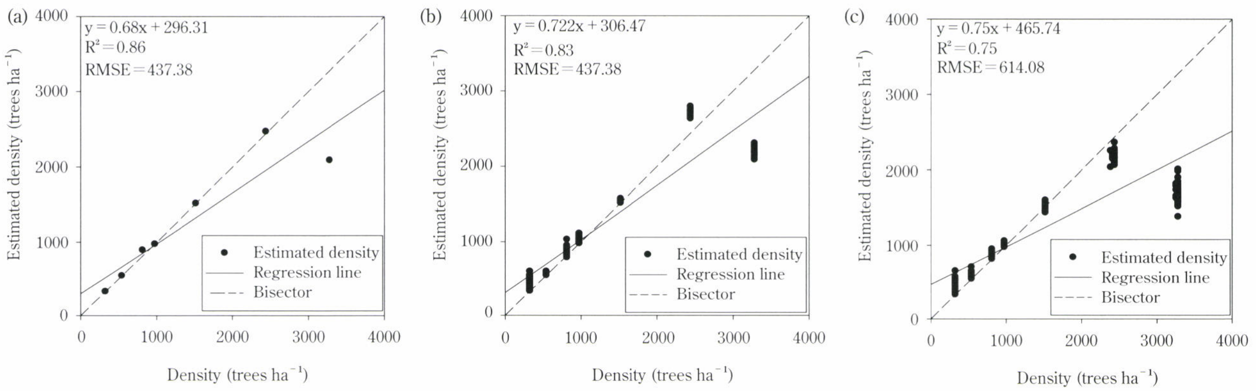

Fig. 4 Stand density estimation using LM filtering and a 5×5 search window for (a) trees in the correct planting position; (b) trees positioned with a 10cm standard deviation from the correct position; and (c) trees positioned with a 30cm standard deviation from the correct position

for 3×3 than other window sizes and discrete Fourier transform, implying that 3×3 LM filtering was too small to reliably estimate density (Fig. 3). On the other hand, the 7×7 LM filtering resulted in many missed trees, especially at higher stand density, resulting in the underestimation of stand density (Table 3). The lowest RMSE for LM filtering was achieved with a 5×5 window size (Fig. 3), though it was still higher than the RMSE obtained from the discrete Fourier transform method (Fig. 3) due to the tendency of the LM filtering method to miss trees at high density (Fig. 4). Increasing the misalignment error induced different responses in each window size, but the effect was only very slight in the 3×3 and 7×7 LM filtering, whereas the accuracy of the 5×5 LM filtering decreased when the misalignment increased from 10cm to 30cm (Fig. 3).

DISCUSSION

The discrete Fourier transform method was superior to LM filtering in estimating stand density from simulated imagery of planted forests, as indicated by a more accurate prediction of density across a range of stand densities, and also across several search window sizes for LM filtering. This result indicated the potential for using discrete Fourier transform for stand density estimation. The biggest problem with LM filtering was that the accuracy was low at certain stand densities (Fig. 4). Hence, using fixed LM filtering is not recommended when there are stands of widely varying density in the area of observation. However, the accuracy of LM filtering might exceed that of discrete Fourier transform at certain densities and window sizes, for example, at high stand density for 3×3 LM filtering and low stand density for 5×5 and 7×7 LM filtering (Table 3). Hence, a method that varies the window size in response to certain parameters (Wulder *et al.*, 2000) may be appropriate when stand density is variable. The window size selection procedure would be extremely important because accuracy appears to depend heavily on an appropriate window size. A method that can estimate density with stable accuracy across a range of densities is needed.

Whereas the LM filtering method returned variable accuracy at different densities and search window sizes, the discrete Fourier transform method, which determines the periodicity of trees, was relatively robust under changing stand conditions, most notably stand density, and therefore has no requirement for identifying the correct window size to achieve high accuracy. The accuracy of the discrete Fourier transform method was also very robust for misalignment errors up to 30cm. However, unlike tree isolation methods such as LM filtering, the discrete Fourier transform method cannot estimate tree positions. The ability to estimate tree positions may improve estimates of stand volume, basal area, and canopy closure (Wulder *et al.*, 2000). Because LM filtering can estimate such parameters, LM filtering has an advantage over the discrete Fourier transform method. It will therefore be necessary to continue development of both methods, and selection of an image processing method will need to weigh the advantages and disadvantages of each against the objectives of the investigation.

CONCLUSION

This study compared the accuracy of forest stand density estimation between the discrete Fourier transform method and the LM filtering method using simulated imagery. The discrete Fourier transform was consistently more accurate at different levels of stand density, whereas the accuracy of LM filtering depended on the stand density and window size. We conclude that the discrete Fourier transform is a potentially powerful technique to estimate the density of even-aged planted coniferous stands and is superior to LM filtering, provided that spatial attributes of tree distribution are not an expected output of the processing method. On the other hand, LM filtering can estimate tree positions. It would be an advantage over the discrete Fourier transform method. Hence, it will be necessary to continue development of both methods.

In this study we used a very simple model to simulate the images. Constant values were adopted for tree size, reflectance ratio, and various other parameters (e.g. sun angle elevation, and sensor position). We also omitted conditions such as topography and gaps caused by dead trees. Further study is needed to verify the applicability of the discrete Fourier transform to estimating density from real imagery.

ACKNOWLEDGMENTS

This study was supported by a Research Fellowship for Young Scientists (no. 2,375) of the Japan Society for the Promotion of Science.

LITERATURE CITED

BRUNIQUEL-PINEL, V. and GASTELLU-ETCHEGORRY, J.P., (1998): Sensitivity of texture of high resolution images of forest to biophysical and acquisition parameters. Remote Sens. Environ. **65**: 61-85

COUTERON, P., PELISSIER, R., NICOLINI, E.A. and PAGET, D., (2005): Predicting tropical forest stand structure parameters from Fourier transform of very high-resolution remotely sensed canopy images. J. Appl. Ecol. **42**: 1121-1128

DELENNE, C., DURRIEU, S., RABATEL, G., DESHAYES, M., BAILLY, J.S., LELONG, C. and COUTERON, P., (2008): Textural approaches for vineyard detection and characterization using very high spatial resolution remote sensing data. Int.J.Remote Sens. **29**: 1153-1167

FOREST AGENCY OF JAPAN., (2008): Annual Report on Trends of Forests and Forestry: Fiscal Year 2007. Japan Forestry Association, Tokyo, (In Japanese)

FUKUCHI, S., YOSHIDA, S., MIZOUE, N. and MURAKAMI, T., (2006): The responses of Cryptomeria japonica associated with tree density using Nelder plot. Proceeding of Japanese Forest Society Congress. **117**: 190 (in Japanese with English summary)

KAYITAKIRE, F., HAMEL, C. and DEFOURNY, P., (2006): Retrieving forest structure variables based on image texture analysis and IKONOS-2 imagery. Remote Sens. Environ. **102**: 390-401

KUZUOKA, S. and ARAI, K., (2002): Trees modeling using ray-tracing technique and its parameters estimation. Journal of the Remote Sensing Society of Japan **22**: 394-404

LECKIE, D.G., GOUGEON, F.A., TINIS, S., NELSON, T., BURNETT, C.N. and PARADINE, D., (2005): Automated tree recognition in old growth conifer stands with high resolution digital imagery. Remote Sens. Environ. **94**: 311-326

LECKIE, D.G., GOUGEON, F.A., WALSWORTH, N. and PARADINE, D., (2003): Stand delineation and composition estimation using semi-automated individual tree crown analysis. Remote Sens. Environ. **85**: 355-369

LI, X. and STRAHLER, A.H., (1992): Geometric-optical bidirectional reflectance modeling of the discrete crown vegetation canopy: Effect of crown shape and mutual shadowing. IEEE Transactions on Geoscience and Remote Sensing. **30**: 276-292

NELDER, J.A., (1962): New kinds of systematic designs for spacing experiments. Biometrics **18**: 283-307

NELSON, T., BOOTS, B. and WULDER, M.A., (2005): Techniques for accuracy assessment of tree locations extracted from remotely sensed imagery. J.Environ.Manage. **74**: 265-271

OTA, T., MURAKAMI, T., KAJISA, T., MIZOUE, N. and YOSHIDA, S., (2007): The relationship between the density of Cryptomeria japonica stands and texture statistics derived from very-high-resolution imagery. -The research using simulated very-high-resolution imagery-. Journal of the Japan society of Photogrammetry and Remote Sensing **46**: 4-15 (in Japanese with English summary)

POULIOT, D.A., KING, D.J., BELL, F.W. and PITT, D.G., (2002): Automated tree crown detection and delineation in high-resolution digital camera imagery of coniferous forest regeneration. Remote Sens. Environ. **82**: 322-334

PROISY, C., COUTERON, P. and FROMARD, F., (2007): Predicting and mapping mangrove biomass from canopy grain analysis using Fourier-based textural ordination of IKONOS images. Remote Sens. Environ. **109**: 379-392

RANSON, K.J., DAUGHTRY, C.S.T. and BIEHL, L.L., (1986): Sun angle, view angle, and background effects on spectral response of simulated balsam fir canopies. Photogrammetric Engineering & Remote Sensing **52**: 649-658

SAKAGUCHI, M., (1961): Studies on basic factors in thinning. Bulletin of FFPRI. **131**: 1-95 (in Japanese with English summary)

SAKAI, M., (1997): Forest owner's mind for forest management and reorganization of forest policy, 1: Negligence of forest operation on planted forest. Bull. Kyushu. Univ. For. **76**: 25-38 (in Japanese with English summary)

SAKAI, M., (1999): Minds of forest owners for management and forest resources policy(in Japanese). J for Eco. **45**: 3-8 (in Japanese)

TAKESHITA, K., (1985): Construction analysis of sugi forest (*Cryptomeria japonica* D. Don) by parabolic modeling of crown form. Bull. Kyushu. Univ. For. **55**: 55-104

WASSENAAR, T., ROBBEZ-MASSON, J.M., ANDRIEUX, P. and BARET, F., (2002): Vineyard identification and description of spatial crop structure by per-field frequency analysis. Int. J. Remote Sens. **23**: 3311-3325

WULDER, M., NIEMANN, K.O. and GOODENOUGH, D.G., (2000): Local maximum filtering for the extraction of tree locations and basal area from high spatial resolution imagery. Remote Sens.Environ. **73**: 103-114

(Received 11 November 2009)
(Accepted 20 March 2010)

Article

The Recommendation for REDD based on the Restrictions of A/R CDM Under the Present Rules

Takashi Fukushima[*1]

ABSTRACT

The Afforestation and Reforestation project activity under the Clean Development Mechanism (A/R CDM) is one of the policies set under the Kyoto Protocol. A/R CDM is to remove greenhouse gases by the afforestation or reforestation project in developing countries and has some specific features: non-permanency, uncertainty, and long-term. The introduction of the new policy targeted on the sink sector, the Reducing Emissions from Deforestation and Forest Degradation in developing countries (REDD), is considered in a next framework starting from 2013. REDD will give positive incentives for the reducing emissions from deforestation and forest degradation. The purpose of this study is focusing on proposal for the promotion of REDD, based on the analysis of the advantages and disadvantages of A/R CDM. To analyze the issues of A/R CDM, this paper especially focused on two stakeholders, project participants and host countries. Project participants regard A/R CDM (and REDD) as "business" and host countries consider them as "development policy." It is often said that much more discussion on implementation of REDD should be done based on the lessons from A/R CDM, but there have been no studies on sorting out problems especially concerned with A/R CDM, and on discussing how to reflect the lessons from A/R CDM to REDD. The research results showed that while A/R CDM had some innovative advantages such as giving financial incentives for the carbon sequestration function of a forest and helping to attain Sustainable Forest Management, there were many problems from the both viewpoints of "business" and "development policy," i.e. complex rules, low profitability, long-term corporation risk, and low priority for many countries. These results lead to the conclusion that there are restrictions and barriers to promote A/R CDM under the present rules and support systems. The recommendations for REDD are as follows; REDD is environmentally- sound and can be evaluated as a good system to contribute the multilateral functions of forest and local job-creation on forest management and conservation, but has disadvantages to restrict all "activities leading to the destruction of forests." The project scale of REDD would be much larger than that of A/R CDM, so that consideration on social aspect would be more significant. It is desirable to make the rules of REDD easy to use and understand for both developed and developing countries, to decrease the long-term corporation risks by structuring the partnership among stakeholders, and so on.

Keywords: A/R CDM, REDD, climate change, viewpoints of stakeholders, bottom-up approach

INTRODUCTION

The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (KP) were adopted in 1992 and 1997, respectively, to prevent climate change. Developed countries (Annex-1 Parties which includes the Organization for Economic Co-operation and Development

Corresponding author: Takashi Fukushima
[*1] Graduate School of Agricultural and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-8657, Japan
(Research Fellow DC of the Japan Society for the Promotion of Science)

[*]Present Address
Graduate School of Human Sciences, Waseda University, 2-579-15, Sangashima, Tokorozawa, Saitama, 359-1192, Japan
(Research Fellow PD of the Japan Society for the Promotion of Science)

(OECD) countries and the countries in transition) aimed to achieve the goals mentioned in KP to reduce greenhouse gases (GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6)) for the first commitment period (2008–2012) through domestic actions and the Kyoto Mechanism. The Kyoto Mechanism (or the Flexible Mechanism) includes the Clean Development Mechanism (CDM), the Joint Implementation (JI), and the Emission Trading, which follows a market mechanism that developed countries can implement for cost-effective actions.

In CDM, developed countries will implement emission reduction projects in developing countries (host countries), and in turn receive credit called Certified Emission Reduction (CER), which can be used to achieve the Kyoto goals. CDM has two main categories: the afforestation and reforestation project activities under CDM (A/R CDM) and emission CDM. The scope of emission CDM includes all but the sink sector[1]. A/R CDM targets on the afforestation (forestation on lands that have not been forested for at least 50 years) and the reforestation (forestation on lands that have not been forested since 1990) and is differs from emission CDM in several points. Based on forest features such as non-permanency (forest will be distinguished), uncertainty (forests would not always grow as expected), and long-term (forests will grow for a long time), the rules for A/R CDM, such as credits with term (tCER and lCER) and longer crediting period (UNFCCC 2001; 2003; 2004; 2009), were determined at COP9 (2003) for normal scale and COP10 (2004) for small scale[2]. As the A/R CDM projects are usually implemented at rural areas, small-scale projects need to be developed or implemented by low-income communities and individuals.

The introduction of another new policy targeted on the sink sector is considered in a next framework starting from 2013. It is the Reducing Emissions from Deforestation and Forest Degradation in developing countries (REDD) which targeted on the avoidance of deforestation and forest degradation. REDD has its roots in the proposal by Costa Rica and Papua New Guinea in COP11 (2005) and gives positive incentives for the reducing emissions from deforestation and forest degradation. The discussion of REDD started from COP13 (2007) and the detailed rules and settings depend on the international future negotiations.

MATERIAL AND METHOD

Stakeholders had different viewpoints on A/R CDM. One viewpoint was "climate policy," but project participants and host countries (governments and local people in the project area) had different viewpoints. Project participants regarded A/R CDM as "business." For example, paper companies intend to acquire pulpwood through A/R CDM. Trading companies are interested in A/R CDM as the emission trading business. Host countries regarded A/R CDM as "development policy" and expect to promote forestation, forest conservation, and local development for their own countries through it. A bottom-up approach is adapted in CDM, so that the viewpoints of project participants and host countries should be considered. It can be said that these viewpoints of stakeholders on REDD are almost same.

