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Article

Monitoring Deforestation and Forest Degradation in the Bago Mountain Area, Myanmar using FCD Mapper

Myat Su Mon[*1], Tsuyoshi Kajisa[*2], Nobuya Mizoue[*2] and Shigejiro Yoshida[*2]

ABSTRACT

While deforestation in the tropics has been well mapped, there is little information on the extent and changes of forest degradation. This study aimed to investigate temporal and spatial patterns of both deforestation and forest degradation in three reserved forests of the central Bago mountain ranges, Myanmar, which have a long history of selective logging activities. We used Forest Canopy Density (FCD) Mapper and Landsat images (1989, 1999, 2003, and 2006) for the investigation. Over 17 years, more than 90% of the total area was kept as forests, defined as FCD ≥ 10%, but closed canopy forests (FCD ≥ 70%) greatly decreased from 98% to 53% of the total area. Medium canopy forests (40% ≤ FCD < 70%) and open canopy forests (10% ≤ FCD < 40%) increased. Gross forest degradation (change to lower FCD) was much larger than gross forest improvement (change to higher FCD) for all sites and periods, whereas differences in gross deforestation (forest to non-forest) and gross reforestation (non-forest to forest) were relatively small. As a result, a high annual net forest degradation rate of 2.5% was observed, although the annual net deforestation rate was relatively low at 0.2% between 1989 and 2006. Our findings on higher forest degradation throw the question about the sustainability of current harvesting levels of selective logging and/or extraction of non-wood forest products and shifting cultivation by local communities if no conservation or remedial measures are taken. This study revealed the importance of monitoring deforestation and forest degradation as well as the usefulness of the FCD Mapper.

Keywords: FCD Mapper, Landsat images, deforestation, forest degradation, reforestation, forest improvement

INTRODUCTION

Tropical forests are critical to the balance of economical, ecological, and environmental factors on our planet because of their high diversity. However, forests in the tropics are depleting at an alarming rate, thus leading to forest degradation and deforestation that have been threatening future sustainability (Verolme *et al.*, 1999; Rudel and Roper, 1997; Laurance, 1999, 2007; Panta *et al.*, 2008). Therefore, identifying forest degradation and deforestation at different spatial and temporal scales could provide useful information for planning and sustainable management of forests (Panta *et al.*, 2008)

Deforestation is loss of forest cover by conversion of forests to other land cover types (FAO, 2000, 2005); it can be relatively easily identified. However, identifying forest degradation, i.e., reduction in capacity of a forest or canopy cover and stocking within the forest to provide goods and services (FAO, 2000, 2005), is a subtle process (Souza Jr *et al.*, 2003; Panta *et al.*, 2008). Forest degradation also represents loss of various environmental functions of the forest, thus being similar to deforestation. While deforestation has been widely emphasized and analyzed in a large number of studies

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using satellite remote sensing (ARMENTERAS *et al.*, 2006; LELE and JOSHI, 2008; PUYRAVAUD, 2003), the extent and rate of forest degradation have not been well documented (SUNDERLIN and RESOSUDARMO, 1996; SOUZA *et al.*, 2003; JOSHI *et al.*, 2006; PANTA *et al.*, 2008).

Remotely sensed estimation of forest canopy density (FCD) has been used to assess the level of forest degradation (TIWARI *et al.*, 1986; PRINCE, 1987; RINGROSE and MATHESON, 1986; FORD and CASEY, 1988; KLEINN, 2001; HADI *et al.*, 2004; JOSHI *et al.*, 2006; PANTA, 2008). Measuring the extent of forest degradation is much more difficult than measuring deforestation (DEFIRES *et al.*, 2007). FCD Mapper (RIKIMARU, 1996) is one of the methods used to quantify FCD as a continuous variable from 0 to 100% (JOSHI *et al.*, 2006). The results of FCD mapping give the stratification of forest cover and therefore outputs is reliable to assess both forest degradation and deforestation. The main advantage of using FCD Mapper is to eliminate the need to undertake time consuming of field measurement of FCD using densitometer or hemispherical photograph (RIKIMARU *et al.*, 2002; CHANDRASHEKHAR *et al.*, 2005; BAYNES, 2007; AZIZI *et al.*, 2008), which is necessary in other remote sensing (RS) technologies, such as artificial neural network, multiple linear regression and maximum likelihood classification method. Although FCD Mapper has been applied in different forest types in tropical regions, very few studies have attempted to monitor changes in forest degradation status using FCD Mapper (PANTA, 2003; ROY, 2004; JAMALABAD, 2004).

Myanmar still has the largest forest cover, almost 50% of the total land area, in mainland Southeast Asia (FAO, 2005). These forests are important sources of biodiversity. Myanmar will face serious problems in the very near future because of its high deforestation rate, i.e., 1.3% per year for 1990–2000 and 1.4% per year for 2000–2005 (FAO, 2005). Forest cover assessment in Myanmar has been mainly based on combined use of RS, geographical information systems (GIS), and ground forest inventory on national and regional scales. LEIMGRUBER *et al.* (2005) performed estimation of forest cover and focused on deforestation assessment throughout the country. However, there is dearth of detail and updated assessment on forest degradation, which makes it difficult for resource planners and decision-makers to implement effective conservation strategies for the remaining forest resources. This study aims to evaluate spatial and temporal patterns of forest degradation and deforestation, using the FCD Mapper and multi-temporal Landsat images in three reserved forests of the central Bago mountain ranges, Myanmar.

MATERIALS AND METHODS

Study Site

The study site was the central region of the Bago mountain ranges consisting of three reserved forests (RFs), namely Khapaung, Middle Nawin, and South Nawin RFs, covering an area of 1,074km². The Bago mountain ranges located in the central part of lower Myanmar (Fig. 1), running from north to south, have renowned natural teak (*Tectona*

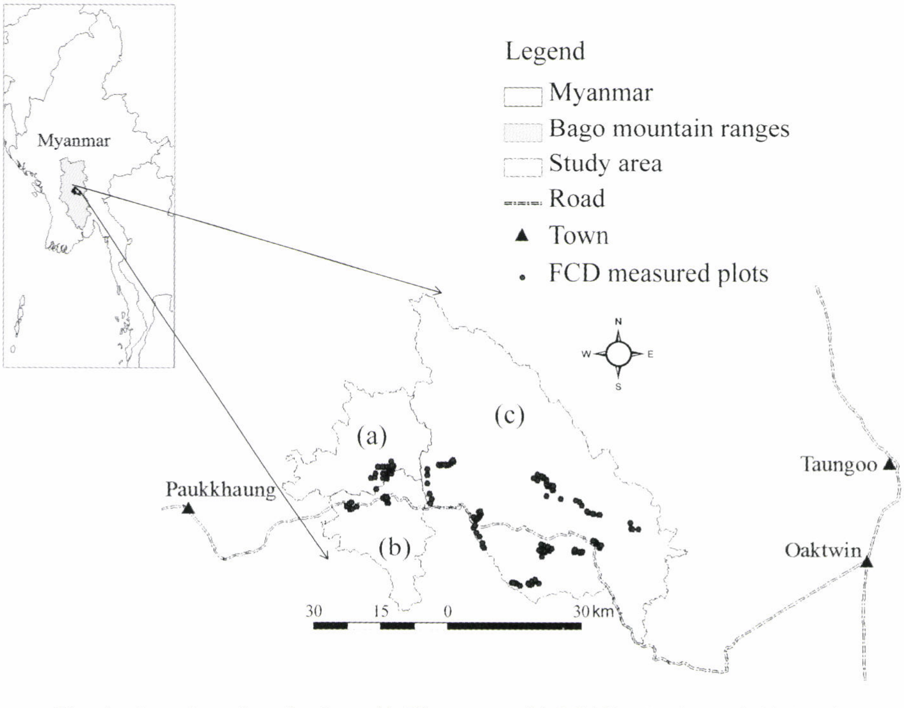

Fig. 1 Location of study sites: (a) Khapaung, (b) Middle Nawin, and (c) South Nawin reserved forests and sample plots measured FCD

grandis) bearing forests. Altitude ranges from 90 to 600m above sea level. The study areas mainly had an eastern or a western aspect. Occurrence of rainfall varies in intensity, depending upon the time of year; it is different between regions. According to some of the nearest meteorological stations, average annual rainfall was 1,917mm for eastern parts and 1,009mm for western parts during 1995 and 2006. Alluvial, red- brown forest soil and lateritic soil are common in the three RFs. Forest type occurred in the study area was commonly mixed deciduous forests, which are by far the most important forests in Myanmar. Under mixed deciduous forest types, moist upper mixed deciduous forest (MUMD) and dry upper mixed deciduous forest (DUMD) are widely distributed depending upon topography of the area. MUMD is characterized by the presence of bamboos, *Bambusa polymorpha* and *Cephalostachyum pergracile*. This forest type occurs on well-grained slopes and good quality soil. These forests contain the finest teak (*T. grandis*), usually associated with pyinkado (*Xylia xylocarpa*) and *Dipterocarpus* species. DUMD is characterized by the presence of bamboo *Dendrocalamus strictus* and occurs on ridge tops and hot aspects. *Bambusa tulda* is also found in stiff soil type of DUMD (Kermode, 1964). Characteristic tree species of DUMD are very similar to that of MUMD. Economically important species such as teak (*T. grandis*), pyinkado (*X. xylocarpa*), padauk (*Pterocarpus macrocarpus*), taukkyan (*Terminalia tomentosa*), thitya (*Shorea oblongifolia*), and ingyin (*Pentacme siamensis*) are growing in two forest types of the study area.

Three RFs have been systematically managed under the selective logging system for teak and other hardwoods, known as the Myanmar Selection System (MSS). Under the MSS, a felling series is divided into 30 blocks of approximately equal yield capacity. Selective logging is carried out in one of these blocks every year and the whole forest is therefore worked over in the felling cycle of 30 years (Dah, 2004). Since forestry sector plays an important role in socio-economic development of the nation, increasing population and growing demand for timber, the study area was under shorter felling cycle (less than 30 years felling cycle) and subjected to repeated logging activities (Brunner *et al.*, 1998; Forest Department, 1995a, 1995b, 2006a, 2006b). Land use history of shifting cultivation practiced by local communities with fallow periods over a 10-year rotation was also observed (Takeda *et al.*, 2005).

There is only one main road that passes through three RFs and joins two towns, namely Okktwin, Taungoo district and Paukkhaung of Pyay district (Fig 1). Although the road condition is relatively good in Middle Nawin and South Nawin RFs, some parts are still under construction in Khapaung RF until 2009. Others are logging roads and that are especially used during summer for logging extraction purpose. The periphery of the study area was more likely to face forest depletion because of its location surrounded by a densely populated area, easily access, fertile soil for agriculture, and rich supplies of timber and bamboo (Htun and Myint, 2002; Thein *et al.*, 2007).

Over the last three decades, commercial forest plantations have been established in the three RFs. However, some older plantations in the Khapaung RF have already been exploited because of the construction of the Khapaung dam. In 2004, the Ministry of Forestry implemented a special afforestation project called the Bago Yoma Greening Project with the aim of conserving and protecting the remaining forest resources.

Procedures of FCD Mapper

The FCD Mapper, a semi-expert system was developed by the International Tropical Timber Organization and Japan Overseas Forestry Consultants Association and it produces FCD with the range of 0 to 100% (Rikimaru, 1996; Rikimaru and Miyatake, 1997). This comprises biophysical phenomenon modeling and analysis, utilizing data derived from four indices:

I. vegetation index (VI), selected from the normalized difference vegetation index (NDVI), advanced vegetation index (AVI) or advanced normalized vegetation index (ANVI),
II. bare soil index (BSI),
III. shadow index (SI), and
IV. thermal index (TI).

These four indices are calculated as new images from the raw Landsat bands 1-7. Based on the indices, FCD Mapper calculates a vegetation density (VD) which includes grassland and forest but excludes bare soil. Grass land is then separated from forest using a scaled shadow index (SSI) and finally FCD is calculated for each pixel of forested land. FCD Mapper produces these indices and integrates them into an FCD as an index ranging from 0 to 100 for each pixel of the final FCD image. The relevant formula and algorithms used in FCD Mapper are shown in Table 1.

The underlying principle for each of the above four main indices is that the VI has a positive relationship with the quantity of vegetation and therefore VI increases from grassland to forest. If there is more tree vegetation, there is more shadow and SI also increases as the forest density increases. If there is less bare soil or lower BSI, there will be a corresponding decrease in the TI. TI decreases as the vegetation quantity increases, i.e. TI is less inside the canopy of a forest due to blocking and absorption of the sun's rays and because of the cooling effect of evaporation from leaves.

Detailed methodology of FCD mapping is mentioned by Rikimaru (1996), Roy *et al.* (1997), Rikimaru *et al.* (2002), and Chandrashekhar (2005) and the FCD Mapper ver.2 user guide. Outputs of the FCD Mapper was then exported to ArcGIS 9.2 (ESRI Inc, USA) environments and used as a grid system of 30m × 30m for GIS analysis.

Table 1 Formula and algorithms used to calculate indices in FCD Mapper

Indices	Formula and algorithms
NDVI	= (Band 4 − Band 3) / (Band 4 + Band 3)
AVI	= [Band 4 × (256 − Band 3) × (Band 4 − Band 3) + 1]$^{1/3}$, (Band 4 − Band 3) > 0
ANVI	This index is synthesized index from NDVI and AVI by principal component analysis.
BSI	= [((Band 5 + Band 3) − (Band 1 + Band 4))/ ((Band 5 + Band 3) + (Band 1 + Band 4))] × 100 + 100
SI	= [(256 − Band 1) × (256 − Band 2) × (256 − Band 3)]$^{1/3}$
TI	This index is calibrated from the value of thermal band.
VD	This index is calculated from the first principal component of VI and BSI.
SSI	This index is calibrated shadow index for the forested land.
FCD	= (VD × SSI + 1)$^{1/2}$ − 1

notes: NDVI: normalized different vegetation index; AVI: advanced vegetation index; ANVI: advanced normalized vegetation index; BSI: bare soil index; SI: shadow index; TI: thermal index; VD: vegetation density; SSI: scaled shadow index; FCD: forest canopy density %

Table 2 Images used for FCD assessment

No.	Year	Acquisition date	Satellites
1	1989	16-01-1989	Landsat TM
2	1999	30-12-1999	Landsat ETM +
3	2003	23-01-2003	Landsat ETM +
4	2006	15-01-2006	Landsat ETM +

Data Sources

Seven bands of Landsat data sets were taken as inputs for the FCD Mapper. This study used 133-47 Landsat TM for 1989 and Landsat ETM+ for 1999, 2003, and 2006 (Table 2). Wavelength and characteristics between Landsat TM and ETM+ are almost the same. Jamalabad and Abar (2004), Roy (2004) and Chandrashekhar *et al.*, (2005) also applied Landsat TM and ETM+ in FCD mapping and used the outputs to study the change detection of forest cover.

Data acquisition date is an important factor when using the FCD Mapper (Roy, 2004) because it models shadow, bare-soil and thermal indices for canopy cover estimation. To avoid seasonal variation in forest cover assessment, we selected four Landsat data sets that were acquired during the same season. It is extremely difficult to obtain images with the same acquisition date within the growing season of the study area, particularly in tropical regions where cloud cover is common (Mas, 1999). However, the data sets used in this study were acquired before leaf-off season, and these can provide effective results in estimating FCD.

The Landsat TM image of 1989 was geo-referenced using topographic maps of scale 1:63360, published in 1945 by the Survey Department of Myanmar. Landsat images of 1999, 2003, and 2006 were geo-referenced using an image-to-image registration method where the 1989 image was taken as the master image and the root mean square error was 0.005 pixels. Image preparation was conducted in ERDAS IMAGINE®9.1 (Leica Geosystems Geospatial Imaging, USA) before FCD mapping.

Assessment of Forest Cover Dynamics

Following the forest definition of FAO (FAO, 2000, 2005), we classified land into non-forest (NF) if FCD < 10% and forest if FCD ≥ 10% based on outputs of FCD mapping. Based on Uryu *et al.* (2008), forests were classified into the following three categories for analysis of change detection matrices: open canopy forests (OCFs; 10% ≤ FCD < 40%), medium canopy forests (MCFs; 40% ≤ FCD < 70%), and closed canopy forests (CCFs; FCD ≥ 70%). To analyze and to detect spatial and temporal patterns of forest distribution, we compared the results between three RFs over different periods: 1989–1999, 1999–2003, 2003–2006, and 1989–2006. Table 3 shows the definitions and rules applied in estimating net deforestation and net forest degradation of the study area.

Accuracy Assessment

Ground data was collected from August to October 2007 and January to February 2009 to coincide with the growing season of forest vegetation and acquisition of images. A purely random sampling design was applied to establish sample plots. Precise locations of the sample plots were recorded using

Table 3 Definitions and rules to calculate deforestation and forest degradation

Change types	Definition and calculation of changes
Gross deforestation	complete conversion of forest to non-forest, i.e., total number of pixels changed from CCF, MCF, and OCF to NF
Gross reforestation	re-establishment of forest from non-forest (PERALTA and MATHER, 2000; NAGENDRA *et al.*, 2006), i.e., total number of pixels converted from NF to OCF, MCF, and CCF
Net deforestation	gross deforestation – gross reforestation
Gross forest degradation	any change to lower FCD within a forest (SAXENA *et al.*, 1997; URYU *et al.*, 2008), i.e., total number of pixels converted from CCF to MCF or OCF as well as MCF to OCF
Gross forest improvement	any change to higher FCD within a forest, i.e., total number of pixels converted from OCF to MCF or CCF as well as MCF to CCF
Net forest degradation	gross forest degradation – gross forest improvement
Annual rate of net deforestation (%)	$\frac{\text{net deforestation}}{\text{total forest areas at initial year of assessment}} \times \frac{1}{\text{assessment periods}} \times 100$
Annual rate of net forest degradation (%)	$\frac{\text{net forest degradation}}{\text{total forest areas at initial year of assessment}} \times \frac{1}{\text{assessment periods}} \times 100$

notes: NF: non-forest; OCF: open canopy forest; MCF: medium canopy forest; CCF: closed canopy forest

Table 4 Error matrix for measured and estimated classes of forest cover

		Measured					
		NF	OCF	MCF	CCF	Total	User's accuracy (%)
	NF	**4**	2	0	0	6	67
Estimated	OCF	0	**10**	7	0	17	59
	MCF	0	2	**22**	11	35	63
	CCF	0	2	9	**102**	113	90
	Total	4	16	38	113	**171**	
Producer's accuracy (%)		100	63	58	90		
Overall accuracy (%)		81					
Kappa coefficient		0.62					

notes: NF: non-forest; OCF: open canopy forest; MCF: medium canopy forest; CCF: closed canopy forest

GPSMAP® 60CSx (Garmin Ltd, USA) in a Universal Transverse Mercator coordinate system with common datum of World Geodetic System 84. Canopy density was measured at five points, i.e., four corners and the center of each plots (30m × 30m, 171 points) (Fig. 1), using a convex densiometer (Forestry Suppliers Inc, USA). Mean canopy density of each plot was calculated for accuracy assessment. Overall mapping accuracy was evaluated by scatter plot and an error matrix between measured and estimated FCD.

RESULTS

Accuracy of FCD Mapping

Fig. 2 shows the relationship between FCD measured using a convex densiometer in the field and FCD estimated using FCD Mapper with $R^2 = 0.81$. The error matrix of measured and estimated classes of forest cover (Table 4) shows the accuracy of the FCD Mapper in classifying forest cover, i.e., 138 of 171 observations were correctly classified with an overall accuracy of 81% and a kappa coefficient of 0.62.

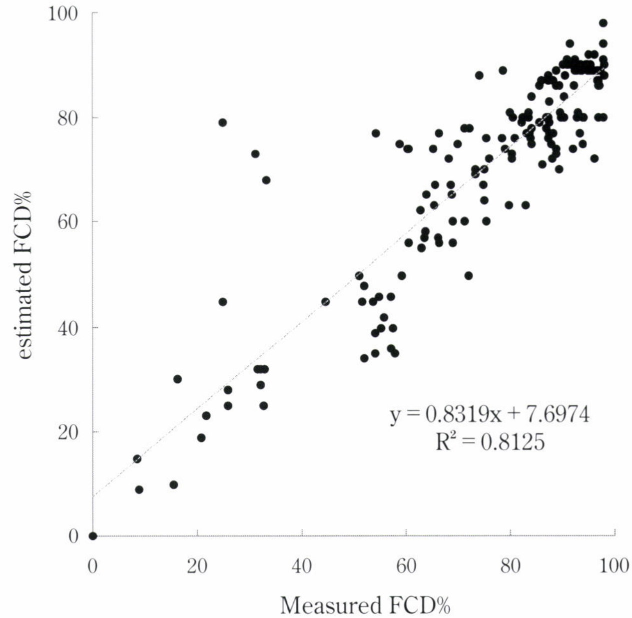

Fig. 2 Scatter plot of measured and estimated FCD%

Forest Cover Change

Fig. 3 shows spatial distribution of four classes of forest cover in each year, and Table 5 indicates percentages of forest cover classes for three RFs. In 1989, almost all land (98%) of the three RFs was covered with CCF, whereas NF comprised only 1% of the total area. Forest cover changes were more prominent in the Middle and South Nawin RFs compared to the Khapaung RF. In the former two RFs, CCF largely decreased to around 30% between 2003 and 2006, whereas MCF increased from 1% to approximately 60% between 1989 and 2006. On the other hand, Khapaung maintained a relatively high percentage of CCF (62%) in 2006, whereas the percentage of MCF was 30%. Changes in NF were relatively

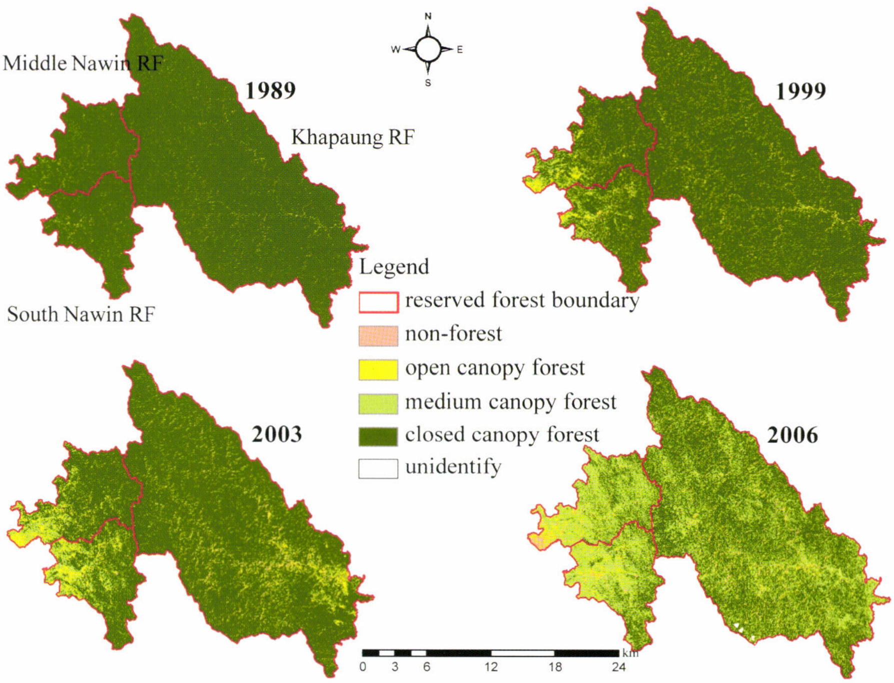

Fig. 3 Forest cover classified by FCD of three RFs for 1989, 1999, 2003, and 2006

Table 5 Percentage of four forest cover types in each year

Study sites	Year	NF (%)	OCF (%)	MCF (%)	CCF (%)
Khapaung	1989	1.0	0.3	0.6	98.1
	1999	1.8	2.8	2.2	93.1
	2003	2.3	3.8	4.5	89.4
	2006	3.8	3.7	30.5	62.1
Middle Nawin	1989	0.8	0.4	1.0	97.8
	1999	1.6	7.5	10.9	80.0
	2003	1.4	9.0	14.8	74.8
	2006	7.2	8.0	58.5	26.2
South Nawin	1989	1.1	0.5	1.2	97.2
	1999	2.3	7.5	9.8	80.5
	2003	1.7	10.7	20.2	67.3
	2006	6.0	7.8	55.6	30.7
Total	1989	1.0	0.3	0.7	98.0
	1999	1.9	4.1	4.5	89.5
	2003	2.1	5.5	8.1	84.3
	2006	4.6	4.9	38.0	52.6

notes: NF: non-forest; OCF: open canopy forest; MCF: medium canopy forest; CCF: closed canopy forest small in all three RFs with a percentage of much less than 10% in 2006. Among different periods, changes during the latest period, i.e., from 2003 to 2006, were the most prominent.

