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CONTENTS

Article

Article

Estimation of Vegetation Cover Ratio in Urban Area Using LANDSAT TM Images

Nobuyuki Abe*[1], I Nengah Surati Jaya*[2] and Hisaaki Kamioka*[1]

ABSTRACT

One of the major problems involved in surveying vegetation cover in urban areas using satellite images is that there are many areas of vegetation which are smaller in size than the resolution of satellite data. By overlaying satellite images with corresponding vegetation maps, we examined the relationship between vegetation cover ratio and vegetation index pixel by pixel. It was found that as the vegetation cover ratio decreases, the difference between it and the vegetation index becomes increasingly more significant. Based on the average vegetation index, we estimated the area of vegetation and found that this method was more accurate than the more widely used method of supervised classification for estimating vegetation areas. This was because our method is capable of estimating areas in proportion to the mix of vegetation cover, that is , it is more suitable for estimation of actual vegetation cover in urban areas.

Keyword: LANDSAT TM, vegetation cover, urban, vegetation index, GIS

INTRODUCTION

The most widely used technique to estimate vegetation cover using satellite images is that of supervised classification. In supervised classification, the result of classification changes depending on the method of ground truthing,. For example, when only pixels with a ratio of vegetation coverage of 100% are used for ground truthings the probability of being unable to classify pixels with mixed vegetation cover is high. If pixels with mixed vegetation cover are used for ground truthing, the classification of pixels with an unknown ratio of vegetation cover is unclear. It is unknown , what proportion of vegetation cover exists within the classified vegetation areas. Therefore, we superimposed vegetation areas on satellite images using GIS, to analyze the change in the digital number of pixels with changing vegetation cover ratio. Then,by using the digital number of pixels corresponding to the ratio of vegetation cover, the extent of vegetation cover in one pixel was analyzed.

Analysis by pixel unit requires various corrections at the time of image processing. Katoh (1994), however, reported that in the case of analysis using a vegetation index, radiometric and atmospheric corrections are not effective. In this study, therefore, correction was not carried out.

The superimposition of map information and satellite data was done visually, but, its accuracy could not be analyzed clearly. Accordingly, the general trends of changes in vegetation index by pixel unit are discussed, and reported in the case of vegetation coverage ratios for cities.

METHODS OF ANALYSIS

Data

In our experiment, we used the LANDSAT TM image of the region taken on 28 May 1993. The path-row was 108-34. As shown in Fig. 1, the region we analyzed was the western part of Niigata City, extracted from the LANDSAT TM data. The area we analyzed comprised 62,269 pixels and each pixel size is 28.5m×28.5m.

Ground truthing of vegetation areas was done using

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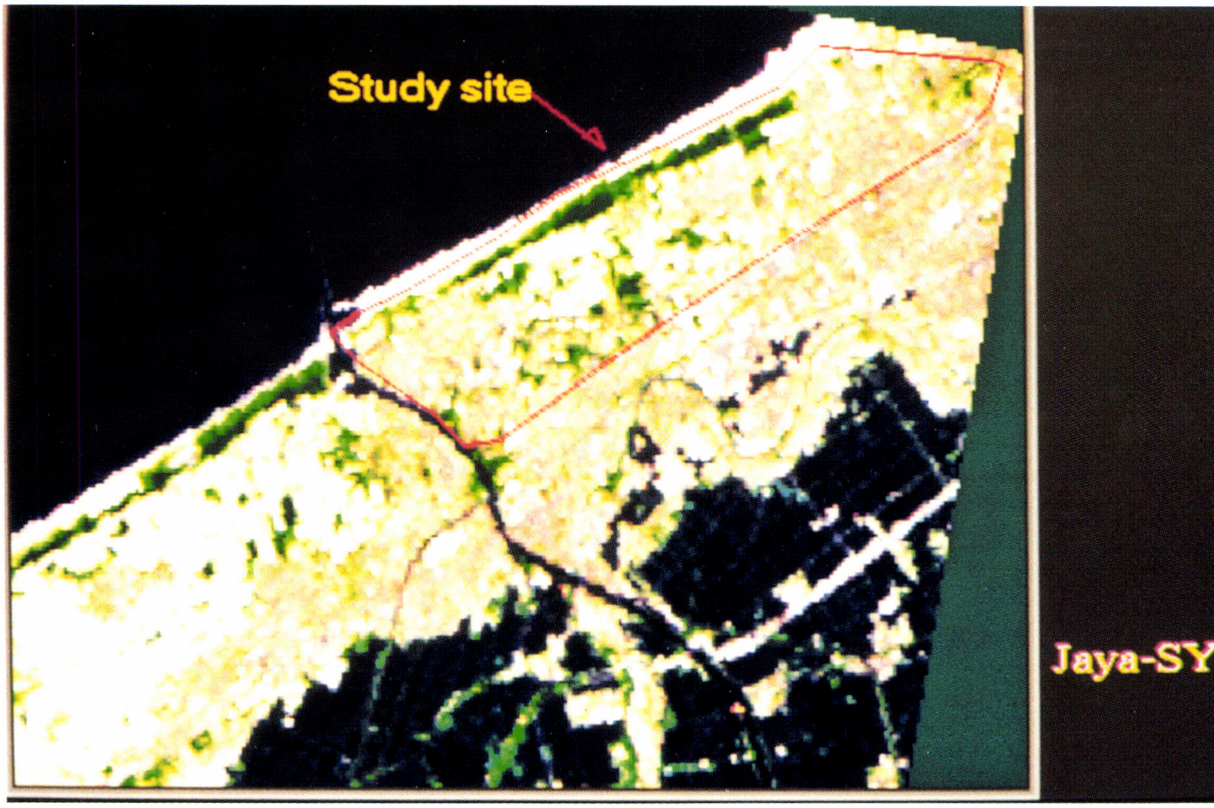

Fig. 1 Portion of the Landsat TM color images over the study area of Western Niigata city.

an aerial photo taken in 1993. Actual places of vegetation cover were located and transcribed onto a topographical map of 1/10,000 in scale. The vegetation of western Niigata is made up mainly of forest (*Pinus thunbergii*) with very little grassy cover and we analyzed only the forest cover in this work. Since the area analyzed was near Niigata University we surveyed actual places of vegetation if they were difficult to locate by means of aerial photos. We entered the areas of vegetation shown on the topographical map as polygons into GIS (Terra Soft) using a digitizer (Fig. 2).

Geometric correction

Geometric correction of the satellite data was done using the plane orthogonal coordinate system of a 1/10,000 topographical map,in which green areas were recorded, and taking 45 points of GCP. The map was constructed using plane orthogonal coordinates to enter the polygons as green areas and the positions of roads. When the map and the satellite images were superimposed and observed, it was considered from the relative positions of roads and vegetation areas in the satellite images that they were superimposed well.

Vegetation index

It is known that plant leaves have particular reflection characteristics. Reflectance of the red wavelength (corresponding to the band 3 of LANDSAT TM Data) is inversely proportional to the quantity of chlorophyll, and reflectance of near infrared wavelengths (corresponding to the band 4) is proportional to photosynthetic activity (JENSEN 1986). Many effective vegetation indices exploiting these properties have been proposed. TUCKER (1979) showed that the ratio of near-infrared Multispectral Scanner (MSS) band 4 and red MSS band 2 is significantly correlated with the amount of green leaf biomass. HONJO and TAKAKURA (1989) defined respective vegetation indices, and analyzed the relation of digital number with the ratio of vegetation coverage by using bands 3 and 4 of LANDSAT. Furthermore, HONJO and TAKAKURA (1987) detected vegetation areas using fuzzy clustering. LAUTENSCHLAGER and PERRY (1981) studied the empirical relationships among vegetation indices and found that they were highly correlated with each other. Vegetation indices such as these are effective for identifying green areas in urban districts (HOWARTH and BOASSON 1983; TODD 1977). They concluded that there were no significant differences

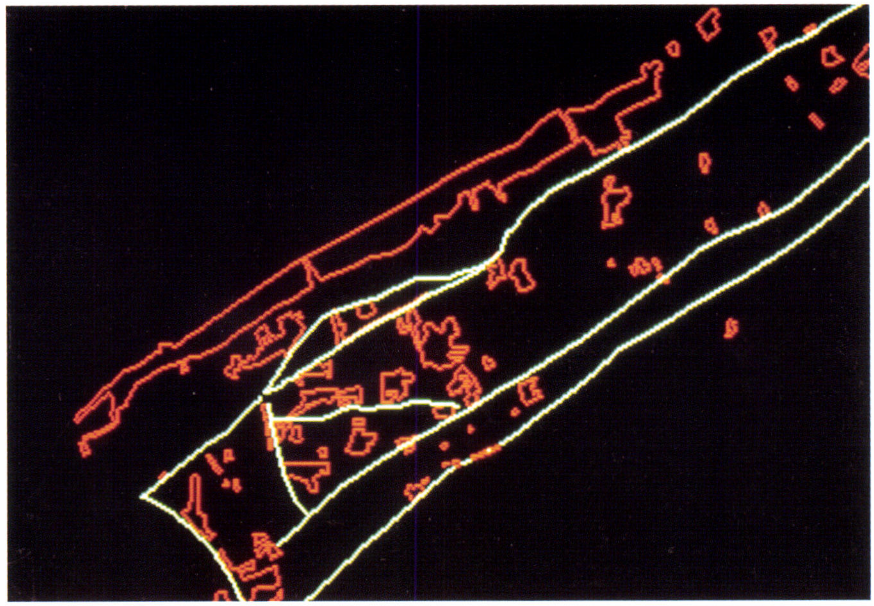

Fig. 2 Vegetation and road shown on the map as polygon using a digitizer

Table 1 Relationships ratio of vegetation and BR (BAND4/BAND3)

Ratio of vegetation	Num. of pixel	Mean of BR	Variance of BR
100%	133	1.8389	0.1694
100-75%	142	1.4519	0.1497
75-50%	68	1.4468	0.1686
50-25%	127	1.3589	0.1239
25% below	186	1.3110	0.1196
0%	97	1.2825	0.0960

between different indices. In our experiment, therefore, we defined the vegetation index (BR) as BR = BAND4/BAND3 and analyzed the relationship between its value and vegetation cover ratios.

Relationship between vegetation index and vegetation cover ratios

The Terra Soft software has the function of overlaying a satellite image (single band) and map information. Using this function, we overlaid the satellite image and the polygons that show vegetation cover after making the appropriate geographical adjustments. Then we read the vegetation cover ratio class and the digital numbers of bands 3 and 4 for each pixel. Specifically, we identified five vegetation cover ratio classes; 100%,100-75%, 75-50%, 50-25% and 25% or less.

Precision of the vegetation cover estimate

The area of vegetation cover can be calculated easily on GIS. Knowing the area of vegetation in the region surveyed, we determined the precision of two estimates: one using the conventional supervised classification method and the other the vegetation index with the vegetation cover ratio in a pixel.

RESULTS

Variation in digital values depending on the vegetation cover ratio

We examined how the vegetation index varies with the vegetation cover ratio of pixels. Table 1 shows the average and variance of the Band 4/Band 3 ratio for each vegetation cover ratio class. Analysis of variance (Table 2) of the vegetation index for the five classes of vegetation cover ratios showed that there was a significant difference

Table 2 Analysis of BR variance

Source	Sum of squares	D.F.	Mean squares	F Ratio	F prob.
Between groups	27.4795	5	5.4959	40.3219	2.22
Within groups	101.81	747	0.1363		
Total	129.2895	752			

Table 3 T-test of difference between each vegetation cover ratio class

	100	100-75	75-50	50-25	25-0	0
100	–	**	**	**	**	**
100-75	–	–	N	**	**	**
75-50	–	–	–	N	**	**
50-25	–	–	–	–	N	N
25-0	–	–	–	–	–	N

** ; Significant
N ; Not 95% Significant

Table 4 Result of classification using vegetation index

Number of category	Pixel number	Area (m²)	Vegetation Area (m²)
Vegetation (BR>=1.83)	537	436,178.25	436,178.25
Mix-vegetation (1.44<=BR<1.83)	936	760,266.0	380,133.0*
Mix-vegetation (1.35<=BR<1.44)	329	267,230.25	66,807.5625**
Non-vegetation (BR<1.35)	4,427	3,595,830.75	0

* : Total vegetation area×50%
** : Total vegetation area×25%

Table 5 Result of supervised classification

Number of category	Pixel number	Area of estimation (m²)
Forest	1,107	899,160.75
Bare soil	895	726,963.75
Urban1 (town1)	1,336	1,085,166.00
Urban2 (town2)	2,891	2,348,214.75

between classes at the 5% level. As shown in Table 3, the digital value of each pixel is affected by the vegetation cover ratio. For example, the 100% vegetation cover class is significantly different to every other vegetation cover class and the lower the vegetation cover ratio, the lower the value of the vegetation index. In supervised classification, estimation is difficult unless the vegetation ratio in a pixel is 100%. If, however, the vegetation index depends on the vegetation cover ratio in a pixel as shown in Table 1, it is possible to estimate the area of vegetation in one pixel by specifying the digital number corresponding to the vegetation cover ratio.