Only a few theoretical studies have been conducted in this area. VERCHOT *et al.* (2007) focused on forest definitions[3] and analyzed how they impact land eligibility from the case studies in Bolivia, Ecuador, Uganda and Kenya. OLSCHEWSKI *et al.* (2005) indicated that A/R CDM projects are economically attractive through the case study in Patagonia. VAN VLIET *et al.* (2003), EcoSecurities (2002), and GROEN *et al.* (2006) estimated the project cost for A/R CDM using some economic models. KIRBY and POTVIN (2007) examined the functional relationship between tree species and carbon stocks in Panama. MINANG *et al.* (2007) analyzed the community capacity to manage the A/R CDM project within community forests in Cameroon. FUKUSHIMA (2006) analyzed the key factors to promote A/R CDM by focusing on corporate social responsibility (CSR). FUKUSHIMA and NAKAJIMA (2008) revealed from a case study in Fiji that local community expects local development through the A/R CDM project. In Japan, studies concerning A/R CDM were initiated primarily by the "CDM/JI Feasibility Study Program." For example, through this program, Sumitomo Forestry CO., LTD. (1999–2004) and Oji Paper CO., LTD. (2003, 2005) have implemented feasibility studies in Indonesia, Madagascar, and Laos. These are just feasibility studies to apply A/R CDM and from only a one-sided viewpoint of the project participants.

No study has attempted to focus on both subject (project participants) and object (host countries) of the project and considered the direction to promote A/R CDM in a comprehensive manner.

Based on this perspective, this study has main two

[1] Any process, activity or mechanism which removes GHGs from the atmosphere. Forests and other vegetation are considered sinks.

[2] The limit of small scale was set 8,000 t-CO_2 per year at COP9 (2003), but raised to 16,000 t-CO_2 per year at COP13 (2007).

[3] Each host country should select the definition of forest at 3 points: (a) a single minimum tree crown cover value between 10-30 percent, (b) a single minimum land area value between 0.05-1 hectare, (c) a single minimum tree height value between 2-5 meters.

purposes: One is focusing on promotion of A/R CDM, and the other is on proposal for the promotion of REDD.

Firstly, to implement and promote A/R CDM, the issues should be analyzed by focusing on advantages and disadvantages for stakeholders, especially for project participants and host countries.

Secondly, it is often said that much more discussion on implementation of REDD should be done based on the lessons from CDM. However, there have been no studies on sorting out problems especially concerned with A/R CDM, and on discussing how to reflect the lessons from A/R CDM to REDD. Therefore, this study aims to consider and recommend the institutional design of REDD based on discussing the problems on A/R CDM.

The research methods were a literature search and stakeholder interviews in Japan and host countries. The period of the survey was from October 2003 to June 2009. This study mainly focuses on Japan because it is a forested country and was one of the leading countries at the international discussion stage for A/R CDM. This case study in Japan, as a pioneer country, will be of some help for following countries.

ADVANTAGES / DISADVANTAGES OF A/R CDM

Advantages of A/R CDM

The first advantage is that A/R CDM is one of the few ways for host countries to participate in KP, which helps in achieving both environmental conservation and local development. While emission CDM projects are usually implemented in urban areas, A/R CDM may be the only way for rural areas in host countries to participate in and receive a benefit from KP. At Third Assessment Report, IPCC (2001) analyzed that GHG emissions from all developing countries were about 25% of the world in 1990 and would surpass 50% by around 2020. It is essential for both developed and developing countries to address climate change, and CDM can support and promote collaboration between them. CDM is required to contribute to sustainable development of host countries (each developing country defines the original definition of "sustainable development"), and the A/R CDM project can support local sustainable development directly if it is well managed (FUKUSHIMA and NAKAJIMA 2008; MINANG *et al.* 2007).

The second advantage is that A/R CDM requirements improve forestation projects for private companies and NGOs. The A/R CDM has various requirements as shown in the Project Design Document (PDD)[4].

[4] For the registration of CDM, the project participants must submit PDD.

Table 1 The contents of PDD

A. General description of the proposed A/R CDM project activity
B. Duration of the project activity / crediting period
C. Application of an approved baseline and monitoring methodology
D. Estimation of ex ante net anthropogenic GHG removals by sinks and estimated amount of net anthropogenic GHG removals by sinks over the chosen crediting period
E. Monitoring plan
F. Environmental impacts of the proposed A/R CDM project activity
G. Socio-economic impacts of the proposed A/R CDM project activity
H. Stakeholders' comments

Source: http://cdm.unfccc.int/Reference/Documents.

- The requirements of PDD are:Environmental: environmental impact assessment according to the host countries' criteria
- Social: socio-economic impact assessment; stakeholders' comments; community participation; care for community customs
- Economical: cost-effective measures through a market mechanism; the redistribution of CDM credit income to the local community; the creation of new jobs

Of the industrial forestation projects thus far, private companies have primarily used the single, exotic and fast-growing tree species, but this may harm local biodiversity and enhance the risk of tree diseases and insect damage (COSSALTER and PYE-SMITH 2003). The large-scale land enclosure accompanying the eviction of local people has also been criticized (FUKUSHIMA 2005). The NGO environmental forestation projects are always concerned with the unstable financial base (FUKUSHIMA 2005). While both these projects face their problems, A/R CDM proposes a new style of forestation project with "triple (environmental, social, and economical) benefits."

The third advantage is that A/R CDM provides market incentive to the carbon sequestration function of a forest. In general, forests have multiple functions (FAO 2007; KANNINEN *et al.* 2007) such as conservation of biodiversity and timber harvest. In particular, the carbon sequestration function draws more attention for mitigating climate change (FAO 2007). The market has provided financial incentives only to the timber harvest function, but A/R CDM can provide new incentives to the carbon sequestration function through GHG credit, which can support activities to conserve or add new forest. This incentive is more important for rural areas where there is less income from logging (KIRBY and POTVIN 2007).

This mechanism can also show a new way of development to the forest industry stuck in a long slump of timber price all over the world.

Disadvantages of A/R CDM

The disadvantages can be classified according to the following viewpoints:

- Business
(1) complex rules
(2) unsellable credit
(3) low profitability
(4) insufficient support
- Development Policy
(5) complex rules
(6) difficulty participating in the local project
(7) long-term corporate risk
(8) low priority for host countries
- Climate Policy
(9) unfavorable attitude of many countries
(10) delay of international discussion

These ten disadvantages can be categorized into four groups: rules, profitability, sustainable forest management (SFM), and priority, and they have a mutual relationship with each other.

Project participants complained about the complex rules and procedures [(1) & (5)]. Special knowledge, skills, technology, and infrastructure are needed for data collection and analysis (Minang *et al*., 2007).

In particular, many project participants regarded the requirement of additionality and replacement duty of the credit as the biggest problems. Project participants should demonstrate that a project has "additionality to business as usual" (UNFCCC 2001). Forestation projects generally have specific risks, and their profitability is lower than that of industrial projects (Olschewski *et al*. 2005). According to this requirement, industries are obligated to implement projects in locations such as sloping, low-productive, and poorly accessible land. The credit used in the first commitment period should be replaced in the next commitment period. In case of A/R CDM, because the credit has a term, replacement duty is more troublesome than emission CDM. This means that project participants must continue the project or implement a new project to receive replacement credit.

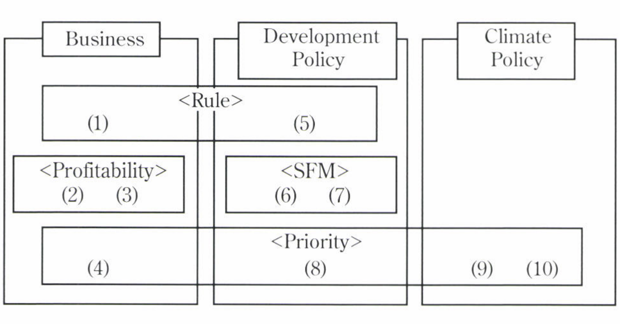

Fig. 1 Disadvantages of A/R CDM
Source: created by author

This complexity is also true for host countries and particularly for local people in a project area. The modalities and information requirements for CDM are beyond community capabilities and skills (Brown *et al.* 2000). Host countries should elaborate the Designated National Authority (DNA), which gives permission for the project and defines forest and low-income communities. However, DNA fails to function well in many countries (Ekoko 2000), and only a few countries have set a definition for a forest and a low-income community. Some aid agencies have indicated that DNA should be elaborated, but it is still insufficient. Georgiou *et al.* (2008) detailed a roadmap for selecting host countries (from a case study of wind energy projects of the emission CDM in Eastern Europe, Middle East and Northern Africa) which can apply to other sectors of CDM. Their roadmap includes the following steps: 1.potential condition, 2.preliminary financial analysis (to estimate by the Internal Rate of Return), 3.CDM eligibility condition, 4.final financial analysis, 5.multicriteria decision analysis. By their roadmap, many host countries are inappropriate for A/R CDM because they lack CDM eligibility.

(2) Unsellable credit and (3) low profitability are attributed to the fixed term of tCER and lCER. In Japan, the New Energy and Industrial Technology Development Organization and Japan Carbon Finance stated that they would not purchase tCER and lCER, and the EU-Emission Trading Scheme has excluded them from their target list. A fixed-term creates a low credit price. The average CER credit price was \$10.90/t-CO_2 in 2006 (Capoor and Ambrosi 2007). However, the Biocarbon Fund[5], which is operated by the World Bank to target the sink sector, set the tCER and lCER credit price at \$3–4/t-CO_2. Olschewski *et al.* (2005) indicated that their minimum price would be \$1.7–4.9/t-CO_2 and Van Vliet *et al.* (2003) demonstrated that \$5/t-CO_2 would not be enough to make most A/R CDM projects profitable. Because credit price depends on market trend, uncertainties and price risks are involved (Van Vliet *et al.* 2003; Groen *et al.* 2006; Capoor and Ambrosi 2007).

In addition, project participants must pay for various costs of forest management, community organising, project registration, and so on.

(6) Difficulty participating in the local project and (7) long-term corporate risk are SFM issues, but are applicable to general forestation projects. Local participation is essential to take care of local communities. Community forestation can deliver environmental, social, and economical benefits and

[5] Biocarbon Fund aims to support the countries which cannot benefit from the Kyoto Mechanism without the fund (Biocarbon Fund 2007). 4 governments and 10 private companies (including 8 Japanese companies) invested to Biocarbon Fund.

help attaining SFM (Scheyvens *et al.* 2007). However, project participants have indicated that local participation is accompanied by many difficulties such as resource tenure, benefit allocation, and governance aspects (Minang *et al.* 2007; De Jong *et al.* 2000), and they have taken various measures to solve these problems. For example, project participants give seedlings to local people, provide forest management, and purchase timbers from them. The local community assumes some participatory projects, such as measuring tree height and destructive sampling, but these technical skills are usually absent in many communities (Minang *et al.* 2007). Because project participants are not always professional, they will face many hardships to implement local participatory projects.

A host country's approval is necessary for CDM, and some project participants expect this rule to assure the host government's commitment to the project. However, political uncertainties of host countries cause long-term corporate risk. For example, Fiji experienced a coup in 2006 and Kenya had a presidential election in 2007, which caused some political confusion. These political uncertainties cause the long-term corporation risk. Furthermore, a change in local leaders at the project area may also cause corporate risks.

(9) An unfavorable attitude by many countries affects (4) insufficient support for project participants, (8) low priority for host countries, and (10) a delay in international discussion.

At the international negotiation stage, the countries opposed to the sink questioned whether it was adequate to utilize the sink for the Kyoto commitment. Some host countries such as China and Brazil were concerned that developed countries might switch the investment to lower cost activities, such as sink. They placed the priority on the energy and waste management sectors and a low priority on the forest sector. Countries belonging to the Alliance of Small Island States (AOSIS), which were especially vulnerable to the bad effects of climate change such as sea level rise, adopted a skeptical attitude to sink because they needed the practical actions for the GHG reduction. This low priority made the capacity building delayed in host countries to accept A/R CDM. The EU and some experts were concerned that CDM would provide perverse incentives for forest conversion.

Although the A/R CDM rules and procedures were determined two years later than those of the emission CDM, there was no consideration for a project start and crediting periods. A/R CDM already has disadvantages, such as uncertainty and long-terrm, and these problems can be further disadvantages for project participants.

A/R CDM support systems and projects have been established in Japan. A forestry agency in charge of A/R CDM created a help desk and implemented three support projects (2003–2007): The Technical Guideline Survey project, The Human Resource Development project, and The Baseline Survey project. The Global Environment Center has implemented the "CDM/JI Feasibility Study Program" since 1999, which is outsourced by the Ministry of the Environment. Project participants criticized these support projects and indicated that they were not useful for their projects as they were geographically, politically, environmentally, and socially different and the subsidy was limited.

CONCLUSION AND DISCUSSION

This research was conducted mainly from the viewpoints of "business" for project participants and "development policy" for host countries. The research results lead to the conclusion that there are restrictions and barriers in implementation and promotion for A/R CDM under the present rules and support systems. However, 1895 CDM projects have been registered thus far; only eight projects has been registered as A/R CDM (as of November 2009).

Based on this survey result, the course of improvement of A/R CDM for its promotion and the proposal for the system design of REDD are discussed in this section.

The Course of Improvement of A/R CDM

We should emphasize the viewpoints of project participants and host countries and create international discussions to promote A/R CDM. Simplifying the rules, improving low profitability by enhancing support systems, and strengthening and assuring the corporations in developed and host countries are ways to improve the present A/R CDM situation. Coordination across multiple sectors will aid in the success of this scheme (Kanninen *et al.* 2007). Some assistance for communities to improve their capacities is also desirable (Minang *et al.* 2007).

A/R CDM rules were only based on three forest features: non-permanency, uncertainty, and long-term. To enhance the project incentive, it would be desirable to take the other three features; multiple functions (forest has multiple functions), publicness (forests have the nature of the commons), and regionality (forests depend on local conditions and the relationship with community varies regionally) into consideration when revising the rules of A/R CDM (and deciding the rules of REDD).

The Recommendation for the System Design of REDD

Finally, here is the discussion on how to consider the lessons from A/R CDM on designing the system of REDD. Recommendation is pointed out according to three advantages and ten problems.

Although both A/R CDM and REDD have something in common character because of the GHG reduction approaches focused on sink, there are also many different points between both. I will make it clear before the detailed discussion.

One of the typical differences is on methods. A/R CDM aims for the increase of carbon removals through activities of afforestation and reforestation. On the other hand, REDD prevents the GHG reduction through the activities for avoidance of deforestation and forest degradation.

The other is on the project scale. The each REDD project would be much larger than that of A/R CDM. A/R CDM has a project based approach. However, it is presently accepted that REDD will take a national or sub-national based approach. Besides, it seems very possible that the main project participants of REDD will be any officials or someone concerned with the government, although the participants of A/R CDM are private companies and NGOs.

There are still some other issues: Should REDD be included in CDM? Which method is better, Credit-type (as same as A/R CDM) or Funds-type? Should it be open-ended or limited the cap?