Since each forest cover map has four classes, sixteen different classes were involved in change detection matrix. They were categorized into five groups: no change, gross forest degradation, gross deforestation, gross reforestation, and gross forest improvement. Table 6 shows percentages of five categories of forest cover change for each RF and period. Among the three RFs, the Khapaung RF had a larger number of no change areas and less gross forest degradation. For all RFs and periods, gross degradation was always much higher than gross forest improvement, thus resulting in net forest degradation; differences between them were larger in later periods. Gross deforestation was also larger than gross reforestation in most cases, thus resulting in net deforestation, except for the period 1999–2003 in the Middle and South Nawin RFs. It should be noted that gross degradation was much larger than gross deforestation in all periods and RFs.

Tables 7 and 8 show annual net deforestation and forest degradation, respectively. The highest deforestation rate of 1.96% occurred in the Middle Nawin RF during the period 2003–2006, followed by that of 1.45% in the South Nawin RF. As expected from Table 6, there were two cases of negative net deforestation rates, i.e., net deforestation in the 1999–2003 periods. Forest degradation rates were always much higher than deforestation rates; the highest forest degradation rates were found in the latest period of 2003–2006, with a maximum forest degradation rate of 16%.

Table 6 Percentage of forest cover change types for four periods

Study sites	Periods	No change (%)	Gross forest degradation (%)	Gross deforestation (%)	Gross forest improvement (%)	Gross reforestation (%)
Khapaung	1989–1999	92.5	4.7	1.6	0.5	0.7
	1999–2003	86.8	6.7	1.8	3.4	1.3
	2003–2006	65.1	27.7	3.0	3.6	0.6
	1989–2006	62.7	33.7	3.1	0.2	0.3
Middle Nawin	1989–1999	79.2	17.9	1.5	0.8	0.6
	1999–2003	74.6	14.4	1.1	8.6	1.3
	2003–2006	38.1	49.0	7.7	4.7	0.5
	1989–2006	27.0	65.7	6.8	0.2	0.3
South Nawin	1989–1999	79.6	16.6	2	0.9	0.9
	1999–2003	68.5	21.1	1.2	7.4	1.8
	2003–2006	48.7	37.8	5.9	7.2	0.4
	1989–2006	31.4	62.2	5.4	0.5	0.5
Total	1989–1999	88.8	8.3	1.6	0.6	0.7
	1999–2003	82.5	9.7	1.6	4.7	1.5
	2003–2006	58.9	32.2	4.1	4.2	0.6
	1989–2006	53.2	42.2	4.0	0.2	0.4

Table 7 Annual net deforestation rate (%) of three reserved forests

Study sites	1989–1999	1999–2003	2003–2006	1989–2006
Khapaung	0.08	0.12	0.50	0.17
Middle Nawin	0.08	−0.05	1.96	0.38
South Nawin	0.12	−0.14	1.45	0.29
Total	0.09	0.06	0.85	0.21

Table 8 Annual net forest degradation rate (%) of three reserved forests

Study sites	1989–1999	1999–2003	2003–2006	1989–2006
Khapaung	0.42	0.82	8.96	1.99
Middle Nawin	1.72	1.47	16.10	3.88
South Nawin	1.58	3.51	11.35	3.66
Total	0.76	1.27	10.35	2.50

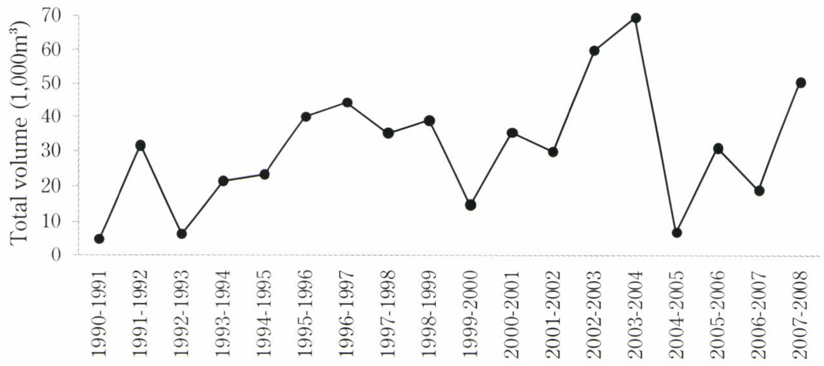

Fig. 4 Total exploited timber volume (1,000m^3) from three RFs (1990–2007)

DISCUSSION

The FCD Mapper was designed for foresters and resource managers to easily collect information on forest canopy with reducing costs and saving time (Rikimaru *et al.*, 1997). In the other words, FCD Mapper eliminates large amount of ground data which are not always easily available. This study demonstrated to detect forest cover change, deforestation, and forest degradation using FCD Mapper. This study achieved an overall mapping accuracy of 81%, which is an acceptable level of FCD mapping in comparison to other studies [71% (Panta, 2003) and 50% (Joshi *et al.*, 2006) in Nepal, 83% (Jamalabad and Abar, 2004) and 84% (Azizi *et al.*, 2008) in Iran, and 80% in India (Chandrashekhar *et al.*, 2005)]. Performance of the FCD Mapper in forest cover assessment provided satisfactory accuracy, thus showing that it can be used to assess forest degradation as well as deforestation.

During the 17-year period, the three RFs maintained a high percentage of forest cover (more than 90%) and the annual net deforestation rate was 0.2% in total, thus being much smaller than the 1.3% or 1.4% values estimated by the FAO (2005) and similar to the estimate (0.3%) by Leimgruber *et al.* (2005). On the other hand, we found that a high degree of forest degradation occurred in all study sites, with an annual net degradation of 2.5% in total. The high percentage of CCF in 1989 gradually decreased in all areas, whereas MCF significantly increased. These findings imply that forest degradation may be more problematic than deforestation in the study sites.

We found that there were differences in deforestation and forest degradation among different RFs and periods. Among the three RFs, forest degradation was larger in the Middle and South Nawin RFs for all periods. As mention in study area, one reason might be because the two RFs are more accessible in terms of road conditions and distance from the road and human settlements in compare with Khapaung RF (Fig. 1). These RFs are therefore more susceptible to fuelwood collection and encroachment by surrounding communities. Among different periods, forest degradation was very rapid during 2003–2006, i.e., 10% in total. Changes in the harvesting volume could be one of the reasons for this. According to records of timber exploitation over 10 years, exploited timber volume was highest during 2003–2004 (Fig. 4). Accordingly, conservation activities including checking annual allowable cuts for selective logging activities for each management unit should be implemented based on updated inventory data, and enrichment planting should be conducted for open and degraded forest areas.

The Bago mountain ranges have been managed for timber production and non-wood forest products (NWFPs) by the Forest Department (Forest Department, 2006a, 2006b). Sustainable forest management for long-term benefit was attempted in the forestry sector by introduction of a rehabilitation project, the Bago Yoma Greening Project (Forest Department, 2004). In this project, both silvicultural treatments in natural forests and socio-economic development were considered in promotion of conservation activities. Assessment and monitoring of forest cover changes using remote sensing data with FCD Mapper as demonstrated in this study will be useful to evaluate and improve effectiveness of this kind of conservation activities.

CONCLUSION

We found that the FCD Mapper is useful technique for monitoring and assessing deforestation and forest degradation, which are significant problems in planning and implementation of sustainable forest management. The study area still had a large percentage of forest area, more than 90% of the total area, over the 17 years considered. However, gross forest degradation was much larger than gross forest improvement, thus resulting in high net forest degradation, especially in recent years. These findings call for conservation activities to improve current land use practices, such as commercial logging and shifting cultivation practices in the study area. This study provides baseline information related to dynamics of forest cover. Future studies should be conducted to identify factors causing deforestation and forest degradation, and find remedial measures for future sustainable forest management.

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Article

Positional Accuracy of National Forest Inventory Plots in Japan

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ABSTRACT

In most countries, the positional accuracy of National Forest Inventory (NFI) plots is unknown, even though the NFI is expected to provide geo-referenced ground data for remote sensing. The present study evaluated the positional error of Japanese NFI plots that had already been located using a Global Positioning System (GPS) for navigational assistance toward target coordinates on a 4-km grid. The actual positions of 82 plots in 4 prefectures were measured using a high-precision GPS with dual-frequency carrier-phase observation in comparison with the target coordinates. The positional error was found to be significantly related to GPS types that had been used for navigation during the establishment of the plot, but not with terrain, canopy types and stand density. The mean error when using differential GPS (DGPS) navigation was 6.2m; significantly lower than the 20.0m obtained using autonomous GPS. We conclude that the positional accuracy of the NFI plots in Japan is acceptable for use as a ground reference for the widely used Landsat satellite images with 30-m resolution if the plots had been located using DGPS navigation. In addition, the position of plots located without the use of DGPS should be re-measured to enhance the availability of NFI data.

Keywords: carrier phase, differential GPS, national forest inventory, navigation, positional accuracy

INTRODUCTION

National Forest Inventories (NFIs) have been performed in several countries, and provide information on the current forest state, condition and dynamics of various aspects in forests, such as timber production and biodiversity, throughout the country (CORONA and MARCHETTI, 2007; GASPARINI *et al.*, 2009; GILLS, 2001; PUUMALAINEN *et al.*, 2003; WINTER *et al.*, 2008). Of the many variables resulting from NFIs, plot position is one of the most fundamental, and accurate spatial positioning enables quick revisitation to the plot for subsequent remeasurement. In addition, accurate information regarding plot position is vital since ground information from NFIs is used as geo-referenced data for spatial analysis using remote sensing (KLEINN, 2002). More specifically, the pixel-level estimates from satellite image are extremely sensitive to field plot dislocation and rectification error (COULSTON *et al.*, 2006; HALME and TOMPPO, 2001). Thus, NFI requires highly accurate spatial positions of resource data to improve the quality of their database (NÆSSET *et al.*, 2000). To our knowledge, however, there has been no detailed report revealing the explicit positional error of NFI plots. HALME and TOMPPO (2001) mentioned that the mean positional error in the Finnish NFI field plots was 20 m, but did not provide detailed information regarding data variability or the methods to quantify error.

In Japan, NFIs commenced in 1999 and the plots, supposed to be located on a 4-km grid, were established during the first measurement, from 1999 to 2003. In many cases, field surveyors used a Global Positioning System (GPS) to navigate toward the target coordinates of the 4-km grid. However, no information is available on the actual coordinates of the plot positions that the surveyors chose while in the field or the subsequent deviation of these coordinates from the target values on the 4-km grid. Many studies have been

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conducted on the positioning accuracy of different types of GPS receivers in forests, as biological and topographic obstacles in forests tend to degrade the accuracy obtained from the GPS observations and, at times, prevent the signals from actually reaching the GPS antenna on the ground (HASEGAWA *et al.*, 1998; KOBAYASHI *et al.*, 2001; NÆSSET, 2001; ODERWALD *et al.*, 2003; PIEDALLU and GEGOUT, 2005; SAWAGUCHI, 2005; SIGRIST *et al.*, 1999; TSUYUKI *et al.*, 2006; WING *et al.*, 2005; WING and EKLUND, 2007; YOSHIMURA and HASEGAWA, 2003). The findings obtained from these past studies in forest surveys can provide a useful basis on which to evaluate the positional accuracy of NFI plots, but cannot be directly applied to prevent the plot position of NFIs. This is because most of the past studies did not deal with GPS error in "navigation", but "positioning" instead, which is evaluated using logging data collected over an observation period at a predetermined position with known coordinates. On the other hand, there is a lack of information on GPS "navigation" error in forests; the deviation of the target coordinate (waypoint) pre-entered in a GPS from the actual position that a surveyor determined in the field by following directions and distance given by the GPS (RINGVALL *et al.*, 2002).

The aims of the present study are to evaluate positional error of Japanese NFI plots that had been located using GPS navigation and to discuss the potential for NFI data to be used as geo-reference data for satellite remote sensing. To accomplish this, the positional errors of 82 NFI plots distributed in 4 prefectures of Kyushu, Japan, were quantified, using a high-precision, dual-frequency carrier-phase GPS and then factors affecting the positional errors were examined.

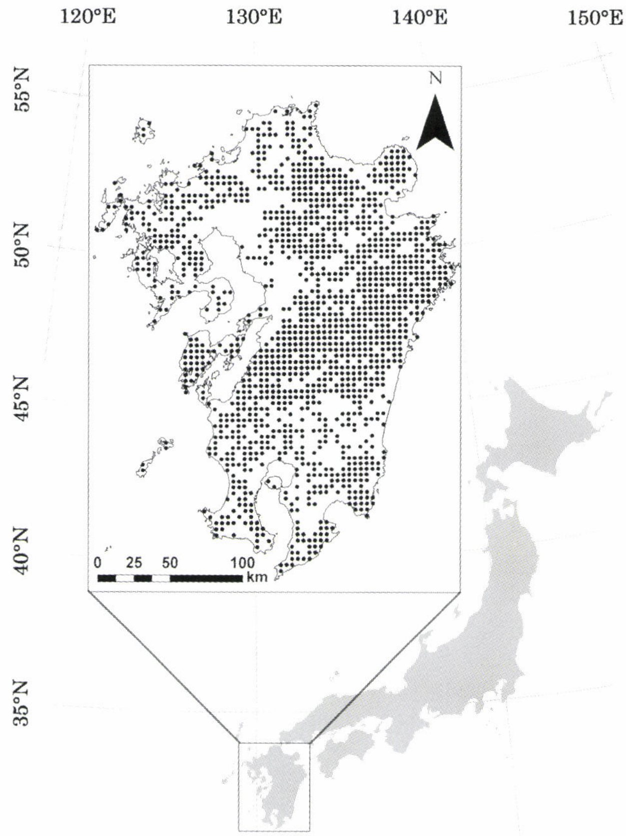

Fig. 1 NFI plot arrangement on the island of Kyushu, Japan.

MATERIALS AND METHODS

Locating the Japanese NFI Plots

The NFI sample plots were designed based on a systematic 4-km grid across the forests of Japan with a total number of about 15,700 plots, and each of the 47 prefectural administrative offices is implementing NFI surveys for private forests within their own prefectures. An example of plot arrangement on the island of Kyushu, in southwestern Japan, including the plots used in this study, is shown in Fig. 1. All plots are expected to be measured every 5 years and about one-fifth of the plots are measured every year. During the first survey term, from 1999 to 2003, field surveyors had located plots with help of GPS navigation toward target coordinates of the 4-km grid. The target coordinates were pre-entered as waypoints in the GPS and the surveyor navigated to these targets by following the direction and distance given by the GPS. GPS directions can be unstable when close to a waypoint (RINGVALL *et al.*, 2002), and the NFI field manual recommends deciding on a plot center after checking changes in GPS directions into north, east, south and west.

Measuring the NFI Plot Position

For the present study, we attempted to measure the center position of 90 plots randomly selected from 4 prefectures of Kyushu, from 2005 to 2006. To maintain confidentiality, these prefectures are referred to as Pref_A, Pref_B, Pref_C and Pref_D. All 90 plots measured in the present study had been located and established using GPS navigation from August 2000 to 2001 after selective availability (SA), an intentional error of up to a 100m for the publicly available navigation signal, was turned off. Surveyors in Pref_A, Pref_B and Pref_C used differential GPS (DGPS) (Pathfinder-Pro, Trimble), and those in Pref_D used autonomous GPS (Pokenabi 38EX, EMPEX) to navigate to the center of the plots.

We used a high-precision GPS with dual-frequency carrier-phase observation (GSR-2600, SOKKIA) to obtain actual coordinates of the plot center that had been already located and marked in the field. This particular GPS features an accuracy of 5 mm + 1 ppm of the horizontal baseline distance for static surveying (POINT INC., 2002). While keeping an antenna height >2m at the plot center (Fig. 2), static observations were conducted over a period of 90 min with a logging interval of 30 s.

Fig. 2 The high-precision, dual-frequency carrier-phase GPS used in the present study (GSR-2600, SOKKIA).

Baseline analysis with Spectrum Survey version 3.96 (SOKKIA) software was applied to the acquired data using data provided by the Geographical Survey Institute (GSI) from the 3 nearest control stations. GSI has established about 1,200 GPS-based control stations throughout Japan, which monitor movement of the land daily, through the GPS Earth Observation Network System. These observational data are made available for actual survey work and for the study of earthquakes and volcanic activity. From this baseline analysis, fixed solutions were found for 82 of the 90 plots; the carrier phase ambiguity was solved, indicating positional error on the order of a few centimeters (HASEGAWA and YOSHIMURA, 2007; NÆSSET *et al.*, 2000). In the present study, only data from these 82 plots were used with fixed solutions; thus providing precise values of the plot positions that had been originally determined by the field surveyors. NFI plots were established according to the plane rectangular coordinate value system of Japan on the Tokyo Datum. ERDAS IMAGINE version 9.1 (ERDAS) was used in order to convert geographic coordinate system to the plane rectangular coordinate system for GPS observation, and TKY2JGD (TOBITA, 2001) was used in order to transcribe coordinates in the Tokyo Datum to Japanese Geodetic Datum 2000 (JGD2000) for target coordinates of a 4-km grid. JGD2000 is almost equal to the WGS84 Datum of GPS (MORIYA *et al.*, 2008).

Statistical Analysis

The positional error of each plot was calculated as the horizontal distance between the plot position that was measured using the high-precision GPS and the target coordinates of the 4-km grid using the following equation:

$$Err = \sqrt{(x - x_t)^2 + (y - y_t)^2}, \quad (1)$$

where *Err* indicates the positional error; x and y are the actual positions of the plot center for longitude and latitude, respectively; x_t and y_t are the target coordinates of the 4-km grid for longitude and latitude, respectively. The root mean square (RMS) is a commonly used measure of random error (HASEGAWA and YOSHIMURA, 2007; YOSHIMURA and HASEGAWA, 2003), and was defined as:

$$RMS = \sqrt{\sigma_x^2 + \sigma_y^2}, \quad (2)$$

where σ_x and σ_y are the standard deviation of positional error for longitude and latitude, respectively.

Based on previous studies of GPS positioning error (NÆSSET, 1999, 2001; NÆSSET *et al.*, 2000; NÆSSET and JONMEISTER, 2002; TACHIKI *et al.*, 2004), multiple linear regression analysis was applied to assess how certain factors affect the positional error. The positional error was the dependent variable, category independent variables (dummy variables) were GPS types (autonomous GPS and DGPS) used during the plot establishment, terrain types (ridge, hillside and valley) and canopy types (conifer and broadleaved tree dominant forest) and the continuous independent variable was the stand density expressed as basal area (m²/ha). The positional error showed asymmetric distribution (KOBAYASHI *et al.*, 2001); therefore, the following model with logarithmic transformation was used for the dependent variable:

$$\ln Err = \beta_0 + \beta_1 \text{Receiver} + \beta_2 \text{Terrain1} + \beta_3 \text{Terrain2} + \beta_4 \text{Canopy} + \beta_5 \text{BA}, \quad (3)$$

where, *Err* is the positional error, Receiver is GPS types (Receiver = 1 if autonomous GPS; Receiver = 0 if DGPS), Terrain1 and Terrain2 are terrain features (Terrain1 = 1 and Terrain2 = 0 if valley; Terrain1 = 0 and Terrain2 = 1 if ridge; Terrain1 = 0 and Terrain2 = 0 if hillside), Canopy is canopy types (Canopy = 1 if coniferous forest; Canopy = 0 if broadleaved), and BA is stand basal area.

RESULTS

The frequency of the positional error and its accumulative values for the 4 prefectures are shown in Fig. 3, and 76% of the 82 plots were under 10-m error. Two outliers were found with around 100-m error in Pref_C and Pref_D and were excluded from the statistical analyses. These outliers may have been a result of mistakes in the GPS settings, such as waypoint data and geodetic datum.

The mean positional error and RMS for each of 4 prefectures, 3 terrain types and 2 stand types are listed in Table 1. The total mean positional error and RMS for 80 plots were 8.6m and 12.6m, respectively. Among the 4 prefectures, the smallest values of error and RMS (5.0m and 5.8m) were found for Pref_C and the largest for Pref_D (20.0m and 23.3m).

The results of multiple linear regression analysis are shown in Table 2 ($R^2 = 0.28$, $p<0.05$). The positional error was significantly affected by GPS types; DGPS had smaller error than autonomous GPS with mean values of 6.2m and 20.0m, respectively. Other valuables, including terrain, canopy types and stand basal area did not significantly affect the positional error.

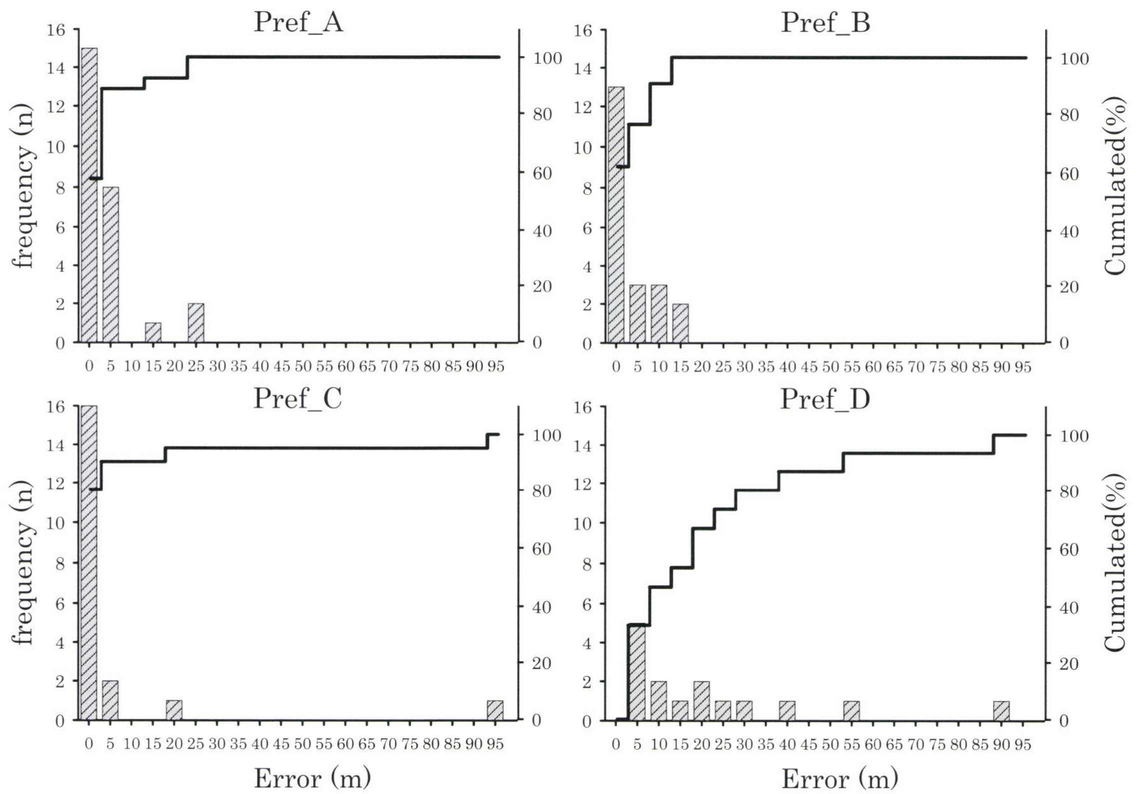

Fig. 3 Frequency and accumulated frequency of the positional errors. The value of the x-axis indicates the lower limit for each error class with 5-m width (e.g., a value of 5 indicates the error class from 5 to <10).

Table 1 Mean positional error and RMS for each of the 4 prefectures, 3 terrain types and 2 canopy types.

Prefecture		Pref_A			Pref_B			Pref_C			Pref_D			Total		
Category		Err	RMS	n	Err	RMS	n	Err	RMS	n	Err	RMS	n	Err	RMS	n
Terrain	ridge	6.4	3.7	3	3.0	3.0	5	4.1	4.0	5	12.4	13.5	3	5.7	7.3	16
	hillside	7.7	10.7	18	7.4	8.6	12	4.0	3.1	11	21.3	24.3	10	9.5	14.1	51
	valley	5.3	5.4	5	7.0	6.5	4	10.3	9.7	3	29.2	-	1	8.8	10.7	13
Canopytype	conifer	7.4	4.9	23	6.3	4.0	15	5.4	6.0	10	21.6	18.7	12	9.6	10.1	60
	broadleaved	4.7	4.2	3	6.1	3.7	6	4.6	3.4	9	10.3	2.6	2	5.6	4.8	20
Total		7.1	9.4	26	6.3	7.4	21	5.0	5.8	19	20.0	23.3	14	8.6	12.6	80

Err: mean error (m), RMS: root mean square (m), n: sample number.

Table 2 The results of multiple regression analysis for positional errors.

Variable	Coefficient	SRC	SE	Level of significance
β_0 (Intercept)	1.23	–	0.28	***
Receiver (autonomous GPS)	1.29	0.49	0.23	***
Terrain1 (ridge)	−0.34	−0.14	0.21	NS
Terrain2 (valley)	0.15	0.06	0.22	NS
Canopy (conifer)	−0.01	0.00	0.24	NS
BA (basal area)	0.01	0.12	0.01	NS

SRC: standard regression coefficient, SE: standard error, NS: not significant, ***: p value<0.05.