Estimating the area of vegetation from the ratio of vegetation coverage

If the trend of digital numbers associated with vegetation cover ratios is obtained, it is possible to estimate the vegetation cover in urban areas more accurately by multiplying the appropriate vegetation cover ratio by the number of pixels. Table 1 shows that the lower the vegetation cover ratio, the lower the vegetation index. As the mean value of BR for the vegetation cover ratio of 100-75% and that for 75-50% are almost the same , these were combined to form a 100-50% class leaving four class. The other classes, 50-25%, less than 25% and 100% were retained, vegetation cover classes. The range of BR corresponding to each vegetation cover ratio was estimated from Table 1. The area of vegetation in pixels from the less than 25%

class was small and it was therefore decided that this value need not be taken into account.

As a result, the total vegetation area was estimated to be 88.31 ha (Table 4, BR value more than 1.35). The total area classified as vegetation on the GIS is 83.57 ha. By comparison, the total vegetation area (expressed as forest) identified using the supervised classification method was estimated to be 89.92 ha. (Table 5) Thus, the estimate using BR was slightly more precise than the estimate using supervised classification. But the supervised classification method can be used to estimate vegetation areas only where one pixel is fully covered by greenery. By, contrast, the BR method makes it possible to estimate vegetation areas and prepare pictures according to the percentage of greenery in each pixel.

The image generated by supervised classification is shown in Fig.3 and the image classified by BR is shown in Fig.4. Four classes are shown in Fig.3 and the green areas indicate forests. Urban districts and districts with quite a few farmhouses are classified as towns. The extensive brown areas near the middle of the image represents the grounds of a university, vacant lots and sand dunes of the seashore zone. In Fig.4, the zones with a vegetation cover ratio of 100% represent vegetation and are shown in green. Zones with a vegetation cover ratio of less than 100% represent areas where vegetation is mixed with other features within one pixel and are shown in yellow. When both figures were compared, it was clear that in Fig.4 mixed vegetation pixels adjoin pixels with 100% vegetation cover. In this way, by using BR,the distribution of pixels corresponding to the ratio of vegetation coverage can be confirmed.

DISCUSSION

Work has been done to estimate vegetation cover in mixed in pixels of satellite data (HARUTA and INOUE 1989; TAKEUCHI 1987; HONJO and TAKAKURA 1989). TAKEUCHI (1987) reported high correlation between vegetation indices and vegetation cover ratios in pixels, but the estimates of vegetation area were determined by cluster analysis, not by ground truthing. HONJO and TAKAKURA (1989) tried to estimate vegetation cover ratios in pixels by using ground truth data that represented the actual picture of the surface to be surveyed. But there were some technical issues when overlaying the ground truth data and the satellite image. We used GIS to overlay the satellite image with vegetation areas identified by aerial photos and on-site surveys. Judging by the positions of roads and the pixels classified as vegetation areas, it was considered that the superimposition was done relatively well. It can therefore be said that the vegetation cover ratio for each pixel represents the actual vegetation cover of each pixel.

HONJO and TAKAKURA (1989) tried to estimate vegetation cover ratios using regression between vegetation indices and vegetation cover ratios, but there was a very wide range of fluctuation. One reason for this was that the overlapping of the satellite image and ground truthing positions was inaccurate. The work estimated vegetation area directly from the values of vegetation index distribution corresponding to vegetation cover ratios. Although there is some overlapping of the distributions of BR values corresponding to vegetation cover ratios, it is possible to estimate the area of vegetation without using mathematical formulas by directly specifying BR. In cases where there are many pixels with a vegetation cover ratio less than 100%, such as in urban areas, the method of ground truthing was difficult. Images for which the value of BR is directly designated such as Fig.4, can also show the pixels in which green areas exist in a mixed state, and is effective for understanding the actual state of vegetated areas.

CONCLUSION

We analyzed the relationship between vegetation index and vegetation cover ratio using GIS, which is capable of superimposing satellite image data and map information. It was found that vegetation index values calculated from LANDSAT TM data varied with vegetation cover ratio at a statistically significant level. It was possible to estimate the areas of pixels which corresponded to different vegetation cover classes. A comparison with the actual area of vegetation showed that in terms of precision, estimates using BR were more precise than estimates using the generally employed supervised classification.

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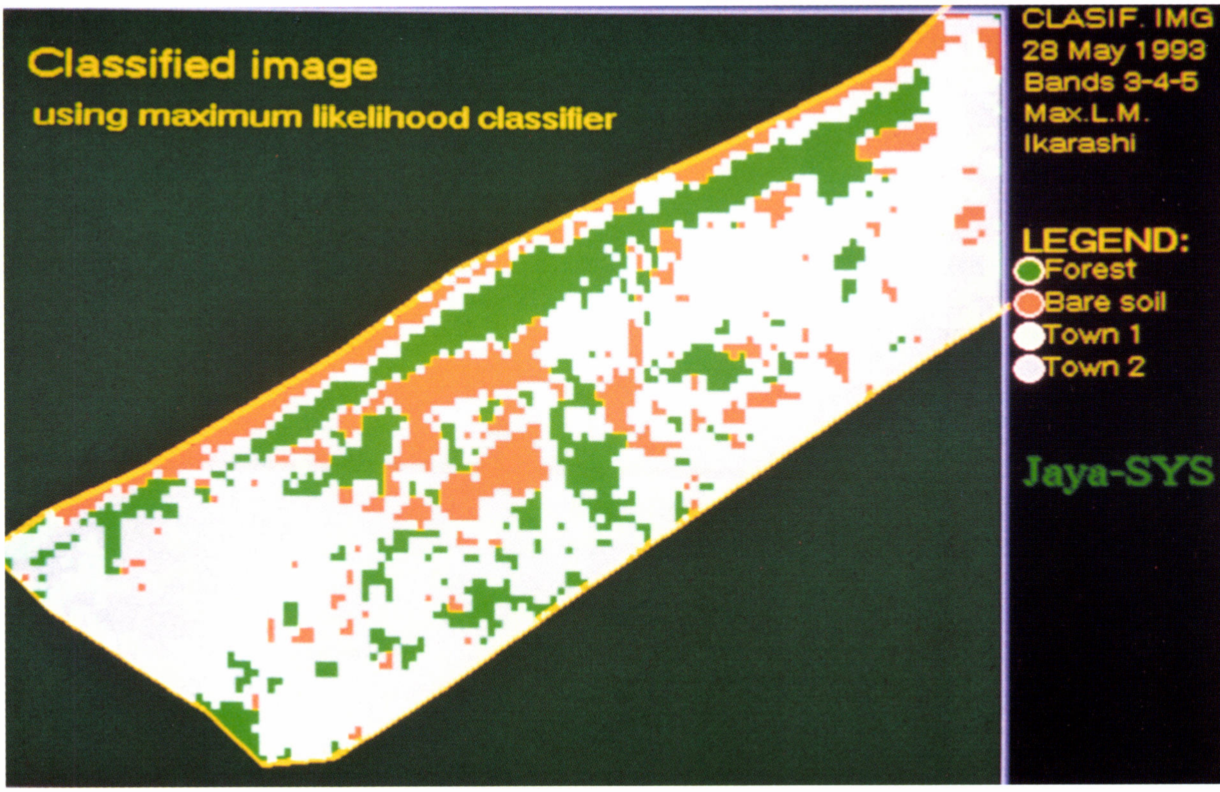

Fig. 3 The image by the supervised classification

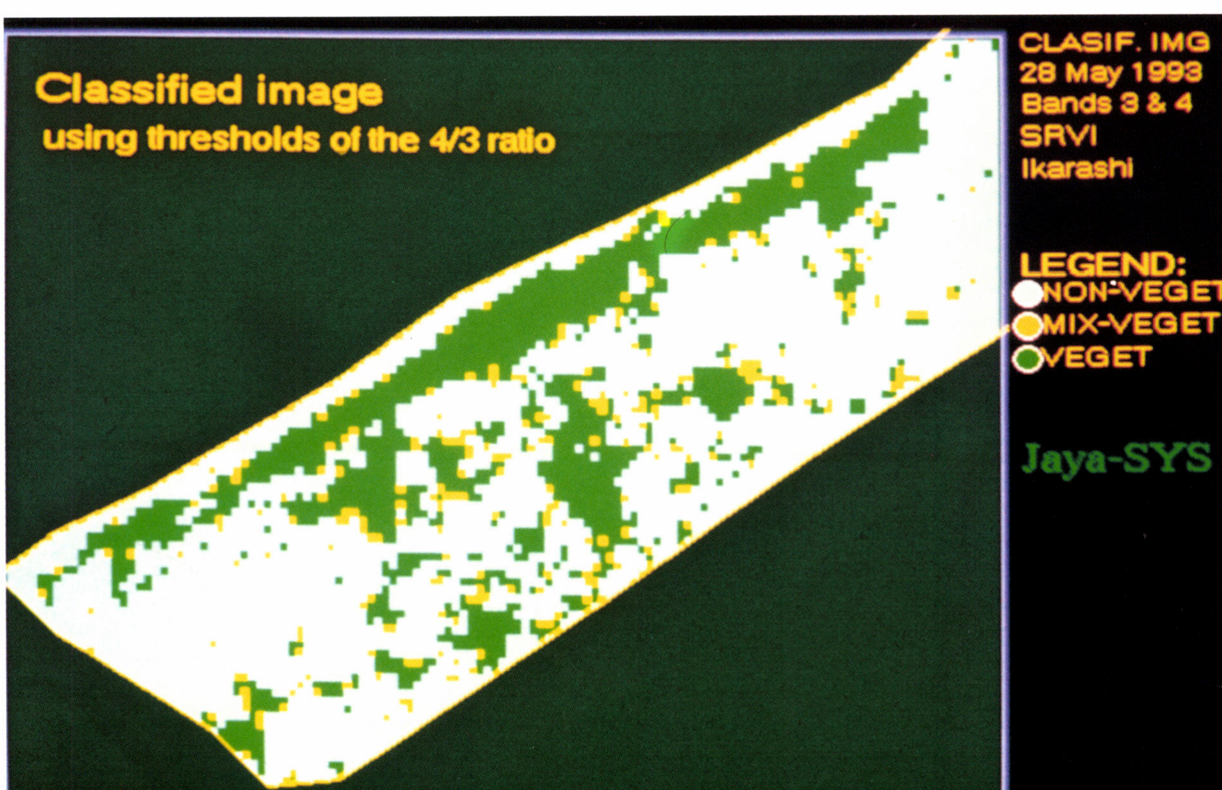

Fig. 4 The image by the BR value classification

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Article

An Analysis of the Recent Situation and Problems in the Cutting Reporting System

Koji Matsushita*

ABSTRACT

This paper clarifies the current status of the cutting reporting system in Japan. This system was enacted as part of the Forest Law after the Second World War. Initially, a cutting permission system was introduced, and this was later changed to the current cutting reporting system. Recently, the percentage of forest owners filing cutting activities by the cutting reporting system has been low. As a result, several problems have occurred, for example, the forest resource database can not be updated. To determine the reasons why forest owners do not file the cutting reporting form, a questionnaire was conducted in July 1995, and responses were obtained from 666 forest owners and 33 forest advisors. It was found that: (1) The percentages of forest owners and forest advisors who are familiar with the cutting reporting system are 49.1% and 66.7%, respectively. Over 20% of both categories are not even aware of the existence of the system. (2) The percentages of forest owners and forest advisors who filed all cutting activities during the past five years were 12.2% and 5.0%, respectively. There were many forest owners who did not file cutting reports even though they were aware of the system. (3) The reasons why forest owners do not file the report are not only a lack of familiarity with the system and its requirements, but also erroneous or deliberate misinterpretation of the system, i.e., a cutting report is not required if cutting activities are small in size. (4) Of the forest advisors, 45.5% recognize the necessity of reporting cutting activities for the promotion of the local forestry program. The importance of the cutting reporting system and the possibility of promoting its use are discussed and six policy recommendations are presented. Most notably, increased publicity must be started as soon as possible.