Discussion from Advantages of A/R CDM

The three points of advantages are same and important as those of REDD: the first is one of the few ways to participate in KP for host countries and to help to achieve both environmental conservation and local development. The second is the policy for realizing triple (environmental, economic, social) benefits. The third is the mechanism to provide the market incentives to carbon sequestration function of a forest.

REDD has an advantage because it is a policy for avoidance of deforestation and forest degradation, and is not necessary to introduce and plant exotic species. In this mean, REDD is environmentally- sound and can be evaluated as a good system to contribute the multiple functions of forest such as biodiversity conservation.

On the other hand, the large project scale would make advantages and disadvantages on social and economic aspects. It can be said that, though the advantage is local job-creation on forest management and conservation, it is disadvantage to restrict all "activities leading to the destruction of forests (including grazing and collecting building materials)," which the local people have ever been doing. It would be better to appropriately take an alternative livelihood with mutual agreement between project participants and local people. However, the local debarment from the project site or the restriction of local traditional / cultural activities might happen according to circumstances. The large project scale would even carry a risk of becoming beyond the reach of small scale matters and neglecting the voices from grassroots as the socially vulnerable.

As mentioned above, consideration on social aspect would be more significant for implementation of REDD and it is much necessary to make the requirement strict.

Discussion from Disadvantages of A/R CDM

Ten disadvantages are considered from four categories.

At first, about complex rules, it is necessary to change and improve on the implementation of REDD as well. It is desirable to make it easy to use and understand for developing countries which have much difficulties in understand rules. It can be expected that developing countries can propose unilateral projects. However, simplified process does not mean and never permit the relaxation of the requirements on environmental, economic, social aspects. It must avoid making the quality degradation of projects.

About profitability, it cannot be fully discussed here because the method (credit or fund) has not been determined yet. It depends on the profitability system. And there are some inevitable restrictions such as non-permanency, uncertainty, and long-term, which are typical features of forest. However, it is necessary to remedy or improve the problems of A/R CDM, which makes "sink" quite unfavorable or inconvenient compared with any other projects/activities.

About the SFM issues, as same as AR CDM, it has almost the same problems concerned with regular forest projects. The solution of the long-term corporation risk is indispensable to make the policies more effective and sustainable. And it is desirable to decrease these risks by structuring the partnership among project participants, the government, and the local people.

Finally about priority. Some countries, which took an opposite standpoint when A/R CDM was introduced, are not on opposite side now about the introduction of REDD. Some developing countries have a positive outlook to accept the goals of GHG reduction, based on the condition of the introduction of REDD. It is fact that REDD is made to be high-priority on negotiation among the mitigation against climate change and is different from the situation of A/R CDM. However, there still are many countries put priority on energy-sector and many countries and organizations concern about the bad effects on local society like debarment of the project areas. They remain firmly opposed to REDD. It would be necessary to take their opinions into consideration.

The implementation and promotion of A/R CDM and REDD are now essential as climate policy because it is a critical problem to reduce GHG by all means and they have many useful side-effects. In addition, deforestation is a global environmental problem and it causes about one fifth of total global GHG emissions (Stern 2006; IPCC 2007). If forest-sector funding declined worldwide (Wunder 2006), a financial incentive from A/R CDM and REDD could provide new funding for a forest sector.

ACKNOWLEDGEMENT

I would like to thank anonymous reviewers for the valuable and helpful comments to the early drafts of this paper.

LITERATURE CITED

BioCarbon Fund, (2003): BioCarbon Fund Brochure-Overview of the BioCarbon Fund. World Bank, Washington, DC, 28pp

Brown, S., Masera, O., Sathaye, J., Andrasko, K., Brown, P., Frumhoff, R., Lasco, G., Leach, G., Moura-Costa, S., Mwakifwamba, G., Phillips, P., Read, P., Sudha, P., Tipper, A., Riedacker, A., Pinard, M., Stuart, M., Wilson, C. and Trexler, M., (2000): Project-Based Activities. In: Watson, RT., Noble, IR., Bolin, B., Ravindranath, NH., Verardo, DJ. and Dokken, DJ. (eds) Land Use, land-use change, and forestry. Cambridge University Press, Cambridge: 285-338

Capoor, K. and Ambrosi, P., (2007): State and Trends of the Carbon Market 2007. World Bank, Washington, DC, 52pp

Cossalter, C. and Pye-Smith, C., (2003): Fast-wood forestry: myths and realities. The Center for International Forestry Research (CIFOR), Bogor, 59pp

De Jong, BHJ., Tipper, R. and Montoya-Gomez, G., (2000): An economic analysis of the potential for carbon sequestration by forests: evidence from southern Mexico. Ecological Economics **33**: 313-327

EcoSecurities, (2002): Evaluation of the potential for developing a carbon programme in the Cameroon Mountains Region (Report for the Cameroon Mountain Conservation Foundation). EcoSecurites, Limbe, 32pp

Ekoko, F., (2000): Balancing politics, economics and conservation: the case of the Cameroon Forestry Law reform. Development and Change. **31**: 131-154

Food and Agriculture Organization of the United Nations (FAO), (2007): State of the World's Forests 2007. FAO, Rome, 157pp

Fukushima, T., (2005): The analysis of framework and sustainability of A/R CDM to focus on interests of stakeholders. Tropical Forestry **63**: 10-16 (in Japanese)

Fukushima, T., (2006): The Characteristics of Project Styles and the Future Issues of A/R CDM. Forest Economy **694**: 1-15 (in Japanese)

Fukushima, T., and Nakajima, M., (2008): The Direction of A/R CDM: Suggestions from the Reforestation Project in Lomawai, Nadroga, Fiji. Journal of Japanese Forest Research **90**(3): 168-175 (in Japanese)

Georgiou, P., Tourkolias, C. and Diakoulaki, D., (2008): A roadmap for selecting host countries of wind energy projects in the framework of CDM. Renewable and Sustainable Energy Reviews **12**(3): 712-731

Groen, T., Nabuurs, GJ. and Schelhaas, MJ., (2006): Carbon Accounting and Cost Estimation in Forestry Projects using CO2FIX V.3. Climatic Change **74**: 269-288

Intergovernmental Panel on Climate Change, (2001): IPCC Third Assessment Report: Climate Change 2001. Cambridge University Press, Cambridge, 397pp (Synthesis Report)

Intergovernmental Panel on Climate Change, (2007): IPCC Fourth Assessment Report: Climate Change 2007. IPCC, Geneva, 52pp (Synthesis Report)

Kanninen, M., Murdiyarso, D., Seymour, F., Angelsen, A., Wunder, S. and German, L., (2007): Do Trees Grow on Money? The implications of deforestation research for policies to promote REDD. The Center for International Forestry Research (CIFOR), Bogor, 73pp

Kirby, KR. and Potvin, C., (2007): Variation in carbon storage among tree species: Implications for the management of a small-scale carbon sink project. Forest Ecology and Management **246**(2-3): 208-221

Minang, PA., Mccall, MK. and Bressers, HTA., (2007): Community Capacity for Implementing CDM Projects Within Community Forests in Cameroon. Environ Manage **39**: 615-630

Olschewski, R., Benitez, PC., Koning, GHJ. and Schlichter, T., (2005): How attractive are forest carbon sinks? Economic insights into supply and demand of CERs. Journal of Forest Economics **11**(2): 77-94

Scheyvens, H., Hyakumura, K. and Seki, Y., (2007): Decentralisation and state-sponsored community forestry in Asia. Institute for Global Environmental Strategies (IGES), Kanagawa, 204pp

Stern, N., (2006): Stern Review: The Economics of Climate Change. Cambridge University Press, Cambridge, 692pp

United Nations Framework Convention on Climate Change (UNFCCC), (2001): Modalities and procedures for CDM as defined in Article 12 of the Kyoto Protocol -Decision 17/CP.7. http://unfccc.int/resource/docs/cop7/13a02.pdf#page=20 (accessed on November 25, 2009)

United Nations Framework Convention on Climate Change (UNFCCC), (2003): Modalities and procedures for A/R CDM in the first commitment period of the Kyoto Protocol -Decision 19/CP.9 (FCCC/CP/2003/6/Add.2). http://unfccc.int/resource/docs/cop7/13a02.pdf#page=20 (accessed on November 25, 2009)

United Nations Framework Convention on Climate Change (UNFCCC), (2004): Simplified modalities and procedures for small scale A/R CDM the first commitment period of the Kyoto Protocol and measures to facilitate their implementation -Decision 14/CP.10 (FCCC/CP/2004/10/Add.2). http://unfccc.int/resource/docs/cop10/10a02.pdf#page=26 (accessed on November 25, 2009)

United Nations Framework Convention on Climate Change (UNFCCC), (2009): Glossary of CDM terms (Version 05). http://cdm.unfccc.int/Reference/Guidclarif/glos_CDM.pdf (accessed on November 25, 2009)

Van Vliet, OPR., Faaij, APC. and Dieperink, C., (2003): Forestry projects under the clean development mechanism? Climatic Change **61**: 123-156

Verchot, LV., Zomer, R., Sutraaten, OV. and Muys, B., (2007): Implications of country-level decisions on the specification of crown cover in the definition of forests for land area eligible for A/R CDM. Climatic Change **81**: 415-430

Wunder, S., (2006): Are direct payments for environmental services spelling doom for sustainable forest management in the tropics? Ecology and Society **11**(2): 23-35

*The English titles are tentative translation from original Japanese titles by the author of this paper.

(Received 26 November 2009)
(Accepted 20 March 2010)

Article

Multiple-criteria Decision-support System for Optimising Spatial Distribution in a Forest Classification Process

Shunsuke Suzuki[*1], Shinichi Tatsumi[*2] and Yojiro Ueno[*3]

ABSTRACT

We propose a new multiple-criteria decision-support (MCDS) system to consider the optimum area distribution and spatial layouts of forest types in forest zoning. We formulated a new index (W') that considers social demand for forests, potential capacities of forests and functional diversity of forests. Area distribution of each forest type (e.g. timber production, ecosystem preservation) was considered by maximising the index (W') using the Lagrange multiplier method. We dealt with the spatial layouts of the forest types by applying 0-1 integer programming. The applicability of the new MCDS system was validated through a case study at a national forest in Fukushima Prefecture, Japan. The following forest types were considered in the case study: timber production, water conservation, soil conservation, recreational land use and ecosystem preservation. The social demand for each forest type was quantitatively evaluated by an opinion poll. Potential capacities were assessed for each sub-compartment using an existing index, regression analysis and valuation standards. We compared results derived from the index W' with results from six other methods. These methods were derived from combinations of the terms included in W'. The results from the new index were the most balanced and had relatively high scores for each item (social demand, potential capacity, functional diversity). The sum total of the scores was highest for the new index amongst all the methods. Each forest type was allocated adequately by integer programming. Thus, we concluded that the new MCDS system provides the most suitable area distribution and spatial layouts of the different forest types, taking account of both aspects of social demand and potential capacity of forest stands.

Keywords: forest zoning, multiple-criteria decision-support system, operations research, potential capacity, social demand

INTRODUCTION

The objective of forest management has recently shifted from cost-effective timber production alone to broader goals such as maintenance of biodiversity and ecosystem processes (KANGAS and KANGAS, 2002; ÖHMAN, 2002; MCDONALD and LANE, 2004). In Japan, the Forest and Forestry Basic Law (revised in 2001) specifies the promotion of multiple-use forestry (NEBUYA, 2005). Accordingly, national forests in Japan are managed based on classification of forests into three broad categories: co-existence of forest and people, conservation of soil and water, and sustainable utilisation of forest resources. The implementation of such site classifications is generally referred to as "forest zoning" in Japanese forestry (e.g. ITO, 2005). In forest zoning, each classified areal unit is assigned to one forest type, each of which has a different primary management objective (e.g. timber production, maintenance of biodiversity, water conservation). The goal of forest zoning is to clearly define and prioritise functional objectives for forests (KAMEYAMA, 2005) and to fulfil many purposes on a landscape scale (MITSUDA *et al.*, 2003).

However, increasing concern has been expressed that resident participation in forest resource management should be improved (KANGAS, 1994; TSUCHIYA, 1995; KAKIZAWA, 2000; SHEPPARD and MEITNER, 2005). Also when making a forest zoning plan, one must consider the social demands of local residents and stakeholders (NEBUYA, 2005). Yet, public

Corresponding author: Shinichi Tatsumi
[*1] ITOCHU Corporation, Tokyo 107-8077, Japan
[*2] Graduate School of Agricultural and Life Sciences, the University of Tokyo, Tokyo 113-8657, Japan
Tel. +81-3-5841-5221; Fax. +81-3-5841-5429
E-mail: tatsumi@fr.a.u-tokyo.ac.jp
[*3] Faculty of Regional Environment Science, Tokyo University of Agriculture, Tokyo 156-8502, Japan

participation in modern forest management is not straightforward (MILLS and CLARK, 2001), given the complex functions of forests today and the conflicting interests of stakeholders (PUKKALA, 2002a; KANGAS and KANGAS, 2005). Thus, forest planning requires the development and adoption of a multiple-criteria decision-support (MCDS) system that can generate alternative solutions (PUKKALA, 2006).

Many of the challenges in forest planning today can be alleviated by using a MCDS system (MARTELL *et al.*, 1998; MILLS and CLARK, 2001). However, most existing approaches in forest planning lack the means to effectively include spatial considerations in numerical optimisations (ÖHMAN, 2002). Therefore, UENO (2000) proposed a MCDS system for prioritising and determining spatial distribution in a forest zoning process. This MCDS system dealt with defining area distributions of forest types based on public participation.

In this study, we propose a new MCDS system that also incorporates a physical evaluation of the forest. ABE and ISHIBASHI (1995) noted that the evaluation standards for multiple-function forestry can be roughly divided into two types: standards for social demands and standards for potential capacities. They suggested that these two standards should be considered comprehensively in a forest zoning process. The former standards represent requests from residents and local officials, as described above. The latter describe physical aspects of forest stands related to stand structure and topographic conditions. They evaluate the potential capacities of forest stands to serve multiple functions. Taking account of suggestion by ABE and ISHIBASHI (1995), we developed a new MCDS system by adding a standard for potential capacity to the system proposed by UENO (2000). We took an operations research approach to solve the problem. The new MCDS system is therefore designed to define the optimum area distribution under both aspects of social demand and potential capacity of forest stands. In addition to defining the area distribution of the forest types, we also examined spatial layout and formulated a decision-support system for forest zoning. We then evaluated the applicability of the system through a case study.