DISCUSSIONS AND CONCLUSION

The present study revealed the positional error of Japanese NFI plots, which had been located using GPS for navigational assistance, toward target coordinates of a 4-km grid. It should be noted, as stated earlier, that the present study assessed error in GPS "navigation" rather than "positioning" error, which has been well studied. The positional error of the plots was found to be significantly smaller when using DGPS for navigation than autonomous GPS. These results are consistent with previous studies of GPS positioning error, but the mean values of 6.2m and 20.0m, for DGPS and autonomous GPS, respectively, approximated the larger limit of the range presented in these earlier studies; 0.5–7.8m and 2.1–21.7m for DGPS and autonomous GPS, respectively (HASEGAWA and YOSHIMURA, 2007; KOBAYASHI, 2002; PIEDALLU and GEGOUT, 2005; TACHIKI *et al.*, 2004; WING *et al.*, 2005; WING and EKLUND, 2007; YOSHIMURA and HASEGAWA, 2003).

In the present study, terrain, canopy types and basal area did not significantly affect the positional errors, which differed from previous studies on GPS positioning accuracy under forest canopies. Positional errors are known to be larger in coniferous forests than in broadleaved forests (TACHIKI *et al.*, 2004; YOSHIMURA and HASEGAWA, 2003), larger in valleys than in ridges (DECKERT and BOLSTAD, 1996) and larger in denser stands as well (KOBAYASHI *et al.*, 2001; NÆSSET and JONMEISTER, 2002; SAWAGUCHI *et al.*, 2001). Finding a relatively large error and no significant relations with these factors may be the result of field surveyors deciding on plots positions based on unstable GPS direction and distance values during navigation, while the GPS positioning accuracy in the earlier studies was quantified using representatives of data logged over a given observation period. Moreover, the positional error of the plot location may also reflect the intentions of surveyors to avoid obstacles such as trees, rocks or steep slopes while establishing the plot location (RINGVALL *et al.*, 2002).

The Change Monitoring Inventory (CMI) program of British Columbia, Canada, adopted the measurement quality objectives of a relative sample location within ±30m (RESOURCES INVENTORY COMMITTEE, 2007), which equals a one-pixel resolution of the widely used Landsat satellite remote sensing data. In the present study, errors within 30m were found in nearly all the cases (98%) using DGSP and in 73% of the cases using autonomous GPS. This indicates that the positional accuracy of plots that had been located using DGPS navigation is acceptable for use as geo-reference data for Landsat images, as well as for revisitation. KAJISA *et al.* (2008) applied the k-Nearest Neighbor (k-NN) method for pixel level stand volume estimation by combining Landsat ETM+ image data with 622 field sample plots from the Japanese NFI on the island of Kyushu that had been located using DGPS navigation, and achieved accuracy similar to other studies. However, the plots located using autonomous GPS should be revisited to collect logging data using DGPS to ensure better accuracy. The remeasurements are particularly needed for the plots established using autonomous GPS before May 2000 when SA was turned off. This is because positional error of autonomous GPS was much larger before SA was turned off, while the DGPS errors were not related with SA (KOBAYASHI, 2002; MORI *et al.*, 2000).

In conclusion, the positional accuracy of NFI plots that had been located using DGPS is acceptable for use during analysis of the widely used Landsat satellite images with 30-m resolution, as well as for revisiting the plots. Plot position should be remeasured to enhance availability of NFI data of plots in which DGPS was not used during the establishment of the plot location; especially if the data is to be used as a geo-reference. In the 3rd term NFI from 2009, the field manual and the field notebook were revised. The coordinates of plot center position measured using GPS has to be filled in the field notebook, and the field manual recommends to use DGPS and to collect logged data. The NFI field manuals may need to include detailed instructions on the proper settings and use of GPS receivers (e.g., elevation mask, PDOP mask, SNR mask, logging interval and minimum number of positions), as is done in the Canadian CMI program (RESOURCES INVENTORY COMMITTEE, 2007), for consistency of data quality among different plots measured by different surveyors.

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Article

Assessing Forest Fragmentation in Southern U.S. Industrial Forest Plans that Accommodate Different Clearcut Size Restrictions

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ABSTRACT

Clearcut size limitations established both for private land and public land may affect and compound the fragmentation of forested landscapes. To better understand how these restrictions influence forest fragmentation, we designed an experiment to test and assess the effects caused by different maximum clearcut size restrictions on landscapes with different spatial patterns of land ownership. First, we developed forest plans with wood-flow and clearcut size constraints, using datasets composed of different land sizes (small, medium, and large) and spatial patterns (clumped, dispersed, and random). Six reasonable maximum clearcut sizes were assumed for industrial landowners of the southern U.S. Landscape metrics were selected as indicators of forest fragmentation; these included number of patches, patch density, total edge, edge density, perimeter-area fractal dimension, mean proximity, contagion. Results show that regardless of forest size and spatial pattern of land ownership, as the maximum clearcut size increased the number of patches, patch density, total edge and edge density decreased, while mean proximity increased. Results also suggest that wood-flow constraints have an effect on measures of fragmentation, and by adding this type of constraint to a forest planning problem, the effects attributable to different clearcut size restrictions may be mitigated.

Keywords: Landscape metrics, simulated annealing, harvest scheduling, multivariate analysis of variance, multiple comparison, edge density

INTRODUCTION

The role of forestlands in many areas of the United States has shifted from mainly providing commodities to providing multiple functions, including aesthetic values, environmental protection, biodiversity, and wildlife habitat conservation. As a result, more attention is now paid to the impact of harvesting activities on other resources when developing forest plans. Therefore, the outcomes of a forest plan now commonly include levels of timber production as well as estimates of the impact of harvest activities on the broader ecological system. The context in which forest plans are developed is important, as a number of wildlife conservation plans and habitat incentive programs in the United States contain goals related to the issue (Bettinger and Sessions 2003).

Recent insight in landscape ecology suggests that management actions (e.g., thinnings, clearcuts) influence human perception of forest fragmentation (Geoghegan *et al.*, 1997), in part because the spatial pattern of landscape features may affect ecological processes occurring on the landscape (Turner, 1989). Carsjens and van Lier (2002) describe fragmentation as a process that spatially segregates landscape features that would normally need to belong in close proximity in order to function optimally. Forest edges created by management activities can be considered either beneficial or detrimental, depending on the wildlife species or context under consideration (Kremsater and Bunnell, 1999). The major impacts of forest fragmentation are on wildlife species that are dependent on size and configuration of habitat,

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however habitat is defined. Most of the research on forest fragmentation has attempted to test the hypothesis that habitat loss is important to the abundance, composition, maintenance, and recovery of specific forest-dependent wildlife and plant species (Opdam, 1991; Wickham *et al.*, 1997; Atauri and de Lucio, 2001; Hernández-Stefanoni, 2005; Barlow *et al.*, 2006). Most studies of the effects of forest fragmentation have also focused on patch dynamics at a local scale (Askins *et al.*, 2007; Hernández-Stefanoni and Dupuy, 2008), and some have suggested that a landscape perspective on these issues is important for the sustainable management of forest and wildlife resources (Hedenås and Ericson, 2008) and for assessing alternative forest policies (Tyler and Peterson, 2004). Thus the measurable effects of fragmentation should vary depending on the broader landscape context and the patterns and processes under investigation (Robinson *et al.*, 1995; Donovan *et al.*, 1997). For example, forests fragmented by agriculture have been shown to result in a higher level of bird nest destruction than forests fragmented by logging (Bayne and Hobson, 1997).

The advancement of geographical information system (GIS) techniques has offered researchers and land managers a variety of tools for analyzing forest fragmentation at the landscape level (Echeverria *et al.*, 2008; Kupfer 2006). In the field of forest planning, GIS techniques have been used as a data development and visualization tool, because the data required increasingly has a spatial component and because viewing the future condition of the forest allows managers to better understand impacts of a plan (Bettinger and Sessions, 2003). In quantifying the adjacency, proximity, and juxtaposition of patches across a landscape, GIS technology can provide valuable information for spatial forest management planning (Baskent and Keles, 2005). We believe as harvest scheduling problems involve more spatial components, GIS techniques should be considered an essential tool for pre-processing data and post-processing results. Measures of forest fragmentation have been incorporated into forest planning methods as well, although most approaches use proximity and timing of activities to control fragmentation (Öhman and Wikstrom, 2008).

In most U.S. National Forest plans, the maximum clearcut area is either regulated or suggested as guidance for implementing management activities. For example, the Chattahoochee National Forest management plan gives guidance of 16 ha for the clearcut size limitations in Georgia (USDA Forest Service, 2004). Some U.S. states have also enacted laws to limit the forest clearcut sizes on private forestlands, such as Oregon and Washington (Bettinger and Sessions, 2003), whereas in the southern U.S., there are few state regulations on harvesting private forest lands. Different regulations may inadvertently cause different levels of forest fragmentation. Barrett *et al.* (1998) examined 4 ha and 32 ha clearcut limitations on some California private forestland and determined that 4 ha clearcut size limits resulted in higher edge-to-area ratio than 32 ha limitations. However, one question that remains is whether fragmentation is affected by both clearcut sizes and the spatial configuration of an ownership. To better understand this, we undertook this study, which has the objective of assessing and comparing levels of fragmentation effects due to varying maximum clearcut sizes and ownership patterns.

METHODS

A number of landscape-related metrics can be used to quantify the structural properties of a landscape (Herzog *et al.*, 2001), although landscape indices commonly reported in the literature have rarely undergone field testing for their association with the life requisites of wildlife species of interest (Schumaker, 1996). In any event, landscape metrics are useful for the quantifying of landscape pattern (Lindenmayer *et al.*, 2002), and individual metrics can be used as surrogates for fundamental dimensions of landscape structure (Schindler *et al.* 2008). All spatial pattern measurements involve measuring basic elements such as area, edge, shape, and distance. An increase in the number of small patches, lengths of edges, complexity of the patch shape, and isolation level may, for example, aggravate forest fragmentation. Perimeter-area ratio and fractal dimension are other metrics that describe the irregularity of edges within a landscape. Contagion and nearest-neighbor distance metrics describe the extent to which patches are aggregated within the landscape. These measures are generally provided at the landscape-level and make comparing alternative forest management plans, with respect to forest fragmentation, possible. Therefore, by computing these measures, one can understand how severely a forest is currently fragmented, and by projecting potential harvests into the future, one can understand how fragmentation may change as a result of a forest plan.

In sum, areas more severely fragmented than others typically have a higher number of individual patches, higher patch density, longer edges, higher edge density, larger perimeter to enclosed area values, higher levels of isolation of similar patches, and higher levels of aggregation of similar patches. Therefore, in this study, seven commonly used metrics were selected for assessing the forest fragmentation. These include number of patches (NP), patch density (PD), total edge (TE), edge density (ED), perimeter-area fractal dimension (PAFRAC), mean proximity index (PROX_MN), and contagion (CONTAG). NP and PD measure area-related characteristics, TE and ED measure edges, PAFRAC measures shape, PROX_MN measures isolation, and CONTAG measures contagion, or the degree of aggregation. Although the number of patches and patch density measure a similar characteristic for a given landscape, we included both in our analysis so that the change in the mean value of both indices can be observed explicitly when using different clearcut size assumptions. The same reasoning was applied to metrics of total edge and edge density.

In landscape ecology, a patch is usually defined as an area with homogeneous vegetation resources that is also spatially continuous (FORMAN, 1995). In this study, a patch is a continuous forest area with one single age class, and an edge is formed at the shared border between two adjacent stands with different age classes. Background boundaries (areas outside the landscape of interest) were not counted as edges. Therefore, number of patches should be equal to or less than the number of stand polygons. Increasing values of NP or PD would indicate a more fragmented forest. Similarly, increasing values of TE or ED also would indicate a potentially high level of fragmentation. The value of PAFRAC ranges from 1 to 2, and higher values suggest a departure from simple Euclidean geometry, like a square or a circle (McGARIGAL and MARKS, 1995), thus perhaps suggesting higher complexity in the landscape. PROX_MN requires a searching radius, which in this study was set as 100 m. A large value of this index implies a less fragmented landscape. CONTAG values range from 0 to 100, and a high value of this index implies that patches are aggregated, i.e., less fragmented. The mathematical formulation of each index can be found in McGARIGAL and MARKS (1995).

Data Description

In forest planning problems, forest stand datasets are generally composed of two parts. One part consists of GIS polygon databases, which describe the spatial relationship between landscape features, such as adjacency or proximity. The other part includes the forest stand characteristics, which primarily include age classes, areas, tree species, measures of density, and a timber growth projections based on a growth and yield models. The GIS databases we used were created by ZHU (2006), and are based on real industrial forests of the southern U.S. According to the size and the spatial pattern of each forestland, ZHU (2006) classified them into (a) small, medium, large databases, and (b) clumped, dispersed and random spatial groups. The three small datasets ranged from 2,922 to 2,942ha in size. The three medium datasets ranged from 5,802 to 5,821ha in size. The three large datasets ranged from 28,028 to 28,550ha in size. Given that each were extracted from operational databases, arriving at exactly the same size clumped, dispersed, and random arrangements was difficult. The small datasets (Fig. 1) contained around 300 polygons, the medium datasets contained around 500 polygons, and the large datasets contained more than 2,000 polygons. The spatial pattern was determined using an ownership pattern index (D_i) described in ZHU (2006). This index computes the average distance between the centroid of each stand in a database and the centroids of each of n number of nearest stands (e.g., 5, 10, or 15 nearest stands). ZHU (2006) confirmed that the clumped databases had the lowest average D_i, indicating that stands were closer to one another than in the other databases. The dispersed databases had the highest average D_i, indicating that stands were farther apart than in the other databases. The random pattern of stands had a D_i that fell in between the clumped and dispersed databases. Seven of the nine ZHU (2006) datasets were used in this study: large clumped, small clumped, small dispersed, small random, medium clumped, medium random, and median dispersed.

Forest stand age classes were originally created randomly using a uniform distribution of stand ages ranging from 1 to 30, which meant that each age class has almost the same initial area. While it may be reasonable to assume that similarly-aged (within a few years) pine stands in the southern U.S. could have the same ecological value if they are older than 50 or 60 years, at younger ages, stands one year different in age than others could contain significantly different live tree volume, dead tree density, etc. Therefore, patches are determined by absolute differences in age, rather than differences in ranges of ages. The growth and yield model used to project timber production within the planning horizon was developed by the Plantation Management Research Cooperative of the School of Forestry and Natural Resources at the University of Georgia. Timber stumpage prices were obtained from Timber Mart-South (4th quarter 2006). We assumed prices of \$36.58 (U.S. dollars) per ton for sawtimber, \$20.40 per ton for chip-n-saw, and \$6.68 per ton for pulpwood. The costs include a regeneration cost of \$606 per hectare (preparation, planting, seedling and herbaceous control) and an annual management cost of \$11.11 per hectare.

Forest Planning Problem Formulation

We formulated a forest planning problem with the objective of maximizing the net present value of planned activities over a 15-year planning horizon. One-year planning periods were recognized in the model. For simplicity, we also assumed that the only management activity available was a clearcut harvest. Four constraints were considered: 1) an ARM (area restriction model) where the summed area of all contiguous stands scheduled to be harvested in the same period could not exceed the predefined maximum clearcut area; 2) wood-flow constraints, which ensure sustainable yields over the entire planning horizon, i.e., the harvested volume in each period should not deviate too far from each other (a maximum 20% deviation in this case); 3) an ending inventory constraint which prevents the depletion of timber stands at the end of planning horizon, and ensures that at least 90% of the original timber volume should remain; and 4) a minimum cutting age constraint, under which trees less than 20 years old are not considered to be cut. These constraints are typical for southern U.S. forest products companies. The formulations are as follows:

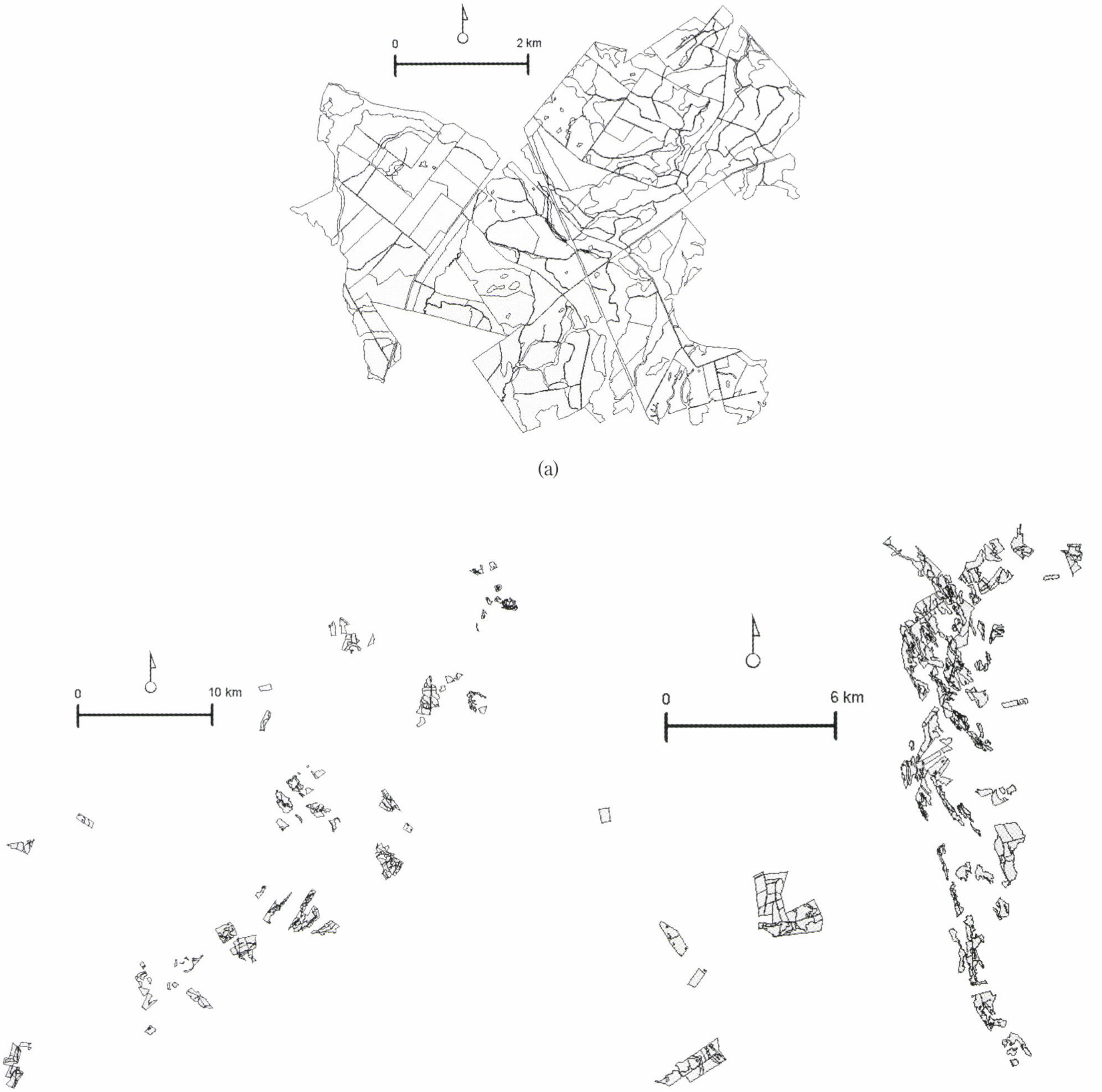


Fig. 1 The clumped (a), dispersed (b), and random (c) arrangement of polygons that represent the small forest landowner

Maximize

$$\sum_{t=1}^{T}\sum_{j=1}^{N}(X_{it}A_i(V_{it,saw}P_{saw}+V_{it,cn}P_{cn}+V_{it,pulp}P_{pulp}-C_r)/1.06^{t-0.5}-C_aT_A(1.06^{14.5}-1)/(0.06)(1.06^{14.5}) \quad (1)$$

subject to

$$X_{it}A_i+\sum_{j\in N_i\cup S_i}X_{jt}A_j\leq MCS \quad \forall i,t \quad (2)$$

$$0.8\times\sum_{i=1}^{N}X_{it}V_{it}\leq\left(\sum_{t=1}^{T}\sum_{i=1}^{N}X_{it}V_{it}\right)/T \quad \text{if} \sum_{i=1}^{N}X_{it}V_{it}<\left(\sum_{t=1}^{T}\sum_{i=1}^{N}X_{it}V_{it}\right)/T \quad \forall t$$
$$\sum_{i=1}^{N}X_{it}V_{it}\geq 0.8\times\left(\sum_{t=1}^{T}\sum_{i=1}^{N}X_{it}V_{it}\right)/T \quad \text{if} \sum_{i=1}^{N}X_{it}V_{it}<\left(\sum_{t=1}^{T}\sum_{i=1}^{N}X_{it}V_{it}\right)/T \quad \forall t \quad (3)$$

$$\sum_{i=1}^{N}V_{it}\geq 0.9\times\sum_{i=1}^{N}V_{i0} \quad (4)$$

$$\sum_{t=1}^{T}X_{it}\leq 1 \quad \forall i \quad (5)$$

$Age_{it} \geq 20$ if $X_{it} = 1$ (6)

Where:
A_i = area of management unit i
Age_{it} = the age of management unit i at time t period
C_a = annual cost ($/unit area)
C_r = regeneration cost ($/unit area)
i, j = an arbitrary harvested unit
MCS = maximum clearcut size
N = total number of harvest units
N_i = the set of all harvest units adjacent to unit i
P_{cn} = stumpage price for chip-n-saw timber
P_{pulp} = stumpage price for pulpwood
P_{saw} = stumpage price for sawtimber
S_i = the set of all harvest units that are connected with any unit in the set of Ni
t = period in which harvest activities occur
T = total number of time periods in the planning horizon
T_A = total planning area
V_{i0} = total timber volume in the stands before any harvest activities
V_{il} = timber volume left on the stands after the planning horizon
V_{it} = timber volume harvested in time period t, from management unit i
$V_{it,\ cn}$ = chip-n-saw volume harvested in time period t, from management unit i
$V_{it,\ pulp}$ = pulpwood volume harvested in time period t, from management unit i
$V_{it,\ saw}$ = sawtimber volume harvested in time period t, from management unit i

In order to examine the forest fragmentation effects due to various clearcut size restrictions, we selected 16.2, 32.4, 48.6, 64.8, 80.9 and 97.1 hectares as six reasonable maximum clearcut sizes for industrial forest management lands in the southern U.S.

Scheduling Process

It is generally not an easy task to find the exact optimal solution to a complex combinatorial problem by traditional methods (i.e., mixed integer programming) due to computational issues associated with NP-complete problems. Heuristic approaches are an alternative for these problems, and a well-designed model can locate very good feasible solutions in a reasonable amount of time. In our study a heuristic method, simulated annealing (HOLLAND, 1975; BETTINGER *et al.*, 2008), was used to solve the forest planning problem previously described. Simulated annealing has been validated for use in problems such as these (BETTINGER *et al.*, 2002), and performs a search process by mimicking the physical annealing process of heated metals. As the simulated annealing search process proceeds, it moves an inefficient feasible solution set to a limited set of highly efficient feasible solutions. At the onset of the search, an initial random solution is generated, and then a random perturbation is made. If the change results in a better solution, it is acceptable and the search proceeds with this better solution. If the change does not result in a better solution, whether this new solution should be accepted or not depends on the solution quality and a probability calculated using the following equation:

$$P(T)e = ^{-|S_c - S_p|/T_t} \quad (7)$$

Where:
S_c = current solution value
S_p = previous solution value
T_t = temperature at time t
$P(T)$ = probability critical value

$P(T)$ is then compared to a randomly drawn number between 0 and 1. We accept the solution if the randomly drawn number is less than $P(T)$. As a result, a worse solution is likely to be accepted at a high temperature, and likely to be refused at a low temperature. Initially, the temperature is high, allowing more non-improving changes to take place. However, as the search progresses, the temperature is "cooled," allowing fewer and fewer non-improving changes to take place. Therefore, the parameters required for simulated annealing include an initial temperature and a cooling rate. After numerous trials, we found that the appropriate initial temperature for the large dataset to be 10,000, and the appropriate initial temperature for the medium and small datasets to be 8,000. A cooling rate of 0.9995 proved to be the most appropriate parameter for each of these problems.

The spatial position of each cutting area was decided based on the process involved in using simulated annealing (randomly selecting cutting areas), and was guided by the problem formulation. For example, simulated annealing will only schedule a harvest if the change in the value of the forest plan either increases, or decreases within some bound (which gets smaller with each iteration) of the previous solution. From the problem formulation, the objective function required one to maximize the net present value of the plan, while also maintaining the size of cutting areas below the adjacency constraint level assumed. Further, harvests were guided by the need to maintain appropriate wood flows and to ensure an appropriate ending inventory. And, harvests were precluded from areas that contained trees younger than the minimum age that was assumed. Therefore, the heuristic selected the spatial position of the cutting areas based on the characteristics of the problem formulation and the characteristics of the simulated annealing search process.

Statistical Analysis

Fifty solutions were developed for each clearcut restriction problem (16.2–97.1 hectare maximum clearcut size). Each of the 50 solutions were developed starting with a different initial random feasible solution. Each solution resulted in a feasible forest plan, and the state of the landscape at the end of the plan (in terms of stand ages) was reported as a vector GIS database. We then converted each vector GIS database to a raster GIS database with a cell size of 5m. BETTINGER *et al.* (1996) showed that relatively small changes to the vector polygon shape and size occur when the conversion process involves grid cells less than 10m in size. For each resulting raster GIS database, the potential fragmentation effects caused by different harvest activities were quantitatively assessed at the end of the time horizon (15 years into the future).