Keyword: cutting reporting system, cutting age, forest owner, questionnaire survey, Forest Law

INTRODUCTION

As cutting activity is the most important forestry practice, governments have made an effort to obtain correct information about such activities. The cutting reporting system requires that forest owners or logging companies who are planning to cut trees in non-national forests to report the cutting plan before proceeding. The system is an important management tool in prefectural governments.

The cutting reporting system is part of the forest planning system in Japan, and is based on the Forest Law. The forest planning system, especially in cases involving the local planning system, is primarily for managing timber production in Japan. Many non-timber utilities are also considered in the forest planning system, but these are generally added factors. However, non-timber values of forests have become more important and as a result, the role of the cutting reporting system is thought to be changing. In addition, recently different types of cutting activities, other than clear cutting, have become more common, and it is important for the local forest planners to obtain correct information on cutting activities.

In Japan, Gifu prefecture is well known for its forest resources information system which uses various kinds of forestry policy programs, including a cutting reporting form. Using a forest resource database connected to the cutting reporting system, SHIRAISHI (1994) studied the intensity of forestry operations from the perspective of accessibility. IWATA and FUJIWARA (1994) and MATSUSHITA

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et al. (1994) also used the database of Gifu prefecture to analyze cutting activities. In the absence of a database connected to the cutting reporting system, cutting activities must be analyzed by calculations based on the cutting reporting forms at the local prefectural government offices or local forest owners associations. In 1992, MATSUSHITA *et al.* calculated that 3,685 cutting reporting forms were available for analysis.

The most important and well-known problem of the cutting reporting system is that the proportion of people who understand the system is low, so, many forest owners tend not to report their cutting activities to the prefectural government. For example, YAMAUCHI *et al.* (1994) pointed out that the ratio of cutting volume estimated by cutting reports was 70% of the cutting volume from clear cutting in Ibigawa Forest Planning Area in Gifu prefecture, the prefecture with the most developed forestry information system in Japan. In cases involving cutting methods other than clear cutting, the percentage must be considerably lower, even in Gifu prefecture. Figures like these are not released to the public by the prefectural governments, but reported cutting activity is estimated to be less than 50% in most areas. As a result, local governments can not obtain correct information on cutting activities.

This paper investigated the current situation and problems in the cutting reporting system in Japan. It is important to clarify the forest owners' attitudes toward the cutting reporting system if the program is to be reformed in the future. Therefore, a questionnaire on cutting activities and the cutting reporting system was conducted in Hokusatsu Forest Planning Area in Kagoshima prefecture in 1995, and the main findings are presented in this paper. The current role of the cutting reporting system and the policy recommendations for the reform of this program are discussed.

SUMMARY OF THE CUTTING REPORTING SYSTEM IN JAPAN

The cutting reporting system was established under the Forest Law (enacted in 1951, last revision 1991). According to Article 10, forest owners who are planning to cut trees in non-national forests are required to report their cutting plan to the prefectural governor 30 to 90 days before cutting. The report must include the place, cutting area, cutting method and cutting age of the forest, and other related matters specified by Ministerial ordinance. Article 10 also specifies exceptional cases. Article 207 specifies penal provisions for the cutting report. A fine not exceeding 300,000 yen (approximately US$3,000) shall be imposed upon a forest owner who cuts trees in non-national forests without filing a cutting report.

The standard cutting report form shown by SHINRIN KEIKAKU SEIDO KENKYUKAI (1992) includes the following items: cutting place, cutting area, classification of final cutting or thinning, classification of clear cutting or selective cutting, cutting ratio, cutting species, cutting age, period for cutting activities and utilization after cutting (for example, farm). A remarks column is included to note the reforestation method after cutting and restrictions on forestry practice under specific laws and regulations such as national park regulations. In the case of protected forests, a separate application for cutting permission is needed.

The cutting report is useful for forest planning. First, to maintain a correct database on forest resources, accurate data on cutting activities is necessary. If forest owners do not file cutting reports, local governments can not update their forestry databases and, as a result, high-aged forests which have already been cut down will be shown as continuing to grow in the database. Another important role of cutting reporting system is to clarify the trends of cutting activities in real time.

One of the basic ideas of Japanese forestry policy after the Second World War, especially forest resource policy, was to ensure freedom in forestry management. After the war, domestic forest resources could not satisfy the high timber demand of the postwar recovery period. Consequently, a permission system for tree-cutting was introduced in the first Forest Law after the war, in 1951. This system was changed to the cutting reporting system under the revision of the Forest Law in 1962. Since then, the cutting report has become the main source of information about cutting activities for prefectural governments. Another important source of information is the subsidy program. Recently, almost all planting has been done with subsidies from the Forestry Agency of the Japanese Government. To be eligible for the subsidy, forest owners must file a cutting report, which allows local government to update the database on forest resources. However, where forestry practices are not subsidized, it is difficult for local governments to obtain information.

FOREST OWNERS' ATTITUDES TOWARD THE CURRENT SYSTEM

Summary of survey area and forest owners

The survey was undertaken in the Hokusatsu Forest Planning Area in Kagoshima prefecture, in the southern part of Kyushu. Sendai River is the main river in this forest planning area. The total forest area in Hokusatsu Planning Area is 127,648 ha, 74.3% of which is privately owned. The main species are *Chamaecyparis obtusa* (37.1%), *Cryptomeria japonica* (20.5%) and broad-leaved trees (31.0%). The total standing volume in 1992 was

17,975,000 m^3, and the average standing volume per ha was 140.7 m^3. The annual cutting volume was between 200,000 m^3 and 250,000 m^3 between 1989 and 1993. In this forest planning area, there are 17,545 forest owners according to the 1990 Agriculture and Forestry Census, and 11,508 of these owned less than 1ha. There are 6 forestry owners associations in the area. In July 1995, a questionnaire was conducted among the representative forest owners (called *Soudai*, total number 1,194) listed with these associations and forest advisors (called *Shidou rinka*, total number 93) in this planning area. Of these, 666 representative forest owners and 33 forest advisors responded, the response rates of 55.8% and 35.5%, respectively. It is desirable to present a profile of representative forest owners and their forest management practices before moving on to the main task. The following items were clarified by the questionnaire.

The average age of forest owners is 64.4-years-old, and the average age of the forest workers (usually the forest owner and his family, but occasionally including temporary employees) is 62.9-years-old for men and 61.0-years-old for women. The issues related to an aging society that are common in all Japanese industries are also found in forestry, where there is a high percentage of old people among private forest owners and forestry workers. The main sources of income for forest owners were annuity (27.5%), agriculture (26.4%) and salary (14.9%). Only 2.6% of owners indicated that their most important income source was forestry. The percentage of forest owners who had any income during the past five years from the forestry sector, including minor forest products such as mushrooms, was only 13.9%.

The average forest holding was 4.4 ha. The number of forest owners classified by the size of their holding was as follows: 14.1% (less than 1 ha), 64.3% (1-5 ha), 12.3% (5-10 ha), 5.4% (10-20 ha), 3.8% (larger than 20 ha). This is typical of forest holdings in Japan, where the management area is very small and this small area is divided into several stands. Most forest owners have artificial forests, mainly of *Cryptomeria japonica* and *Chamaecyparis obtusa*. For 41.7% of forest owners, over 80% of their forest was artificial, and for 60.5%, over 50% was artificial. A high proportion of forest owners (39.9%) did not have any artificial forests older than 41 years, the standard rotation age in this forest planning area. Most artificial forests in the area are in the age-class that require tending.

The percentage of forest owners who worked in the forest during the past five years is shown in Table 1. Overall, 27.1% of forest owner did not perform any of the work listed in this table. The forest practices commonly done by the owner are thinning of trees less than 35 years old (62.0%), pruning (59.7%), weeding (57.8%) and cleaning-cutting (56.1%). The main labor force is the forest owner, his family and forest workers from the forest owners associations. In thinning and final cutting, the role of the forest owners association is important. The survey area had suffered typhoon damage in 1993, and a number of forest owners had been doing salvage work. The rates of activity shown in Table 1 are slightly higher than expected because of the typhoon damage.

Generally, the logs produced by thinning do not always sell. For example, the percentage of forest owners who sold all logs produced by thinning forests less than 35-years-old was only 14.7% and 43.9% of forest owners could not sell any logs produced by thinning. The percentage of forest owners who used even a small portion of

Table 1 Forest practices during the past 5 years

(person, %)

Forest practice	Total		Family		Cooperatives[1]		Other	
	Number	Ratio	Number	Ratio	Number	Ratio	Number	Ratio
Planting	105	22.4	61	13.0	32	6.8	12	2.6
Weeding	271	57.8	149	31.8	98	20.9	24	5.1
Pruning	280	59.7	155	33.0	98	20.9	27	5.8
Cleaning cutting	263	56.1	116	24.7	124	26.4	23	4.9
Climber cutting	165	35.2	78	16.6	73	15.6	14	3.0
Thinning (1-35 years)	291	62.0	117	24.9	153	32.6	21	4.5
Thinning (over 36 years)	78	16.6	24	5.1	45	9.6	9	1.9
Clear cutting (artificial forest)	92	19.6	9	1.9	76	16.2	7	1.5
Clear cutting (natural forest)	39	8.3	6	1.3	27	5.8	6	1.3
Natural forest improvement	22	4.7	7	1.5	9	1.9	6	1.3
Multi-storied forest	5	1.1	3	0.6	0	0.0	2	0.4
Forest road construction	15	3.2	2	0.4	10	2.1	3	0.6
Spur road construction	33	7.0	6	1.3	21	4.5	6	1.3
Other	9	1.9	1	0.2	7	1.5	1	0.2

Note: 1) Forest owners associations.

thinning for domestic consumption was 37.1%. It is worth noting that thinning does not always produce income in Japan.

Recognition of the cutting reporting system

Several questions related to the cutting reporting system were prepared for the forest owners' questionnaire. The forest owners surveyed were divided into 2 groups, namely, representative forest owners of local forest owners associations and forest advisors in the survey area. The advisory system is managed by the prefectural government, and the main objective of the system is to support the forest owners by providing local forestry extension services. In this analysis, representative forest owners are called Group A and forest advisors are called Group B.

The awareness among forest owners of the cutting reporting system is shown in Table 2. The percentage of the forest owners who were not aware of the existence of the system was 25.2% in Group A and 21.2% in Group B. The cutting reporting system is a basic and important policy program for forest resource management and is specified in the Forest Law, a basic law on forest resources and forestry. Nevertheless, one-fourth of forest owners and over one-fifth of forest advisors, do not even know of the existence of the system. Extensive publicizing of the cutting reporting system is strongly recommended in the light of this finding. The percentage of forest owners who indicated awareness of the system was 49.1% in Group A and 66.7% in Group B. It is not clear what percentage of forest owner know the actual contents of the cutting reporting system, for example, the exceptional rule, as there were no questions in the questionnaire to check whether forest owners knew the details of the system. It should be required that forest advisors in the prefectural government understand the contents of the system.

The current percentage of owners who file cutting reports is summarized in Table 3. In Group A, 55.9% of forest owners answered that they have not cut at all during the past five years. When compared to the forestry activity rates shown in Table 1, it seems that the forest owners who did not answer must have cut trees during the past five years, so a second ratio was calculated representing the percentage of owners who had done some type of cutting during the past five years. Using this calculation, the percentage of forest owners who did not file a cutting report was 53.1% of Group A and 60.0% of Group B. It is surprising that over half the forest owners, including forest advisors, did not file any cutting reports during the past five years. The percentage of forest owners who filed all cutting reports was only 12.2% in Group A and 5.0% in Group B. Why is it that such a small number of forest

Table 2 Awareness of the cutting reporting system

(person, %)

Answer[1]	Group A		Group B	
	Number	Ratio	Number	Ratio
I know of the system.	327	49.1	22	66.7
I have heard of the system.	159	23.9	4	12.1
I do not know of the system.	168	25.2	7	21.2
No answer	12	1.8	0	0.0
Total	666	100.0	33	100.0

Note: 1) Question was "Are you aware of the cutting reporting system?".