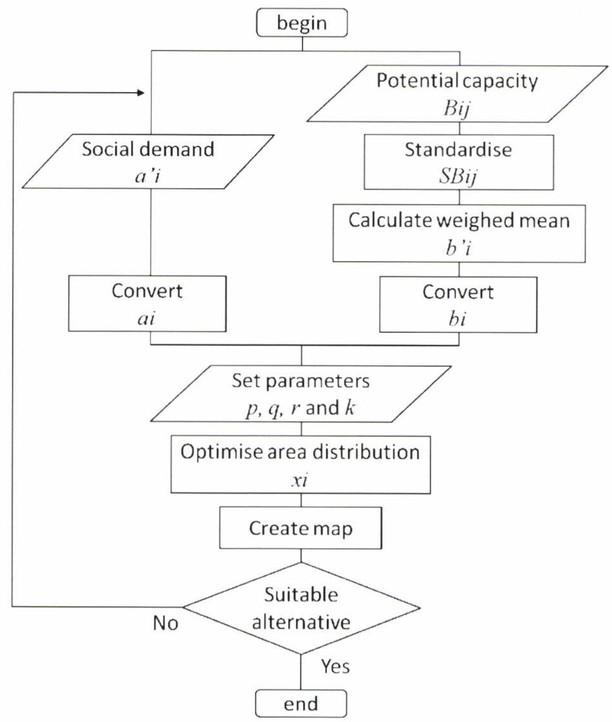

Fig. 1 Flowchart of the new multiple-criteria decision-support (MCDS) system

SYSTEM DEVELOPMENT

The new MCDS system is presented as a flowchart in Fig. 1.

Structure of the New Index (W')

UENO (2000) proposed a MCDS system to determine the area distribution of forest types based on public participation. First, he defined the index W:

$$W=-\sum_{i=1}^{m} x_i \ln x_i + \sum_{i=1}^{m} a_i x_i \qquad \sum_{i=1}^{m} x_i = 1, \quad 0 \le x_i \le 1 \qquad (1),$$

where m is the number of relevant forest types, x_i is the percentage of total stand area assigned to the ith forest type (ratio of the percent area to the total) and a_i is the quantitative evaluation of social demand on the ith forest type (described hereafter in detail).

The first term in eq. (1) represents Shannon's diversity index (SHANNON, 1948), a frequently used measure that increases with species richness (PIELOU, 1969). However, in eq. (1), the diversity index is used to offer an equivalent area distribution of each forest type to moderate their proportion. The second term in eq. (1) is a product sum of a_i and x_i, which can be determined using decision analysis tools such as the contingent valuation method (CVM) and the hedonic price method (HPM) (DAVIS *et al.*, 2001). Thus, the second term contributes to assigning larger areas to forest types with a higher social demand.

UENO (2000) determined the area distribution of each forest type by optimising W subject to $\sum x_i = 1$. He then compared these results to those determined using three other methods and concluded that W produced the most suitable results for defining the area distribution given social demands (see UENO, 2000 for more details). In the present study, we introduced physical evaluation of the study site into W. Thus, the new index (W') includes the evaluation of potential capacity for each forest type on each stand (scale of the areal unit can be defined as other than "stand", depending on the subject of management planning, e.g. compartments, sub-compartments). W' can be described as follows:

$$W'=-p\sum_{i=1}^{m} x_i \ln x_i + q\sum_{i=1}^{m} a_i x_i + r\sum_{i=1}^{m} b_i x_i \qquad \sum_{i=1}^{m} x_i = k, \quad 0 \le x_i \le k \quad (2),$$

where b_i is the evaluation of potential capacity of the ith forest type (described hereinafter in detail); p, q and r are parameters; and k is the sum of x_i. Other variables are as defined for eq. (1).

Parameters p, q and r are ratios weighing the three terms of the index. They quantitatively determine which term to emphasise in decision-making. k is normally fixed at 1, but by giving k a value greater than 1, more than one objective function can be applied to each stand. For example, when k is set to 2, each stand will be assigned to two forest types for preferential management in the zoning plan.

The third term in W' shows the product sum of b_i and x_i, where b_i describes the mean potential capacity for the ith forest type at the study site. Potential capacities are evaluated in relation to each stand using quantification analysis with environmental and topographic variables (e.g. ZHENG and NAGUMO, 1994; PUKKALA, 2002b). However, each forest type will be assessed using different criteria and different units. Thus, these values should be standardised (converted into values between 0 and 1) using the following equation:

$$SB_{ij}=\frac{B_{ij}-B_i\min}{B_i\max+B_i\min} \qquad (3),$$

where SB_{ij} is the standardised value of potential capacity for the ith forest type on the jth stand, B_{ij} is the evaluation of potential capacity for the ith forest type on the jth stand before standardisation, $B_i\min$ is the lowest evaluation of a stand in the ith forest type and $B_i\max$ is the highest evaluation of a stand in the ith forest type.

Next, weighted means (weighted by the size of each stand) for each forest type are calculated using the following equation:

$$b'_i=\frac{\sum_{j=1}^{n} SB_{ij}y_{ij}}{\sum_{j=1}^{n} y_{ij}} \qquad (4),$$

where b'_i is the weighted mean of the potential capacity of the ith forest type for the entire study site, n is the number of stands in the study site and y_{ij} is the size of the jth stand with the ith forest type.

To make the new index (W') more intelligible, both variables of social demand and potential capacity were converted such that $\sum a_i=\sum b_i=1$. Originally, no need existed for this conversion step, since the ratio of these two variables can be controlled by the parameters q and r. However, we presume that by incorporating this step, the significance of the two variables can be more easily compared in the decision-making process. The variables were converted as follows:

$$a_i=\frac{a'_i}{\sum_{i=1}^{m} a'_i} \qquad (5),$$

$$b_i=\frac{b'_i}{\sum_{i=1}^{m} b'_i} \qquad (6),$$

where a_i is the converted value of social demand for the ith forest type, a'_i is the estimate of social demand for the ith forest type before conversion, b_i is the converted value of the potential capacity of the ith forest type and b'_i is the evaluation of the potential capacity of the ith forest type before conversion.

Consequently, the index W' incorporates both aspects of social demand (a_i) and potential capacity of the study site (b_i) in forest planning, and also takes functional diversity of the forest into consideration. Thus, we presume that W' will provide a suitable area distribution (x_i) for forest planning. W' will be maximised subject to $\sum x_i=k$, by use of the Lagrange multiplier method. The solution is as follows:

$$x_i=\frac{k\exp\left(\frac{q}{p}a_i+\frac{r}{p}b_i\right)}{\sum_{j=1}^{m}\exp\left(\frac{q}{p}a_i+\frac{r}{p}b_i\right)} \qquad (7),$$

where the variables are as defined above.

Spatial Layout

Stands of each forest type were mapped by applying the method proposed by ZHENG (1996). This method is based on 0-1 integer programming. Stands are allocated to forest types so as to maximise total SB_{ij} for the study site. Each stand is preferentially assigned to the forest type to which the highest potential capacity of the stand belongs. The programme is subject to the area distribution (x_i) defined in eq. (7). The following problem is considered:

Maximise

$$\sum_{i=1}^{m}\sum_{j=1}^{n} SB_{ij}\theta_{ij} \qquad (8)$$

subject to

$$\sum_{j=1}^{n} h_j=H \qquad (9),$$

$$Hx_i-\frac{H}{n}\leq\sum_{j=1}^{n} h_j\theta_{ij}\leq Hx_i+\frac{H}{n},\quad \forall_i \qquad (10),$$

$$\sum_{i=1}^{m}\theta_{ij}=1,\quad \forall_j \qquad (11),$$

$$\theta_{ij}=\{0,1\},\quad \forall_j \qquad (12),$$

where θ_{ij} is a decision variable that takes the value of 1 when the jth stand is assigned to the ith forest type, and otherwise takes the value of 0; h_j is the size of the jth stand; and H is the total size of the study site. The other variables are as defined above.

Eq. (8) sums SB_{ij} for the entire study site: the higher this value, the more efficiently each stand is assigned to each forest type. Eq. (9) defines the total size of the study site. Eq. (10) defines the lower and upper bounds of the total area of the stands assigned to each forest type. Hx_i in eq. (10) reflects the area defined in eq. (7). Thus, originally, $\sum h_j\theta_{ij}$ should correspond exactly to Hx_i. However, it is hardly possible to have $\sum h_j\theta_{ij}=Hx_i$ since each stand has its own fixed size. Therefore, Hx_i must have an allowable range for calculation, to some extent. In this study, we have assumed that an area equal to one stand will be a suitable size for this problem. Thus, the mean size of the stands was used as an allowable range. Eq. (11) ensures that all stands will be assigned to one of the forest types. Eq. (12) shows that θ_{ij} has a value of either 0 or 1.

VALIDATION

We validated the applicability of the new MCDS system through a case study.

Study Site

The case study was conducted in a national forest encompassing the village of Tenei and the city of Shirakawa, in Fukushima Prefecture, Japan (37°19-34'N, 140°00-23'E; 360-1100m above sea level (a.s.l.)). We defined sub-compartment as an areal unit for this case study. The site consisted of 91 compartments and 2,238 sub-compartments, with an area of 11,968ha. The low-elevation eastern part of the site was mostly covered by plantations of *Cryptomeria japonica* D. Don and *Chamaecyparis obtusa* Sieb. et Zucc. The frequency of broad-leaved trees such as *Quercus serrata* Thunb. increased with elevation (to the west). Parts of the study site more than 800 m a.s.l were mostly covered by natural forest dominated by *Fagus crenata* Blume and *Quercus crispula* Blume.

The study area serves multiple functions for residents with varying interests. Water from Lake Hatori, an artificial lake located in the central part of the study site, is used to irrigate the Shirakawa region. The western part of the site, including Lake Hatori, is designated as a national park, and many tourists are attracted to the scenic views. Recreational facilities such as campgrounds and cycling roads are found lakeside. Ski resorts and resort villas are located south-west of the lake. The study site is part of a larger expanse of forest that stretches from the western part of the site to the Ohu Mountains, and supports numerous plants and animals.

Variables

Five forest types were considered in this case study: timber production (TP; $i=1$), water conservation (WC; $i=2$), soil conservation (SC; $i=3$), recreational land use (RL; $i=4$) and ecosystem preservation (EP; $i=5$). To evaluate the social demand (a_i) for each of the five forest types, we used results from a public opinion poll on multiple-use forestry (Cabinet Office, Government of Japan, 2007). The nationwide public poll surveyed 3000 people over 20 years of age. Respondents were asked to choose the three (out of 12 choices) forest applications that they most valued. We equated the choices offered in the public poll to the five forest types defined above to determine social demand values (a'_i). Table 1 shows the items from the opinion poll, social demand (a'_i) and converted values of social demand (a_i).

Potential capacity for TP (B_{1j}) was evaluated using a growth and location index (Akahori *et al.*, 1993), which is defined as the product of a location index (defined as the distance between forest stands and timber markets; Akahori *et al.*, 1993) and a site index. The growth and location index takes into account both the economics of transportation and stand productivity (Konohira, 2001).

Next, we evaluated WC (B_{2j}) by means of multiple regression analysis of forest soil macropores (Institute of Water Science, 1973). The physical features of forest soils, which include high porosity and therefore the ability to store large amounts of water (Tsukamoto, 1998), render forest soils effective at purifying and regulating water resources. We thus analysed macropore density (l/m^3) in relation to elevation, geology, soil type, depositional type, forest type (e.g. *C. japonica* plantation, natural *Fagus crenata* forest), stand age and region (classified by prefecture). Parameters in the regression analysis were as defined by the Institute of Water Science (1973).

Similarly, SC (B_{3j}) was evaluated through a multiple regression analysis of the size of the A_0 layer (Institute of Water Science, 1973). The A_0 layer prevents sheet erosion and thus contributes to soil formation and conservation (Tsukamoto, 1998). We analysed the amount of A_0 layer (kg/m^2) in relation to elevation, topography, soil type, slope, forest type, growing stock and region. Parameters in the regression analysis were as defined by the Institute of Water

Table 1 Results from an opinion poll on multiple-use forestry (Cabinet Office, Government of Japan, 2007), the related forest types, and converted social demand values

Items on the opinion poll	Forest type	Social demand (%) a'_i	Converted value a_i
Production of timbers	TP	14.6	0.091
Storage of water resources	WC	43.8	0.272
Prevention of disasters (e.g. landslide, flood)	SC	48.5	0.302
Land use for healings and comforts	RL	31.8	0.198
Habitats for plants and animals	EP	22.1	0.137
Total		160.8	1.000

TP timber production, *WC* water conservation, *SC* soil conservation, *RL* recreational land use, *EP* ecosystem preservation.

SCIENCE (1973).

RL (B_{4j}) was evaluated using valuation standards from the FORESTRY AGENCY (2004). Each sub-compartment was evaluated based on six standards: scenery, stand structure, existence of lakes and rivers, existence of historic sites, existence of community facilities and conditions of trails. Each standard was scored on a 3-point scale (0, 1 and 2). The total score was considered to represent the recreational benefit of the site.

We evaluated EP (B_{5j}) in reference to the valuation standards of the HOKKAIDO FORESTRY RESEACH INSTITUTE (2004). We used two standards to evaluate each site: vegetation type (e.g. bare land, plantation, secondary forest, old-growth forest) and site condition (e.g. understorey vegetation, presence of nuciferous species, marsh, bare land). The former standard was scored on a 4-point scale (0, 1, 2 and 3), and the latter on a 5-point scale (−2 to +2). The total score was considered to represent the ecosystem health of the site.

Spatial Distribution of Potential Capacities of the Five Forest Types

The potential capacities of the five forest types were evaluated for each sub-compartment (B_{ij}) using forest inventory data and forest base maps of the study site. Standardised values (SB_{ij}) and converted values (b_i) were then calculated according to eqs. (3) and (6), respectively. Table 2 shows the mean values and standard deviations of B_{ij}, weighted means of SB_{ij} (*i.e.* b'_i) and converted values (b_i).

Distribution maps of SB_{ij} for the five stand types are shown in Fig. 2. ArcGIS version 9.2 (ESRI, 2006) was used to make the maps. TP (SB_{1j}) was high in the eastern plantation area and low in the western natural forest area (Fig. 2a). WC (SB_{2j}) was high in the southern part of the site, especially in the south-western area near Lake Hatori (Fig. 2b). SC (SB_{3j}) was high in the north-western natural forest area (Fig. 2c). RL (SB_{4j}) was high around Lake Hatori (Fig. 2d). EP (SB_{5j}) was evenly distributed throughout the area (Fig. 2e).

Parameters

As explained above, the new index (W') includes terms that relate to functional diversity, social demand and potential site capacity. In this case study, however, there was no indicator to decide which term to emphasise in the forest planning process for the study site. Therefore, parameters p, q and r were all set to 1, so the three terms were given equal weight. Parameter k was also set to 1, since we only assigned each sub-compartment to one forest type in this case study. We consider these values of the parameters as defaults that enable us to validate the index W' objectively.

Comparison between the New Index (W') and Other Methods

We validated the applicability of the new index (W') by comparing it to six other area-distribution methods (methods A, B, C, D, E and F). These methods were derived from combinations of the terms included in W'. Method A determines area distribution (x_i) with an emphasis on maximising the functional diversity index ($-\sum x_i \ln x_i$), which is the first term in W'. Method B determines x_i by maximising the second term in W' ($\sum a'_i x_i$), reflecting the social demands for the forest type. Method C determines x_i by maximising the third term in W' ($\sum b'_i x_i$) to efficiently identify the potential capacities of the site. Method D considers both the functional diversity index ($-\sum x_i \ln x_i$) and the second term of W' ($\sum a'_i x_i$), and determines x_i by maximising the sum of the two terms. Method E calculates x_i by maximising the sum of $-\sum x_i \ln x_i$ and the third term of W' ($\sum b'_i x_i$). Method F maximises the sum of $\sum a'_i x_i$ and $\sum b'_i x_i$.