A multivariate analysis of variance (MANOVA) was used first to test whether the maximum clearcut size had an overall effect on the response variables which were indicators of the degree of fragmentation (number of patches (NP), patch density (PD), total edge (TE), edge density (ED), perimeter-area fractal dimension(PAFRAC), mean proximity (PROX_MN) and contagion (CONTAG)). One independent factor was the maximum clearcut size (MCS). If the MANOVA test showed significant effects by the treatment factor, then univariate analysis of variance (ANOVA) and Tukey's HSD multiple comparison method were used to determine which variable was most affected by clearcut size restrictions and which factor group was statistically significantly different from the others.

During the analysis, we suspected that there were some confounding factors related to the problem formulation and the GIS data, which may substantially affect the results. One important factor was the wood-flow constraints, which controlled the amount of timber harvested in each time period. Wood-flow constraints may impact fragmentation, since when using them, cutting activities were spread out evenly over 15 years, which made the chance of producing large patches with the same age class remote. We also observed there were many small roads (less than 10m in width) that separated stands. In our analysis, all roads were treated as background and did not enter the fragmentation calculation process.

GIS Techniques

GIS techniques were closely integrated with the forest planning problem at the stages of pre-planning, mid-planning, and post-planning (Fig. 2). At the pre-planning stage, GIS techniques were largely used in spatial database management, which includes data storage, editing, conversion, and other manipulations for the vector GIS databases. During the planning process, GIS techniques were used in two ways: for

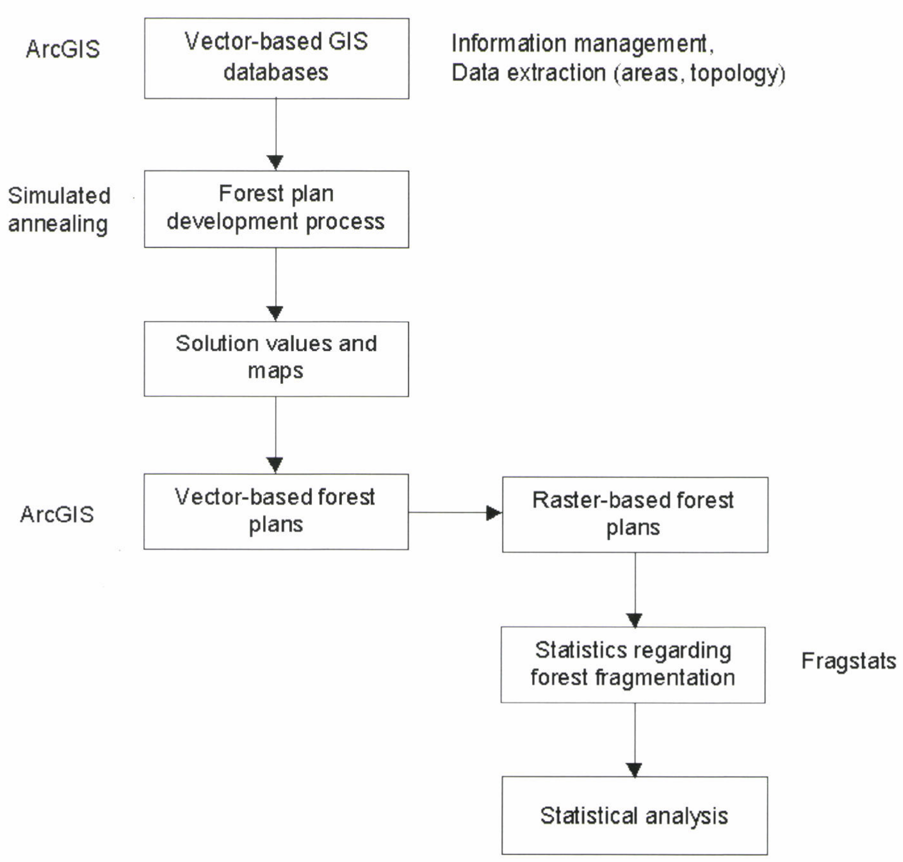


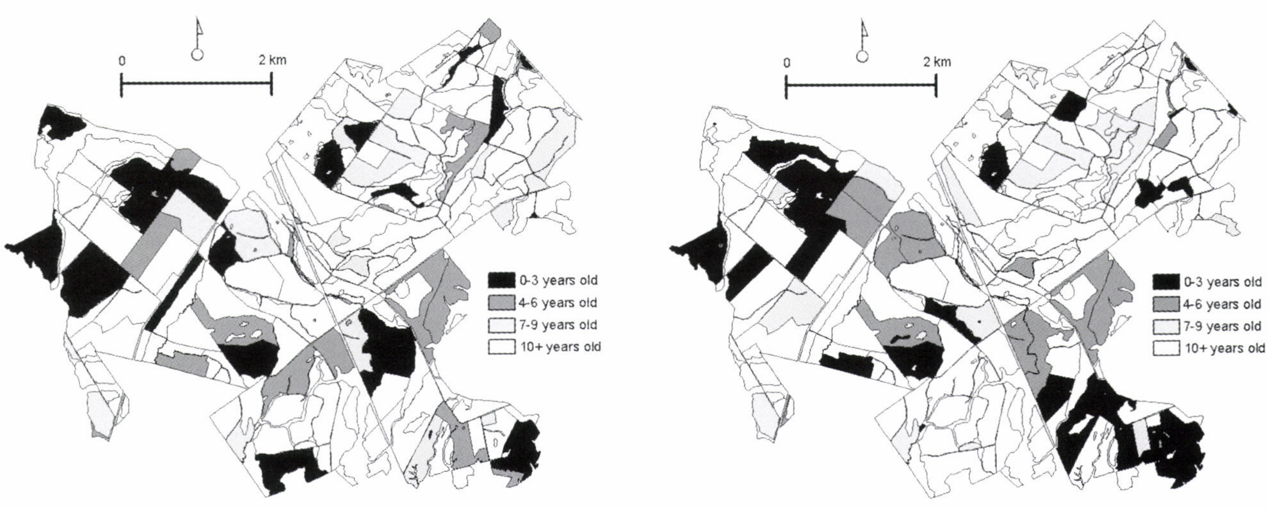
Fig. 2 Integration of GIS into the forest planning process

information extraction as an input to the planning process, and for forest plan visualization after a plan had been developed. As many may know, in spatial forest planning, adjacency relationships between stands are an essential piece of information, and used to compose adjacency constraints in the optimization problem formulation. The extraction of the adjacency information is very problem-specific. For instance, we may consider two stands adjacent in one problem, if the distance between edges of these two stands is less than a certain value. We may also treat two stands as neighboring stands in another problem, if the centroids of these two stands are within a certain distance. Through GIS functions, extraction of the spatial information can be convenient and flexible. All forest plans produced by the heuristic search can be presented as a GIS thematic map. In the post-planning stage, each plan was converted from vector to raster data, as we previously mentioned. Fragstats (McGarigal and Marks, 1995) was used to develop the spatial pattern indices based on the forest condition at the end of the plan. For each of the seven hypothetical landscapes we generated 300 forest plans using the simulated annealing heuristic, 50 for each of the six clearcut size restrictions. Each of the 300 forest plans was then input into Fragstats for a landscape-level analysis.

RESULTS

The multivariate analysis of variance indicated that all seven datasets had a significant Wilk's likelihood ratio ($p<0.0001$), which indicates that the maximum clearcut size restriction had an overall effect on estimated forest fragmentation. These results are consistent with Barrett *et al.* (1998) and Gustafson (2007) who demonstrated this in other areas of North America. Tables 1 to 7 provide more depth to the analysis: Tables 1 to 3 represent the 3 small landowner datasets, Tables 4 to 6 are for the 3 medium landowner datasets, and Table 7 is for the large landowner clumped dataset. What we found is that NP, PD, TE, ED and PROX_MN were all significantly different among different clearcut size groups ($p<0.01$). Except for the large clumped dataset, CONTAG was not significantly different among the clearcut size restrictions. When examining the shape index PAFRAC, only the large clumped dataset showed a strong significant effect ($p<0.0001$), and the small clumped dataset showed a weak significant effect ($p=0.0291$). The multiple comparison of the results should be ignored if the univariate ANOVA test failed to suggest evidence of any significance, although different group labels may still be assigned to different groups for some indices.

When viewing Tables 1 to 7, one can see a clear trend that with an increase of maximum clearcut size from 16.2ha to 97.1ha, index values of NP, PD, TE and ED decreased, and index values of PROX_MN increased, except for a few cases, this trend was not as clear when moving from 80.9 to 97.1ha. This decrease in the number of patches, patch density, total edge, and edge density, and the increase in mean proximity implied less fragmentation as the maximum clearcut size increased from 16.2 to 97.1ha. Although clearcut sizes were only controlled one year at a time, the aggregate effect is that when smaller maximum clearcut sizes are assumed, the interspersion of age classes is higher than then larger maximum clearcut sizes are assumed (Fig. 3). It was also interesting to notice that the CONTAG value seemed to decrease slightly as the clearcut size increased when the large clumped dataset was considered, which indicated less



(Fig. 3a) (Fig. 3b)

Fig. 3 A set of age classes representing the final condition of the small, clumped land area when using the 40 ha maximum clearcut size (a), and the 240 ha maximum clearcut size (b) after harvests for the time horizon have been scheduled

Table 1 Multiple comparison of landscape indices among six maximum clearcut size groups for the small clumped parcel dataset.

Landscape index	p-value		Maximum clearcut size restriction (ha) 16.2	32.4	48.6	64.8	80.9	97.1
NP	<0.0001	Group	A	B	C	CD	D	D
		Mean	270.4	269.3	268.5	267.8	267.5	267.6
		Std. Dev.	1.16	1.31	1.51	1.91	1.98	2.06
		CV	0.43	0.49	0.56	0.71	0.74	0.77
PD	<0.0001	Group	A	B	C	CD	D	D
		Mean	9.32	9.29	9.26	9.24	9.22	9.23
		Std. Dev.	0.040	0.045	0.052	0.066	0.068	0.071
		CV	0.43	0.49	0.56	0.71	0.74	0.77
TE	<0.0001	Group	A	B	B	C	CD	D
		Mean	113,207	112,803	112,564	111,911	111,711	111,475
		Std. Dev.	429	549	644	1,104	1,026	1,553
		CV	0.38	0.49	0.57	0.99	0.92	1.39
ED	<0.0001	Group	A	B	B	C	CD	D
		Mean	39.0	38.9	38.8	38.6	38.5	38.4
		Std. Dev.	0.148	0.189	0.222	0.381	0.354	0.535
		CV	0.38	0.49	0.57	0.99	0.92	1.39
PAFRAC	0.0291	Group	AB	ABC	BC	C	A	AB
		Mean	1.135	1.134	1.134	1.134	1.135	1.135
		Std. Dev.	0.001	0.001	0.001	0.002	0.002	0.002
		CV	0.09	0.13	0.12	0.18	0.16	0.19
PROX_MN	<0.0001	Group	D	C	C	B	BA	A
		Mean	71.5	83.5	85.5	100.7	108.5	109.8
		Std. Dev.	10.3	10.0	18.5	22.4	26.8	27.1
		CV	14.40	12.03	21.68	22.19	24.68	24.68
CONTAG	<0.0001	Group	A	AB	AB	AB	B	AB
		Mean	52.1	52.0	52.0	51.9	51.8	52.0
		Std. Dev.	0.630	0.584	0.786	0.750	0.715	0.722
		CV	1.21	1.12	1.51	1.45	1.38	1.39

Std. Dev. = standard deviation, CV = coefficient of variation (%), NP = number of patches, PD = patch density, TE = total edge (meters), ED = edge density (meters / ha), PAFRAC = perimeter-area fractal dimension, PROX_MN = mean proximity index, and CONTAG = contagion.

Table 2 Multiple comparison of landscape indices among six maximum clearcut size groups for the small dispersed parcel dataset

Landscape index	p-value		Maximum clearcut size restriction (ha) 16.2	32.4	48.6	64.8	80.9	97.1
NP	<0.0001	Group	A	B	C	BC	C	C
		Mean	271.1	270.3	269.5	269.8	269.4	269.5
		Std. Dev.	1.13	1.60	2.23	1.90	1.82	2.17
		CV	0.42	0.59	0.83	0.70	0.67	0.80
PD	<0.0001	Group	A	B	C	BC	C	C
		Mean	9.31	9.28	9.25	9.26	9.25	9.25
		Std. Dev.	0.039	0.055	0.077	0.065	0.062	0.074
		CV	0.42	0.59	0.83	0.70	0.67	0.80
TE	<0.0001	Group	A	A	B	B	C	BC
		Mean	73,166	72,831	72,839	72,362	72,009	72,328
		Std. Dev.	390	663	1,018	919	928	1,013
		CV	0.53	0.91	1.41	1.27	1.29	1.40
ED	<0.0001	Group	A	A	B	B	C	BC
		Mean	25.1	25.0	24.9	24.8	24.7	24.8
		Std. Dev.	0.134	0.227	0.349	0.315	0.319	0.348
		CV	0.53	0.91	1.41	1.27	1.29	1.40
PAFRAC	0.4275	Group	A	A	A	A	A	A
		Mean	1.212	1.214	1.213	1.213	1.211	1.213
		Std. Dev.	0.004	0.006	0.006	0.008	0.005	0.006
		CV	0.30	0.52	0.53	0.64	0.42	0.50
PROX_MN	<0.0001	Group	C	B	B	A	A	A
		Mean	22.4	27.6	30.2	38.2	36.0	34.6
		Std. Dev.	2.90	8.90	11.35	13.03	13.01	13.28
		CV	12.94	32.20	37.62	34.08	36.11	38.42
CONTAG	0.1337	Group	A	AB	B	AB	AB	A
		Mean	52.2	51.9	51.8	51.9	52.0	52.1
		Std. Dev.	0.544	0.670	0.786	0.763	0.770	0.689
		CV	1.04	1.29	1.52	1.47	1.48	1.32

Std. Dev. = standard deviation, CV = coefficient of variation (%), NP = number of patches, PD = patch density, TE = total edge (meters), ED = edge density (meters / ha), PAFRAC = perimeter-area fractal dimension, PROX_MN = mean proximity index, and CONTAG = contagion.

Table 3 Multiple comparison of landscape indices among six maximum clearcut size groups for the small random parcel dataset

Landscape index	p-value		16.2	32.4	48.6	64.8	80.9	97.1
			Maximum clearcut size restriction (ha)					
NP	<0.0046	Group	A	AB	AB	AB	C	AB
		Mean	313.4	313.0	312.6	312.5	312.4	312.7
		Std. Dev.	1.18	1.18	1.32	1.92	1.68	1.52
		CV	0.38	0.38	0.42	0.61	0.54	0.49
PD	<0.0047	Group	A	AB	AB	AB	C	AB
		Mean	10.66	10.65	10.64	10.63	10.63	10.64
		Std. Dev.	0.040	0.040	0.045	0.065	0.057	0.052
		CV	0.38	0.38	0.42	0.61	0.54	0.49
TE	<0.0001	Group	A	AB	B	C	C	C
		Mean	72,580	72,458	72,294	71,886	71,922	71,983
		Std. Dev.	252	317	442	1,021	846	733
		CV	0.35	0.44	0.61	1.42	1.18	1.02
ED	<0.0001	Group	A	AB	B	C	C	C
		Mean	24.7	24.7	24.6	24.5	24.5	24.5
		Std. Dev.	0.086	0.108	0.150	0.347	0.288	0.249
		CV	0.035	0.44	0.61	1.42	1.18	1.02
PAFRAC	0.9328	Group	A	A	A	A	A	A
		Mean	1.235	1.236	1.236	1.235	1.235	1.234
		Std. Dev.	0.006	0.005	0.005	0.007	0.007	0.006
		CV	0.49	0.40	0.43	0.54	0.57	0.51
PROX_MN	<0.0001	Group	C	BC	B	A	A	A
		Mean	12.1	16.2	20.3	25.6	25.1	27.1
		Std. Dev.	3.03	5.63	8.83	12.90	14.65	16.53
		CV	25.03	34.71	43.52	50.47	58.46	61.05
CONTAG	0.1303	Group	AB	B	A	AB	A	AB
		Mean	52.5	52.2	52.5	52.3	52.5	52.4
		Std. Dev.	0.730	0.765	0.722	0.770	0.712	0.755
		CV	1.39	1.47	1.37	1.47	1.36	1.44

Std. Dev. = standard deviation, CV = coefficient of variation (%), NP = number of patches, PD = patch density, TE = total edge (meters), ED = edge density (meters / ha), PAFRAC = perimeter-area fractal dimension, PROX_MN = mean proximity index, and CONTAG = contagion.

Table 4 Multiple comparison of landscape indices among six maximum clearcut size groups for the medium clumped parcel dataset

Landscape index	p-value		Maximum clearcut size restriction (ha) 16.2	32.4	48.6	64.8	80.9	97.1
NP	<0.0001	Group	A	B	C	D	D	D
		Mean	501.3	499.5	498.5	497.2	497.2	496.5
		Std. Dev.	1.33	2.04	2.24	2.02	2.49	2.11
		CV	0.26	0.41	0.45	0.41	0.50	0.43
PD	<0.0001	Group	A	B	C	D	D	D
		Mean	8.77	8.74	8.72	8.70	8.70	8.69
		Std. Dev.	0.023	0.036	0.039	0.035	0.044	0.037
		CV	0.26	0.41	0.45	0.41	0.50	0.43
TE	<0.0001	Group	A	B	C	D	D	D
		Mean	221,873	220,932	22,0275	219,243	218,944	219,172
		Std. Dev.	471	970	1,196	1,404	1,831	1,590
		CV	0.21	0.44	0.54	0.64	0.84	0.73
ED	<0.0001	Group	A	B	C	D	D	D
		Mean	38.8	38.6	38.5	38.4	38.3	38.3
		Std. Dev.	0.082	0.170	0.209	0.246	0.320	0.278
		CV	0.21	0.44	0.54	0.64	0.84	0.73
PAFRAC	0.0291	Group	A	A	A	A	A	A
		Mean	1.213	1.213	1.213	1.212	1.212	1.213
		Std. Dev.	0.001	0.002	0.002	0.001	0.002	0.002
		CV	0.10	0.12	0.13	0.11	0.14	0.16
PROX_MN	<0.0001	Group	E	D	C	B	A	A
		Mean	74.2	84.5	93.7	107.6	116.5	118.0
		Std. Dev.	6.5	9.8	13.2	15.5	15.9	14.4
		CV	8.79	11.63	14.08	14.40	13.65	12.21
CONTAG	<0.0001	Group	A	A	A	A	A	A
		Mean	52.3	52.3	52.3	52.2	52.3	52.3
		Std. Dev.	0.437	0.487	0.327	0.464	0.482	0.378
		CV	0.84	0.93	0.62	0.89	0.92	0.72

Std. Dev. = standard deviation, CV = coefficient of variation (%), NP = number of patches, PD = patch density, TE = total edge (meters), ED = edge density (meters / ha), PAFRAC = perimeter-area fractal dimension, PROX_MN = mean proximity index, and CONTAG = contagion.

Table 5 Multiple comparison of landscape indices among six maximum clearcut size groups for the medium dispersed parcel dataset

Landscape index	p-value		Maximum clearcut size restriction (ha) 16.2	32.4	48.6	64.8	80.9	97.1
NP	<0.0001	Group	A	B	BC	C	D	D
		Mean	480.6	479.5	479.0	478.7	478.0	477.9
		Std. Dev.	0.67	1.45	1.67	1.60	1.71	1.85
		CV	0.14	0.30	0.35	0.34	0.36	0.39
PD	<0.0001	Group	A	B	BC	C	D	D
		Mean	8.24	8.22	8.21	8.21	8.20	8.20
		Std. Dev.	0.011	0.025	0.029	0.027	0.029	0.032
		CV	0.14	0.30	0.35	0.33	0.36	0.39
TE	<0.0001	Group	A	B	B	C	D	D
		Mean	119,726	119,285	118,904	118,378	117,548	117,823
		Std. Dev.	186	576	769	1,167	1,596	1,397
		CV	0.16	0.48	0.65	0.99	1.36	1.19
ED	<0.0001	Group	A	B	B	C	D	D
		Mean	20.5	20.5	20.4	20.3	20.2	20.2
		Std. Dev.	0.032	0.099	0.132	0.200	0.274	0.240
		CV	0.16	0.48	0.65	0.99	1.36	1.19
PAFRAC	0.0291	Group	A	A	A	A	A	A
		Mean	1.230	1.230	1.230	1.230	1.230	1.231
		Std. Dev.	0.001	0.002	0.002	0.001	0.003	0.003
		CV	0.10	0.17	0.20	0.09	0.21	0.22
PROX_MN	<0.0001	Group	E	D	C	B	A	A
		Mean	11.0	16.9	20.8	25.8	31.8	34.3
		Std. Dev.	1.9	5.7	7.2	9.5	13.7	14.3
		CV	17.70	33.59	34.69	36.94	43.12	41.76
CONTAG	<0.0001	Group	A	A	A	A	A	A
		Mean	52.8	52.7	52.8	52.9	52.9	52.9
		Std. Dev.	0.532	0.601	0.578	0.487	0.398	0.455
		CV	1.01	1.14	1.10	0.92	0.75	0.86

Std. Dev. = standard deviation, CV = coefficient of variation (%), NP = number of patches, PD = patch density, TE = total edge (meters), ED = edge density (meters / ha), PAFRAC = perimeter-area fractal dimension, PROX_MN = mean proximity index, and CONTAG = contagion.

Table 6 Multiple comparison of landscape indices among six maximum clearcut size groups for the medium random parcel dataset

Landscape index	p-value		Maximum clearcut size restriction (ha) 16.2	32.4	48.6	64.8	80.9	97.1
NP	<0.0001	Group	A	B	C	C	C	D
		Mean	556.6	555.9	555.2	554.9	555.0	554.1
		Std. Dev.	0.97	1.57	1.62	1.67	1.62	2.02
		CV	0.17	0.28	0.29	0.30	0.29	0.36
PD	<0.0001	Group	A	B	C	C	C	D
		Mean	9.55	9.54	9.53	9.52	9.53	9.51
		Std. Dev.	0.017	0.027	0.028	0.029	0.028	0.035
		CV	0.17	0.28	0.29	0.30	0.29	0.36
TE	<0.0001	Group	A	B	C	C	C	D
		Mean	141,514	140,991	140,357	140,180	140,009	139,463
		Std. Dev.	205	652	1,173	1,440	1,413	1,476
		CV	0.15	0.46	0.84	1.03	1.01	1.06
ED	<0.0001	Group	A	B	C	C	C	D
		Mean	24.3	24.2	24.1	24.1	24.0	23.9
		Std. Dev.	0.035	0.112	0.201	0.247	0.243	0.253
		CV	0.15	0.46	0.84	1.03	1.01	1.06
PAFRAC	0.0291	Group	A	A	A	A	A	A
		Mean	1.256	1.256	1.256	1.257	1.256	1.256
		Std. Dev.	0.002	0.002	0.002	0.003	0.002	0.003
		CV	0.13	0.13	0.14	0.28	0.16	0.20
PROX_MN	<0.0001	Group	D	C	C	B	B	A
		Mean	44.7	50.3	52.8	57.6	58.0	62.1
		Std. Dev.	4.0	5.6	6.7	9.8	9.8	10.4
		CV	8.95	11.17	12.67	17.03	16.96	16.68
CONTAG	<0.0001	Group	A	A	A	A	A	A
		Mean	53.2	53.1	53.1	53.0	53.1	53.2
		Std. Dev.	0.410	0.402	0.385	0.467	0.309	0.368
		CV	0.77	0.76	0.73	0.88	0.58	0.69

Std. Dev. = standard deviation, CV = coefficient of variation (%), NP = number of patches, PD = patch density, TE = total edge (meters), ED = edge density (meters / ha), PAFRAC = perimeter-area fractal dimension, PROX_MN = mean proximity index, and CONTAG = contagion.