Table 3 Filing cutting report

(person, %)

Answer[1]	Group A			Group B		
	Number	Ratio[2]	Ratio[3]	Number	Ratio[2]	Ratio[3]
I have not cut at all.	372	55.9	-	13	39.4	-
I have filed all reports.	36	5.4	12.2	1	3.0	5.0
I have filed some reports.	38	5.7	12.9	4	12.1	20.0
I have not filed any reports.	156	23.4	53.1	12	36.4	60.0
No answer	64	9.6	21.8	3	9.1	15.0
Total	666	100.0	100.0	33	100.0	100.0

Note: 1) Question was "Have you filed cutting report during the past five years?"
2) Percentage for all items.
3) Percentage without "I have not cut at all".

owners filed the report?

Table 4 shows the relationship between awareness of the cutting reporting system (Table 2) and the filing of cutting reports (Table 3). Considering of those forest owners who indicated an awareness of the cutting reporting system, 30 forest owners filed reports for all cutting activities, 26 forest owners filed reports for some cutting activities and 52 forest owners did not file at all. Thus, almost half of the forest owners who were aware of the cutting reporting system did not report their cutting activities during the past five years. Of course, almost all of the forest owners who were not aware of the system did not file reports or did not answer this question. The responses of forest owners who had only heard of the system and did not know its contents were similar to those forest owners who were not aware of the system. To increase the number of cutting reports filed, it is necessary not only to promote understanding of the system, but also to teach forest owners how to file the report with the local forestry office.

Reasons why forest owners do not report their cutting activities

As shown in Table 4, almost half of forest owners who were aware of the cutting reporting system did not report their cutting activities at all. Why did they ignore the law? Table 5 indicates some reasons. This question applied only to forest owners who did not file at all (156 persons in Group A, 12 persons in Group B) or who filed some but not all reports (38 persons in Group A, 4 persons in Group B) during the past five years (see Table 3). The number of answers for this question was 184 from Group A, a response rate of 94.8%. Similarly, 81.3% of Group B responded. The percentage of answers to this question was high and indicated that the forest owners do not consider it illegal to cut their own trees without filing a report. However, it is against the Forest Law to cut trees without filing a report before the cutting activities begin. Most forest owners say they are decidedly against the rule.

Many owners (42.4%, Table 4) also indicated that they believed that the cutting area was so small that the cutting report was not required. Generally in Japan, the management area of privately owned forest is very small and the size of forest practice is small. However, there are no regulations on cutting report relating to the size of the cutting area. A cutting report is required for all cutting activities regardless of size.

Another problem is related to the system itself. Among those responding, 32.1% indicated that they did not know of the existence of the system and 19.6% indicated

Table 4 Relationship between awareness and filing

(person)

Awareness of the cutting reporting system	Filing cutting report[1]					
	No cut	All	Part	Not filed	No answer	Total
I know of the system.	190	30	26	52	29	327
I have heard of the system.	96	5	9	34	15	159
I do not know of the system.	78	1	2	70	17	168
No answer	8	0	1	0	3	12
Total	372	36	38	156	64	666

Note: 1) Items are shown in Table 3.

Table 5 Reasons why forest owners did not file cutting report

(person, %)

Answer[1]	Group A		Group B	
	Number[2]	Ratio[3]	Number[2]	Ratio[4]
I do not know of the existence of the system.	59	32.1	4	30.8
I do not know the contents of the system.	36	19.6	3	23.1
I do not know where to file cutting report.	3	1.6	0	0.0
Procedure for filing cutting report is cumbersome.	9	4.9	1	7.7
As the cutting area was small, thought the roport was not required.	78	42.4	5	38.5
I was afraid that the cutting report would be used for taxation.	2	1.1	0	0.0
Other	35	19.0	2	15.4

Note: 1) Question was "Why did you not file a cutting report for all of your cutting activities?".
2) Plural answers.
3) Percentage of persons who answered this question (184 persons).
4) Percentage of persons who answered this question (13 persons).

they did not know the contents of the system. It is a problem that such an important system is not widely and correctly understood by forest owners. In addition, it is also problem that forest owners who do not know the contents of the system tend to ignore the law. They ought to obtain advice on what to do from a forest advisor. However, as shown in Table 2, Table 3 and Table 5, the situation is almost the same among advisors (Group B). If owners wish to obtain more information on the system, they have to go to the forestry extension agent for advice.

The percentage of answers relating to filing procedures for the cutting report was not as high. The filing procedure was considered cumbersome by 4.9% in Group A and 7.7% in Group B. The percentage of forest owners who answered that they were afraid to use the cutting report because of taxation was only 1.1% in Group A and 0 in Group B. This finding was limited by the questionnaire for forest owner.

It is worth considering whether small cutting activities should be reported. As already indicated, currently it is illegal not to report because of the small size of the cutting area. Article 10 of the Forest Law includes several exceptions for reporting. One exception is cutting for domestic consumption, and 37.1% of forest owners who had thinned forests less than 35-years-old during the past five years used at least some of the thinning domestically. Although cutting for domestic use is excepted under Article 10 of the Forest Law, a different form must be filed specifying that the cutting is for domestic consumption. Furthermore, cutting for domestic consumption is limited by regulations relating the Forest Law to 2ha in Hokkaido, and 1 ha outside Hokkaido. I cannot say for certain how many forest owners are aware of this rule, but probably there is lower awareness of this rule than of the cutting reporting system. Another exception under Article 10 is clearing-cutting. It is possible that forest owners think of various forest practices, including cleaning-cutting, thinning, and final cutting, as "cutting". Accordingly, it is almost certain that there are some cases that do not require reporting of the cutting activities.

DISCUSSION

Importance of the cutting reporting system

In this section, the current significance of the cutting reporting system is discussed. To begin, a few remarks should be made concerning the role of the cutting reporting system after the second World War. In 1951, the Forest Law was enacted, and the permission and reporting system on cutting was created. In the 1951 law, permission was required if the forest was protected or the age of the forest was less than the specified rotation age and reports were required for other reasons. As the supply of domestic forest resources was poor because of destructive cutting during and just after the war, strict forest resource control was necessary to maintain forest resources and increase the future supply of forest products without importing. In the 1957 amendment to the Forest Law, the cutting limitation for broad-leaved trees outside protected forests was abolished, and changes were made to the reporting system. In the 1962 amendment to the law, cutting limitations for needle-leaved trees were also abolished. In the 1974 amendment, prefectural governors were given the authority to order forest owners to change their cutting plans, and a new permission system for conversion of forest land was created.

The cutting reporting system was gradually introduced, replacing the permission system for cutting activities. The main reason why the permission system was changed to the reporting system was the reduced cutting pressure on domestic forests, especially in private forests. Recently in Japan, the self-sufficiency rate of log supply has decreased, reaching 22.4% in 1994. By comparison, the rate was over 90% in the 1950s. The percentage of logs imported from foreign countries has steadily increased in this time, and the productive capacity of private forests has decreased relative to that of foreign countries due to the small labor force and the delay of mechanization. The total growing stock of domestic forest resource was approximately 3,483 million m^3 at the end of fiscal 1994 (FORESTRY AGENCY 1996), and the total cutting volume was 32,638 thousand m^3 in fiscal 1994 (FORESTRY AGENCY 1995), so the ratio of cutting volume to growing stock is currently only 0.9%. We have 158 regional forest planning areas in all of Japan, and there are no planning areas with a cutting volume exceeding the sustained yield. Under these conditions, the importance of the permission system declined.

It is possible that recently the cutting reporting system has not been enforced by prefectural governments, at least from the perspective of maintaining local forest resources. The current percentage of total growing stock that is cut (0.9%) is not likely to increase, because the growing stock is expected to continue increasing for a while. Thus, the role of the cutting reporting system in sustaining or improving forest resources is not as important as the past role of the permission system. The cutting reporting system, however, has four other important roles.

The first role is that the cutting reporting system will contribute to building accurate databases on forests in Japan. The basic database related to forest resources, called *Shinrinbo*, is managed by the prefectural governments. This database includes data about forest owners and forest land. In the first category, the name of the forest owner, their occupation, whether the forest owner lives in the area, existence of an approved forest operation plan and so on are included. In the second category, compartment number, sub-compartment number, species, age, volume, volume at the cutting period, locality class, and various legal regulations are included. This is a unique database covering all private forests. However, this database has several weak points. The most serious one is the lack of an effective updating system. Basically, this database is updated by the cutting reporting form, although data from some permission forms for the conversion of forest land and several forestry programs is also used for updating. However, the most important source of updated information on forest resources is the cutting reporting form, and the percentage of reporting to actual activities is low. As a result, for example, the database may indicate an old-age forest which has actually been cut and newly replanted. Such discrepancies have been increasing, and one reason is the inadequacy of the cutting reporting system. The database requires an effective updating procedure, and the cutting reporting system can fulfill this role.

The cutting reporting system also contributes to the regional forestry economic information system. In the Japanese forestry sector, especially in the administrative sector, the utilization of computers has not progressed quickly. However, several information systems, including a Geographical Information System, have recently been considered, and various kinds of regional forestry information centers have also been suggested to assist the development of the forest economy. In Japan, the holding size of forests in the private sector is very small, and the distribution system from log production to mill is inefficient. The introduction of an information system has been widely discussed to improve domestic log supply. Information on cutting activities and an accurate forest resource database would be useful for the development of such a local forestry information system.

The third important role of the cutting reporting system relates to the requirement that forms be filed 30 days to 90 days before cutting. Most information on forest resources and forestry is *ex post facto* data. The cutting reporting system is reports in advance, and although currently the utilization of this cutting reporting form is almost always limited to updating the database, it could be used for forecasting regional cutting activities. In regional forest planning, forecasting the cutting volume over a planning period is important. Currently, this forecasting is a long-run estimation based on the supply side model, using *Gentan Probability* theory, an application of the Markov chain model. However, accurate data from the cutting reporting system could be effectively utilized. The cutting reporting form reports the area to be cut, and the cutting volume has to be calculated using other data, for example, species, age and site index. If all forest owners in a forest planning area filed their cutting schedules correctly in advance, the local forestry office or forestry information center could make short-term log supply forecasts. This would also allow optimal labor force distribution.

The fourth role of the cutting reporting system is its contribution to the understanding of the overall structure of forestry and wood related industries. The person obligated to file a cutting reporting form is, strictly speaking, the person who is planning to cut. In most case, this is forest owner himself, but sometimes, it is the buyer of standing trees. Currently, precise data on log distribution is not clear in most areas, especially concerning the buyer of standing trees. If the cutting reporting system is properly carried out, we could obtain many important economic facts for the local secondary forestry industries which would be useful for the development of local forestry policy. Recently in Japan, stumpage price and log production has decreased. As a result, the economic importance of forestry is decreasing. Establishing economic development policies in rural areas is an important issue and understanding the economic structure is the first step in developing effective local policies.

Possibility of promoting the cutting reporting system

This study found that the percentage of people filing cutting report forms is low, despite the penal provisions for cutting without reporting of Article 207 of the current Forest Law. To improve this situation, strengthening the application of the law may be an available and effective method. However, this is not in accordance with the basic philosophy of post-war forest extension policy.

First, what do forest owners think about promotion of the cutting reporting system? Table 6 shows the opinions of the advisory forest owners (Group B) on the necessity of promoting the cutting reporting system. Approximately half of the forest advisors are aware of the necessity. The problem is the other half, especially, the 27.3% of forest advisors who responded that it would be difficult to promote the cutting reporting system, although they recognize the necessity of such a program. The reasoning behind this opinion was not investigated in this questionnaire, but there may be some good reasons why forest owners do not wish to cooperate with the basic forest policy. Recently, most

Table 6 Necessity of filing promotion of cutting report

(person)

Answer[1)]	Number	Ratio
Necessary to promote local forestry	15	45.5
Difficult to promote	9	27.3
Do not understand	1	3.0
Other	3	9.1
No answer	5	15.2
Total	33	100.0

Note: 1) Question was "What do you think about the promotion of filing cutting report?"

forestry practices such as planting, thinning, and forest road construction, are performed under Government subsidy. Government subsidies also support local forest owners associations, and contribute to the construction of most forest roads. Final cutting is not subsidized, although many government subsidies may have been invested in growing the trees to final cutting age. The reporting of cutting of subsidized trees seems to be an obligation in these circumstances. Nevertheless, it is a serious situation that many forest owners even in advisory positions have given up on promoting the cutting reporting system.