Results of the Comparisons

The results from the new index (W') and from methods A through F are listed in Table 3. In the case of method A, an equal proportion of the area was assigned to each forest type. In methods B and C, the whole area were assigned to either SC or EP, which had the highest value for a'_i and b'_i (Table 1;

Table 2 Mean, standardised and converted values of potential capacity for each forest type

Forest type	Potential capacity B_{ij}	Standardised values b'_i	Converted value b_i
TP	43.0 (±35.7)	0.259	0.134
WC	175.2 (±14.0)	0.410	0.213
SC	2802.0 (±960.2)	0.381	0.198
RL	1.1 (±1.1)	0.239	0.124
EP	4.2 (±1.9)	0.639	0.331
Total		1.928	1.000

TP timber production, *WC* water conservation, *SC* soil conservation, *RL* recreational land use, *EP* ecosystem preservation. Numbers in parentheses are standard deviations. The units for *WC*, *SC*, *RL* and *EP* are l/m³, g/m², points and points, respectively.

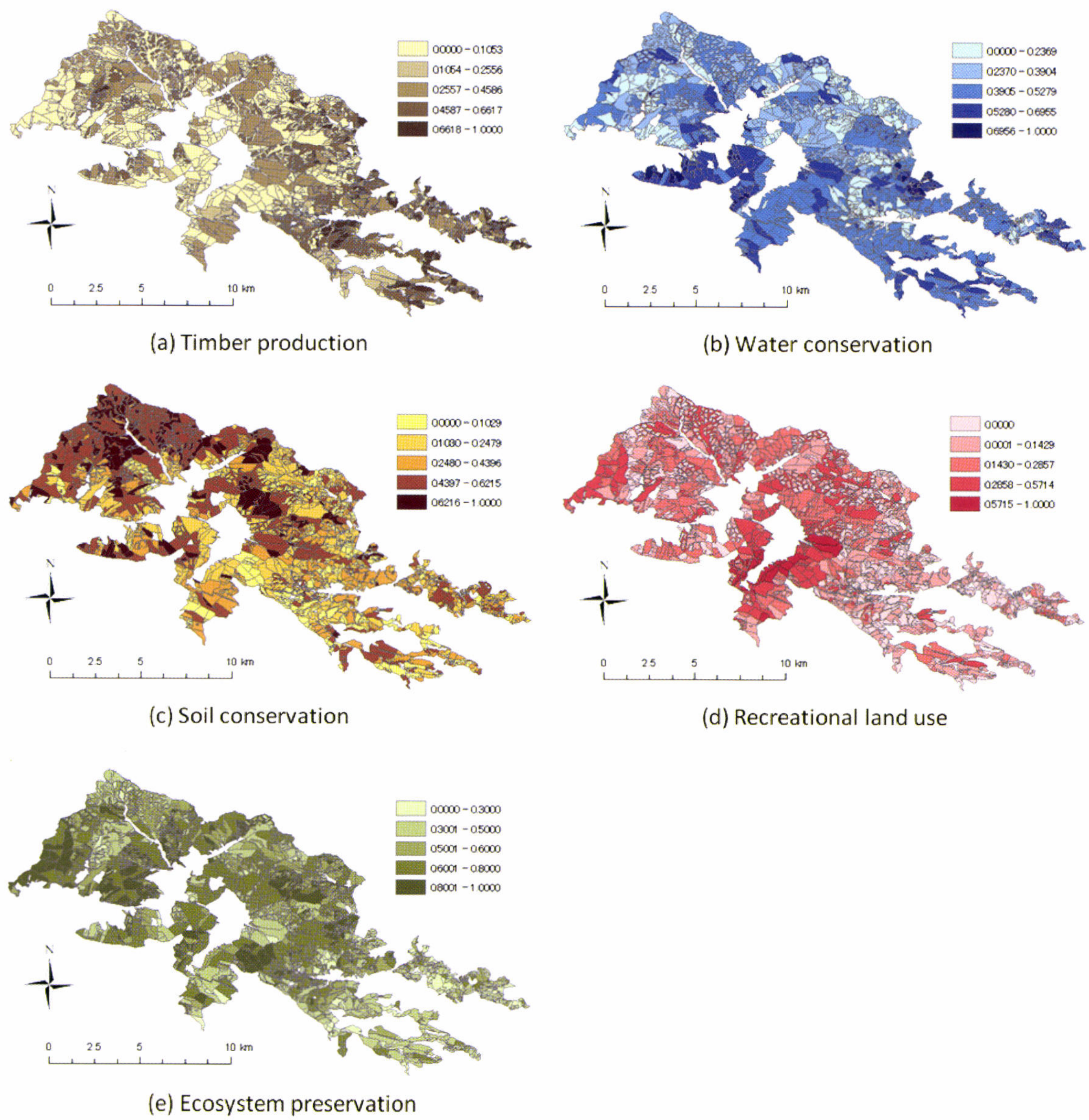

Fig. 2 Distribution map of the standardised value of potential capacity for the five forest types in each sub-compartment

Table 2), respectively. In methods D and E, large proportion of area were preferentially assigned to the forest types which had high value in a'_i and b'_i, respectively. In method F, the whole area were assigned to SC, which had the highest value in $a'_i + b'_i$. In the new index (W'), larger proportion of the area were assigned to each forest type in descending order of its value in $a'_i + b'_i$.

The highest value for the functional diversity index ($-\sum x_i \ln x_i$) was determined using method A (1.610), whereas W' had the fourth highest value (1.604). Methods B and F had the highest score for $\sum a'_i x_i$ (0.302), whereas W' had the fourth highest value (0.206). $\sum b'_i x_i$ was highest in method C (0.332), and third highest (0.205) in W'. Finally, the sum total of terms ($-\sum x_i \ln x_i + \sum a'_i x_i + \sum b'_i x_i$) was highest in W' (2.0152). Each method from A to F had at least one term that ranked lower than 5 out of 7, whereas the terms in W' all ranked higher than 4.

Results of the Spatial Layouts of the Five Forest Types

The results derived from integer programming, subject to x_i and defined by W', are shown in Fig. 3. We used the Rglpk package (THEUSSL and HORNIK, 2009) in R version 2.9.0 (R Development Core Team, 2009) for calculation. Sub-compartments in the study site were all assigned to one of the forest types. Sub-compartments in the eastern part of the site were mainly assigned to TP and EP. Those in the north-western area were assigned to SC. RL was allocated mainly around the lake

Table 3 Comparison of area distribution and each term calculated by the new index and methods A through F

Forest type	Area distribution xi	Term: Functional diversity $-xi \ln xi$	Social demand $ai\,xi$	Potential capacity $bi\,xi$	Sum total
New index (*W'*)					
TP	0.167	0.299	0.015	0.022	
WC	0.217	0.331	0.059	0.046	
SC	0.220	0.333	0.066	0.043	
RL	0.184	0.311	0.036	0.023	
EP	0.213	0.330	0.029	0.071	
Sum		1.604 (4)	0.206 (4)	0.205 (3)	2.0152 (1)
Method-A					
TP	0.2	0.322	0.018	0.027	
WC	0.2	0.322	0.054	0.043	
SC	0.2	0.322	0.060	0.040	
RL	0.2	0.322	0.040	0.025	
EP	0.2	0.322	0.027	0.066	
Sum		1.610 (1)	0.200 (5)	0.200 (4)	2.0094 (4)
Method-B					
TP	0	0*	0	0	
WC	0	0*	0	0	
SC	1	0	0.302	0.198	
RL	0	0*	0	0	
EP	0	0*	0	0	
Sum		0 (5)	0.302 (1)	0.198 (6)	0.4992 (5)
Method-C					
TP	0	0*	0	0	
WC	0	0*	0	0	
SC	0	0*	0	0	
RL	0	0*	0	0	
EP	1	0	0.137	0.332	
Sum		0 (5)	0.137 (7)	0.332 (1)	0.4690 (7)
Method-D					
TP	0.179	0.308	0.016	0.024	
WC	0.214	0.330	0.058	0.046	
SC	0.221	0.334	0.067	0.044	
RL	0.199	0.321	0.039	0.025	
EP	0.187	0.314	0.026	0.062	
Sum		1.606 (3)	0.206 (3)	0.200 (5)	2.0128 (2)
Method-E					
TP	0.187	0.313	0.017	0.025	
WC	0.202	0.323	0.055	0.043	
SC	0.199	0.321	0.060	0.039	
RL	0.185	0.312	0.037	0.023	
EP	0.228	0.337	0.031	0.076	
Sum		1.607 (2)	0.200 (6)	0.206 (2)	2.0123 (3)
Method-F					
TP	0	0*	0	0	
WC	0	0*	0	0	
SC	1	0	0.302	0.198	
RL	0	0*	0	0	
EP	0	0*	0	0	
Sum		0 (5)	0.302 (1)	0.198 (6)	0.4992 (5)

TD timber production, *WC* water conservation, *SC* soil conservation, *RL* recreational land use, *EP* ecosystem preservation.
*Limit value at $x_i \to 0$. Numbers in parentheses show the rank order of the methods under each term or sum total.

near the central part of the site, and sub-compartments in the south-western area were assigned to WC.

DISCUSSION

In this study, we proposed a new MCDS system for considering the optimum area distribution and spatial layouts of forest types in forest zoning. The new system considers both aspects of social demand and potential capacity of forest stands. We formulated a new index (W') by introducing a standard that represents the potential capacity of forest stands to the existing system proposed by UENO (2000). We took an operations research approach to solve the problem. We also dealt with the spatial layouts of forest types by applying the 0-1 integer programming proposed by ZHENG (1996). As a result, we developed a decision-support system for the forest zoning process (Fig. 1).

Through a case study, we validated the applicability of the new index (W') by comparing it with six other methods. The results derived from the new index were the most balanced and had relatively high scores for each term (Table 3). The sum total of the scores was also the highest for the new index amongst all methods. Therefore, the new index produced the most suitable results for defining area distributions, taking both the aspects of social demand and potential capacity into account. However, in most methods (W', method A, B and C), proportions of the values of social demand and potential capacity were smaller than that of functional diversity. For example, in W', the sums of social demand (0.206) and potential capacity (0.205) were almost one-eighth of the sum of functional diversity (1.604). Therefore, in the case when these two factors (social demand and potential capacity) need to be stressed, the parameters q and r should be fixed to values larger than 1.

Sub-compartments were allocated to forest types by integer programming, subject to the area distribution defined by the new index (Fig. 3). Each sub-compartment was preferentially assigned to the forest type to which the highest potential capacity of the sub-compartment belonged. Thus, each stand types were allocated in the most efficient way to harness the potential capacity of the study site. Parts of the layouts of the forest types defined by the new index, method A, D and E are compared in Fig. 4. As seen in the figure, several sub-compartments were adequately assigned to different forest types according to the methods used.

In the new system, both social demand and potential capacities of the site are treated numerically. In addition, the parameters p, q and r can be used to differentially weight the three terms that comprise W'. As a consequence, two important factors in the decision-making process, social demand and potential capacity (ABE and ISHIBASHI, 1995), can be described and compared objectively. Also, maps derived from integer programming help to provide visual information to the participants in the decision-making process. These characteristics of the new system that provide logical and visual information are especially important, since recent decision-making processes have required intelligible and specific decision-alternatives (SHEPPARD and MEITNER, 2005).

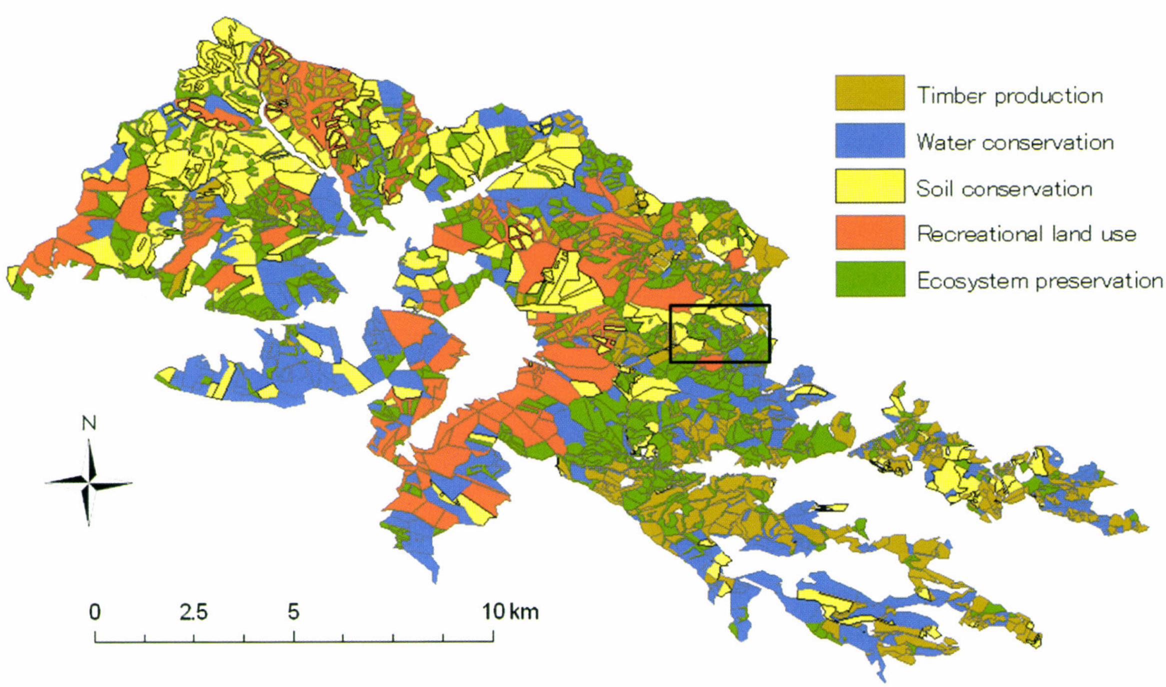

Fig. 3 Layouts of the five forest types. Enlarged figure of the area framed by the rectangle is shown in Fig. 4.

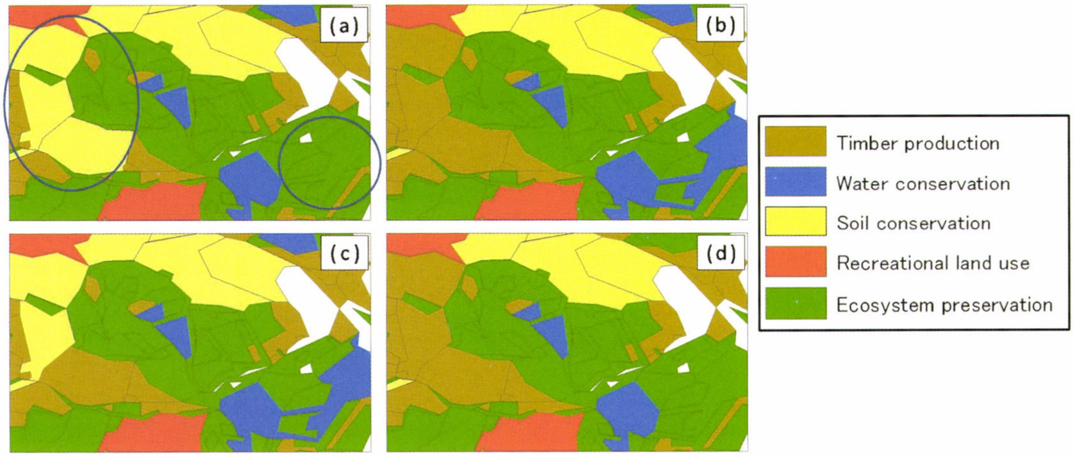

Fig. 4 Enlarged figures of the layouts of the forest types defined by (a) the new index, (b) method A, (c) method D and (d) method E. The circles show that the forest types of framed areas differs among the figures.