Table 7 Multiple comparison of landscape indices among six maximum clearcut size groups for the large clumped parcel dataset with wood-flow constraints

Landscape index	p-value		Maximum clearcut size restriction (ha) 16.2	32.4	48.6	64.8	80.9	97.1
NP	<0.0001	Group	A	B	C	D	CD	CD
		Mean	2,650.1	2,639.4	2,622.0	2,619.5	2,620.0	2,620.4
		Std. Dev.	3.18	4.73	7.18	6.93	7.06	6.05
		CV	0.12	0.18	0.27	0.26	0.27	0.23
PD	<0.0001	Group	A	B	C	D	CD	CD
		Mean	9.24	9.20	9.14	9.13	9.13	9.13
		Std. Dev.	0.011	0.016	0.025	0.024	0.025	0.021
		CV	0.12	0.18	0.27	0.26	0.27	0.23
TE	<0.0001	Group	A	B	C	D	D	D
		Mean	1,153,566	1,149,285	1,133,629	1,131,518	1,132,126	1,131,756
		Std. Dev.	1,284	1,882	4,524	3,623	4,473	3,415
		CV	0.11	0.16	0.40	0.32	0.40	0.30
ED	<0.0001	Group	A	B	C	D	D	D
		Mean	40.2	40.1	39.5	39.4	39.5	39.4
		Std. Dev.	0.045	0.066	0.158	0.126	0.156	0.119
		CV	0.11	0.16	0.40	0.32	0.40	0.30
PAFRAC	0.0291	Group	A	A	B	B	B	B
		Mean	1.182	1.182	1.181	1.181	1.181	1.181
		Std. Dev.	0.001	0.000	0.001	0.001	0.001	0.001
		CV	0.06	0.04	0.08	0.08	0.07	0.07
PROX_MN	<0.0001	Group	E	D	C	B	B	A
		Mean	53.8	65.0	112.7	116.0	116.4	119.8
		Std. Dev.	2.10	4.41	8.68	7.79	7.23	8.53
		CV	3.90	6.77	7.70	6.72	6.21	7.12
CONTAG	<0.0001	Group	A	A	B	B	B	B
		Mean	53.2	53.2	52.5	52.5	52.5	52.5
		Std. Dev.	0.136	0.141	0.221	0.197	0.212	0.228
		CV	0.25	0.26	0.42	0.38	0.40	0.43

Std. Dev. = standard deviation, CV = coefficient of variation (%), NP = number of patches, PD = patch density, TE = total edge (meters), ED = edge density (meters / ha), PAFRAC = perimeter-area fractal dimension, PROX_MN = mean proximity index, and CONTAG = contagion.

Table 8 Multiple comparison of landscape indices among six maximum clearcut size groups for the large clumped parcel dataset without wood-flow constraints

Landscape index	p-value		Maximum clearcut size restriction (ha) 16.2	32.4	48.6	64.8	80.9	97.1
NP	<0.0001	Group	A	B	C	D	E	F
		Mean	2,648.8	2,629.1	2,586.1	2,574.7	2,570.4	2,566.7
		Std. Dev.	3.68	7.26	8.86	8.46	8.05	10.16
		CV	0.14	0.28	0.34	0.33	0.31	0.40
PD	<0.0001	Group	A	B	C	D	E	F
		Mean	9.23	9.16	9.01	8.97	8.96	8.94
		Std. Dev.	0.013	0.025	0.031	0.029	0.028	0.035
		CV	0.14	0.28	0.34	0.33	0.31	0.40
TE	<0.0001	Group	A	B	C	D	E	E
		Mean	1,153,365	1,142,165	1,109,468	1,100,263	1,097,633	1,097,923
		Std. Dev.	1,345	4,251	5,215	6,352	5,546	5,976
		CV	0.12	0.37	0.47	0.58	0.51	0.54
ED	<0.0001	Group	A	B	C	D	E	E
		Mean	40.2	39.8	38.7	38.3	38.3	38.3
		Std. Dev.	0.047	0.148	0.182	0.221	0.193	0.208
		CV	0.12	0.37	0.47	0.58	0.51	0.54
PAFRAC	0.0291	Group	A	B	D	D	D	C
		Mean	1.182	1.181	1.180	1.179	1.179	1.180
		Std. Dev.	0.001	0.001	0.001	0.001	0.001	0.001
		CV	0.04	0.05	0.09	0.08	0.09	0.10
PROX_MN	<0.0001	Group	F	E	D	C	B	A
		Mean	52.1	78.1	174.8	194.5	210.9	224.2
		Std. Dev.	2.26	4.48	10.45	13.71	12.91	14.08
		CV	4.34	5.74	5.98	7.05	6.12	6.28
CONTAG	<0.0001	Group	B	A	F	E	D	C
		Mean	59.1	59.4	56.2	56.5	56.7	56.9
		Std. Dev.	0.279	0.226	0.281	0.271	0.298	0.351
		CV	0.47	0.38	0.50	0.48	0.53	0.62

Std. Dev. = standard deviation, CV = coefficient of variation (%), NP = number of patches, PD = patch density, TE = total edge (meters), ED = edge density (meters / ha), PAFRAC = perimeter-area fractal dimension, PROX_MN = mean proximity index, and CONTAG = contagion aggregation for the larger maximum clearcut sizes. But we believe this did not mean more fragmentation for the larger clearcut size groups, because all values for CONTAG ranged around 52 or 53. It should also be noted that the relationship between index values and clearcut sizes was not linear. Therefore, linear regression models were not suggested for use in this analysis.

For the small and medium landowners, it seemed that the spatial pattern (clumped, dispersed and random) did not affect the multiple comparison results very much, although fewer significant differences for some landscape indices were found for the small random dataset compared to the small clumped and the small dispersed datasets. For the three small landowner datasets, the clumped pattern had more significantly different groups than the dispersed pattern and the random pattern for the NP, PD, TE, ED and PROX_MN landscape indices. One major difference attributable to the different spatial patterns was the magnitude of the value PROX_MN. Clumped patterns (both small and medium sizes) had much larger PROX_MN values than their corresponding dispersed and random patterns, which was self-evident, since PROX_MN measures isolation, and random or dispersed patterns contained more isolated polygons than the clumped patterns.

To further examine the impact of wood-flow constraints on the level of fragmentation, we relaxed the constraint and generated 300 new forest plans using the large, clumped database. Comparing Table 8 with Table 7, we can see that the removal of wood-flow constraints led to slightly fewer patches, slightly fewer edges, a drop in the PROX_MN values, and an increase in the CONTAG values. We can also see that more significant groups were formed for the landscape indices. For example, for the NP, PD, TE, ED, PROX_MN, and CONTAG indices, each clearcut size formed its own unique statistically significant group. Prior to removing wood-flow constraints, PAFRAC and CONTAG only had two statistically significant groups. This is also the first major change in contagion compared to the previous results (from the small, medium, and large landowners). This suggests that an increase in the interspersion and juxtaposition of different aged stands has occurred when the wood-flow constraint was removed. These changes were dramatic, because not only did the index values change, but also the multiple comparison results were different. However, despite the observed differences, the overall pattern of decreased fragmentation with an increase in maximum clearcut size remained the same.

DISCUSSION

Two components of the human use of a landscape are important in developing an understanding of their impact on other natural resources: the density and pattern of management activity (THEOBALD *et al.*, 1997). The main impacts of human development on wildlife habitat, for example, are best seen in conjunction with the removal and change in the structure of native or mature vegetation (THEOBALD *et al.*, 1997). The spatial and temporal arrangement of forests obviously influences how much habitat is available for certain dependent wildlife species, and therefore plays a role in the regulation of wildlife dynamics (MCGARIGAL and MCCOMB, 1995). For example, the size and arrangement of older forests is important to the reproductive success of certain species of birds (SCHMIEGELOW *et al.*, 1997). As a result, while they may be regularly present in larger areas of older forest, certain groups of wildlife may be absent from smaller areas of similar habitat conditions (AMBUEL and TEMPLE, 1983). Regardless of different forest sizes and landscape spatial structure, all seven of our analyses support the idea that effects on forest fragmentation decrease in terms of number of patches, patch density, total edge, edge density and mean proximity, as the maximum clearcut size increases. In other words, larger maximum clearcut size restrictions can reduce the forest fragmentation to some extent. This is contrary to the recent voluntary and regulatory efforts to reduce the size of harvest openings. However, patch shape and level of contagion are not affected much by different clearcut size restrictions, especially when forest size is relatively small and even wood-flow constraints are used in forest planning process.

Contrary to what one might think, human development of the landscape does not necessarily affect all natural resources equally. For example, in some cases fragmented landscapes have been found to reduce bird species diversity (MCINTYRE, 1995), yet this is not universally true. For example, bird species richness has been found to be greater in some fragmented forests because these habitats can accommodate species of birds that would normally only be associated with edge habitats (HOBSON and BAYNE, 2000). The pattern of change would therefore seem important within a managed landscape, however, we found that the effects on forest fragmentation due to different maximum clearcut sizes do not differ much for different landscape spatial patterns, although a clumped ownership pattern tends to strengthen the impact arising from different clearcut size restrictions. Organizational policy constraints that require an even wood-flow have an obvious impact on forest fragmentation, and by adding these constraints to a forest planning problem, the effects on forest fragmentation due to different maximum clearcut sizes are mitigated.

The impacts of forest fragmentation on natural resources are complex. A broad-scale landscape perspective is necessary to assess many of the impacts. From a geoprocessing point of view, whether small roads (less than 10m in width) should be counted as edges in landscape metric calculations or be treated as pure background affects the results only slightly, because the overall trends in forest fragmentation effects due to maximum clearcut size restrictions do not change dramatically. We also need to reiterate that this study is only applied to intensively managed forests of the southern region in the U.S., because our spatial data and the growth and yield model are all based on southern loblolly pine stands. One should be cautious in extending our results to other locations with different tree species and different geospatial characteristics.

CONCLUSIONS

From a pragmatic point of view, we modeled only the typical green-up and adjacency policies of industrial landowners situated in the southern U.S. Although we used a one-year green-up period in this study, future studies may want to expand the research by extending the green-up period to 2 or 3 years and observing whether there are any changes in fragmentation pattern in the projected forest plans. Future studies may also extend what we have done to create or enhance a single fragmentation index that can be used to visualize the extent of fragmentation of the landscape graphically, similar to the vegetation similarity index created by BETTINGER (2003). The work presented here contributes to the existing body of science in a number of ways. First, it confirms what other literature have previously reported, that measures of fragmentation change as clearcut sizes increase, and that more fragmentation is noticed with smaller maximum clearcut sizes. Second, this work suggests for the first time that there are little differences in measures of fragmentation when patterns of ownerships vary from random to clumped arrangements of parcels. Finally, we noticed that wood-flow constraints tend to mitigate or mask the effects of the maximum clearcut size restrictions.

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Article

Estimation of Growth Parameters using the Local Yield Table Construction System for Planted Forests throughout Japan

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ABSTRACT

We applied the Local Yield Table Construction System (LYCS), a computer program that predicts stand growth using various stand density controls, to sugi (*Cryptomeria japonica*), hinoki (*Chamaecyparis obtusa*), and karamatsu (*Larix leptolepis*) plantated forests throughout Japan. The parameters were estimated from yield tables of karamatsu forests produced by the managers of the national forests in the Hokkaido, Iwate, Dewa, and Shinshu regions of Japan. The diameter at breast height (DBH) and the number of trees measured in permanent plots were used as the parameters for estimating the effect of stand density on diameter growth. We used these parameters to estimate stand growth in terms of tree height, DBH, and tree diameter distribution. The estimated stand growth data calculated using these parameters were comparable to data in the original yield tables and observed values obtained from permanent plots. These results enabled us to construct yield tables for various stand density control plans for karamatsu forests.

Keywords: Local Yield Table Construction System, planted forests, stand density, stand growth

INTRODUCTION

The resources in planted forests that are managed with standard density controls can be estimated using yield tables (IMADA, 1998). The System Yield Table is a computer program that predicts growth and yields using a growth model based on a variety of thinning plans (KONOHIRA, 1995; SHIRAISHI, 2005); the application of this method has previously enabled stand growth parameters under various thinning regimes to be estimated.

Diverse silvicultural practices and thinning intensities have been applied in private forests in Japan (NAKAJIMA *et al.*, 2005; 2006a; b; 2007), therefore it would be useful to have the ability to make predictions about resources in forests with different stand density controls when planning future thinning regimes. System Yield Tables have been valuable in the past for predicting forest resources and developing management plans. In Japan, the Local Yield Table Construction System (LYCS), a variation of a System Yield Table, has been previously applied to forest management (NAKAJIMA and SHIRAISHI, 2007). Growth models based on the LYCS have been developed for sugi and hinoki stands in the Tokyo University Forest in Chiba (SHIRAISHI, 1986). In addition, MATSUMOTO (2004) attempted to apply the LYCS to various thinning methods including mechanical and line thinning, while NAKAJIMA and SHIRAISHI (2007) used the LYCS to develop a forest management strategy.

The LYCS has been applied to evergreen sugi (*Cryptomeria japonica*) and hinoki (*Chamaecyparis obtusa*) forests in some areas of Japan where data for permanent plots are available (SHIRAISHI, 1986; MATSUMOTO, 1997). However, the LYCS has not yet been applied across the whole of Japan because of difficulties in obtaining permanent plot data for

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many regions. In addition, no study has examined the efficacy of the LYCS for forests of the deciduous tree species karamatsu (*Larix leptolepis*). Since karamatsu is less shade tolerant than sugi and hinoki, karamatsu forests are managed with relatively low stand density controls (TAKAHASHI, 1960; KAN, 1983). Therefore, comparisons between karamatsu and sugi or hinoki growth parameters throughout forests of Japan will be particularly important for future management efforts. Here, we expand on the current methods used for estimating the growth parameters of Japanese sugi, hinoki, and karamatsu stands. We also analyze case examples to evaluate the adaptability of the estimated parameters for permanent plots as well as yield tables of Japanese planted forests.

MATERIALS AND METHODS

Data Sources

The data used to estimate parameters were obtained from stand yield tables of sugi, hinoki, and karamatsu forests throughout Japan. Sugi data were obtained from the Akita (REGIONAL FORESTRY OFFICE, 1944), Aomori (AOMORI REGIONAL FORESTRY OFFICE, 1955), Ibaraki (FORESTRY AGENCY, 1959a), Yamagata (FORESTRY AGENCY, 1960), North Kanto Abukuma (FORESTRY AGENCY, 1955),Kishu (FORESTRY AGENCY, 1952b), San-in (OHOSAKA REGIONAL FORESTRY OFFICE, 1969), Tosa (FORESTRY AGENCY, 1952b), Kagoshima (FORESTRY AGENCY, 1952c), Echigo and Aizu (FORESTRY AGENCY, 1956a), Amagi (FORESTRY AGENCY, 1956b), and Ohi and Tenryu areas (FORESTRY AGENCY, 1964). Hinoki data were obtained from the Kishu (FORESTRY AGENCY, 1952a), Ohi and Tenryu (FORESTRY AGENCY, 1952d), Chugoku (FORESTRY AGENCY, 1952e), Aichi and South Gifu (FORESTRY AGENCY, 1959b), Amagi (FORESTRY AGENCY, 1954a), Fuji and Hakone (FORESTRY AGENCY, 1954b), Kiso (FORESTRY AGENCY, 1954c), Tosa (FORESTRY AGENCY, 1957), Kanto (FORESTRY AGENCY, 1961a), and Kyushu areas (FORESTRY AGENCY, 1961b). Karamatsu data were obtained from the Hokkaido (ISHIBASHI *et al.*, 2006), Iwate (AOMORI REGIONAL FORESTRY OFFICE, 1961), Dewa (FORESTRY TESTING AREA of the FORESTRY AGENCY, 1966), and Shinshu areas (FORESTRY TESTING AREA of the FORESTRY AGENCY, 1956).

Each dataset included the thinning age, the numbers of dominant trees and trees to be thinned per hectare, the mean diameter at breast height (DBH), mean tree height, and stand volume for every site index. The data source for the Hokkaido area included the permanent plot data of the karamatsu forests used to construct the yield tables. These data include records of mean DBH, mean tree height, and stand density measurements taken every five years.

Growth Model

We applied the LYCS to Japanese sugi, hinoki, and karamatsu planted forests and estimated parameters of the growth model equations by applying a relational expression contained within the LYCS to the data sources mentioned above using the parameter estimation method (MATSUMOTO, 1997). The growth model consisted of the following five formulas:

Height growth curve:

$$H = M\,[1 - L\exp(-kt)] \qquad (1)$$

where H is stand height (m), t: stand age (year) M, L and k are parameters.

Decreasing number of trees:

$$N = \exp\{a\,[1 + b\exp(-ct)]\} \qquad (2)$$

where N is the number of trees per ha and a, b and c are parameters.

Relationship between stand density and mean DBH:

$$\log N + d\log D = K \qquad (3)$$

where D is the mean DBH (cm) and d and K are parameters.

Rate of increase in DBH:

$$r = m\exp(-n\,t) \qquad (4)$$

where r: is the rate of increase in mean DBH (%/year) and m and n are parameters.

Growth model for the diameter increment using results from (2)–(4):

$$r = m\exp(-n\,t) + p\,(K - \log N - a\log D) \qquad (5)$$

where p is a parameter.

The parameters for equation (1) were estimated by applying MITSCHERLICH's equation to the tree height growth curves derived from the yield tables. The parameters for equation (2) were estimated by curve-fitting the GOMPERTZ function to the number of trees per hectare for every site index. The parameters M, a, and b in equation (2) are shown as functions of the site index (MATSUMOTO, 1997).

The parameters for equation (3) were estimated by applying a linear curve to a log–log scale by plotting the stem number per hectare and the mean DBH. The parameters for equation (4) were estimated by applying GOMPERTZ functions to the growth rate curves of the annual DBH growth rate (% per year), sorted by stand age. The parameters m and n in equation (4) had two variations because the relationship between stand age and increment rate of the mean DBH changes with the inclination of the growth rate (MATSUMOTO, 1997). Consequently, we applied the GOMPERTZ function to the data before and after the specific stand age separately.

Parameter p of equation (5) , which reflects the degree to which stand density affects the DBH growth rate, was estimated by applying the nonlinear least-squares method to the DBH growth of the trees in permanent plots using the methods developed for sugi and hinoki stands (SHIRAISHI, 1986). We used the quasi-Newton method because it is suitable for nonlinear data (NAKAGAWA and KOYANAGI, 1982). When analyzing the Hokkaido area, we extracted the data from permanent plots where a standard stand density control was used and randomly selected one plot from the Asahikawa, Kitami, Obihiro, and Hakodate areas. The selection of the permanent plots prevented parameter p from being influenced by the data from other permanent plots in which thinning was especially intense.

The estimation of the value of parameter p was difficult in some areas due to a lack of data from permanent plots. In such cases, we used parameter p values from Hokkaido for karamatsu forests. Similarly, we applied the value of parameter p for the Tokyo University Forest in Chiba (SHIRAISHI, 1986) to sugi and hinoki forests in other areas. Using parameter p obtained from other areas, NAKAJIMA and SHIRAISHI (2007) confirmed the adaptability of the LYCS for predicting diameter growth under long-rotation silvicultural systems. Therefore, in this study, we assumed that diameter growth estimates could be obtained using parameter p values derived from Hokkaido or the Tokyo University Forest in Chiba.

The DBH and tree heights estimated by the LYCS were compared to the values in the original yield tables. We then examined the estimated values using these parameters and the observed data from the Ikutahara karamatsu forest permanent plot, which is managed by the Hokkaido Regional Forestry Office. The permanent plot was established when the stand was 14 years old and has been measured eight times since establishment. The most recent measurement was taken when the stand was 49 years old. Thinning was conducted 19 and 29 years after the stand was established. We set the initial observed values of the diameter distribution of the stand to that found when it was 14 years old and then input the thinning plan to the LYCS according to the historical records of silvicultural practices in the plot. We then compared the estimated and observed values of the mean DBH, diameter distribution, and tree height.

RESULTS AND DISCUSSION

Growth Parameters and Adaptability of the Original Yield Tables

Tables 1–4 show the estimated parameters obtained from equations (1)–(4) for sugi, hinoki, and karamatsu forests in each region. Parameter p was estimated to be 1.3 in the Hokkaido karamatsu stands. The other parameters of the LYCS for the three tree species throughout Japan were estimated using the method described by MATSUMOTO (1997). The parameter M in Table 1 and parameters a and b in Table 2 differed from those of the site class, suggesting that tree height, growth, and number of stems per hectare vary with site class. MATSUMOTO (1997) reported that the parameters M, a, and b for sugi planted forests in Kyushu district are dependent on site class. Furthermore, parameter M was very high for sugi, which represents the saturation point in the tree height curves compared to hinoki and karamatsu, indicating that sugi planted exhibit more growth than the latter two species.

The parameters listed in Tables 3 and 4 did not depend on site class, indicating that the standard density control level and diameter growth rate under standard density control are independent of site class. Similar results were reported by MATSUMOTO (1997).

Using the parameters in Tables 2 and 3, we introduced the differences in stand density controls between districts into the LYCS. These parameters differed between districts and tree species, suggesting that the way standard stand density controls affect DBH growth varies with district. We estimated the average stand density control in various districts using these parameters. Fig. 1 shows the standard density curves obtained for sugi, hinoki, and karamatsu throughout Japan (derived from Table 3), compared with the full density curves for each tree species estimated by SAKAGUCHI (1961). The standard density curves of karamatsu were lower than those of sugi and hinoki, suggesting that forest managers should maintain lower stand densities in karamatsu forests than in stands of sugi and hinoki to avoid self-thinning. We recommended this strategy because the full density curve of karamatsu is lower than those of sugi and hinoki, and decreasing the full stand density level promotes increased self-thinning in karamatsu stands. Due to the lower shade tolerance of karamatsu compared to sugi and hinoki (CHIBA

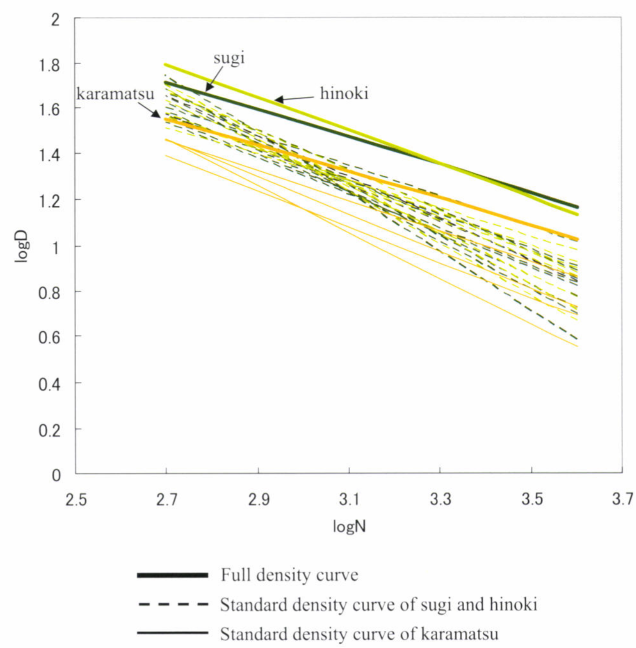

Fig. 1 Standard density curves of sugi, hinoki, and karamatsu throughout Japan, derived from Table 3.
Dark blue, green, and orange lines represent sugi, hinoki, and karamatsu, respectively.

and NAGANO, 1981), karamatsu forests are managed under relatively low stand-density controls (HARADA, 1983). Our results support previous assumptions that the density of karamatsu stands is consistently lower during the course of time than that of sugi and hinoki stands, which allows the incorporation of the stand-density control level into the growth predictions based on the parameters in Table 3.

Using the parameters in Table 4, we were able to introduce the differences in average DBH growth rate between districts into the LYCS. The parameters m and n for the ages when the parameters in Table 4 were changed are shown in parentheses. The average parameter m indicating the DBH growth rate was 24.357, 11.972, and 14.064, for young stands of sugi, hinoki, and karamatsu, respectively. These results indicate that sugi grows more rapidly than hinoki and karamatsu. The diameter increment rate was affected by stand age as well as the standard density curve in a given area. The parameters m and n did not show any clear tendency of being associated with area because the stand density curve differed depending on the area (see Table 3).

Using permanent plot data, SHIRAISHI (1986) estimated parameters m, n, and p based on the least squares method and calculated K and b parameters for sugi and hinoki by applying linear curves to a log-log scale and plotting the stand density and the mean DBH. In contrast, MATSUMOTO (1997) calculated m, n, K, and d parameters from a sugi yield table and estimated parameter p by substituting these parameters and the observed increase in mean DBH into formula (5). In our study, the parameters m, n, K, and d for karamatsu were derived from the yield table, and parameter p was estimated by applying the least squares method to permanent plot data where the measurement period was longer than that used in the dataset used by MATSUMOTO (1997). Therefore, the methodologies for estimating parameters and the original dataset differ between SHIRAISHI (1986), MATSUMOTO (1997), and this study. In addition, the permanent plot data that we used for parameter estimations have been used for constructing yield tables (ISHIBASHI *et al.*, 2006) and also comprise the original data for parameter estimation in this study. Using a yield table based on the permanent plot data, we confirmed that the estimated

Table 1 Height growth curves from the yield tables

	Area	$H = M(1 - L\exp(-k\,t))$ M	L	k
Sugi	Aomori	50.81 − 6.81S	1.076	0.016
	Akita	64.99 − 11.25S	1.068	0.015
	Yamagata	59.26 − 10.75S	1.114	0.017
	Echigo and Aizu	56.01 − 9.02S	1.082	0.017
	North Kanto Abukuma	48.30 − 6.35S	1.036	0.020
	Ibaraki	28.22 − 3.20S	1.215	0.049
	Amagi	29.22 − 4.15S	1.260	0.043
	Ohi and Tenryu	29.42 − 4.36S	1.197	0.048
	Kishu	43.52 − 6.47S	1.077	0.026
	San-in	52.63 − 6.78S	1.065	0.019
	Tosa	41.25 − 5.90S	0.980	0.023
	Kagoshima	28.61 − 4.35S	1.186	0.039
Hinoki	Kanto	33.9 − 5.30S	0.989	0.021
	Amagi	39.0 − 6.19S	1.019	0.015
	Fuji and Hakone	37.7 − 6.32S	1.023	0.014
	Ohi and Tenryu	28.7 − 3.87S	1.004	0.026
	Kishu	49.4 − 6.98S	1.030	0.013
	Kiso	44.0 − 6.27S	1.029	0.012
	Aichi and South Gifu	27.1 − 2.91S	1.074	0.028
	Tosa	29.7 − 4.48S	1.116	0.028
	Chugoku	30.6 − 4.04S	1.061	0.030
	Kyushu	46.5 − 7.97S	1.020	0.016
Karamatsu	Hokkaido	45.31 − 10.07S	1.060	0.039
	Iwate	37.87 − 5.13S	1.086	0.032
	Dewa	34.02 − 5.02S	1.218	0.037
	Shinshu	42.11 − 8.15S	1.124	0.037

S is a value corresponding to site quality class (Upper: 1, Middle: 2, Lower: 3).

parameters provided good fits not only to data in the yield table but also to the specific stand growth parameters observed in the permanent plot data, as described below.