Finally, I would like to conclude this analysis by making policy recommendations for promotion of the cutting reporting system. The following six points are strongly recommended.

(1) Since recognition of the system is low, activities related to disseminating information about the cutting reporting system must be initiated. There are many opportunities for publicity campaigns, for example, the annual meetings of forest owners associations, regular meetings in the community, discussion meetings between town or village offices and inhabitants, and training courses on forestry techniques.

(2) Promotion and teaching about the system is also necessary. Owners need to be taught when reporting is required, how to file the form, where to file the form, and the definition of exceptional cases. Of forest owners who indicated awareness of the cutting reporting system in Table 2, approximately half of the forest owners did not understand the system in detail. Materials are also needed for forest advisors to promote the system.

(3) It is also important that forest owners also understand the roles of the cutting reporting system in the development of forestry planning policy. Although the size of cutting areas is generally small in Japan, gathering data of small cutting areas can help identify patterns in cutting activities. As further changes are made in forest management, the role of the cutting reporting system will increase.

(4) Improvements in the cutting reporting system must be simultaneous with improvements in the utilization system. One reason for the inadequacy of the current system is the poor use of the information. The system includes useful information for local forestry management, and can be used to update resource databases, in return providing better information for planning and management.

(5) The current system has several weak points in practice. For example, some of the exceptions enacted in Article 10 of the Forest Law are complicated and more simple rules would be easier to understand. For example, "all cutting activities except cleaning-cutting must file a report" would be more understandable for forest owners. Modifications are also needed to cope with the various cutting methods that have been introduced into private forest management recently. In the current cutting reporting system, the clear-cutting system is assumed to be the standard.

(6) The cutting reporting system is important for managing forest resources at the local level. An extension program, including the advisory system, facilitates communication between the administrative office and the numerous forest owners. However, responses to this questionnaire suggested that forest advisors and extension staff have not played an adequate role, at least in this survey area. A program to improve the extension sector is also needed.

CONCLUSION

In this paper, the current status of the cutting reporting system in Japan has been clarified using a questionnaire in Hokusatsu Forest Planning Area in Kagoshima Prefecture. The cutting reporting system replaced the cutting permission system initiated after the Second World War. Since then, great changes have occurred in economic development, social conditions in mountainous regions and forestry conditions, but the system has remained unchanged. As a result, many forest owners do not even know of the existence of the cutting reporting system, and the forest resource database contains many errors resulting from cutting reports not being filed. In the information age, the cutting reporting system assumes new roles in addition to its traditional roles. Strengthening the publicity given to the cutting reporting system as well as restructuring the system itself would be highly advantageous to local forestry development.

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Article

Improvement of the Stand Density-Control Diagram and Construction of Yield Tables for Shii (*Castanopsis* spp.) Stands

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ABSTRACT

This report deals with yield tables of natural shii (*Castanopsis* spp.) stands for timber production developed using a stand density-control diagram. Since natural hardwood stands such as shii stands don't generally have normal diameter distributions, mean diameter doesn't give appropriate information about the numbers of trees. Median or upper-hinge diameter, however, give direct information about tree number for any distribution types. In the light of the discussions, the shii stand density-control diagram was improved by replacing equivalent mean diameter lines with equivalent upper hinge lines. Then management plans for timber production were discussed and a site index table was compiled. These led to the development of yield tables for different goals of timber production goals.

Keyword: yield table, *Castanopsis* spp., stand density-control diagram, upper hinge

INTRODUCTION

Shii (*Castanopsis* spp.) forests occurs in southwest Japan, and is the main species in the evergreen hardwood forests there. shii stands are managed for production of wood-chips because of their rapid growth and easy management, although in the past they have been managed for timber production to make good use of the straight stems. Timber production has become of interest again recently because timber provides greater returns than wood-chips, but yield tables for timber production are required.

Stand density-control diagrams and accompanying management methods were developed by Ando (1968) and are the most popular management method for softwood plantations in Japan. Awaya and Matsumoto (1986) constructed a stand density-control diagram for shii stands, but it was based on mean diameter which may be questionable for natural hardwood stands.

The purpose of this paper is to improve the stand density-control diagram for natural shii stands, and to construct yield tables for timber production.

STAND DENSITY-CONTROL DIAGRAM AND A QUESTION

Stand density-control diagram

Ando (1968) developed the stand density-control diagram and the accompanying management methods based on the theory of density effect described by Kira *et al*. (1953, 1957a, 1957b, 1957c). The stand density-control diagram shows the relationships between stand density, stem volume, tree height and diameter on a plane. The condition of a stand is represented by a dot on the diagram, and the growth and treatment of the stand is represented by the transition of the dot; a line in short. The characteristics of stand density-control diagrams were described by Konohira (1996).

Ando first constructed diagrams for softwood plantations, such as sugi (*Cryptomeria japonica*), hinoki (*Chamaecyparis obtusa*), akamatsu (*Pinus densiflora*) and

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karamatsu (*Larix leptolepis*). ANDO and others made various diagrams for other softwood species and various regions. Then the method was extended to regenerated hardwood stands such as kunugi (*Quercus acutissima*), buna (*Fagus crenata*) and shii on the assumption that their diameter distribution were similar to that of artificial softwood stands.

A question of stand density-control diagram on natural hardwood stands

Stand density-control diagrams were developed for artificial softwood stands. Since these stands are uniform, their diameter distributions can be assumed to be approximately normal. In a normal distribution, mean diameter indicates not only maximum frequency, but also an approximate center of distribution. In short, half of the trees are bigger than the mean, and half are smaller.

On the other hand, what about diameter distributions of natural hardwood stands? Fig. 1 shows the typical diameter distribution of a natural hardwood stand in Kyushu region. It is an L-type distribution and the mean doesn't give important information about the number of trees. Thus, the mean gives inadequate information about distribution characteristics and the number of trees in natural hardwood stands. Although there is no space for an extended discussion about diameter distributions on natural hardwood stands, it is sufficient to say that in general, they are not normal.

Therefore, it can be said that mean diameter is inappropriate for natural hardwood stands, and we should search for another value that can represent the characteristics of their diameter distribution successfully.

IMPROVEMENT OF THE STAND DENSITY-CONTROL DIAGRAM FOR SHII STANDS

Median and upper hinge

While mean is the most common statistic used to describe the distribution of data, median must not be forgotten. The median is defined as the center value when data are arranged in order from minimum to maximum. The median represents the center of distribution, and half the population is bigger than the median value. It is important to note that this definition doesn't change with any distribution type.

Exploratory data analysis, which was developed by TUKEY *et al.* (1977), regards median as the most important value to represent data. It also regards hinges as important values. A hinge is defined to be the median between median and maximum, or between median and minimum. The hinge between median and maximum is called the upper hinge, and the hinge between median and minimum is called the lower hinge. According to the definition, half of the data will be between the upper and the lower hinges, and a quarter of the data will be between the upper hinge and the maximum. Fig. 2 shows a box-and-whisker plot and 5 numbers, which helps clarify the relationship of these values.

Fig. 3 shows locations of mean, median and upper hinge on the same distribution as Fig. 1. This figure shows that when the distribution is not normal, the mean does not represent the center of the diameter distribution of the stand. The median and upper hinge, however, can give important information about the number of the trees whose diameters are bigger than them, although the distribution is not normal.

It is useful to be able to estimate how many trees are bigger than a specified diameter for timber production.

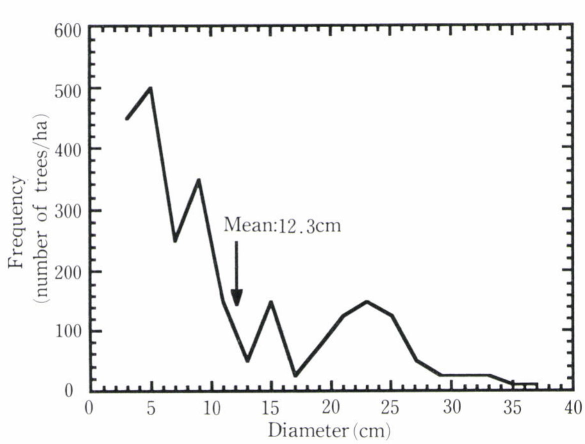

Fig. 1 Diameter distribution of a natural hardwood stand

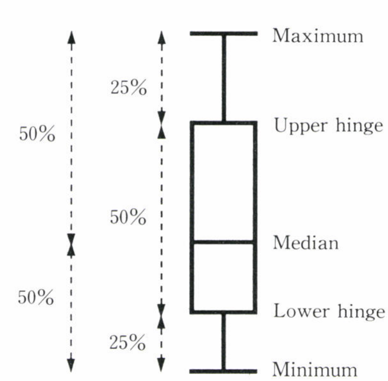

Fig. 2 Box-and-whisker plot and 5 numbers

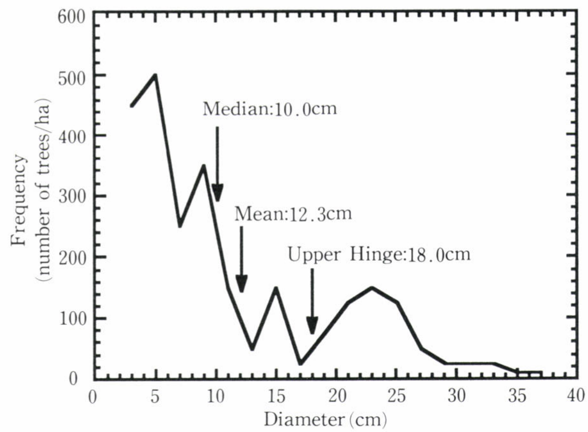

Fig. 3 Mean, median and upper hinge of the diameter distribution of a natural hardwood stand

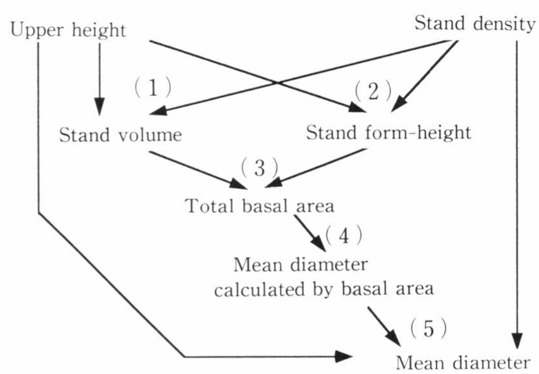

Fig. 4 Flow chart to calculate mean dimeter from a stand density-control diagram

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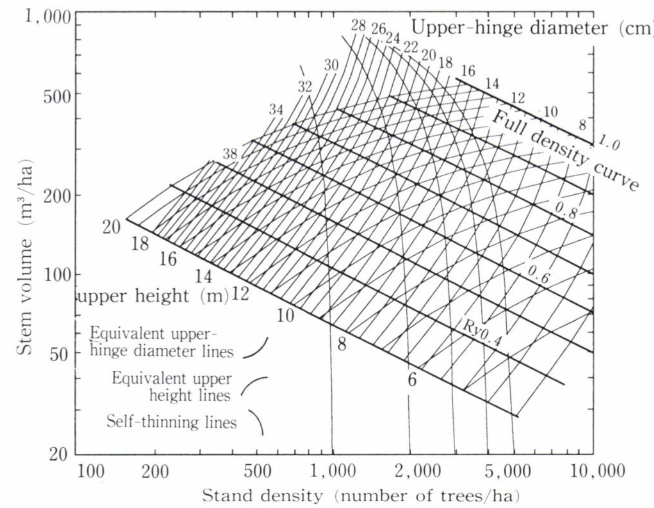

Fig. 5 Improved stand density-control diagram for regenerated shii (*Castanopsis* spp.) stands

This diagram is based on the stand density-control diagram for shii regenerated stands which was construncted by AWAYA and MATSUMOTO (1986). Equivalent mean diameter lines on the original diagram were replaced with equivalent upper-hinge diameter lines.

Median and upper hinge would be convenient for this purpose. The upper hinge, especially, is useful in L-type distributions.