Using the new system, participants will be able to modify management plans by fixing variables and parameters explicitly to reach consensus.

Any kind of assessment criteria can be used to evaluate social demand and potential capacity in the new index, as long as they provide numerical results. For example, as we saw in the case study, low-cost research method from existing information, such as forest inventory data, can be used when lacking labor, cost or time.

In the present case study, we did not modify the parameter k, which indicates the percentage of the area assigned to each forest type. By giving this parameter a value greater than 1, more than one objective function can be applied to each sub-compartment. Whilst the original intent of forest zoning is to clearly define management objectives of individual areal units by classifying them as a single forest type, more suitable forest zoning plans may be possible by taking into account the co-existence of forest types (OHTA, 2005; MITSUDA *et al.*, 2009). Forest zoning that accepts more than one functional objective in each areal unit, by implementing k, has yet to be studied.

ACKNOWLEDGEMENTS

We are grateful to the Kanto Regional Forest Office for providing us with the site data. We thank Drs. Toshiyuki Tsuchiya and Masahiro Iwaoka for their helpful discussions and the anonymous reviewers for their valuable comments.

LITERATURE CITED

ABE, M. and ISHIBASHI, S., (1995): Development of a composite method of evaluating multiple forest types. Jpn. J. For. Plann. **25**: 33-56 (in Japanese with English summary)

AKAHORI, S. *et al.*, (*Edited by* 67 other editors) (1993): Glossary of terms relating to forest, forestry and wood. J-FIC. Tokyo. 375pp. (in Japanese)

Cabinet Office, Government of Japan, (2007): Shinrin to seikatsu ni kan-suru yoron chousa. http://www8.cao.go.jp/survey/h19/h19-sinrin/index.html (December 2007)

DAVIS, L.S., JOHNSON, K.N., BETTINGER, P.S. and HOWARD, T.E., (2001): Forest management: to sustain ecological, economic, and social values. 4th ed. McGraw-Hill. New York, 804pp.

ESRI, (2006): ArcGIS 9.2. Environmental System Research Institute, Inc., Redlands, CA, USA

FORESTRY AGENCY, (2004): Shinrin keikaku gyoumu hikkei. J-FIC, Tokyo, 1400pp.

HOKKAIDO FORSTRY RESEACH INSTITUTE, (2004): Shinrin kinou hyouka kijun. Sapporo, 30pp.

INSTITUTE of WATER SCIENCE, (1973): Shinrin no koueki-teki kinou keiryou-ka kiso chousa houkoku-sho. Tokyo, 351pp.

ITO, T., (2005): Potentials of zoning for recreation in natural areas. J. Jpn. For. Soc. **87**(6): 513-521 (in Japanese with English summary)

KAKIZAWA, H., (2000): Ecosystem management. Tsukiji-shokan. Tokyo. 206pp. (in Japanese)

KAMEYAMA, A., (2005): Zoning for land use planning. Shinrin kagaku. **43**: 4-10 (in Japanese)

KANGAS, J., (1994): An approach to public participation in strategic forest management. For. Ecol. Manage. **70**: 75-88

KANGAS, J. and KANGAS, A., (2002): Multiple criteria decision support methods in forest management: An overview and comparative analyses. *In*: Multi-objective forest planning. PUKKALA, T. (ed.), 207pp., Kluwer Academic Publishers, Dordrecht, 37-70

KANGAS, J. and KANGAS, A., (2005): Multiple criteria decision support in forest management – the approach, methods applied, and experiences gained. For. Ecol. Manage. **207**: 133-143

KONOHIRA, Y., (2001): Encyclopedia of forest and forestry. The Japan Forestry Association (ed.), 1236pp., Maruzen Co., Ltd., Tokyo, 691 (in Japanese)

MARTELL, D.L., GUNN, E.A. and WEINTRAUB, A., (1998): Forest management challenges for operational researchers. Eur. J. Operational Res. **104**: 1-17

McDonald, G.T. and Lane, M.B., (2004): Converging global indicators for sustainable forest management. For. Pol. Econ. **6**: 63-70

Mills, T.J. and Clark, R.N., (2001): Roles of research scientists in natural resource decision-making. For. Ecol. Manage. **153**: 189-198

Mitsuda, Y., Iehara, T., Matsumoto, M. and Oka, H., (2009): Methodologies of forest planning using criteria and indicators. Jpn. J. For. Plann. **42**(1): 1-14 (in Japanese)

Mitsuda, Y., Ito, S., Matsushita, K., Fukuzato, K. Taniguchi, T., Mizoue, N. and Shimizu, O., (2003): ESC (Ecological Site Classification) based DSS for Japanese forest landscape suffering frequent rainstorms. *In* Decision support for multi purpose forestry CD-Proceedings, Vienna, 23-25 April 2003, 10pp.

Nebuya, T., (2005): Forest planning system and forest zoning in Japan. Shinrin kagaku. **43**: 27-31 (in Japanese)

Öhman, K., (2002): Spatial optimisation in forest planning: A review of recent Swedish research. *In*: Multi-objective forest planning. Pukkala, T. (ed.), 207pp., Kluwer Academic Publishers, Dordrecht, 153-172

Ohta, T., (2005): Multiple functions of forest and zoning. Shinrin kagaku. **43**: 11-17 (in Japanese)

Pielou, E.C., (1969): An introduction to mathematical ecology. Wiley-Interscience, New York, 286pp.

Pukkala, T., (2002a): Introduction to multi-objective forest planning. *In*: Multi-objective forest planning. Pukkala, T. (ed.), 207pp., Kluwer Academic Publishers, Dordrecht, 1-19

Pukkala, T., (2002b): Measuring non-wood forest outputs in numerical forest planning. *In*: Multi-objective forest planning. Pukkala, T. (ed.), 207pp., Kluwer Academic Publishers, Dordrecht, 173-207

Pukkala, T., (2006): The use of multi-criteria decision analysis and multi-objective optimisation in forest planning. *In*: Sustainable forest management: Growth models for Europe. Hasenauer, H. (ed.), 398pp., Springer, Berlin, 263-284

R Development Core Team, (2009): R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0, URL http://www.R-project.org (June 2009)

Shannon, C.E., (1948): A mathematical theory of communication. The Bell Syst. Tech. J. **27**: 379-423

Sheppard, S.R.J. and Meitner, M., (2005): Using multi-criteria analysis and visualisation for sustainable forest management planning with stakeholder groups. For. Ecol. Manage. **207**: 171-187

Theussl, S. and Hornik, K., (2009): R/GNU Linear programming kit interface. http://R-Forge.R-project.org/projects/rglp/ (June 2009)

Tsuchiya, T., (1995): Public participation in forest planning in USDA Forest Service. For. Econ. **48**(1): 2-11 (in Japanese)

Tsukamoto, Y., (1998): Shinrin mizu tsuchi no hozen: Shitsujun hendou-tai no suimon chikei-gaku. Asakura Publishing. Tokyo. 138pp.

Ueno, Y., (2000): The optimum allocation of various forest types in forest planning. J. Jpn. For. Soc. **82**(4): 360-363 (in Japanese with English summary)

Zheng, Y., (1996): An integrated management planning system for multiple-use of forests. J. Jpn. For. Soc. **78**(3): 319-326 (in Japanese with English summary)

Zheng, Y. and Nagumo, H., (1994): A forest activity classification method using a geographic information system. J. Jpn. For. Soc. **76**(6): 522-530 (in Japanese with English summary)

(Received 19 September 2009)
(Accepted 19 July 2010)

Short communication

Stand Dynamics of Tropical Seasonal Evergreen Forest in Central Cambodia

Dana Kao[*1], Nobuya Mizoue[*2], Neth Top[*3], Tsuyoshi Kajisa[*2] and Shigejiro Yoshida[*2]

ABSTRACT

Information on tree and stand growth is essential to ensure sustained timber yield in tropical natural forests, but very little is known about stand dynamics of tropical seasonal forests, especially in the mainland Southeast Asia. Stand dynamics of seasonal evergreen forest in central Cambodia were estimated from 20 sample plots measured in 1998 and 2003. Data for all trees with diameter at breast height (DBH) ≧ 10cm and for commercial species DBH ≧ 10cm or DBH ≧ minimum diameter cutting limit (MDCL) were evaluated. In 1998, 67 species, of which 19 were commercial trees with DBH ≧ MDCL, were found at tree densities of 544.5 and 23.4 trees/ha, basal areas of 23.8 and 6.3m^2/ha, and stem volumes of 192.9 and 64.3m^3/ha. The mean diameter increment between 1998 and 2003 was 0.33 for all species and 0.32cm for commercial species; mean mortality rates were 2.4% and 0.5%, mean recruitment rates were 2.5% and 1.4% and volume increments were 1.09 and 0.86m^3/ha. These values are similar to those reported from tropical rain forests in Amazon and Southeast Asia. Estimated volume increment (0.86m^3/ha/year) for commercial trees with DBH ≧ MDCL was significantly larger than the figure (0.33m^3/ha/year) previously used in Cambodian management systems.

Keywords: tropical seasonal forests, volume increment, recruitment, mortality, commercial species

INTRODUCTION

There is increasing concern about the effect of selective logging in tropical natural forests on sustainability, the global carbon budget (e.g., Malhi and Grace, 2000) and biodiversity conservation (e.g., Myers *et al.*, 2000). Information on tree and stand dynamics is required to evaluate silvicultural options for sustainable timber yield. Cutting cycles and minimum diameter cutting limits are often based on diameter increment and/or volume increment of commercial species (e.g., Silva *et al.*, 1995; Sist *et al.*, 2003; Sist and Ferreira, 2007).

Although there are data for some tropical rain forests, especially in Brazilian Amazonia (e.g., Silva *et al.*, 1995; van Gardingen *et al.*, 2006; Valle *et al.*, 2006) and in Borneo (e.g., Sist and Nguyen- Thé, 2002; Phillips *et al.*, 2002; Kammesheidt *et al.*, 2003), very little is known about the stand dynamics of tropical seasonal forests in mainland Southeast Asia, such as those in Cambodia, where strong seasonality of precipitation is found (Kumagai *et al.*, 2005 and Kumagai *et al.*, 2009).

About 59% of Cambodia is covered by forest. There are three dominant forest types, evergreen (22.2%), deciduous (25.8%) and semi-evergreen forest (7.5%) (FA, 2007), in two classes, production forest (34% of total land area) and protection forest (25%). A selective logging system with a 25- to 30-year cutting cycle has been adopted in evergreen and semi-evergreen forests (Kimphat *et al.*, 1999) and the annual allowable cut has been calculated using an assumed volume increment of 0.33m^3/ha/year (DFW, 2001). This value was derived from the average of virgin forest studies reported by the FAO in 1962 (DFW, 2001) and is considered to be too low (DFW, 2001). However there are no data to verify the volume

Corresponding author: Dana Kao
[*1] Department of Forest and Forest Product Sciences, Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University, 6-10-1 Hakozaki, Higashi-Ku, Fukuoka 812-8581, Japan
E-mail: kaodana@yahoo.com
[*2] Faculty of Agriculture, Kyushu University, 6-10-1 Hakozaki, Higashi-Ku, Fukuoka 812-8581, Japan
[*3] Ministry of Interior, No. 275, Norodom Blvd., Phnom Penh

increment value.

The present study was designed to measure stand dynamics of seasonal evergreen forest in Kampong Thom Province, central Cambodia using two consecutive measurements of 20 permanent sample plots (PSPs) in 1998 and 2003. The main questions are: 1) whether tree growth, mortality and recruitment in Cambodian forests differ from tropical rain forests elsewhere, especially in Amazon and Southeast Asia; and 2) whether volume increment is significantly higher than $0.33m^3$/ha/year.

MATERIALS AND METHODS

Study Site and Data Collection

Kampong Thom Province in central Cambodia lies between 12°11' and 13°26' north and 104°12' and 105°44' east. The total area is 1,244,763ha, about 7% of the country (FA, 2007). The climate is tropical monsoon; the rainy season extends from May to October and the dry season from November to April. Between 1996 and 2000, the mean annual rainfall and temperature were 1,700mm and 28°C (Top *et al.*, 2009).

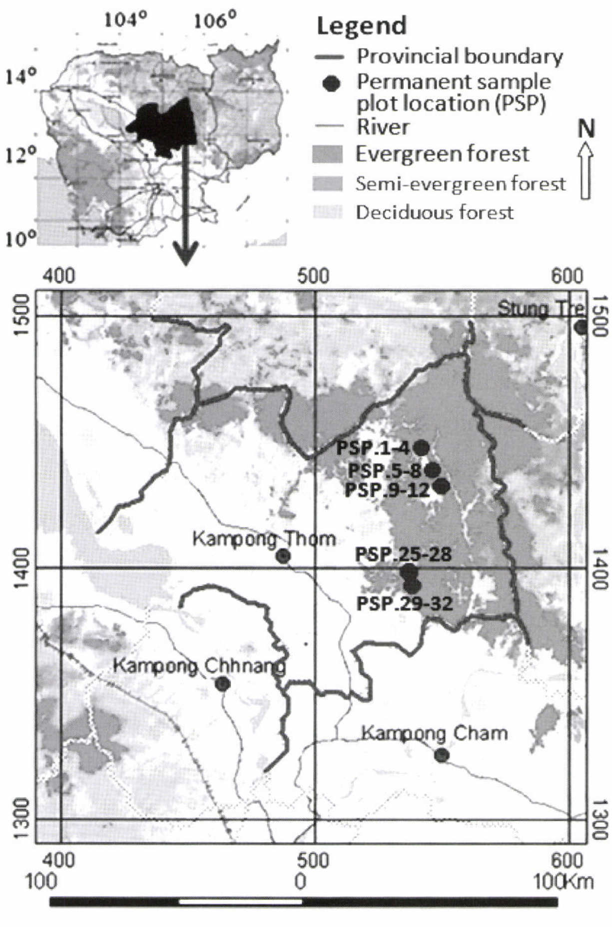

Fig.1 Location of 20 permanent sample plots (PSPs) distributed in 5 different places, each of which includes 4 plots
The sequence plot number of each location is shown; e.g., PSP25-28 indicates the plot number 25, 26, 27 and 28.
Source: Forestry and Wildlife Research Institute, Forestry Administration, Cambodia

Twenty PSPs were located in dense evergreen forests on flat terrain 9-100m above sea level (Fig. 1). Although these PSPs in this evergreen forest have not been heavily disturbed, they have been subject to some illegal extractions of fuelwood and timber (Top *et al.*, 2009). The plots were established in April 1998 and the trees measured in 1998 and December 2003. Each main plot was 50×50m and contained a 20×20m sub-plot. All trees with diameter at breast height (DBH) of 7.5-29.9cm in the sub-plot and ≧30cm in the main plot were measured and recorded. In 2003, new trees in each of the main plot and sub-plot with DBH ≧30cm and ≧7.5cm were also measured. Missing or dead trees were recorded as natural death or human disturbance (illegal logging).