Fig. 2 compares tree heights estimated by the LYCS to those reported in the original yield tables of karamatsu forests in Hokkaido. This comparison indicates that the values are almost identical, with an average difference of approximately 1%, although there was a 5% error rate for younger trees.

Fig. 3 compares the mean DBHs estimated by the LYCS

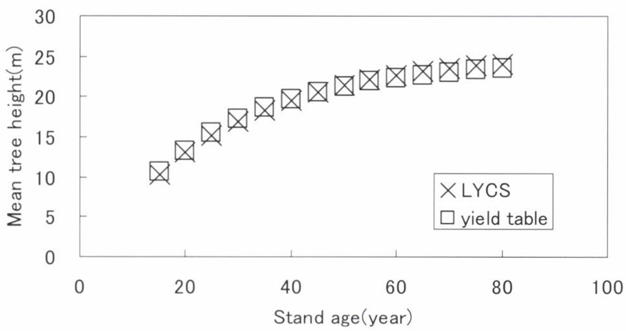

Fig. 2 Tree height comparison between the LYCS and the original yield table for karamatsu forests in Hokkaido (Site quality class: middle)

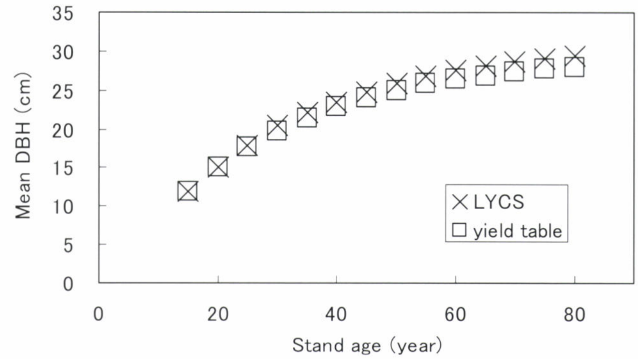

Fig. 3 Mean DBH comparison between the LYCS and the original yield table for karamatsu forests in Hokkaido (Site quality class: middle)

Table 2 Decreasing number of trees in the yield table

	Area	$N = \exp(a(1 + b\exp(-ct)))$		
		a	*b*	*c*
Sugi	Aomori	3.779 + 0.286*S*	1.202 − 0.116*S*	0.011
	Akita	5.716 + 0.134*S*	0.772 − 0.037*S*	0.043
	Yamagata	5.246 + 0.370*S*	0.708 − 0.084*S*	0.028
	Echigo and Aizu	5.280 + 0.280*S*	0.640 − 0.064*S*	0.030
	North Kanto Abukuma	5.068 + 0.156*S*	0.695 − 0.039*S*	0.020
	Ibaraki	5.973 + 0.225*S*	0.531 − 0.043*S*	0.041
	Amagi	5.363 − 0.293*S*	0.545 − 0.032*S*	0.022
	Ohi and Tenryu	6.039 + 0.238*S*	0.474 − 0.047*S*	0.041
	Kishu	4.198 + 0.399*S*	1.068 − 0.140*S*	0.019
	San-in	4.055 + 0.297*S*	1.126 − 0.109*S*	0.016
	Tosa	4.949 + 0.273*S*	0.754 − 0.068*S*	0.023
	Kagoshima	5.413 + 0.216*S*	0.587 − 0.028*S*	0.024
Hinoki	Kanto	4.343 + 0.512*S*	0.991 − 0.203*S*	0.013
	Amagi	5.576 + 0.385*S*	0.619 − 0.079*S*	0.020
	Fuji and Hakone	5.114 + 0.270*S*	0.646 − 0.056*S*	0.012
	Ohi and Tenryu	4.639 + 0.099*S*	0.827 − 0.044*S*	0.012
	Kishu	4.542 + 0.370*S*	1.025 − 0.096*S*	0.024
	Kiso	5.735 + 0.190*S*	0.531 − 0.034*S*	0.019
	Aichi and South Gifu	5.220 + 0.155*S*	0.656 − 0.040*S*	0.020
	Tosa	4.632 + 0.850*S*	0.834 − 0.390*S*	0.014
	Chugoku	5.826 + 0.231*S*	0.516 − 0.010*S*	0.041
	Kyushu	5.831 + 0.255*S*	0.549 − 0.052*S*	0.029
Karamatsu	Hokkaido	4.722 + 0.710*S*	0.422 − 0.066*S*	0.030
	Iwate	5.213 + 0.309*S*	0.477 − 0.040*S*	0.031
	Dewa	5.607 + 0.170*S*	0.393 − 0.002*S*	0.042
	Shinshu	4.195 + 0.498*S*	0.789 − 0.110*S*	0.024

S is a value corresponding to site quality class (Upper: 1, Middle: 2, Lower: 3).

to those provided by the original yield table for dominant trees. Although the error rate for some stand ages was as high as 5%, both DBHs were similar, with an average difference of approximately 3%.

NAKAJIMA and SHIRAISHI (2007) reported that the average error rate for both the average tree height and DBH of hinoki forests in the Jingu Shrine Forest was 3%. Comparing the results of the predicted DBH and tree height for the karamatsu and hinoki yield tables indicates that DBH and tree height growth of karamatsu can be predicted with the same level of accuracy as that observed for hinoki.

In addition, a high degree of adaptability was confirmed in the Iwate, Dewa, and Shinshu areas. For reference, Fig. 4 compares the time course of diameter growth estimated by the LYCS to that described in the original yield table for the Iwate area.

The error rates were within 10% for the estimated and original DBH, although the diameter growth parameter p obtained in Hokkaido was used for the Iwate area. This finding suggests that diameter growth from the Hokkaido data could be used to estimate the parameter p for other areas where permanent plot data are unavailable. As indicated in previous studies, once the parameter p is calculated in one area, it can be used for the same tree species in other areas. For example, NAKAJIMA and SHIRAISHI (2007) reported that an estimated value of parameter p for the Tokyo University Forest in Chiba

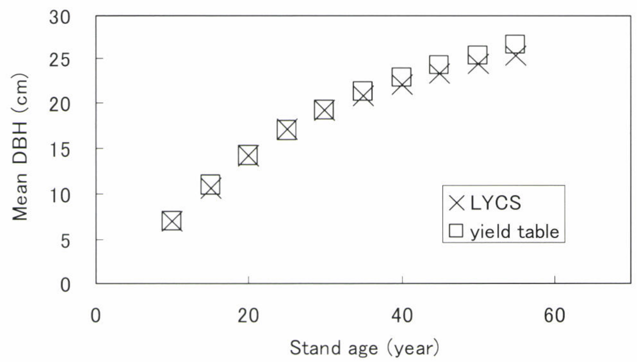

Fig. 4 Mean DBH comparison between the LYCS and the original yield table for karamatsu forests in Iwate (Site quality class: middle)

Table 3 Relationships between stand density and mean DBH.

	Area	$\log N + d \log D = K$	
		d	K
Sugi	Aomori	0.773	4.057
	Akita	1.323	4.780
	Yamagata	0.942	4.265
	Echigo and Aizu	1.110	4.485
	North Kanto Abukuma	1.266	4.666
	Ibaraki	1.084	4.545
	Amagi	1.122	4.609
	Ohi and Tenryu	0.933	4.279
	Kishu	1.268	4.651
	San-in	1.174	4.607
	Tosa	1.380	4.869
	Kagoshima	1.118	4.552
Hinoki	Kanto	1.046	4.415
	Amagi	1.138	4.610
	Fuji and Hakone	0.911	4.258
	Ohi and Tenryu	1.430	4.936
	Kishu	1.493	4.927
	Kiso	1.277	4.713
	Aichi and South Gifu	0.887	4.196
	Tosa	1.372	4.844
	Chugoku	1.274	4.669
	Kyushu	1.270	4.707
Karamatsu	Hokkaido	1.530	4.925
	Iwate	1.236	4.505
	Dewa	0.991	4.147
	Shinshu	1.294	4.496

could be applied to growth predictions in other districts. Therefore, we can use the parameter p obtained in this study for growth predictions for the same species in other districts.

Adaptability to the Permanent Plot

Figs. 5 and 6 show observed and estimated data for the mean DBH and tree height, respectively. The average error rate for the DBH was 5%, with a maximum of 7%. For estimations of tree height, the accuracy was consistently within 2% of the average error rate in stands older than 28 years. NAKAJIMA *et al.* (2009) reported that average error rates for the average stand height and DBH of sugi forests in the University of Tokyo Forest in Chiba were 7% and 9%, respectively. A comparison between the predicted DBH and tree height in sugi forests indicated that stand growth of karamatsu can be predicted with the same level of accuracy as that observed in sugi stands.

Fig. 7 compares estimated and observed diameter distributions. Setting the diameter distribution at age 13 years as the initial value, we predicted the diameter distribution of the stand at 43 years old. The results of this prediction were accurate, but the distribution curves of the observed and estimated data were different for some DBH classes. The

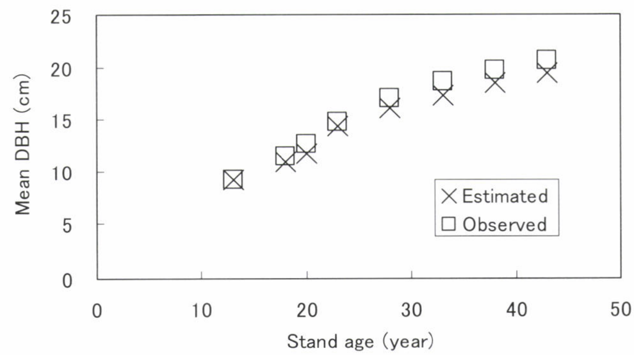

Fig. 5 Mean DBH comparison between the observed and estimated data for permanent plots of karamatsu in the Hokkaido area

Table 4 Rate of increase in DBH

	Area	$r=m\exp(-kt)$				Stand age when the inclination of the growth
		m		n		
Sugi	Aomori	28.027	(7.123)	0.094	(0.043)	30
	Akita	8.548	(2.824)	0.047	(0.021)	45
	Yamagata	49.338	(3.094)	0.122	(0.024)	30
	Echigo and Aizu	14.400	(2.979)	0.065	(0.024)	45
	North Kanto Abukuma	11.276	(2.278)	0.060	(0.019)	45
	Ibaraki	43.726	(4.866)	0.139	(0.051)	30
	Amagi	20.616	(3.302)	0.097	(0.027)	30
	Ohi and Tenryu	18.952	(4.098)	0.094	(0.042)	30
	Kishu	51.027	(2.913)	0.143	(0.029)	30
	San-in	22.215	(4.783)	0.100	(0.041)	30
	Tosa	8.738	(3.819)	0.061	(0.030)	30
	Kagoshima	15.418	(4.595)	0.090	(0.042)	30
Hinoki	Kanto	13.244	(3.959)	0.069	(0.030)	45
	Amagi	11.166	(2.741)	0.051	(0.021)	55
	Fuji and Hakone	21.988	(3.125)	0.077	(0.024)	45
	Ohi and Tenryu	10.131	(4.101)	0.056	(0.029)	45
	Kishu	10.010	(3.700)	0.049	(0.026)	55
	Kiso	5.430	(2.309)	0.034	(0.014)	45
	Aichi and South Gifu	11.276	(2.278)	0.060	(0.030)	45
	Tosa	13.100	(5.020)	0.059	(0.036)	35
	Chugoku	19.832	(2.806)	0.091	(0.028)	35
	Kyushu	9.066	(4.117)	0.049	(0.029)	40
Karamatsu	Hokkaido	6.379	(3.024)	0.046	(0.035)	30
	Iwate	18.376	(4.687)	0.094	(0.050)	35
	Dewa	24.627	(6.345)	0.095	(0.053)	35
	Shinshu	11.937	(5.488)	0.065	(0.035)	45

Numbers in parentheses indicate the parameters after the stand age when the inclination of the growth rate changes.

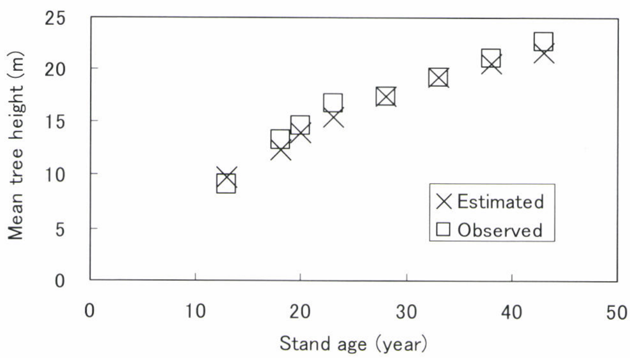

Fig. 6 Average tree height comparison between the observed and predicted data for permanent plots of karamatsu in the Hokkaido area

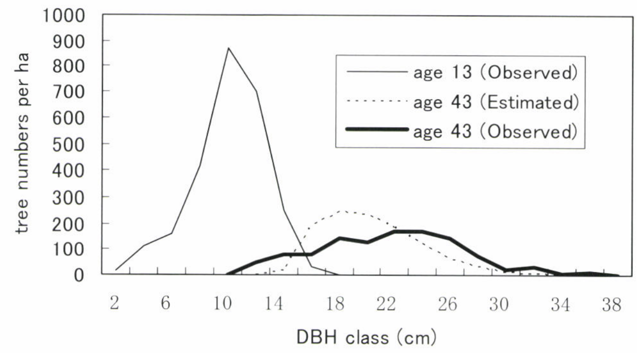

Fig. 7 Diameter distribution comparison between the observed and predicted data for permanent plots of karamatsu in the Hokkaido area
The diameter distribution of the 14-year-old stand is shown as a solid line. The estimated and observed values for 49 years are indicated by the dotted and thick solid line, respectively.

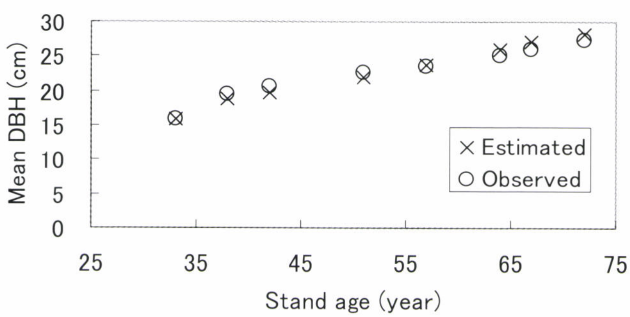

Fig. 8 Comparison of the average mean DBH between the observed and predicted data for permanent karamatsu plots in the Shinshu area

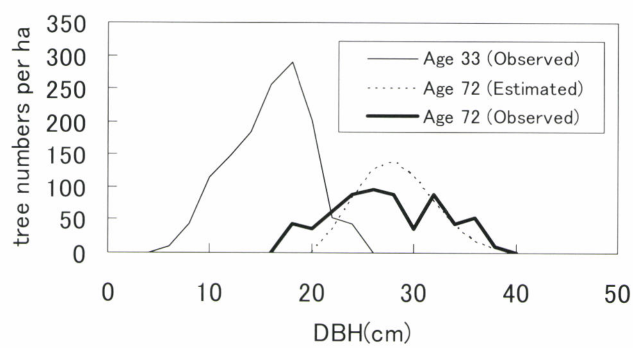

Fig. 9 Diameter distribution comparison between the observed and predicted data for permanent karamatsu plots in the Shinshu area.
The diameter distribution of the 33-year-old stand is shown as a solid line. The estimated and observed values for 72 years are shown by the dotted and thick solid lines, respectively.

differences between the observed and estimated coefficients of variation (CVs) for the diameter distributions at ages 20, 28, and 43 years were 4.0%, 2.3%, and 5.0%, respectively. These results indicate that the diameter distribution can be estimated with a CV difference of less than 5%.

The range of the observed distribution was larger than that of the estimated distribution. However, this is unlikely to have a substantial effect on prediction accuracy because the observed value itself was very small. These results suggest that the parameters provide a good fit to the observed diameter distribution.

Fig. 8 and 9 show observed and estimated data for the mean DBH and diameter distribution in the karamatsu stands in the Shinshu area, respectively. The average error rate for the DBH was 2.7%, with a maximum of 4.1%. By setting the initial diameter distribution at age 33 years, we predicted the diameter distribution of the stand at 72 years. The diameter distribution prediction was accurate, but the distribution curves for the observed and estimated data differed for some DBH classes. The differences between the observed and estimated CVs for the diameter distributions at ages 43, 57, and 72 years were 2.7%, 3.3%, and 5.5%, respectively. Generally, the difference in the CVs calculated from Hokkaido and Shinshu permanent plot data increased with the length of the forecast period. However, the differences in the CVs were less than 5% for a 30-year prediction period.

Overall, our results suggest that the model parameters provide good fits to the observed DBH and diameter distribution data in the permanent plots. SHIRAISHI (1986) and MATSUMOTO (1997) did not check the accuracy of all estimated average tree height, observed DBH, and diameter distribution values in their yield tables or permanent plot data for a prediction period of more than 30 years. Therefore, the results of our study confirm the adaptability of karamatsu parameters for predicting stand growth for relatively long forecast times.

RECOMMENDATIONS

Given our results, we recommend that the LYCS should be applied to other species and areas. In particular, three real datasets are available that could be used in conjunction with the LYCS to predict stand growth parameters. The first consists entirely of permanent plot data, the second comprises plot data and yield tables constructed with these plot data, and the third only includes yield tables. In the first case, it may be possible to estimate growth parameters and apply them to estimate individual stand growth (SHIRAISHI, 1986). In the second case, it should be possible to estimate the parameters by adjusting them according to the individual stand growth and yield table for karamatsu forests in Hokkaido that was used in this study. Finally, the third dataset can be used to estimate the growth parameters from yield tables, except for parameter p, which describes the influence of thinning on DBH growth. In this case, without an estimate of parameter p, the LYCS cannot be applied to the study area. However, if the species of interest has been examined elsewhere, the parameter p can be used from another district to predict growth parameters. Our calculated values of parameter p for sugi, hinoki, and karamatsu allow the use of the LYCS to predict future growth in the absence of permanent plot data.

CONCLUSIONS

We estimated LYCS parameters for Japanese sugi, hinoki, and karamatsu stands throughout Japan. The tree height and DBH values predicted by the LYCS provided good fits to data in the original yield tables. For the Hokkaido area in particular, the estimated values for tree height, DBH, and diameter distribution were all similar to the observed data in permanent plots. We therefore conclude that parameter p can be used to estimate karamatsu forest resources under various types of stand density controls.

ACKNOWLEDGEMENT

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Article

Relationship between the Japanese CSR Activities and the Companies' Business: An Approach from the Forest-Related Activities of Japanese Enterprises

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ABSTRACT

According to society's demand for the companies' commitment to the social responsibilities and public responsibilities, Corporate Social Responsibility (CSR) is gaining increased attention. CSR is defined variously and even currently there is no definitive definition that can pinpoint what CSR is. This is due to the CSR concept emerging out of varying conditions depending on the individual country or region, and that it is also strongly subject to the backdrop of the period. This study targets the CSR in Japan. The purpose of this study is to clarify the significance of CSR activities, to describe the characteristics of forest-related activities of Japanese companies, and to discuss how the relationship between CSR and business should be. About the significance of CSR activities, the survey results are as follows: 1) The significance of CSR activities for companies includes to enhance their reputation and to establish their corporate brand. 2) CSR is unclear in its profitability despite its costliness in time and funds, and disregarding eco-efficiency, it falls short of evidence in how it may benefit the company. 3) The relationship between CSR and competitiveness is issues and the dialogues with diverse stakeholders become complex and unclear. 4) Japanese companies are especially inclined to view social contribution through business, namely the provision of products and services to the society, as CSR. Reflecting this view, CSR is referred to as "a social contribution through business; nothing out of the ordinary" in Japan. On the other hand, 62% of the companies have been involved in some kind of forest-related activities and much participation to forest-related activities in industries other than forestry and related industries. The objectives of investing in forest-related activities also varied from activities related to business operation such as materials procurement, to forest conservation, CSR, employee education, regional contribution and biodiversity conservation. So, these activities are more CSR-like in nature. These interests in forest-related activities are the characteristics of Japanese CSR activities. These survey results showed that the actual state could not be sufficiently captured in the CSR concept of "social contribution through lines of business." In conclusion, the current mainstream concept of CSR "social contribution through business" must be separated into the narrow sense and broader sense and defined individually. In order to promote environmental efforts including forest-related activities, CSR in the broader sense also needs to be evaluated and accordingly it must be incorporated into the core of the management strategy. In order to realize this, internal and external requests by the diverse stakeholders and new incentives would be necessary.

Keywords: (Japanese) CSR, japanese enterprise, forest-related activities, companies' business

INTRODUCTION

As the existence and continuation of a company have been evaluated and justified by its efficient performance of economic obligations and the level of achievement of economic benefits, its economic functions have long been prioritized over governing functions and social functions.

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Social and environmental activities and community contributions apart from their lines of business are not the foremost issue for a company. However, given the current situation that asks for sustainability to be placed at the core of management (ITOH, 2004), economical, governing, and social issues that concern the continuation and prosperity of the company must be resolved by the company itself. DRUCKER (1957) and HART (2005) argue that companies have a greater potential than governments and civil societies to lead the world to a sustainable direction, if their profit-pursuing activities were directed in such a way, in cooperation with the NGOs, government, and international organizations. The conditions for corporate continuation under the global environment age are, firstly, to have the foresight to discern long-term, global environmental problems, and secondly, to coexist with the society with the sensitivity to capture the changes in civic values, and thirdly, to have the power to overcome constraints that allows for flexible response to changes in natural environment and reforms of social system (SETO, 2000). Today, business administrators are challenged to conduct management on a dual pillar of economic and social aspects (ITOH, 2004), and a company must consider social fairness and environmental issues as well as profitability by establishing a sustainable management system demanded by the markets (KIKUCHI, 2007).

SUZUKI (1992) classifies corporate responsibilities broadly into three types. The first type is a company's responsibility to efficiently meet its economic functions, i.e. the economic responsibility. Secondly, a company owes a responsibility to use due care in fulfilling its economic functions in relation to the changing social values and priorities – the social responsibility. Thirdly, a company takes on the public responsibility, which is a newborn responsibility that will arise out of the company's expanded future commitment to be involved in active improvement of social environments. Under these circumstances, Corporate Social Responsibility (CSR) is gaining increased attention. The increased interest in CSR can be seen as the society's demand for the companies' commitment to the social responsibilities and public responsibilities.

MATERIAL AND METHOD

As many institutions and scientists pointed, CSR is defined variously and even currently there is no definitive definition that can pinpoint what CSR is. This, as subsequently will be explained in detail, is due to the CSR concept emerging out of varying conditions depending on the individual country or region, and that it is also strongly subject to the backdrop of the period.

EC (2001) described CSR as the "companies' voluntary integration of social and environmental concerns in their business operations and interaction with their stakeholders beyond what is legally required and expected." The European Parliament (2007) adds that "CSR policies should be promoted on their own merits and should represent neither a substitute for appropriate regulation in relevant fields, nor a covert approach to introducing such legislation." WBCSD (1999), assuming diversity in the content of CSR according to company, defines it as "the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as of the local community and society."

Looking Japan, in the Nihon Keizai Shimbun (1974), CSR (Kigyo-no-Syakaiteki-Sekinin) is defined as "to responsibly fulfill the functions the company is or should be responsible for socially." It also gives its three elements: "to not harm the society," "to fulfill the fundamental function of a company" and "to actively and widely contribute to the improvement of social environment such as participating in and/or cooperating to the resolution of social problems" beyond the frame of a company's fundamental functions. KAWAGUCHI (2007) defines CSR as "understanding the company in which you are employed at from the inside and out, and reconfirming that understanding."

As such, CSR is presently given a broadly diverse definition. However, the two common keywords found in many definition suggestions are "triple bottom-line (1. Economy, 2. Environment and 3. Society)" and "stakeholders" (UMEDA, 2006) and the elements typically included are "sincerity," "accountability" and "transparency."