These discussions raise the question of whether the upper hinge or median can be used instead of the mean for yield prediction in natural hardwood stands. Does the usage of upper hinge contradict mean in a stand density-control diagram?

Fig. 4 shows the relationships between equations in a stand density-control diagram. The fundamental equation of the diagram is concerned with relationships among number, upper height and stem volume, and has no relation to mean diameter. Mean diameter is calculated from mean basal area, tree number and upper height. This proves that the upper hinge does not contradict mean diameter, but can also be used in a stand density-control diagram.

Improved stand density-control diagram for shii stands

In the light of the discussion above, the stand density-control diagram for shii stands was improved by replacing equivalent mean diameter lines with equivalent upper hinge lines as shown in Fig. 5.

The improved diagram is based on the stand density-control diagram for shii regenerated stands constructed by AWAYA and MATSUMOTO (1986). The upper hinges were calculated from the same inventory data set as used in the base diagram. The data set contains 531 plots data of natural shii stands in Yamaguchi, Ehime, Kohchi, Nagasaki, Ohita, Miyazaki and Kagoshima prefectures. Several computer programs developed by MANABE (1980) and YAMANE (1987a, 1897b) were used to calculate the various equations and draw the diagram.

The equations for the improved stand density-control diagram for shii stands are as follows.

$$V=(0.042817H^{-1.089462}+12533.6H^{-3.268385}/N)^{-1} \quad (r=0.9562) \qquad (1)$$

$$HF=0.753302+0.398777H+0.107474\mathrm{sqr}(N)H/100 \qquad (2)$$

$$G=V/HF \qquad (3)$$

$$dg=200\mathrm{sqr}(G/\pi N) \qquad (4)$$

$$d=0.458288+0.812639dg+0.047813\mathrm{sqr}(H)N/100 \quad (5)$$

$$d_{UH}=0.0438704+1.19213dg-0.690099\mathrm{sqr}(H)N/100 \quad (6)$$

$$Ry=V/V_{Rf} \quad (7)$$

$$V_{Rf}=(0.0428179H^{-1.089462}+12533.6H^{-3.268385}/N_{Rf})^{-1} \quad (8)$$

$$\log N_{Rf}=6.35612-2.178923\log H \quad (9)$$

Where V: volume (m³/ha), H: upper height (m), N: stand density (number of trees/ha), HF: stand form-height (m), G: total basal area (m²/ha), dg: mean diameter calculated by basal area (cm), d: mean diameter (cm), d_{UH}: upper-hinge diameter (cm), Ry: relative yield, V_{Rf}: volume on full density (m³/ha), N_{Rf}: stand density on full density (number of trees/ha).

CONSTRUCTION OF YIELD TABLES

Management plan

Goal and diameter When shii is used for timber products such as construction timbers or pallet boards for transportation, the diameter of the logs should be greater than 18cm. The diameter goal, therefore, should be a diameter greater than 18cm.

Cutting period Since the growth of shii stands is rapid, the cutting period for wood chips is about 20 years in general. Although longer rotations have the advantage of greater timber production, old shii stands are susceptible to trunk heart rot. KAWABE *et al*. reported that 23-100 % trees had caught the disease by 40-50 years old, but no tree had caught it by 30 years old (DOHZONO *et al*. 1984; KAWABE *et al*. 1984, 1986). The disease gives the trees fatal defects as timber products, and thus the cutting period should be 30-40 years.

Site index table Using the same data set (531 plots) as used for the construction of the diagram, and additional investigations (40 plots) in Kyushu region, the author compiled a site index table shown as table 1. In this table, the site index is defined to be height at 40 years old, corresponding to the cutting period discussed above. This table was calculated using the following equation, which describes relationship between stand age and upper height.

$$H=17.49(1-\exp(-0.03818t))\mathrm{k} \quad (10)$$

Where, H: upper height (m), t: stand age (years) and k: parameter.

Stand density at harvesting According to the original diagram by AWAYA and MATSUMOTO (1986), to harvest trees whose mean diameters are bigger than 18cm, the stand density should be 1,230 trees/ha for site index 18, or 1,040 trees/ha for site index 16. Thus, for timber production, stand density should be about 1,000 trees/ha at harvest.

Site index and production goals Suppose stand density is 1,000 trees/ha, mean diameter is 18cm, and the upper height is estimated to be 15.6m on the original diagram. This tells us that timber production requires bigger site index than 16. In another case, if the stand

Table 1 Site index table for natural shii (*Castanopsis* spp.) stands

Stand	Site Index : Upper height at 40 years old								
Age	13	Mean	14	15	16	17	18	19	20
years									m
5	2.9	3.0	3.1	3.3	3.5	3.8	4.0	4.2	4.4
10	5.3	5.6	5.7	6.1	6.5	6.9	7.3	7.7	8.1
15	7.2	7.6	7.8	8.3	8.9	9.5	10.0	10.6	11.1
20	8.9	9.3	9.5	10.2	10.9	11.6	12.3	13.0	13.6
25	10.2	10.8	11.0	11.8	12.6	13.3	14.1	14.9	15.7
30	11.3	11.9	12.2	13.1	13.9	14.8	15.7	16.5	17.4
35	12.2	12.9	13.2	14.1	15.1	16.0	16.9	17.9	18.8
40	13.0	13.7	14.0	15.0	16.0	17.0	18.0	19.0	20.0
45	13.6	14.4	14.7	15.7	16.8	17.8	18.9	19.9	21.0
50	14.1	14.9	15.2	16.3	17.4	18.5	19.6	20.7	21.7
55	14.6	15.3	15.7	16.8	17.9	19.0	20.2	21.3	22.4
60	14.9	15.7	16.1	17.2	18.4	19.5	20.7	21.8	22.9

density is 1,000 trees/ha and the goal of upper hinge is 28 cm, the site index should be bigger than 20.

Site index and production goal leads possible management plans automatically. Fig. 6 shows a flow chart which can be used to determine a management plan.

Stand density control Because stands regenerated naturally by coppice may have over 10,000 trees/ha in the first several years, density control such as cleaning and thinning is necessary for timber production. Only a limited number of thinnings are realistic because the returns for shii timber are moderate. A plan for density control is shown in table 2.

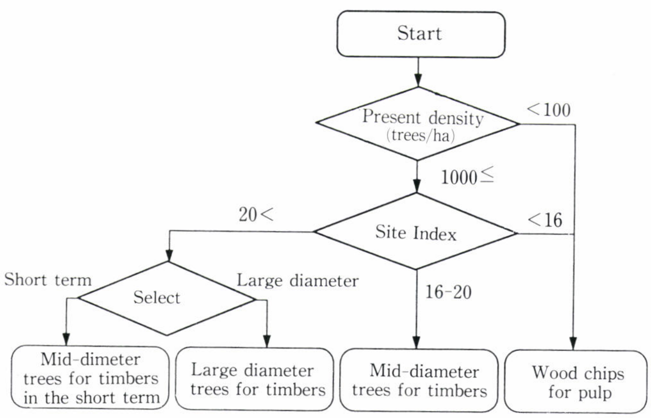

Fig. 6 Flow chart to decide the production goal for shii (*Castanopsis* spp.) stands

Table 2 A plan for stand density control

Stand age	Stand density	Activity
(years)	(trees/ha)	
5	8,000	Cleaning cutting of sprouts
15	4,000	Thinning
25	2,000	Thinning
35	1,000	Thinning
40	1,000	Clear cutting

Yield tables of shii for timber production

The improved stand density-control diagram, the original diagram, the site index table and the plan of density control can be used to construct various yield tables for different goals. In the light of the discussion in the previous section, three types of yield tables were constructed. A common characteristic of these yield tables is that they show both mean diameter and upper-hinge diameter in the table.

The constructed yield tables are as follows.

For production of mid-diameter trees Table 3 aims at production of mid-diameter trees on a site of index 17. This table estimates that the upper hinge will be 25.1 cm at harvesting. Thus, one-quarter of the harvested trees, or 250 trees/ha, will have a diameter greater than 25.1cm.

For production of large diameter trees Table 4 aims for the production of large diameter trees on a site of index 20, which is very high for shii stands.

For production of mid-diameter trees in the short term Table 5 aims for the production of mid-diameter trees in the short term. This table is useful for high site index stands where trunk heart rot is predicted.

These tables are available for the Kyushu region which is covered by both the improved stand density-control diagram and the site index table.

Table 3 Yield table for shii (*Castanopsis* spp.) stands for production of mid-diameter trees (Site index : 17m)

Stand Age	Upper height	Stand density	Diameter		Stand volume	
			Mean	Upper hinge	Major trees	Sub trees
(years)	(m)	(trees/ha)	(cm)	(cm)	(m^3/ha)	(m^3/ha)
5	3.8	8,000				
10	6.9	4,000	8.2	8.9	91	32
15	9.5	4,000	9.2	13.0	175	
20	11.6	2,000	12.5	16.6	198	51
25	13.3	2,000	13.4	17.2	259	
30	14.8	1,000	17.5	23.2	241	70
35	16.0	1,000	18.2	24.3	282	
40	17.0	1,000	18.9	25.1	317	

Table 4 Yield table for shii (*Castanopsis* spp.) stands for production of large diameter trees
(Site index : 20m)

Stand Age	Upper height	Stand density	Diameter		Stand volume	
			Mean	Upper hinge	Major trees	Sub trees
(years)	(m)	(trees/ha)	(cm)	(cm)	(m^3/ha)	(m^3/ha)
5	4.4	8,000				
10	8.1	4,000	8.4	10.0	129	36
15	11.1	4,000	9.8	13.6	233	
20	13.6	2,000	13.5	17.3	269	53
25	15.7	2,000	14.3	18.5	344	
30	17.4	1,000	19.1	25.4	332	75
35	18.8	1,000	17.7	26.4	384	
40	20.0	1,000	20.2	27.2	427	

Table 5 Yield table for shii (*Castanopsis* spp.) stands for production of mid-diameter trees in the short term
(Site index : 20m)

Stand Age	Upper height	Stand density	Diameter		Stand volume	
			Mean	Upper hinge	Major trees	Sub trees
(years)	(m)	(trees/ha)	(cm)	(cm)	(m^3/ha)	(m^3/ha)
5	4.4	8,000				
10	8.1	4,000	8.4	10.0	129	36
15	11.1	4,000	9.8	11.9	233	
17	12.2	2,000	12.9	16.5	219	52
20	13.6	2,000	13.5	17.4	269	
24	15.3	1,000	17.8	23.8	259	72
25	15.7	1,000	18.1	24.1	272	
30	17.4	1,000	19.1	25.5	332	

DISCUSSION AND CONCLUSION

Upper hinge

These yield tables include both mean and upper-hinge diameter. Because forest managers are interested in bigger trees that can be used for timber production, upper-hinge diameter is important information for them.

This paper dealt with natural stands of shii, which generally don't have a normal diameter distribution, and used of the median and upper hinge instead of the mean. The method, however, is not available only for natural hardwood stands such as shii stands, but for any stands, even if the type of diameter distribution cannot be assumed.

It follows from the results of the yield tables and the discussion, that it is efficient to use the median and upper hinge to construct yield tables for any kind of stand for which diameter distribution cannot be assumed.

Yield tables of shii stands for timber production

Management of shii for timber production requires very high site indices. Although table 3 is fundamental for timber production, even it requires a site index of 17. Since the site index table (Table 1) shows that the mean site index is 13.7, 17 is very high. Therefore, it is important to estimate the site index of the stand carefully when making a management plan for timber production.

Managers also have to take the disease, trunk heart rot, into consideration. Because it gives the trees fatal defects as timber products, short-term management should be considered for sites where the disease is predicted, even if the site index is high enough for timber production.

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Article

Influence of Forestry on the Formation of National Park Policy in Japan

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ABSTRACT

The national park system of Japan was the first to integrate regulatory land use zoning within scenic areas that encompass a diversity of landownership patterns. This was because zoning regulation was the only practical way to establish national parks in a country lacking public land. The most influential factors determining the park and its zoning boundaries were land ownership and the regulation of forest management of 1933. 90% of proposed park lands was forested and often used for forestry. The boundaries of parks were determined after consideration of landownership: Public forests were preferred, and the restrictions governing private forests were relaxed in the case of inclusion. As a result, only 13% of the park lands were private when the twelve original parks were designated by 1936. As the majority of public land was national forest, the national park system of Japan was based on these forests as cores. This was due to following reasons. First, the national park policy could coexist with forestry when economic pressure was low and harvesting was not mechanized. Second, promoters of national parks were associated with forestry education, and sustainable forestry was popular issue among them. Third, case-study models like the American parks and the domestic Forest Law suggested that management of forested areas in the parks could continue. Thus, forestry was the real force behind the national park policy in Japan. Before the Second World War, influence of forestry on the national park policy was acceptable. However, as economic demands on forests increased after the War, easily manipulated forest landscape guidelines and double agency management made the forest areas in the national parks vulnerable to economic demands and jeopardized national park management.