Data Analysis

As with selective logging systems in other tropical countries, only commercial species with DBH more than the predetermined Minimum Diameter Cutting Limit (MDCL) may be harvested. A Cambodian Government decree (RGC, 2005) sets different MDCLs for each commercial species ranging from 30 to 60cm. The stand-level attributes (stand structure in 1998 and 2003, mortality, recruitment, illegal cut and volume increment) for the two sampling years were examined separately for all trees with DBH ≧ 10cm and all commercial trees with DBH ≧ MDCL. The annual rates of mortality, recruitment and illegal cut were estimated by using the widely used logarithmic equation (e.g. Lewis *et al.*, 2004 a):

$$Y = 100^{*}\{\ln N_{t} - \ln (N_{t} - X)\}/t,$$

where Y is the rate of mortality, recruitment or illegal cut, N_t is the number of trees measured in 1998, X the number of mortality, recruitment or illegal cut, and t the time (5.75 years = December 2003 − April 1998). Diameter increments of individual trees were examined for all trees and commercial trees with DBH ≧ 10cm. Although the minimum DBH of field measurements was 7.5cm, a DBH of 10cm was selected to be consistent with other studies (Valle *et al.*, 2006; Silva *et al.*, 1995; Rice *et al.*, 1998). Two outliers with unrealistically large annual diameter increments (10.3 and 10.4cm/year) were excluded from the analysis. These unrealistic values may have been due to misidentification of the trees to be measured or mistakes in data recording.

Volume increment is defined as the net annual production of the forest from growth, mortality and recruitment (Valle *et al.*, 2006). In the present study, we calculated volume increment for all trees with DBH ≧ 10cm and commercial trees with DBH ≧ MDCL, defined by:

$$I = (V_2 - V_1 + C) / (t_2 - t_1)$$

where I is the volume increment (m³/ha/year), V_2 the volume at measurement in 2003 (m³/ha), V_1 the volume at measurement in 1998 (m³/ha), C the volume of illegally logged trees (m³/ha) and $t_2 - t_1$ the time (in years) between the 2003 and 1998 measurements. In this formula, volume gains from the growth of existing stems and recruitment into the size class of interest (≧10cm or ≧MDCL), as well as losses due to mortality, are condensed into one increment value for the entire observation period (VALLE *et al.*, 2006), while excluding illegally logged trees from the calculation. Volume (m³) of individual trees was estimated as a function of DBH (cm) developed for different DBH classes and species groups (Table 1, FA, 2003).

RESULTS AND DISCUSSION

Stand Structure

For all trees with DBH ≧ 10cm in 1998, 67 species were found across all of 20 0.25-ha sized plots (a total of 5ha), and the mean values (±SD; standard deviation) of the 20 plots were 544.5±106.3 trees/ha of tree density, 23.8±5.1m²/ha of basal area and 192.9±46.4m³/ha of stem volume (Table 2). For commercial trees with DBH ≧ MDCL in 1998, 19 species were found across all the plots, resulting in 23.4±9.7 trees/ha of tree density, 6.3±3.4m²/ha of basal area, and 64.3±36.9m³/ha of stem volume. There was no significant difference (P>0.05, the two-tailed paired t-test) in the mean values of stand structure between 1998 and 2003 (Table 2).

There were fewer species and a lower stocking rate (basal area/ha) in this seasonal forest than in other primary tropical rain forests, despite the similar tree density recorded in the present study. About 200 species/ha are reported from primary lowland dipterocarp forests in Borneo (SIST and SARIDAN, 1999) and Amazonian rain forests (PHILLIPS and GENTRY, 1994; BREWER and WEBB, 2002) compared with 67 in 5ha in the present study. Similarly, the mean basal area (23.8m²/ha) in this study is lower than reports from primary tropical rain forests; 31.5±4.2m²/ha in East Kalimantan (SIST and NGUYEN-THÉ, 2002), 35.5±2.8 (±SE; Standard Error) m²/ha for 11 locations in Borneo and Peninsular Malaysia, 34.4±1.4 (±SE) m²/ha for 15 plots in Central Kalimantan (van GARDINGEN *et al.*, 2003) and 28.1±12.0 (95% CI; Confidence Intervals) m²/ha in Amazonia (LEWIS *et al.*, 2004), while being closer to values reported for logged-over forests; 25.2m²/ha in East Kalimantan (van GARDINGEN *et al.*, 2003), 26.0±6.4m²/ha and 24.1±7.1m²/ha in Sarawak, Malaysia (KAMMESHEIDT *et al.*, 2003), 20.3 and 25.9m²/ha in Brazilian Amazon (SILVA *et al.*, 1995).

On the other hand, tree densities of all trees with DBH ≧ 10cm in this study were similar to values documented for primary lowland dipterocarp forests elsewhere in Southeast Asia; 521±36 (±SE) trees/ha in Borneo and Penisular Malysia, and 583±19 (±SE) trees/ha in Central Kalimantan (van GARDINGEN *et al.*, 2003), 531 trees/ha in East Kalimantan (SIST and NGUYEN-THÉ, 2002), as well as to 581±16 (±95%CI) trees/ha obtained from 50 plots distributed over rain forests in South America (LEWIS *et al.*, 2004).

Table 1 Volume equations by species group, DBH range and forest type (FA, 2003)

Tree Species Group	Diameter class	Evergreen forest
Dipterocarp	Below 15cm	Volume = 0.022 + 3.4 DBH²
	Above 15cm	Volume = − 0.0971 + 9.503 DBH²
Non-dipterocarp	Below 30cm	Volume = 0.03+2.8 DBH²
	Above 30cm	Volume = − 0.331 + 6.694 DBH²

DBH, diameter at breast height.

Table 2 Stand structure in 1998 and 2003

Year	Group	Number of species	Density (trees/ha)		Basal Area (m²/ha)		Volume (m³/ha)	
			Mean ± SD[a]	Range	Mean ± SD	Range	Mean ± SD	Range
1998	All trees ≧ 10cm	67	544.5 ± 106.3	408.0～814.0	23.8 ± 5.1	14.6～32.8	192.9 ± 46.4	103.8～ 259.1
	Commercial ≧ MDCL[b]	19	23.4 ± 9.7	8.0～ 44.0	6.3 ± 3.4	1.3～13.0	64.3 ± 36.9	11.1～ 127.4
2003	All trees ≧ 10cm	67	531.6 ± 147.0	185.0～793.0	23.9 ± 5.4	15.9～34.8	193.9 ± 49.1	102.1～ − 274.9
	Commercial ≧ MDCL	20	24.4 ± 9.8	8.0～ 44.0	6.5 ± 3.6	1.4～14.2	66.3 ± 39.2	12.0～ 137.9

[a] SD: standard deviation
[b] MDCL: Minimum diameter cutting limit

Diameter Increment

Table 3 shows the periodic annual diameter increment, which was calculated from individual trees and summarized for all trees and only commercial trees. There are not large differences in the results between all trees and commercial trees, with the total mean values (±SD) being 0.33±0.09 and 0.32±0.08cm/year, respectively. There was no significant difference between growth rates for commercial and all trees (the two-tailed t-test, Table 3). The lowest increment values were recorded from the smallest DBH classes (10-19cm and 20-29cm), and there was no significant correlation between DBH class and increment for classes with DBH ≧ 30cm (Table 3).

In tropical forests, diameter increments in any class of trees may vary greatly due to environmental conditions (SILVA *et al.*, 1995), silvicultural treatments (de GRAAF *et al.*, 1999; KAMMESHEIDT *et al.*, 2003) and other reasons. Nevertheless, the mean values found in this study are similar to reported values for tropical rain forests. For example, SILVA *et al.* (1995) reported 0.3 and 0.4cm/year for all trees and commercial species 11 years after logging and 0.2cm/year for unlogged trees in Brazilian Amazonian rain forest. In East Kalimantan, SIST and NGUYEN-THÉ (2002) reported trees grew about 0.39cm/year in logged dipterocarp forest and 0.22cm/year in unlogged control plots. DAUBER *et al.* (2005) reported a mean annual diameter increment of between 0.22 and 0.41cm/year from PSPs in different eco-regions of Bolivia.

Recruitment, Mortality and Illegal Cut

Table 4 presented the annual density and percentage of recruitment, mortality and illegal cut for all trees ≧10cm and ≧ MDCL. For all trees, mean annual mortality±SD was 12.2± 14.6 trees/ha (2.4±4.3% of total number of trees in 1998), similar to the recruitment rate of 12.6±9.3 trees/ha (2.5± 2.2%). On the other hand, the recruitment of commercial trees with DBH ≧ MDCL, 0.3±0.4 trees/ha (1.4±4.9%), was larger than the mortality of 0.1±0.3 trees/ha (0.5±1.3%). Human disturbances were 1.0±1.8 trees/ha (0.2±0.4%) and 0.03±0.2 trees/ha (0.1±0.9%) annually for all trees with DBH ≧ 10cm and commercial trees with DBH ≧ MDCL, respectively, due to the collection of timber and/or non-timber forest products.

Although mortality and recruitment may vary between species and diameter class, the mean rates for the present study were very similar to or well within the range of reported values from tropical rain forests in Amazon and Southeast Asia (CLARK and CLARK, 1992; CONNELL *et al.*, 1984; KAMMESHEIDT *et al.*, 2003; SIST *et al.*, 2003; BUNYAVEJCHEWIN, 1999). PHILLIPS *et*

Table 3 Annual diameter increment (cm/year) for diameter classes

DBH class (cm)	Commercial species trees at DBH ≧ 10cm						All species trees at DBH ≧ 10cm					
	n	Max	Mean	Min	SD	CV%	n	Max	Mean	Min	SD	CV%
10 - 19	129	0.85	0.21	0.00	0.10	45	258	0.85	0.22	0.00	0.07	31
20 - 29	36	1.17	0.25	0.02	0.17	70	65	1.17	0.31	0.00	0.25	81
30 - 39	60	1.10	0.42	0.00	0.19	44	156	2.94	0.46	0.00	0.20	42
40 - 49	46	1.39	0.44	0.00	0.39	87	77	1.39	0.39	0.00	0.32	82
50 - 59	17	1.32	0.36	0.00	0.27	76	24	1.32	0.35	0.00	0.21	62
60 - UP	40	1.18	0.41	0.03	0.22	546	67	1.98	0.42	0.00	0.17	41
Total	328	1.39	0.32	0.00	0.08	26	647	2.94	0.33	0.00	0.09	28

n, number of observations; CV, coefficient of variation; SD, standard deviation; Max, maximum; Min, minimum

Table 4 Annual values of recruitment, mortality and illegal cut

Group	Density (trees/ha/year)		Percentage of 1998 (% of 1998)	
	Mean±SD[a]	Range	Mean±SD	Range
All trees ≧ 10cm				
Recruitment	12.6 ± 9.3	0.0～30.4	2.5±2.2	0.0～ 6.5
Mortality	12.2 ±14.6	0.0～54.3	2.4±4.3	0.0～17.2
Illegal cut	1.0 ± 1.8	0.0～ 5.0	0.2±0.4	0.0～ 1.1
Commercial trees ≧ MDCL[b]				
Recruitment	0.3 ± 0.4	0.0～ 1.4	1.4±4.9	0.0～19.1
Mortality	0.1 ± 0.3	0.0～ 1.4	0.5±1.3	0.0～ 4.4
Illegal cut	0.03± 0.2	0.0～ 0.7	0.1±0.9	0.0～ 3.9

[a] SD: standard deviation
[b] MDCL: Minimum diameter cutting limit

al. (2004) compiled data for tree mortality in mature rain forests throughout the Amazon Basin, reporting mean values (±SE) of 2.30±0.14% per year (number of sample (n)=31) for mortality and 2.33±0.13% per year (n=32) for recruitment. PHILLIPS and GENTRY (1994) collected data from mature South East Asian rain forests, reporting mean values (±SD) of 1.72±0.70% per year (n=9) for mortality and 1.75±0.66% per year (n=9) for recruitment. SIST and NGUYEN-THÉ (2002) found that logging and yarding increase mortality in undisturbed primary at a rate of 1.5% per year.

Volume Increment

The mean (±SD) volume increment for all trees with DBH ≧ 10cm was 1.09±3.35m³/ha/year and that for commercial trees with DBH ≧ MDCL was 0.86±1.33m³/ha/year. The value for commercial trees (0.86m³/ha/year) was significantly greater ($P < 0.05$, one tailed one sample t-test) than the value (0.33m³/ha/year) presently used in Cambodia as the standard figure for the calculation of cutting level. However, the value for all trees with DBH ≧ 10cm (1.09m³/ha/year) was not significantly larger than 0.33m³/ha/year ($P > 0.05$, one tailed one sample t-test). The coefficient of variation for all trees among different plots was 300%.

Volume increment may change substantially depending on minimum threshold DBH used for measurements or calculations, monitoring length (VALLE *et al.*, 2006) and species (SILVA *et al.*, 1995). Therefore, data from the present study cannot be directly compared to other studies. Nevertheless, our mean values (1.09 and 0.86m³/ha/year) are well within the range between 0.5 and 2.0m³/ha/year reported from most tropics mixed forests (RICE *et al.*, 1998) and the ranges obtained from the Brazilian Amazon (VALLE *et al.*, 2006).

CONCLUSION

Information on forest stand dynamics is essential to ensure sustainable yield, and there are abundant data for tropical rain forests, especially those in mainland of Southeast Asia; however, there have been few reports on tropical seasonal evergreen forest. From the preliminary results presented here, we conclude:

1) While species richness and stocking level in terms of basal area are smaller in tropical seasonal forest than in tropical rain forest, tree density, recruitment, mortality and volume increment are similar.

2) The measured mean annual volume increment (0.86m³/ha/year) for commercial trees with DBH ≧ MDCL was significantly larger than the value (0.33m³/ha/year) that has been used in Cambodian management systems; however, this cannot be confirmed for the values for all trees with DBH ≧ 10cm.

Further data from longer periods and other locations are required to provide reliable estimates of sustainable yield to forest managers and planners.

ACKNOWLEDGEMENTS

We are grateful for H.E. Kimsun CHHENG, the General Director of Forestry Administration, who provides time to communicate with us for the successful data collections. We thank H.E. Sokhun TY, the former General Director of the Forestry Administration of Cambodia for his approval to research on this topic in order to use it in Cambodia and the FA Forest Officers assisted in tree enumerations. We appreciated our colleagues who played important roles to comments. We thank reviewers, who gave valuable comments and suggestions on the draft manuscript. This work was supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan.