The next is about the background of the emergence of CSR. Countries and regions have developed their own views on CSR. In this study, cases of Japan, Europe and the U.S. are separately explained referring to SUZUKI (1992), FUJII (2005), SETO (2000) and UMEDA (2006).

In Europe, the CSR developed in the backdrop of serious unemployment issues associated with the establishment of the EU. In contrast to the interest of Japanese enterprises centering on environmental concerns, CSR in Europe deals with a wide range of social and human rights issues. Furthemore, Europe still carries political responsibility for their former African colonies, and an issue of developing countries is one of the pillars of CSR in Europe.

CSR in the U.S. centers on returning profits to the community, with which Japan is familiarized from trade friction experiences. The characteristic of American CSR is described as "philanthropy × community." As such, CSR is more commonly referred to as "corporate community service" in the U.S. While CSR in the U.S. developed under the social condition that calls for societal contribution, philanthropy and addressing diversity, after the Enron incident in 2001, the focus of interest has shifted to corporate governance.

CSR in Japan provided the purpose of a company as the creation of clients, and based on DRUCKER's concept that profit is its result, integrated the American marketing concept (i.e. consumer-oriented management principle), human relations theory (i.e. labor-management cooperation management principle), a view of the heterogeneous society (i.e. management principle with balanced social authority and responsibility) and the combination of a better productivity movement and nationalism (i.e. economic nationalism), developing a uniquely Japanese theory of social responsibility (SUZUKI, 1992). In addition to heavy political focus on environmental problems caused by pollution, and due to corporate scandals accounting for most legal violations, CSR in Japan is unique in a way that the term is used synonymously with compliance with laws and regulations. OGAWA (2007) pointed the aspect of the corporate ethics becomes stronger connected with the concept of the internal control. CSR in Japan is also characteristic that the ISO triggered the interest in CSR. By packaging the inherent problems of companies into the loanword "CSR," they attempted to give it social propulsion. On the other hand, the political theory that shapes the centerpiece of CSR has been dropped off in the process of casually introducing CSR to Japan (FUJII, 2005).

Given the variation in the meaning of CSR and the background of its emergence by country and region, this study targets the CSR in Japan. The basic part of this study consists of literature reviews of CSR theories regarding Japanese CSR and aims to clarify the significance of CSR activities. This is followed by describing the characteristics of forest-related activities of Japanese companies. Finally, this study discusses how the relationship between CSR and business should be and how forest-related activities based on CSR should be undertaken.

The method of study centers on literature research concerning CSR theories and shall be discussed in reference to the results of a questionnaire survey titled "CSR Activities Relating to Forests." Subject corporations of the questionnaire survey were extracted from two surveys "Environmental Brand Survey 2008"[1] and the "11th Environment-Conscious Management Survey."[2] The top 100 companies were selected from "Environmental Brand Survey 2008." In consideration of industrial balance, 30 companies were selected from manufacturing, 10 companies were each selected from sectors of non-manufacturing 1 (retail, food service), non-manufacturing 2 (finance), non-manufacturing 3 (trading), non-manufacturing 4 (transportation), non-manufacturing 5 (warehousing, real estate, others), non-manufacturing 6 (communications, service), electricity and gas, and construction, thus sampling a total of 110 companies from "11th Environment-Conscious Management Survey." Out of these 110 companies, 32 companies overlapped with the 100 companies sampled from EB, making the total number of subject companies 178.

The period of the questionnaire survey was from August to September 2008 and the response rate was 39% (69 companies out of 178). The contents of survey were about corporate forest-related activities, emission trading activities, and the activities of A/R CDM[3].

RESULTS

Significance of CSR Activities for Companies

CSR is based on the recognition of society, and thus is subject to change whenever there is a change in economy and society (FUJII, 2005; SUZUKI, 1992). Therefore, social responsibility

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[1] The survey was conducted by Nikkei Business Publications ECO Management Forum. The subjects of this online survey were general consumers (Responses: 20,233). 560 target companies were selected primarily from top sales enterprises in different industries. The major index was "Environmental brand indices" which consists of the degree of exposure to environment-related information, as well as the environmental communication index, environmental image index and environmental evaluation index.

[2] Annual survey of Nikkei, conducted from 1997, targeting companies for questionnaire responses. Respondent companies include companies listed on JASDAQ and other publicly-held companies, and non-listed major companies. The main index is "Environmental management score," which evaluates management system, long-term goals, anti-pollution measures, resources recycling, product measures, global warming efforts, and office.

[3] The Clean Development Mechanism (CDM) is a political measure based on the Kyoto Protocol imposing emission reduction goals for greenhouse gas (GHG) on industrialized countries. Based on the CDM, industrialized countries will undertake GHG emission reduction programs in developing countries, for which credits (CER: Certified Emission Reduction) are issued according to the resulting reduction amount and shared among the participants. The target of A/R CDM (CDM for GHG absorption) is afforestation (tree planting in areas which have not been forested for over 50 years) and reforestation (tree planting in areas which have not been forested since 1990). FUKUSHIMA (2006; 2009) and FUKUSHIMA and NAKAJIMA (2008), drawing on the results from interview surveys on relevant A/R CDM actors and onsite surveys they conducted in Fiji and Madagascar, pointed out the limitations of political promotion concerning A/R CDM under present rules.

is not performed by companies without a general principle, but is carried out in a way that social problems are resolved for the maximization of profit. In order to understand CSR, the modern society must first be understood, which specifically means to gain an insight into the society as well as consider the company itself in terms of its value, integrity as an organization, and its external influence. Business management that places foresight as the most important requirement for corporate survival must also undertake pioneering management without depreciating such changes in values (SETO, 2000). If CSR is simply conceived as "to follow rules and to be sincere" without including the socio-structural context such as the changes in role-sharing between government and companies and the direct impact of the developing countries' social governance issues on corporate activities, its essence is forgotten.

The significance of CSR activities for companies includes to enhance their reputation (UMEDA, 2006) and to establish their corporate brand (TAKA, 2004; FUJII, 2005; ITOH, 2004). These two consequentially points in the same direction. This is because while A) CSR undertakings minimize the risks of scandals that hurt corporate brand and of conflicts with civil society, companies can also B) enhance their corporate brand to make it more appealing for stakeholders through CSR activities. In addition, if C) CSR can improve employees' risk awareness and sensitivity, it can remove risk elements (brand risk, brand liabilities) in the stakeholders' trading with the company with the said corporate brand value. This will consequently contribute to the sustainability of the company. In such a way, CSR in recent years is rather more commonly positioned as a concept that evolves and innovates the management itself (ITOH, 2004). CSR introduces control from a multilateral perspective to corporate strategies, which tend to be pursued under the single standard of profit, and thus may contribute to enhancing management quality (MINATO, 2007).

What is required of a company is to reposition the corporate brand in the its social composition and to reconfirm and reestablish the corporate brand in the broader social term (FUJII, 2005). CSR activities should be regarded as an opportunity of 'dialogue' for polishing and enhancing corporate brand (ITOH, 2004).

Challenges in CSR

As such, CSR has now become a vital, socially-demanding element for sustainable growth of the company. However, on the other hand, CSR is accompanied with a variety of challenges such as those listed below (FUJII, 2005):

Against these challenges, several essential elements for successful CSR have become apparent:

The above items in need of improvement are all crucial. To develop CSR in the future, it is necessary to proceed with concept diffusion, promotion of commitment and establishment of partnership.

For companies, in relation to the significance of participating in CSR, the relationship between CSR and competitiveness is also a great concern. The correlation between the progress of CSR and the performance as a subject of investment remains unproven (TAKAOKA, 2004). Whether the CSR activity leads to improved competitiveness or not depends greatly on how it is approached, and to use CSR for the competitiveness of the company, CSR efforts must be incorporated in all lines of business (FUJII, 2005). With only social contribution as the standpoint, CSR will not be long-lasting with limited budget. Even when the company has ample budget at time of good performance, if a turn of the tide implicates immediate budgetary reduction, CSR will contain vulnerabilities in continuity and scale. The rapid subsiding of

Table 1 The Challenges of CSR

- CSR is unclear in its profitability despite its costliness in time and funds, and disregarding eco-efficiency, it falls short of evidence in how it may benefit the company.
- CSR requires great efforts including adaptation to new ways of operation in relation to the introduction of CSR and restructuring of the organization.
- There are not enough information and examples of actual approaches by companies.
- Consideration of environmental and social impacts of the company and the dialogues with stakeholders may become both complex and unclear.
- The borderline of responsibility is unclear – Which part of the organization, geographically and/or in terms of supply chain layer, should be held responsible?
- Stakeholders must be identified according to the issue.
- Priorities in CSR approaches include those conflict each other.
- Companies that cannot afford to participate in CSR due to lean budget and companies that do not place much importance in reputation may become involved in activities that contradict CSR.
- The term 'CSR' itself is, in particular, inapproachable to small-to-medium scale companies.
- State governance and the rule of law are weak in developing countries, and thus there is a shortfall in socially-underpinning facilities. Moreover, stakeholders are also powerless without sufficient funds.

Source: Created by author referring to FUJII (2005).

Table 2 The Essential Elements for Successful CSR

- Broad recognition of CSR among consumers and investors
- Commitment of executives, business owners, and senior management
- Integration of CSR efforts visions with the corporate culture
- Integration of CSR practice into the pivotal part of process and policy in corporate strategies, core businesses, and management control.
- Active collaboration with external stakeholders and discussions on issues, goals, and progress
- Access to specific advice to which companies can refer to, effective and reliable policies, and initiatives
- In regard to developing countries, legal environment that protects basic rights must be developed and stakeholders, labor unions, and civil social organizations such as NGOs should be present.

Source: Created by author referring to Fujii (2005).

Table 3 Specifics of CSR for Japanese companies (multiple answers allowed)

Items	Rate (%)
Provision of better products and services	93.1
Compliance with laws and regulations; Ethical conduct	81.4
Securing of profit; Tax payment	74.9
Distribution of dividends to stockholders and owners	67.6
Contribution to global environment protection	61.9
Development of new technologies and knowledge	51.6
Contribution to the development of communities	52.1
Creation of job opportunities	48.0
Philanthropy and mecenat	21.8
Contribution to the efforts against poverty and conflicts in the world	3.6

Source: Cited from Keizai Doyukai (2003), p.172.

the philanthropy movement and mecenat, which became a trend in the 1990s, reflects this problem. Therefore, in order to make CSR effective and sustainable in terms of developmental contribution, it is inevitable that CSR be positioned as a part of the actual lines of corporate business (FASID, 2008).

Relationship between CSR and Business

In the increasing interest in CSR, companies have come to acknowledge that CSR, which was previously considered a mere cost factor to clear pollution regulations in the same line as environmental efforts, is a management risk indispensable as an element of corporate value and that the capital injection to CSR is not a cost but an investment (Itoh, 2004). Besides, the CSR demanded today is not of the nature that unilaterally imposes burden on the companies. Instead, in CSR, companies seek to effectively use their management resources on the resolution of local problems and the support of socially vulnerable people with the understanding and cooperation from citizens, consumers, and employees, while exploring stronger competitiveness (Taka, 2004). Under such conditions, the recognition that the "CSR management is a necessity to facilitate corporate governance. A fair and open corporate management is now an important element in earning credibility from the clients and market," has become increasing prevalent.

In 2003, Keizai Doyukai (Japan Association of Corporate Executives) conducted a survey concerning the specifics of CSR for Japanese companies.

The results of the survey revealed that Japanese companies are especially inclined to view social contribution through business, namely the provision of products and services to the society, as CSR.

Reflecting this view, the Nikkei CSR Project Office (2004) referred to CSR as "a social contribution through business; nothing out of the ordinary." Under the circumstances where there is a strong trend of companies combining social contribution and their lines of business (FASID, 2008), the question here is "how" business is to be conducted (Fujii, 2005). Faced with environmental problems to which everyone is subject, companies are expected to take on a major role in combating such problems. Consideration of CSR includes reviewing the production system and business system for the 21st century, and involves issues of corporate philosophy and environmental ethics (Iwabuchi, 2000). Umeda (2006) argues that to contribute to the fair and sustainable growth of the society and economy in the lines of business that use the company's abilities and resources may be the objective of the

CSR Japanese companies should aim for.

Indeed profit is not an objective but a means of continuing business activities (Kawaguchi, 2004), but for companies whose primary reason for existence is to exert its economic functions, it cannot completely escape from the pursuit of self-interest even in the name of social contribution. Companies use the efforts to process environmental problems, the "external diseconomy," with "business logics" while exploring the approaches to global environmental problems and organizational re-creation on their own responsibility. In future community contributions, a practice of contributing to the community in their business activities is expected even from the aspect of off-market value creation. This stands on the nature of the CSR that as long as CSR mirrors social crises, regionality cannot be disregarded from CSR, as observed in the concept developed in the U.S. In consideration of the above, the idea of "discerning self-interest" (Umeda, 2006) will be an answer to "how" business should be conducted.

On the other hand, it is becoming increasingly difficult to draw a clear line between the actual lines of business and social contribution activities. However, regardless of whether the activity is based on the company's image boosting strategy or eco-business development, as long as it is tangibly effective for environmental conservation, such activities cannot be denied and eliminated as companies are naturally bound by the capitalistic market economy logic (Suzuki, 1992). CSR must also contribute to corporate growth as well as render service to the society's sustainable development (Fujii, 2005). Otherwise, corporate approaches to CSR themselves are not sustained. For companies, environmental efforts are also an opportunity for attaining further growth. What is necessary is active encouragement from the citizens' (movement's) side and that citizens develop the power to do so, and thus environmental conservation can be promoted as part of corporate responsibility. In doing so, it should be publicized that company-driven environmental efforts are a corporate responsibility in and of themselves.

However, the reality of CSR in Japan is that CSR is directed solely towards compliance with laws and regulations, namely the ethical responsibility. This is largely due to the fact that consumer interests are focused on limited subjects and that it is difficult to appropriately communicate corporate efforts to consumers. Abiding by laws and ordinances is a prerequisite that comes before the discussion of social responsibility (Suzuki, 1992). The point that it was the Japanese consumers' conception that popularized the idea among companies that compliance with laws and regulations is the pivot of CSR suggests that the citizens' awareness must change. CSR is a corporate social responsibility that also needs to transform into a "citizens' social responsibility" (Taka, 2004). Without citizens paying attention to corporate undertakings, evaluating them and taking actions based on that evaluation, corporate activities founded on social responsibility cannot be sustained. Present exertion of corporate social responsibility is lead by corporate leadership, but inevitably CSR will go through the discussion of citizens' social responsibility that calls for the understanding and cooperation of citizens.

The Results of the Questionnaire Survey "CSR Activities Relating to Forests"

The above sections dealt with the review of the theory of CSR in Japan. Through identifying the current status of the forest-related CSR activities, I will discuss its relationship with companies' business at the next section. I implemented the questionnaire survey "CSR Activities Relating to Forests," focusing on the corporate forest-related activities, emission trading activities and the activities of A/R CDM, from August to September 2008. The survey result is as below:

1) About CSR, 60% of companies responded as "CSR being a business opportunity" and "Non-implementation of CSR being a business risk." 2) 62% of companies are involved in forest-related activities in some way, irrespective of industry. 3) About the interest in the carbon sinks in relation to the Kyoto Protocol, domestic forest conservation activities achieved most interest from companies (41%) but 20% of companies are interested in overseas afforestation/reforestation (sink CDM). 4) 23% of companies have purchased emission credits, and 67% of companies have the high level of interest in carbon offsets, 5) About A/R CDM, 71% of companies have high recognition but 75% of companies are at the "Information collecting stage" with regard to participation.

In this paper, the important survey result is about B) Forest-related activities. While significant differences are observed in the content of activity, in terms of target country/region, area of activity and investments, the survey result revealed that 62% of the companies have been involved in some kind of forest-related activities or are planning to take part in such activities. Furthermore, much participation to forest-related activities is also observed in industries other than forestry and related industries. The objectives of investing in forest-related activities also varied from activities related to business operation such as materials procurement, to forest conservation, CSR, employee education, regional contribution and biodiversity conservation. Forest-related activities, other than materials procurement, such as employee education and regional contribution are more CSR-like in nature.

DISCUSSION

Based on the literature study and the results of the questionnaire survey above, I will discuss the relationship between CSR activities and the lines of business found in Japanese companies, as an approach from corporate forest-related activities.

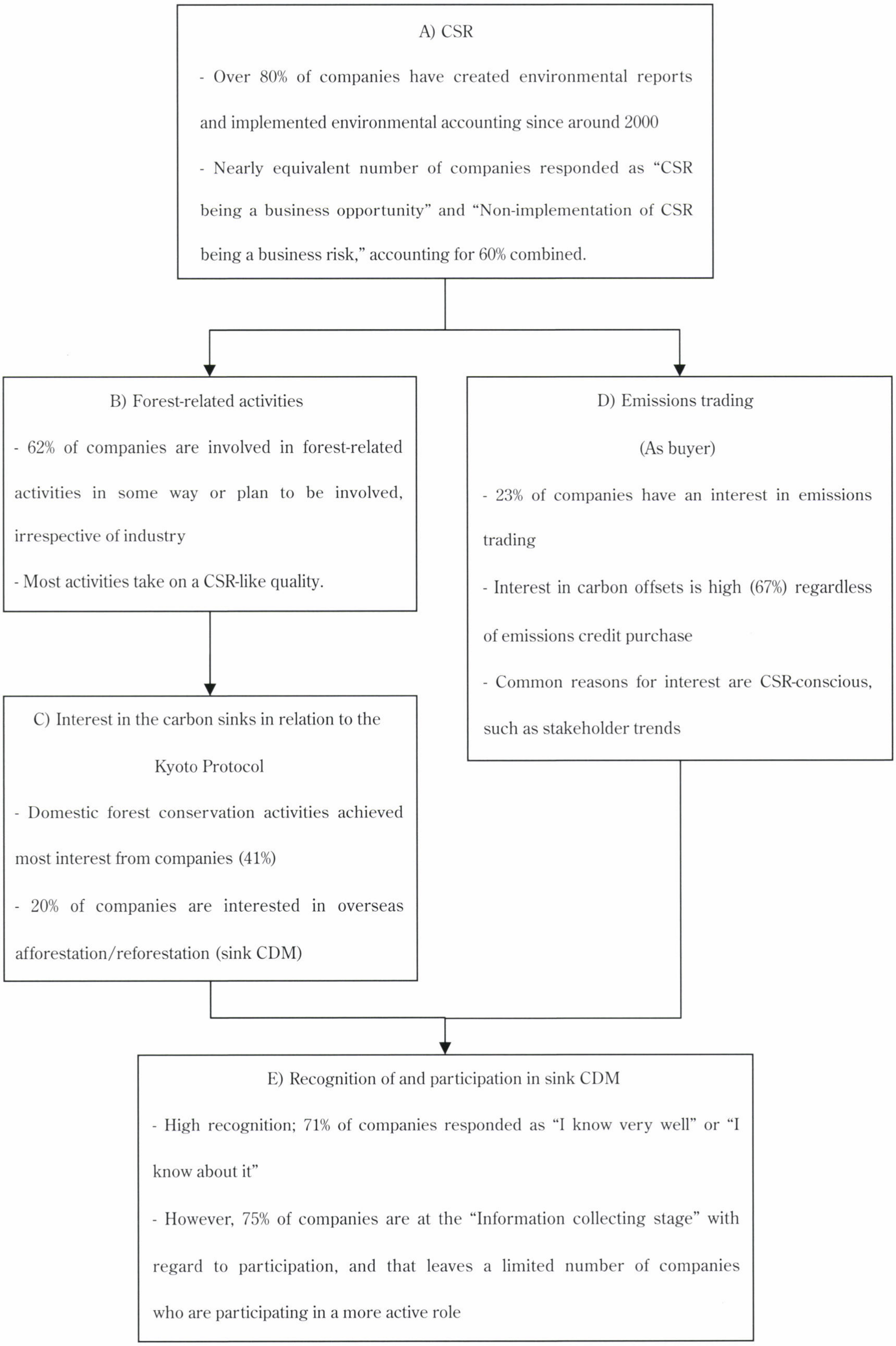

Fig. 1 Summary of CSR Survey Results
Source: Created by author based on survey results.

Relationship between the Lines of Business and Forest-related CSR Activities

TAKA (2004) categorized CSR into three phases: (1) Compliance in a narrow sense, (2) Practice of ethics (compliance in a broader sense), and (3) social contribution. CARROLL (1991) categorized corporate social responsibility into four groups: a) Economic responsibility, b) legal responsibility, c) ethical responsibility, and d) charitable responsibility. The a) economic responsibility is the base of the social responsibility pyramid, with d) charitable responsibility on the very top.

Normally, a company would consider Phase 1 and a part of Phase 2 in TAKA's (2004) categorization as targets that require actions to fulfill their corporate social responsibilities, in relation to the company's lines of business. In CARROLL's categorization, a) economic responsibility and b) legal responsibility fall in that range. Given this perception, a conclusion "forest-related activities and corporate lines of business are remotely related" can be drawn. This means that the actual state revealed by the survey, i.e. that many companies have an interest in forest-related activity or have already participated in such activity, cannot be sufficiently captured in the CSR concept of "social contribution through lines of business," advocated by TAKA (2004) and many other researchers. Therefore, this study defines CSR as "social contribution activities through and beyond the lines of business.' The philanthropy and mecenat, which became a boom in CSR activities in the 1990s, are activities categorized in Phase 3 of the TAKA (2004) categorization and d) charitable responsibility in CARROLL's (1991) categorization. These activities themselves can be valued as corporate activities and can be recognized as a CSR activity using the above definition provided that it is a social contribution activity that goes beyond the lines of business.

Among environmental activities required of a company, it goes without saying that measures of environmental protection in the lines of business come first in line. To give an example, promotion of GHG emission reduction and energy-saving in plants and offices through introducing regulations and technical development would be a measure in the lines of business. Another example would be to develop and deliver environmentally friendly products. On the other hand, there are criticisms of the CSR activities of Japanese companies where activities "beyond lines of business" tend to attract more attention and are thus implemented. A criticism in this regard is not based on the non-performance of these projects, which are fundamentally charitable activities, but on the tendency to restrict the amount of monetary investment because there is no requirement of scale. In fact, along with the collapse of the bubble economy and the demise of the boom, most philanthropic and mecenat activities disappeared. Another criticism from an environmental perspective argues that companies should concentrate on social contributions relating to the lines of business, such as "producing environmentally friendly products" and "reducing GHG in the course of production" as mentioned previously.

As such, the range of the lines of business has been discussed as being the economic and legal responsibilities, but considering that no company would do without paper in their course of business, forest-related activities can be associated with the lines of business in this sense. Philanthropy and mecenat, categorized in the said charitable activities, lead to the establishment of a corporate brand, and in broader terms that could also be considered to be in the lines of business. To what extent TAKA (2004) and other studies perceive 'lines of business' is not explained and therefore this exposes the limit of the CSR theories presented by Taka and other studies.

To overcome this limit, it is necessary to consider the range of the lines of business and CSR in portions. In relation to this, there are numerous suggestions to be also found in literature published in 2003, the so-called 'first year of CSR (in Japan),' and earlier. STEINER (1975) divided social responsibility into two categories "internal social responsibility" and "external social responsibility," and defined that the former is obligatory responsibility and the latter as responsibility beyond that. Similarly, TSUCHIYA (1991) presented the division "duty responsibility" and "response responsibility." MORIMOTO (1994) made the division "social responsibility in the narrow sense" and "social responsibility in the broader sense" and included legal responsibility, economic responsibility, and institutional responsibility in the former while adding spontaneous activities in the latter.

In the light of the above, the current mainstream concept of CSR "social contribution activity through the lines of business" advocated by Taka and others must be separated into the narrow sense and broader sense and defined individually.

Forest-related activities discussed in this study are basically activities beyond the lines of business (except in the case of paper and lumber companies), it shall be categorized as CSR activity in a broader sense. Traditionally, as pointed out in numerous studies, activities that go beyond CSR in a narrow sense (but fall under CSR in a broader sense) have not developed in investment scale. The survey results prove that while the high interest in forest-related activities was considered favorable in the light of promoting this field, the scales of projects and investments varied by company and were not significant. In the future, in order for a company's forest-related activity as CSR projects to be conducted in an 'appropriate' scale (the scale of activity considered 'appropriate' is determined by the society at the time and therefore specific numbers will not be given here), as one direction, there needs to be a change in recognition that activities categorized as CSR in broader terms are included in the range of social responsibilities taken on by companies and in correspondence with that change CSR must be incorporated into the core part of management strategies.

However, while such a flow may promote forest-related activities of an 'appropriate' scale, it may also work in the direction of decreasing forest-related activities without clear intentions, such as those intended to be used as environmental PR. If observed only from the perspective of forest conservation and recovery this may not be the desired direction, but considering the positioning of CSR activities in Japanese companies in general, and from a longer-ranged perspective of the sophistication of individual activities, such a shakeout shall be considered inevitable and not a matter to be denied.