Keyword: national parks, national forests, zoning, landownership, forest landscape management

INTRODUCTION

Japan initiated its national park system in 1931 after studying other systems, mainly those of the United States. However, there are several fundamental distinctions in the Japanese system. The most often quoted distinction concerns the diversity of landownership. The National Parks of Japan are designated over scenic areas which include private lands, and land use zoning applies within the boundaries. Parks in the United States were mainly established on federal lands by reserving public domains. However, recently zoning regulations have become very popular all over the world, a reflection that exclusive designation of national parks is almost impossible even in sparsely populated countries. Therefore, zoning regulation is becoming more and more common, and is used even by the United States in Greenline Parks. Among the many countries adopting regulatory zoning for national parks, Japan's approach can be distinguished by the strong influence of forestry in determining each park boundary and zone.

Japan's national parks often include forested areas with active timber operations. Forested areas cover 89% of park lands, and national forests occupy 59% of park lands. (SUGIURA 1971). The ratio of national forests gets higher in core areas such as Special Areas. The national forests are managed by the Forestry Agency in the Ministry of Agriculture, Forestry and Fishery, and national parks are under the responsibility of the Environment Agency in the Prime Minister's Office. Thus the same park land is often under

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the control of two agencies. This is a striking contrast to American parks, where scenic national forest areas were often transferred from the Forest Service to the Park Service to be included in the national park system.

This paper sheds light on these issues, recognizing forestry as a moving force behind Japan's zoning regulation and the importance of double agency management during the formation of the national parks policy in Japan. The early development of Japan's national park has been divided into the following four stages, with each slightly overlapping: petitions (1911- 1920), survey (1921 - 1926), legislation (1927- 1931), and designation (1932 -1936). The influence of forestry on both national and private lands at each stage is discussed.

In regard to sources, the unpublished documents from Tsuyoshi Tamura Library in the Environment Agency were often consulted. Tamura is said to be the father of Japan's national parks, and his publications (TAMURA 1948, 1951) are often quoted as almost an official national park history. However, this author tried to consult original sources as often as possible to avoid depending too much on the personal views shown in Tamura's books.

THE FIRST STAGE: FLOODING PETITIONS TO ESTABLISH NATIONAL PARKS

The first stage started in 1911 when two national park petitions and a proposal were submitted to the Imperial Diet. One was for the Nikko area, the others for the Mt. Fuji area. By the end of the park movement, the number of such petitions had amounted to almost two hundred (TAMURA 1927). The petitioners were strongly motivated by an expectation of economic benefits and nationalism. The superiority of the landscapes in Japan was often mentioned by the promoters. The landscapes were recognized as a resource which would attract foreign tourists. Thus, the monumentalism and nationalism stimulated by the sudden influx of Western culture played important roles in the inauguration of the park movement. The expectation of economic development by international tourism reflected the depressed economy of the time.

These motivations are common with those of the national park movement in the United States. The characteristics important in the development of American national parks, such as nationalism towards monumental landscapes and the land being regarded as worthless except for tourism (RUNTE 1979), were also important in the movement to establish national parks in Japan. However, none of the petitions were recognized seriously at this stage, and conflicts over the use of natural resources like forests, minerals and water were not obvious yet. Therefore, the relationship between forestry and the national park was not discussed in the Diet. This was partially because the Forest Law of 1907 already provided for twelve types of Protection Forests, including scenic protection. This regulation was effective in conserving private forests, as they occupied 20% of the Protection Forests. In addition, the Forestry Bureau started to designate Preservation Forests in national forests according to the notification by the director in 1915. These were designated on the basis of scientific and cultural importance. In 1919, the City Planning Law and the Historic Sites, Scenic Beauty and Natural Monument Preservation Law were passed, and had considerable influence over the later National Park Law. In short, landscapes in both private and national forests already had some protection when the national park movement was initiated.

THE SECOND STAGE: FIELD SURVEY TO CHOOSE PROPOSED SITES

TAMURA, who majored in forestry and landscape architecture at the Imperial University of Tokyo, began to play a vital role from this stage. In 1920 he was hired by the Sanitary Bureau in the Ministry of Home Affairs. The Bureau had experience of public park management since 1873 and had been interested in national park management since 1911. In 1921, he and his assistant launched a field survey to identify suitable national park areas. The survey was interrupted by TAMURA's year-long trip to United States and Europe. While he was abroad, the Great Earthquake of 1923 demolished Tokyo, and the survey was interrupted for several years even after his return. However, this delay allowed TAMURA to develop fully as a national park planner with experience abroad. A flood of papers were published after his return, and many of his ideas were reflected in the formation of the national parks in Japan.

By 1927, the survey was finished, and sixteen areas were identified as possible national parks. In 1930, the Sanitary Bureau published the survey result. The report consisted of a descriptive volume (THE SANITARY BUREAU 1930a) and maps (THE SANITARY BUREAU 1930b). The report identified only fourteen of the original sixteen areas. This was a result of combining three parks into one, the Nihon Alps. The names and boundaries of two national parks were changed in the first supplement (THE SANITARY BUREAU 1932a). Daisetsuzan was added as the 15th proposed site in the second supplement (THE SANITARY BUREAU 1932b), after TAMURA's visit to the Daisetsuzan area in June, 1931.

Five topics were discussed for each proposed area: 1. studied area, 2. suitable park boundary, 3. qualification such as natural features, 4. current facilities and use, and 5. future development possibility. Landownership was discussed in detail in the park boundary section and the

Table 1 Landownership of the Proposed National Park Areas (March 1930)

Number	Park Name	Park Area (ha)	Imperial Lands (ha)	National Lands (ha)	Public Lands (ha)	Religious Lands (ha)	Private Lands (ha)	Ratio of Private Lands (%)
1	Akan	84,800	24,500	37,600	0	0	22,700	26.8
2	Noboribetsu	6,500	0	5,400	0	0	1,100	16.9
3	Onuma	19,400	0	9,200	0	0	9,500	49.0
4	Towada	47,900	0	46,800	0	0	1,100	2.3
5	Bandai-Azuma	66,300	0	36,300	21,400	0	8,600	13.0
6	Nikko	83,900	11,900	33,000	500	3,800	34,700	41.4
7	Fuji	87,600	25,700	2,900	41,400	300	17,300	19.7
8	Nihon Alps	204,100	5,900	174,000	16,500	0	7,700	3.8
9	Odaigahara-Ominesan	35,400	4,400	1,100	10,400	0	19,500	55.1
10	Daisen	19,300	0	9,200	8,100	0	2,000	10.4
11	Yashima-Shodoshima	1,300	0	530	200	70	500	38.5
12	Aso	75,300	0	10,000	43,800	0	21,500	28.6
13	Unzen	11,100	0	8,700	2,000	0	400	3.6
14	Kirishima	22,080	0	21,100	0	80	900	4.1
	Total	764,980	72,400	395,830	144,300	4,250	147,500	19.3

Source: The Sanitary Bureau 1930a

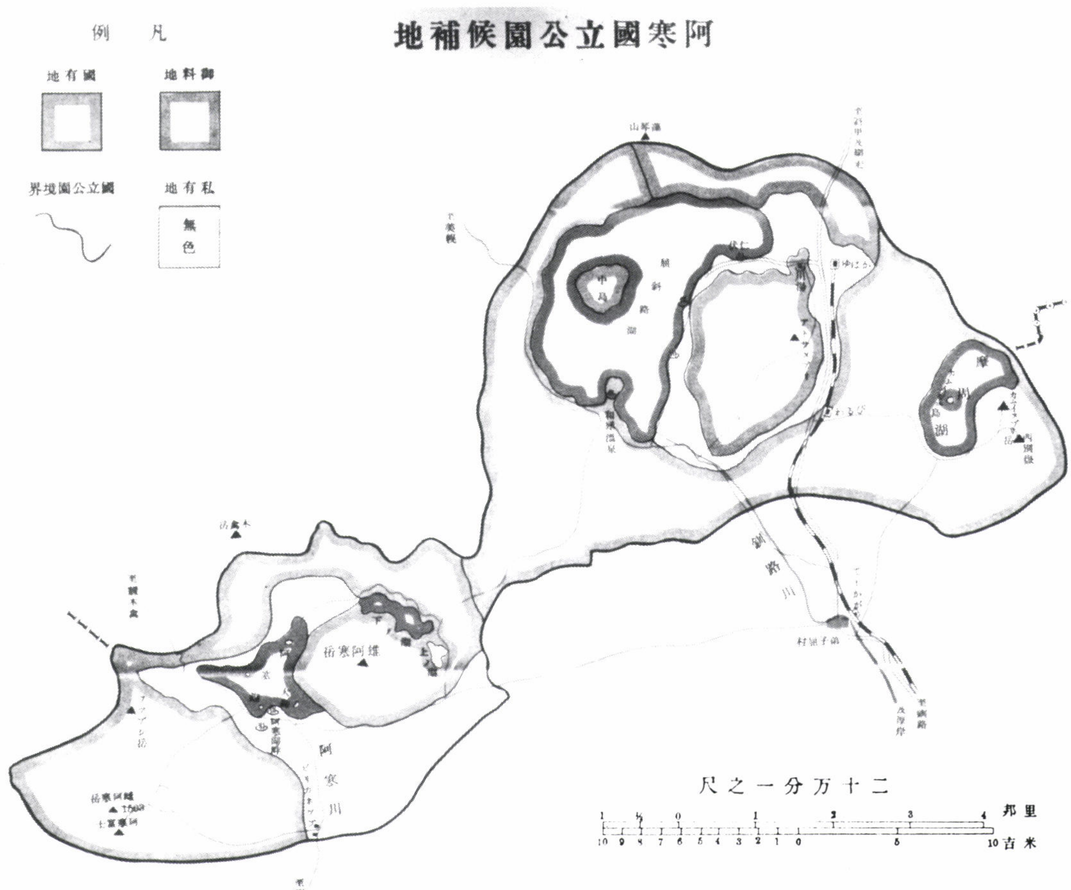

Fig. 1 Map of Proposed Akan National Park (the Sanitary Bureau 1930)

attached table about the areas of the proposed parks . Ownership was divided into five categories; Imperial, national, public, religious and private (Table 1). Public lands are those owned by prefectures, cities, towns or villages. Religious lands are owned by Buddhist temples or Shinto shrines. The extent of religious land is a reflections that sublime mountains have been recognized as sacred monuments and protected for a long time in Japan.

On separate color maps of the proposed parks, landownership within the proposed boundary was divided into seven categories by separately identifying army-owned land from national land and prefectural land from public land, if applicable (Fig.1) . These maps also contain information such as major routes and place names which are relevant to accessibility. However, the major objective of these maps was to show landownership clearly by colored boundary lines. Thus, TAMURA was well aware of the regulation problems related to private landownership. His response was to designate park areas in various public lands, especially national forests, and he tried to avoid private lands, to prevent land use conflicts.

TAMURA's visit to the United States in 1923 was commissioned by two agencies. The Forestry Bureau in the Ministry of Agriculture and Forestry commissioned Tamura to study forest recreation in U.S. national forests. The Ministry of the Home Affairs expected an investigation of the national parks. The report on forest recreation was published partially in 1925 then in detail in 1926 (TAMURA 1925, 1926) . The reports on the national parks were printed by the Sanitary Bureau in 1927 and 1930 (TAMURA 1927, 1930) . This double contract meant two things. First, the Forestry Agency had a certain interest in recreational development in their national forests at this stage. Second, TAMURA had not decided which agency was more suitable to manage the national parks before his departure to the United States. After his trip, however, the reports suggest he tended to favor park management by the Ministry of Home Affairs, mainly because the national park lands were not limited to national forests. He did not mention any other reasons. However, his preference for the Ministry of Home Affairs was presumably influenced by his meeting with Arthur CARHART in Denver in August, 1923. CARHART was employed as the first recreation engineer in the U.S. Forest Service in 1919, but quitted at the end of 1922, frustrated by the lack of understanding of recreational development by the foresters in the Forest Service (ITO, 1992) .