LITERATURE CITED

BREWER, S. and WEBB, M.A.H., (2002): A seasonal evergreen forest in Belize: unusually high tree species richness for northern Central America. Botanical Journal of the Linnean Society. **138**: 275-296

BUNYAVEJCHEWIN, S., (1999): Structure and dynamics in seasonal dry evergreen forest in northern Thailand. Journal of Vegetation Science **10**: 787-792

CLARK, D.A. and CLARK, D.B., (1992): Life history diversity of canopy and emergent trees in a neotropical rain forest. Ecology Monographs. **62**: 315-344

CONNELL, J.H., TRACEY, J.G. and WEBB, L.J., (1984): Compensatory recruitment, growth and mortality as factors maintaining rain forest tree diversity. Ecology Monographs. **54**: 141-164

DAUBER, E., FREDERICKSEN, T.S. and PEÑA, M., (2005): Sustainability of timber harvesting in Bolivian tropical forests. Forest Ecology and Management. **214**: 294-304

de GRAAF, N.R., POELS, R.L.H. and VAN RAMPAEY, R.S.A.R., (1999): Effect of silvicultural treatment on growth and mortality of rainforest in Surinam over long periods. Forest Ecology and Management. **124**: 123-135

DFW (Department of Forestry and Wildlife), (2001): Forest Concession Management Planning Manual. Forest Administration, Phnom Penh, Cambodia

FA (Forestry Administration), (2003): Development of growth and yield studies and establishment of permanent sample plots. Project credit No. 3365-KH. Forestry Administration, Phnom Penh, Cambodia, pp. 132

FA (Forestry Administration), (2007): Cambodia: Forestry Statistics 2006: Planning and accounting Finance Office, Forestry Administration, Phnom Penh, Cambodia, pp. 80

KAMMESHEIDT, L., DAGANG, A.A., SCHWARZWALLER, W. and WEIDELT, H., (2003): Growth patterns of dipterocarps in treated and untreated plots. Forest Ecology and Management. **174**: 437-445

KIMPHAT, N., OUK, S., UOZUMI, Y. and UEKI, T., (1999): Forest management problems in Cambodia–a case study of forest management of F company. J. Jpn. For. Plan. **5**: 65-71

KUMAGAI, T., SAITOH, TM., SATO, Y., TAKAHASHI, H., MANFROI, OJ., MOROOKA, T., KURAJI, K., SUZUKI, M., YASUNARI, T. and KOMATSU, H., (2005): Annual water balance and seasonality of evapotranspiration in a Bornean tropical rainforest, Agricultural and Forest Meteorology. **128**: 81-92

KUMAGAI, T., YOSHIFUJI, N., TANAKA, N., SUZUKI, M. and KUME, T., (2009): Comparison of soil moisture dynamics between a tropical rain forest and a tropical seasonal forest in Southeast Asia: Impact of seasonal and year-to-year variations in rainfall. Water Resource Research. **45**: 1-14

LEWIS, S.L., PHILLIPS, O.L., BAKER, T.R., LLOYD, J., MALHI, Y., ALMEIDA, S., HIGUCHI, N., LAURANCE, W.F., NEILL, D.A., SILVA, J.N.M., TERBORGH, J., TORRES LEZAMA, A., VASQUEZ MARTINEZ, R., BROWN, S., CHAVE, J., KUEBLER, C., NUNEZ VARGAS, P. and VINCETI B., (2004): Concerted changes in tropical forest structure and dynamics: evidence from 50 South American long-term plots. The Royal Society. **359**: 421-436

LEWIS, S.L., PHILLIPS, O.L, SHEIL, D., VINCETI, B., BAKER, T.R., BROWN, S., GRAHAM, A.W., HIGUCHI, N., HILBERT, D.W., LAURANCE, W.F. LEJOLY, J., MALHI, Y., MONTEAGUDO, A., VARGAS, P.N, SONKE, B., SUPARDIM M.N., TERBORGH, J.W and MARTINEZ, R.V., (2004a) Tropical forest tree mortality, recruitment and turnover rates: calculation, interpretation and comparison when census intervals vary. Journal of Ecology. **92**: 929-944

MALHI, Y. and GRACE, J., (2000): Tropical forests and atmospheric carbon dioxide. Trends Ecol. Evol. **15**: 332-337

MYERS, N., MITTELMEIER, R.A., MITTELMEIER, C.G., DA FONSECA, G.A.B. and KENT, J., (2000): Biodiversity hotspots for conservation priorities. Nature. **493**: 853-858

PHILLIPS, O. L., BAKER, T. R., ARROYO, L., HIGUCHI, N., KILLEEN, T.J., LAURANCE, W.F., LEWIS, S.L., LLOYD, J., MALHI, Y., MONTEAGUDO, A., NEILL, D.A., VARGAS, P., SILVA, J.N.M., TERBORGH, J., VASQUEZ MARTINEZ, R., ALEXIADES, M., BROWN, S., CHAVEL, J., COMISKEY, J.A., CZIMCZIK, C.I., FIORE, A. DI., ERWIN, T., KUEBLER, C., LAURANCE, S.G., NASCIMENTO, H.E.M., OIVIER, J., PALACIOS, W., PATINO, S., PITMAN, N.C.A., QUESADA, C.A., SALDIAS, M., TORRES LEZAMA, A. and VINCETI, B., (2004): Pattern and process in Amazon tree turnover, 1976-2001. R. Soc. Lond. **359**: 381-407

PHILLIPS, O.L. and GENTRY, A.H., (1994): Increasing turnover through time in tropical forests. Science **263**: 954-958

PHILLIPS, P.D., YASMAN, I., BRASH, T.E. and van GARDINGEN, P.R., (2002): Grouping tree species for analysis of forest data in Kalimantan (Indonesia Boreno). Forest Ecology and Management. **157**: 205-216

RGC (Royal Government of Cambodia), (2005): Sub-degree No. 089. Minimum Diameter Cutting Limit (MDCL). Date 14 February 2005. Forestry Administration. Ministry of agriculture, forestry and fisheries, Phnom Penh, Cambodia. (In scientific and Khmer names by tax classes)

RICE, R.E., SUGAL, C.A., RATAY, S.M. and FONSECA, G.A.B., (1998): Sustainable forest management: a review of conventional wisdom. Adv. Appl. Biodiver. Sci. **3**: 1-29

SILVA, J.N.M., de CARVALHO, J.O.P., LOPES J. do, C., de ALMEIDA, B.F., COSTA, D.H.M., OLIVEIRA, L.C., VANCLAY, J.K. and SKOVSGAARD, J.P., (1995): Growth and yield of a tropical rain forest in Brazilian Amazon 13 years after logging. Forest Ecology and Management. **71**: 267-274

SIST, P. and FERREIRA, F.N., (2007): Sustainability of reduce-impact logging in Eastern Amazon. Forest Ecology and Management. **243**: 199-209

SIST, P. and NGUYEN-THÉ, N., (2002): Logging damage and the subsequent dynamics of a dipterocarp forest in East Kalimantan (1990-1996). Forest Ecology and Management. **165**: 1-3

SIST, P., PICARD, N. and GOURLET-FLEURY, S., (2003): Sustainable cutting cycle and yields in a lowland mixed dipterocarp forest of Borneo. Ann. For. Sci. **60**: 803-814

SIST P. and SARIDAN A., (1999): Stand structure and floristic composition of a primary lowland dipterocarp forest in East Kalimantan, J. Trop. For. Sci. **11**: 704-722

TOP, N., MIZOUE, N., ITO, S., KAI, S., NAKAO, T. and TY. S., (2009): Effects of population density on forest structure and species richness and diversity of trees in Kampong Thom Province, Cambodia. Biodivers Conserv. **18**: 717-738

VALLE, D., SCHULZE, M., VIDAL, E., GROGAN, J. and SALES, M., (2006): Identifying bias in stand level growth and yield estimations: a case study in eastern Brazilian Amazonia. Forest Ecology and Management. **236**: 127-135

van GARDINGEN, P.R., MCLEISH, M.J., PHILLIPS, P.D., FADILAH, D., TYRIE, G. and YASMAN, I., (2003): Financial and ecological analysis of management options for logged-over Dipterocarp forests in Indonesian Borneo. Forest Ecology and Management. **183**: 1-29

van GARDINGEN, P.R., VALLE, D. and THOMPSON, I., (2006): Evaluation of yield regulation options for primary forest in Tapajo's National Forest, Brazil. Forest Ecology and Management. **231**: 183-195

(Received 15 June 2010)
(Accepted 2 August 2010)

GUIDE FOR CONTRIBUTORS

Please refer to the following guidelines when submitting a new manuscript to the JOURNAL OF FOREST PLANNING ("the *Journal*"), of the Japan Society of Forest Planning ("the *Society*"), so that your manuscript may be handled expeditiously.

Type of Papers: Each paper is classified into one of three types: article, review, or short communication. A paper should be a report of original research that has not been submitted elsewhere (other than as an abstract).

Contributors: The first author of a paper of any type should be a member of the *Society* unless he/she is invited by Chief Editor. The authors can apply for memberships on submission.

Copyright: The *Society* reserves all rights to the papers for the *Journal*. Written permission by the Chief Editor is required for reproduction or republication.

Decision for Publication: The Editorial Board makes the decision to accept, reject, or suggest corrections of a manuscript in accordance with the results of reviews by knowledgeable referees selected by the Editorial Board.

Manuscript: Manuscripts should be written in English in line with the guidelines in "Manuscripts Preparetion" below. For the sake of prompt manuscript handling, authors are highly encouraged to provide an electronic manuscript as well as the printed ones.

English: All authors whose first language is *not* English should ask a native speaker to refine the written English before submission.

Final Manuscript and Authors' Corrections: When the manuscript is accepted, the authors will be asked to send the final manuscript in both printed and electronic forms. The required formats will be indicated in the final manuscript instruction. The author's proof will be sent only once for misprint corrections.

Expenses on Publication: Authors will be charged the following items on publication of the paper.

- Page charge: ¥6,000 per printed page
- Color pages/special printings: actual expense
- Reprints (exceeding 50 copies): ¥20,000/50 copies
- Annual membership (for authors without membership):

(All prices are subject to change.)

Submission and Inquiry: One original copy and one complete photocopy of the manuscript, and a submission form should be sent to Chief Editor, whose address can be found on the inside cover of the *Journal*. An electronic file of the abstract in text format on a floppy diskette or a CD should be attached if available. Inquiries about submission may also be sent to the Chief Editor.

Manuscripts Preparation

Style: A manuscript should be arranged as follows: (1) Title of paper, authors' full names and affiliations with addresses, (2) Abstract, (3) Keywords (no more than five), (4) Main Text, (5) Literature cited, (6) Figures and tables, (7) Messages to Editors.

Typing: Manuscripts should be typewritten, double-spaced on one side of A4 (or Letter size) white paper with margins of 3cm on top, bottom and both sides. The desired location of tables and figures should be indicated in the text with red ink in the right margins.

Text Style: Text to be printed in *italic*, **bold** and SMALL CAPITAL fonts should be indicated by single, wavy and double underlines, respectively.

Abstract: An abstract is required for any type of papers, and should be no more than 500 words.

Literature Cited: Literature cited should be listed alphabetically by first author's surname (family name). For the style, consult the examples given below. Literature in the text may be cited by author's surname and year of publication in parentheses after the statement concerned. If there are more than two authors, citations should quote the surname of the first author and the words "*et al.*". All author's names should be included in the list.

a. For periodicals: YAMAMOTO, N. and SASAKI, S.,(1976): Electron microscope study on polysome formation during pine seed germination. J. Jpn. For. Soc. 58: 65-66
b. For books: LEVITT, J., (1972): Responses of plants to environmental stresses. Academic Press, New York & London, 697pp
c. For edited books: GADOW, K. v., (2005): Science-based forest design and analysis. In: Naito K. (eds) The role of forests for coming generations. Jpn. Soc. For. Plan. Press, Utsunomiya: 1-19
d. For Internet resources: McGAUGHEY, R. J., (1999): SVS - Stand Visualization System. USDA Forest Service, Pacific Northwest Research Station. http://faculty.washington.edu/mcgoy/svs.html (accessed on Feb.14, 2009)

Tables: Tables must be numbered with Arabic numerals according to their sequence in the text (Table 1, Table 2 etc.). Each table should be prepared on a separate sheet. Each table should have a brief and self-explanatory title. Any explanation for tables should be given as a footnote at the bottom of the table.

Figures: Figures must be numberd with Arabic numerals according to their sequence in the text. Each figure should be prepared on a separate sheet. Each figure's legend should be prepared on another separate sheet. Figures should be of publication quality. Color figures can be included for an extra printing charge. A figure for color printing should be indicated by a note, "COLOR", on the margin of the sheet.

Submission Form: The submission form should be filled out and attached to the manuscript on submission. The form can be found at the last page of the *Journal*. Non-member authors can apply for memberships of the Society at the time of submitting their paper by enclosing the application form, which can be found on the inside of the back cover of the *Journal*.

Text File: The abstract should be saved as a text file on a 3.5" floppy diskette or a CD. The file should be arranged as follows: (1) Title of paper, authors' full names and affiliations with addresses, (2) Abstract. The 3.5" floppy diskette should be an MS-DOS formatted. The file name should be the prefix "a_ (underscore)" followed by the surname of the first author, and then the suffix ".txt" (e.g. "a_koshika.txt"). The title and authors of the manuscript should be noted on the surface label of the diskette or the surface of the CD.

(May, 2001)
(revised September, 2002)
(revised February, 2009)

JOURNAL OF FOREST PLANNING
Submission Form

1 . Date of submission: ____________

2 . Name of author(s): ____________

____

3 . Title of manuscript: ____________

____

4 . Correspoding author: ____________

5 . Affiliated institution: ____________

6 . Mailing address: ____________

____

Telephone: ____________ Fax: ____________

E-mail: ____________

Maililng address in Japanese (if available): ____________
（確実に郵送できるように送付先を研究室名等までお書きください）

____

____

7 . Classification of manuscript*: ☐ article ☐ review ☐ short communication
*Plaese tick one of the boxes.

8 . Number of pages including abstracts: ____________

9 . Number of tables: ____________ Number of figures: ____________

10. Necessary number of reprints: ____________

11. Please tick either which apply:
☐ The written English has been proofread by a native speaker.
☐ I am from an English-speaking country.

Filled by the Editorial Board

受付番号 ____________

受付日 ____________ 受理日 ____________

Japan Society of Forest Planning
Membership Application Form
(for a person who lives outside Japan)

To join the "Japan Society of Forest Planning", please copy and fill out this membership application form and send it to secretary of the Japan Society of Forest Planning.

An individual membership fee for one year (from March to next February) is ¥2,500 and member of this society can receive Journal of Forest Planning (2 issues/year). Organization membership fee is ¥2,500 for each issue of Journal of Forest Planning.

(Please Print or Type Clearly)

Name: (Last) ________ (First) ________ (Middle) ________

Company/Organization: ________

Street/P.O.: ________

City: ________ State: ________ Zip: ________ Country: ________

Phone: ________ Fax: ________ E-Mail: ________

Type of Membership:

Outside Japan

- ☐ Individual ¥2,500/year
- ☐ Organization ¥2,500/issue

In Japan

- ☐ Individual ¥8,000/year
- ☐ Individual (student) ¥2,000/year
- ☐ Organization ¥2,500/issue

Payment:

☐ Bank Transfer

Saitama Resona Bank, Limited
SWIFT: SAIBJPJT
Branch code: 584
Branch Address: 4-6 Motomachi, Chiichibu city, Saitama pref. JAPAN 368-0044
Account No. : 4449008
Account Name : Shinrinkeikakugakkai daihyousha Fujiwara Akio

This form should be sent to : The Japen Society of Forest Planning
Research Division, University Forests
Graduate School of Agricultural and Life Sciences,
The University of Tokyo
1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657 Japan
Fax; +81-3-5841-5494

Japan Society of Forest Planning