I would like to state another point regarding the direction CSR will have to take in the future. This is drawn from the "sustainable growth" concept, a factor facilitating the increase of interest in CSR. That is to say, even for the company who is expected to contribute to creating a sustainable society, "sustainability" is an element required in every aspect including management and thus CSR should be considered in a longer span. In view of all that, activities aimed at establishing a corporate brand that were previously undervalued in the conventional short-term timeline may be considered to contribute to the company's sustainable growth in the light of a longer span, and consequently be given more weight in business strategic aspects. This has great possibilities in terms of encouraging forest-related activities categorized under CSR in broader terms that extend beyond the narrow sense, with an additional advantage of being able to accommodate the long-term nature of forest-related activities.

Toward the Promotion of Environmental Efforts through CSR

In order to promote environmental efforts including forest-related activities, CSR in the broader sense also needs to be evaluated and accordingly it must be incorporated into the core of the management strategy. In order to realize this, internal and external requests and new incentives would be necessary. Here, I would like to especially focus on the diverse stakeholders, a characteristic of CSR, and in particular review and discuss this in relation to climate change and forest-related activities.

CSR in Japan has been led by the initiatives of economic bodies, such as the Nippon Keidanren (Japan Federation of Economic Organizations) and Keizai Doyukai, and some multinational companies (GOTO, 2007). On this account, guidelines provided by the Nippon Keidanren and Keizai Doyukai have great impact on companies. For example, Nippon Keidanren established the 1% Club in 1990, encouraging spontaneous spending of 1% or more of the company's ordinary income and disposable income on social contribution activities. This is an introduction of efforts conducted in the U.S., where there is a 3% Club and 5% Club. An establishment of a 3% Club and 5% Club under the Nippon Keidanren would boost CSR activities. At the initiative of Nippon Keidanren, various social action programs, relating to environment, social welfare, education, international cooperation and so on, have been conducted (The Committee of Promotion of Philanthropic Activities of Nippon Keidanren, 2008). As for the activities of biodiversity which has received a lot of attention in recent years, Nippon Keidanren takes a leading role in the activities by domestic companies. It announced "Declaration of Biodiversity by Nippon Keidanren" in March 2009, which is for the International Year of Biodiversity in 2010. This initiative led to the actions of Japanese companies (KOHSAKA and TOKUYAMA, 2009) as below:

- 90% of companies considered biodiversity as a topic which needed to be taken into consideration in management decisions.
- 80% of companies were involved in the field of nature protection and biodiversity conservation, and 74% of companies were involved in the field of nature education.
- The companies referred to nature protection (74%), nature education (56%) and biodiversity conservation (38%) in corporate policies or management policies.

What is required of citizens, including consumers, is to put pressure on corporate activities in the form of public opinion and to check and evaluate CSR activities. The development of the "Corporate Social Responsibility" into the "Citizens' Social Responsibility" advocated by TAKA and Nikkei CSR Project (2004) has significance in backing such a reform of recognition. "Diversity" would become an increasingly important keyword (Keizai Doyukai, 2006) and citizens would be required to evaluate the individualization and differentiation in corporate activities. Therefore, citizens need to cultivate the ability to make decisions not easily influenced by mass media.

NGO activities that play a part in citizens' activities and the role of Social Responsibility Investment (SRI) are both indispensable elements in the promotion of CSR. NGO activities are not substantially active in Japan, and although its scale is gradually expanding, the scale of SRI is insignificant compared to those of the U.S. and Europe. In the U.S. and Europe, SRI implementation organizations do not limit their activities to investment but also offer meaningful company rankings to common consumers. This, of course, has great meaning for companies subject to ranking. For companies to position CSR activities at the center of their strategy, such encouragement from external factors is required.

Other influential factors include stockholders and the local residents who claim environmental development in the vicinities of company plants. The Nikkei "CSR Ranking" mentioned previously, and the "Environment Ranking" by the Sustainable Management Forum of Japan and Shiga Bank – the number of evaluation approaches are still small, but such approaches are expected to play a more active role in the aspects of CSR evaluation and diffusion. Furthermore, as pointed out by CHAPPLE and MOON (2005) and FORTANIER and KOLK (2007), multinational companies tend to have stronger interest in CSR. A pioneering role as an opinion leader is expected of multinational companies.

Lastly, this study offers a discussion based on an approach from a particular sector, namely the forest-related activities. Approaches from other sectors would be reviewed in the future.

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Short Communication

A Robust Estimator of the Density of Trees Exhibiting Regular Spatial Patterns

Stanko Trifković[*1] and Hirokazu Yamamoto[*2]

ABSTRACT

The c-tree sampling method has been proposed in the past as a rapid approach to estimate forest stand parameters. However, the use of c-tree sampling is not as simple as previously thought. In order to use it, we should have a broad knowledge on statistical methodology and estimators as well as on spatial patterns and their indices. Otherwise, the use of c-tree sampling could lead into wrong conclusions. Depending on exhibited spatial patterns and the type of estimator, c-tree sampling can yield a relatively high bias. Difficulties associated with accessing information on spatial patterns have been a reason to favoring robust estimators and there was a need to derive a new estimator of tree density which would be applicable in forest plantations. Density estimates with a newly derived estimator, named to as the "GM estimator", are compared with those obtained with the $(c-0.5)$ estimator and the $(c-1)$ estimator. The results have shown that the GM estimator can be used in a wide range of populations exhibiting regular spatial patterns; spatial patterns ranging from highly regular to those of random. This study is a step forward in promoting the use of c-tree sampling in forestry.

Keywords: forest plantations, Mean of Ratios, distance sampling, population density, spatial pattern

INTRODUCTION

The c-tree sampling method is a method designed along point sampling procedures and has a fixed (constant) number of individual trees per each sampling location (Fig. 1). By using it we attempts to assess information on forest parameters by statistically analyzing associated variable circular plots or plot radiuses. The method is also referred to as the density-adapted sampling (JONSSON *et al.*, 1992), the plotless ordered distance sampling (ENGEMAN *et al.*, 1994) or the n-tree distance sampling method (LESSARD *et al.*, 1994; HUSCH *et al.*, 2002).

The bias associated with c-tree sampling when estimating density of forest trees was the reason to avoid the use of this otherwise rapid method to inventorying forest resources; density estimates are influenced by spatial distribution of individual trees and the type of estimator (PAYANDEH and EK,

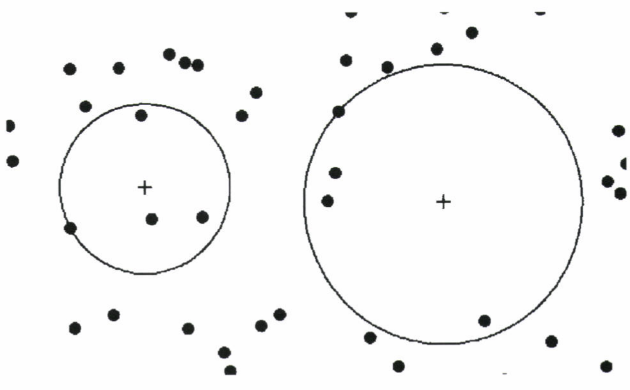

Fig. 1 The 4-tree sampling method; "+" represents centers of circular sampling plots and black dots represent individual trees

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1986; ENGEMAN *et al.*, 1994). Looking at variable circular plot areas as on statistical variables has shown to be especially practical since that approach is known by its robustness and it was proposed for the use in forest stands having regular, random or aggregated distribution of individual trees (EBERHARDT, 1967; PAYANDEH and EK, 1986; LESSARD *et al.*, 1994; LYNCH and RUSYDI, 1999).

Defining circular plot areas by a measurement of distances from sampling points to the centers of ordered constant number of trees (Fig. 1), we may find difficult to determine how many individual trees are contained on average in variable sized circular sampling plots. That resulted in different assumptions and thus in different estimators proposed in the past. One of the most studied density estimators in the past is that one proposed by EBERHARDT (1967), assuming that sampling plots contain $c-1$ trees on average:

$$\hat{\theta}_{c-1}=\frac{c-1}{n\pi}\sum_{i=1}^{n}\frac{1}{r_i^2} \tag{1}$$

where c is a constant and it is determined prior to the sampling procedure; the c represents an ordered number of the nearest trees from sampling points which is used to define the plot radius (following the Fig. 1., $c=4$). r_i are radiuses of variable circular plots or the distances measured to the c tree. n is the number of measured distances or the number of sampling plots (following the Fig. 1., $n=2$).

Comparison studies in the past have suggested that the $(c-1)$ estimator (Eq. 1) can be appropriate in forest stands having random or moderately clustered distribution of individual trees (PAYANDEH and EK, 1986; LESSARD *et al.*, 1994; LESSARD *et al.*, 2002). On the other hand, LYNCH and RUSYDI, (1999) have suggested that the $(c-0.5)$ estimator (Eq. 2) is more appropriate in forest plantations where the bias involved in the $(c-1)$ estimator was higher.

$$\hat{\theta}_{c-0.5}=\frac{c-0.5}{n\pi}\sum_{i=1}^{n}\frac{1}{r_i^2} \tag{2}$$

Originally proposed by PRODAN (1968) as an estimator of a stand basal area in the 6-tree sampling method, the $(c-0.5)$ estimator follows from an assumption that sampling plots contain $c-0.5$ trees on the average and it can be used to estimate stand density as well (PAYANDEH and EK, 1986; LYNCH and RUSYDI, 1999). The $(c-0.5)$ estimator (Eq. 2) is referred to as the generalized Prodan estimator (PAYANDEH and EK, 1986) or the Prodan's estimator (LYNCH and RUSYDI, 1999).

Applicability of the $(c-0.5)$ estimator in forest plantations having exhibited regular spatial patterns (LYNCH and RUSYDI, 1999) and its bias in forest stands having randomly or aggregately distributed trees (PAYANDEH and EK, 1986) have induced us to consider the probability that a variation involved in a sample of circular plot areas in regular populations is minimal and will increase in random and aggregated populations. The increase in the amount of a bias, occurring in density estimates with c-tree sampling, therefore might be proportional to the increase in variation of plot area sizes; similarly to the bias occurring when averaging major and minor diameters in estimations of elliptical tree basal areas (BIGING and WENSEL, 1988).

BIGING and WENSEL (1988) have shown that the use of the geometric mean can minimize a bias in estimations of elliptical tree basal areas. The geometric mean has also found the use in forestry when measurements follow exponential growth; for example, calculating the mean values in the statistical time series (KOPRIVICA, 1997). It is also known that the geometric mean of data sets is always smaller than or equal to the arithmetic mean. The geometric mean is equal to the arithmetic mean if all members of the data set are equal. Known statistical properties of both $(c-1)$ estimator and $(c-0.5)$ estimator, as well as statistical properties of the geometric mean, have induced us to propose a new density estimator. The new density estimator applies the geometric mean to averaging variable circular plot areas. We have denoted it to as the GM estimator. The GM estimator can be written as:

$$\hat{\theta}_{GM}=\frac{c-0.5}{\pi}\left(\prod_{i=1}^{n}\frac{1}{r_i^2}\right)^{\frac{1}{n}} \tag{3}$$

The objective of this paper is to propose the GM estimator as a robust estimator of the density of trees for cases when the trees exhibiting a regular spatial pattern.

METHODOLOGY

Simulating Regular Point Populations

Forest plantations can be planted in a form of triangular, regular square, rectangular network or following some other regular or irregular pattern (POTOČIĆ *ed.* 1987). In this paper we present three regularly distributed point populations where each point represents an individual tree in forest plantations. These are the regular-square, the lattice-regular and the rectangular point population (Fig. 2).

The regular-square point population was simulated in a form of regular squares having a 10-meter distance between points (Fig. 2). Spatial patterns of individual trees planted in regular spacing might highly differ than those theoretically simulated. That is mostly because the use of planting machinery can be highly interfered by terrain conditions particularly in mountainous areas where seedlings are usually planted manually. Foresters may not insist to plant seedlings in exactly equal spacing and such plantations could possibly have similar properties to that of the lattice-regular point population simulated by ENGEMAN *et al.* (1994) or LIU (2001). We have simulated the lattice-regular point population by laying regular squares having 10-meter sides. The points in each square were distributed randomly so the lattice contained one point per 100m² (Fig. 2). The rectangular point population was simulated along the rectangular network having 20 × 5-meter sides. Each

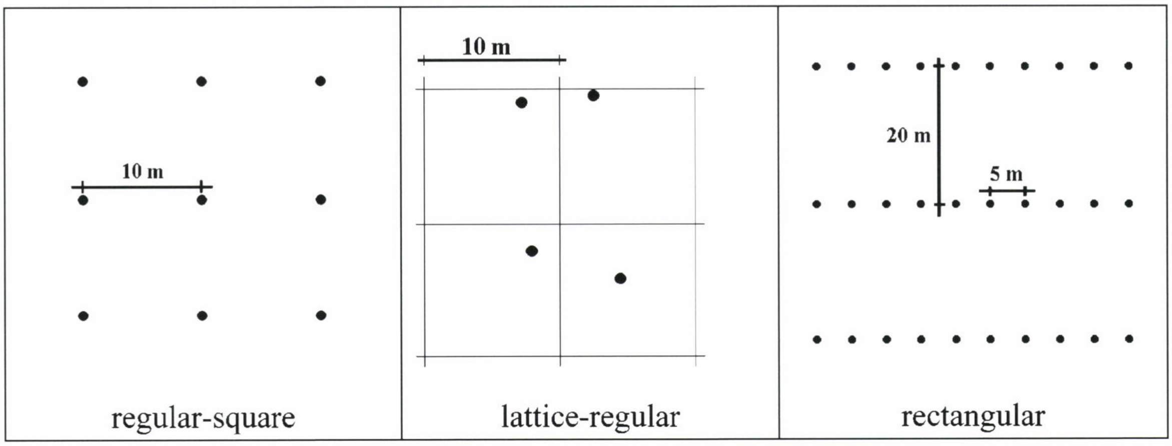

Fig. 2 Simulated regular point population patterns

simulated population is infinite in size so the edge-effect could not influence the density estimates.

Simulating Random Point Populations

We have simulated random point populations by using the computer random number generator along the homogenous spatial process according to, for example, LIU (2001). Assigning randomly derived numbers to the X and assigning other randomly derived numbers to the Y, in a homogenous Cartesian coordinate system ranging from 0 to 1, would result in a complete spatially random point population. Some statisticians, however, could argue that random numbers generated by using computers are not "perfectly" random, but such practices have found a broad use in biostatistical analysis (ZAR, 1999). We here present the random point population which is created in a Cartesian coordinate system by randomly distributing 100,000 points on a 100ha area (1,000 points/ha). Such a large point population was simulated because this random population is finite in size and the buffer-zone needed to be set in order to ensure that there is no influence of the edge-effect to the density estimates.

Field Survey

Field measurements are conducted at 6.48 ha of forest plantation established in 1906 at the Tokyo University Forest in Chiba. The total count of all trees was necessary in order to find the true density, but the research time limit did not allow us to map the tree positions. The measured plantation have had 243.25 trees/ha on average. It was difficult to conduct a random sampling procedure so we performed the measurement of distances from systematically distributed sampling points, as that is the practice in majority of forest inventories. We also did not insist on precisely distributing systematical sampling points so the spatial distribution of sampling points might be close to that of the lattice-regular (Fig. 2). A total number of 58 systematically distributed sampling points were established. Steep slopes at the Tokyo University Forest in Chiba, and at the measured plantation, make field surveys difficult. Therefore, we measured the distances up to the sixth ordered tree.

RESULTS

Density estimations are presented on the basis of their relative error:

$$\text{Relative error} = ((\text{estimated density} - \text{true density}) \times 100) \,/\, \text{true density} \quad (4)$$

Simulated Regular Point Populations

The $(c-1)$ estimator (Eq. 1) tends to underestimate density in simulated regular-square and lattice-regular point populations. The $(c-0.5)$ estimator (Eq. 2) and the GM estimator (Eq. 3) have produced very proximate density estimates in regular-square point populations. However, the $(c-0.5)$ estimator tends to overestimate density of lattice-regular point populations. In lattice-regular point populations, the GM estimator has had the smallest error. The error applying $c \geq 5$ was not noticeable and it could be neglected.

Density estimates in the rectangular point population does not follow the trend present in regular-square and lattice-regular point populations. The rectangular point population is a special case of regularly distributed point populations as it can also be regarded as an aggregated population composed by linearly distributed clusters. It should be emphasized that the estimates are generally getting closer to the true density with the increase in the c value. Relative errors observed when applying the $c=10$ sampling could be neglected and regardless to the estimator used in this study (Fig. 3).

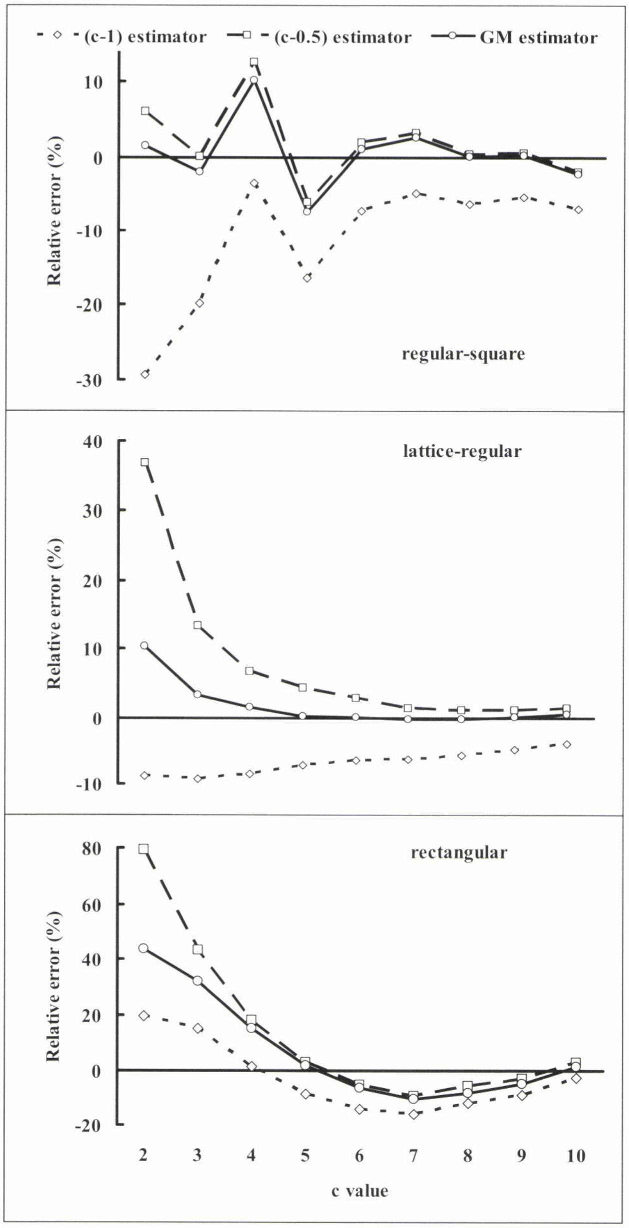

Fig. 3 Relative error of density estimates in simulated regular point populations

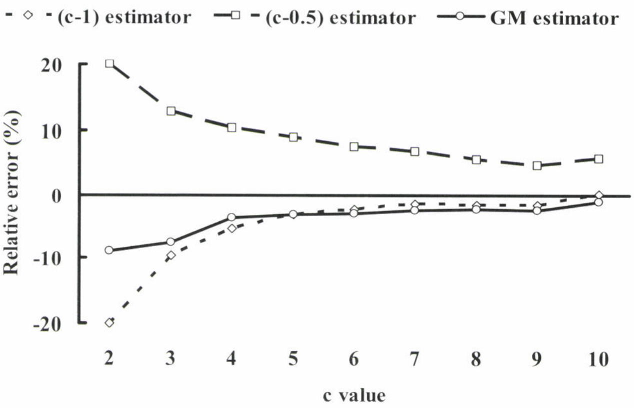

Fig. 4 Relative error of density estimates in simulated random point population

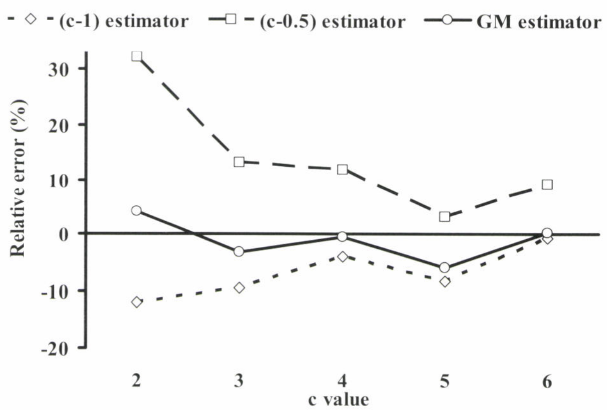

Fig. 5 Relative error of density estimates in aged forest plantation at the Tokyo University Forest in Chiba

Simulated Random Point Populations

In random populations, the $(c-0.5)$ estimator tend to overestimate the true density while that is opposite with the $(c-1)$ estimator. However, the $(c-1)$ estimator has produced estimates closest to the true density when applying $c \geq 5$ sampling. These estimates were slightly more accurate than the estimates with the GM estimator which has been more accurate when applying $c=2$, $c=3$ and $c=4$ sampling (Fig. 4).

Field Survey

The surveyed old-growth forest plantation has exhibited a regular spatial pattern but it has not significantly departed from the complete spatial randomness. The $(c-0.5)$ estimator has overestimated the stand density for all applied c values. The $(c-1)$ estimator tends to underestimate the true density but the $c=6$ sampling was highly accurate in this forest plantation. The GM estimator has produced the most accurate density estimates and for all c values except for the $c=5$ sampling where density estimates with the $(c-0.5)$ estimator were closest to the true density when compared to other estimators (Fig. 5).

DISCUSSION

Extensive efforts in the past were given to understand statistical properties of c-tree sampling and to bring this attractive approach to the practical use. Increasing needs set to forest inventories, and various sort of information needed to collect, are also the reason to further explore potentials of the "distance sampling" in overall and not only the potential of the c-tree sampling method. SHIVER and BORDERS (1996) have wisely noted that we unfortunately do not have a sampling method which is "so flexible and so efficient that it could be used regardless of the forest type and inventory objective". That and similar opinions have resulted into many studies on different kinds of statistical methods, like the "distance methods" discussed by BUCKLAND *et al.* (2001), or have brought to consider again many different estimators such as that one proposed by POLLARD (1971). All those studies are indeed very important to consider if we are decisive to using sampling methods being alternative to those conventionally used. That is also the case if we are decisive to using c-tree sampling to meet some of our forest inventory objectives. That is in fact the difficult part of applying these otherwise attractive and useful methods. Along to being able to perform and to think statistically, we should expertise the theory of spatial patterns and further studying spatial distributions of ecological populations such as a forest itself. If we are able to meet all these requirements, we would be able to consider c-tree sampling as an attractive sampling approach and would consider it for the use in forest inventories.

In cases when the trees are regularly or randomly distributed, the increase of constant number of individual trees per plot with c-tree sampling is able to produce estimates of the tree density which are reliable enough for many of our objectives in forest planning and management. Thus increasing the c value can reduce the need to completely remove the bias. Increasing the number of measurements would also not result into the increase of the bias and that would produce a lower statistical variance, thus giving us a higher confidence for our decisions.

Increasing the c to some high value, and using the c-tree sampling method to meet some of forest inventory objectives, could not be a practical approach. Fortunately, we can find a good use of spatial pattern indices. That is also recommended to test in all cases where c-tree sampling is to be used. There are simple and straightforward methods to choose from and they can obtain needed information on spatial patterns. We can recommend indices being proposed by LIU (2001) or the use of the method proposed by ASSUNÇÃO (1994).

Studies on the $(c-1)$ estimator suggested to use $c \geq 10$ (PAYANDEH and EK, 1986) or $c=5$ (LESSARD *et al.*, 1994). That is an example of the tradeoff between the practical applicability and required accuracy. That also depends on spatial patterns of trees in measured populations as it is known that the $(c-1)$ estimator would be accurate enough in nearly random populations when $c=5$. While, it is also known that the Pollard estimator (POLLARD, 1971) would be a better choice in populations exhibiting a complete spatial randomness; because of its likelihood properties which induce a smaller variance. On the other hand, the $(c-0.5)$ estimator can be acceptably accurate for most of our objectives when applying higher c values in regular populations which highly departing from a complete spatial randomness; such as the regular-square point population (Fig. 3). However, the $(c-0.5)$ estimator tends to overestimate density when applied to populations exhibiting a completely random pattern (Fig. 4) or in populations where spatial pattern indices do not show a large deviation from a spatial randomness such as the lattice-regular point population (Fig. 3) or the old-growth forest plantation at the Tokyo University Forest in Chiba (Fig. 5). Therefore, using the GM estimator can be justified. Considering its robustness, the GM estimator can be used in a wide range of populations exhibiting regular spatial patterns.

Here it should be emphasized that the estimates with the GM estimator should be taken with caution in cases where aggregation (clustered spatial pattern) is present in measured populations. That is the case with estimates in the rectangular point population (Fig. 3). The rectangular point population can be looked at as a population compiled by linearly (regularly) distributed clusters. In such and similar cases we can consider using other methods but there is also a real challenge to derive new estimators. And finally, utilizing all potential of distance sampling would not be possible without building capacities able to understand theories of spatial statistics. Once we succeed in that, we would be able to get reliable information out of otherwise biased methods.

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