THE THIRD STAGE: ENACTMENT OF NATIONAL PARK LAW

The third stage began when water development plans in several proposed areas were disclosed around 1927. These proposals made the park promoters realize the urgency of the park establishment. The same year the national newspaper Mainichi held a campaign to identify "The Eight Most Outstanding Landscapes of Japan". This campaign clearly promoted public awareness of the national parks. The campaign asked the public to choose the best landscapes from eight categories such as mountains and lakes on 9 April 1932. This was similar landscape classification method to the one Tamura was employing to select proposed national park areas. Actually he became a member of the campaign selection committee and manipulated the result to include some proposed national park sites like Kamikochi (TANAKA 1981, IINUMA *et al.* 1993) . The campaign provoked a national fever and attracted more than 93.4 million postcards in just one month (OSAKA MAINICHI SHINBUNSHA 1927) . It effectively accelerated the national park movement. Taking advantage of the increasing interest in landscapes among Japanese, in December of the same year, the National Parks Association was organized by influential politicians and businessmen to further promote national parks (NATIONAL PARK ASSOCIATION 1951) .

Following these successes, establishment of a National Park Study Committee was declared at a cabinet meeting on 14 January 1930. The Committee was located in the Ministry of Home Affairs because the Minister ADACHI, whom TAMURA and other national park promoters had consulted, became interested in adding national parks to his Ministry, which had been responsible for city park management since 1873. However, the cabinet considered support from other agencies to be necessary, and the Committee had thirty-five members from various interests, including forestry specialists like Tomoaki HIRAKUMA, the Director of the Forestry Bureau and Suzuo TAKEI, the Chief of the Operations Department of the same Bureau.

The first Committee meeting was held on 11 July 1930. The Committee organized two subcommittees for detailed investigation and drafting of possible legal structure and selection guidelines. The first subcommittee prepared a draft national park bill. Its members studied foreign models, especially those of the United States and Italy, as well as various domestic laws. The draft bill proposed that parks be created by designating specific areas, including private lands, and that land-use be controlled by zoning with Ordinary and Special Areas within the park. The idea of designating parks over non-governmental lands was borrowed from the Italian national park system. The idea of regulatory zoning came from the Forest Law of 1897, the City Planning Law of 1911, and the Historic Sites, Scenic Beauty and Natural Monument Preservation Law of 1911 (THE SANITARY BUREAU 1931a) . The Forest Law had regulations on Protection Forests for various environmental effects, while the City Planning Law stipulated the designation of Scenic Districts to protect amenity in good residential areas.

The second Committee meeting was opened 31 October 1930 and a draft park bill prepared by the structural subcommittee was discussed (THE NATIONAL PARKS STUDY COMMITTEE 1930). Questions regarding the draft bill were focused on the harvesting restriction of forested areas, which covered about 90% of park lands. In Special Areas, the private landowners had to obtain permission for harvesting and other land-use changes, according to the draft. If the private landowners suffered any economic loss because permission was rejected, the government had to compensate according to Article 9 of the draft bill. To simplify the permission process, it was proposed that the national forest management plan be adjusted in advance with the Forestry Bureau. The same procedure was extended to the private forests. Thus, even in private forests permission was not necessary if the owner had a forest management plan agreed to in advance. It became clear that a suitable forest management plan could substitute for the procedure stipulated in Article 8 of the bill, even in forests designated as Special Areas. A member of the subcommittee, AKAGI, mentioned that the regulation may prevent the interruption of harvesting in private forests designated as Special Areas and would avoid the compensation issue. This comment reflects the dilemma of the compensation article, which stipulates compensation against economic loss without budget allocation (SEINO 1993). It was a time of world depression and the budget was extremely tight.

During the same session, another subcommittee member, OKA, expressed an opinion favoring national park management by the Forestry Bureau for several reasons. First, the majority of national park lands belonged to national forests; especially seven of the proposed areas which were almost entirely national forests. Second, park management by an existing organization was more economical and the Forestry Bureau already had 193 offices, 1,500 workers and an annual revenue of 3.7 million yen. Third, the Bureau had field specialists including foresters and forest engineers to manage the national forests according to the Forest Law. However, this opinion was not expressed by the Forestry Bureau directly. The chief of the Bureau was a member of the National Park Study Committee and he had the chance to express any opinion on park management if he wished. As already mentioned, the Forestry Bureau had some interest in managing recreation in the 1920s. His silent response to OKA's opinion suggests that park management by the Ministry of Home Affairs was already settled by that time. TEZUKA (1984) explains that this inconsistency was a result of prior political agreement between the Ministers of Home Affairs and Agriculture and Forestry. This also explains why this committee was organized by the Ministry of Home Affairs with the clear objective of bringing the national park system under its control.

TAMURA knew that national parks in Italy were partially managed by the Forestry Bureau. Therefore, he was aware of the possibility of park management by the Forestry Bureau. However, he also learned that several new national parks were being created from national forests in the United States when he visited. Therefore, he stated in his report that national parks of Japan had to cover various lands and that independent national park management organization would be preferable (TAMURA, 1925). Reflecting his endorsement, a member mentioned that not all the park lands belong to the national forest, and national park management by the Ministry of Home Affairs was justified.

The National Park Law was passed on 1 April 1931. On 29 September of the same year, the third and last National Park Study Committee was held. The members ratified the selection guidelines in the report from the subcommittee (THE NATIONAL PARK STUDY COMMITTEE 1931a). The primary principle of national park selection was to preserve the outstanding sceneries of which Japan is so proud. Three specific selection guidelines were mentioned as follows.

1. The best one in each landscape category
2. Large-scale natural scenery
3. Outstanding geological features and landscape variation

These reflect the monumentalism and nationalism found in early national parks petitions. As secondary guidelines, the following six factors were mentioned.

1. Capacity to accept mass-recreational use
2. Abundance of cultural resources such as temples and historic sites
3. Maximum use of public landownership
4. Geographic distribution convenient to the public
5. Little influence over industries
6. Existing facilities and future prospective to new ones.

THE FOURTH STAGE: BOUNDARY DETERMINATION AND ZONING REGULATION

The fourth stage began when the National Park Law was enforced and the new National Park Committee was organized on 1 October 1931. The mandate given to this new Committee was the selection and designation of specific areas as national parks.

The first meeting was held on 24 November 1931, and the chairman reported the selection guidelines already approved by the former National Park Study Committee (THE NATIONAL PARK COMMITTEE 1931b). These guidelines were adopted by the new Committee without objection. Then, TAMURA described in detail the fourteen areas which had been proposed on the basis of the guidelines. In addition to these, Daisetsuzan was recommended as a promising area. Expecting difficulty for choosing the most suitable areas from these proposals, the chairman organized a subcommittee for the site selection. TAMURA and HIRAKUMA were included in the eleven members.

During the session, a document titled Data of National Parks (THE SANITARY BUREAU 1931b) was supplied to the members. There were fourteen categories of information in this document. TAMURA explained that the first seven categories were related to the primary requirements of the selection guidelines. The first three were tables on landownership, private lands and national forests in each proposed area. The table on private lands ranked the fourteen areas by the ratio of private land; the smaller the ratio, the higher the priority. The table on national forest includes a similar ranking based on ratio but in the opposite order; the bigger the ratio, the higher the priority. This table also included forest management categories such as ordinary or restricted (Table 2). The forests without any cutting regulations were classified as ordinary. Forests already classified as Protection Forests or Preservation Forests were recognized as restricted or semi-restricted depending on the degree of restriction. From these tables it became evident that land ownership was the key factor of various conditions. The role of national forests was especially recognized, and the forestry practice restrictions were seriously investigated.

By the second meeting of the National Parks Committee , the subcommittee on site selection had made several field investigations and held sixteen meetings with heated discussions to choose the most suitable areas from the fifteen proposed areas. During the year-long process, the contents of the areas were modified from the original survey report (Table 3). Most notably, private areas were drastically reduced. Finally, twelve national park areas were selected, and Noboribetsu-Shikotsu, Onuma and Bandai-Azuma were omitted. This result was reported to the second Committee meeting held on 8 October 1932 (THE NATIONAL PARK COMMITTEE 1932), but the reasons for the exclusion of these three areas were not mentioned.

The second Committee meeting approved the twelve areas as national parks, although the boundaries were not determined yet. The boundary issues were closely related to industrial use and local interests. The Committee organized a special subcommittee on boundaries to discuss the matter in detail by the next meeting.

To decide the national park boundaries, the forestry regulations in the parks were discussed with the Forestry Bureau. As noted above, certain forests in Japan were already under some protection, and Directive No. 30 of the Ministry of Agriculture and Forestry in 1907 originally specified fundamental forest practice rules such as cutting methods and size (THE FORESTRY BUREAU 1940). As the TAMURA Library contains several underlined papers on the Protection Forests and their treatment methods, he was sure to have consulted these rules before defining the forest landscape management guidelines for national parks.

On 25 September 1933, the Forestry Bureau asked about the detailed restriction of forestry in Unzen and Setonaikai national parks. On 6 October, the Ministry of

Table 2 Status of Imperial and National Forests in the Proposed National Park Areas (November 1931)

Number	Name	Park Area	Imp. & Nat. Forests	Ratio of Imp. & Nat. Forests	Forestry Practice Categories and the Ratios in the Imp. & Nat. Forests							
		(ha)	(ha)	(%)	Ordinary	(%)	Semi-restricted	(%)	Restricted	(%)	Left-over	(%)
1	Akan	76,100	50,846	66.8	24,439	48.1	0	0	23,963	47.1	2,444	4.8
2	Noboribetsu	6,500	4,926	75.8	504	10.2	0	0	4,337	88	85	1.7
3	Onuma	19,400	6,346	32.7	0	0	6,346	100	0	0	0	0
4	Towada	50,300	43,810	87.1	16,118	36.8	18,110	41.3	2,962	6.8	6,620	15.1
5	Bandai-Azuma	65,000	33,415	51.4	20,173	60.4	1,771	5.3	10,045	30.1	1,426	4.3
6	Nikko	53,500	31,974	59.8	7,630	23.9	3,566	11.2	17,980	56.2	2,798	8.8
7	Fuji*	86,800	25,592	29.5	7,859	30.7	0	0	2,587	10.1	3,575	14
8	Nihon Alps	174,600	150,918	86.4	30,366	20.1	30,777	20.4	50,372	33.4	39,403	26.1
9	Odaigahara-Ominesan	35,100	5,240	14.9	3,747	71.5	0	0	1,461	27.9	32	0.6
10	Daisen	18,300	8,244	45.0	5,688	69	373	4.5	2,183	26.5	0	0
11	Setonaikai**	2,400	481	20.0	0	0	0	0	450	93.6	31	6.4
12	Aso	30,800	2,786	9.0	2,186	78.5	378	13.6	181	6.5	41	1.5
13	Unzen	10,400	7,957	76.5	2,565	32.2	1,598	20.1	648	8.1	3,146	39.5
14	Kirishima	19,500	18,450	94.6	11,108	60.2	5,984	32.4	40	0.2	1,318	7.1
	Total	648,700	390,985	60.3	132,383	33.9	68,903	17.6	117,209	30	60,919	15.6

* Total area includes transferable lands of 11,571ha.
**Name was changed from Yashima-Shodoshima, and water surface was excluded from figures.
Source: THE SANITARY BUREAU (1931b)

Table 3 Landownership of the Proposed National Park Areas (October 1932)

Number	Name	Park Area (ha)	Imperial Lands (ha)	National Lands (ha)	Public Lands (ha)	Religious Lands (ha)	Private Lands (ha)	Ratio of Private Lands (%)
1	Akan	76,100	22,400	43,500	0	0	10,200	13.4
2	Daisetsuzan*	204,700	26,400	172,900	5,400	0	0	0.0
3	Noboribetsu-Shikotsu**	116,100	91,100	23,500	0	0	1,500	1.3
4	Onuma	19,400	0	9,200	700	0	9,500	49.0
5	Towada	50,300	0	49,200	0	0	1,100	2.2
6	Bandai-Azuma	65,000	0	35,000	21,400	0	8,600	13.2
7	Nikko	53,500	13,100	18,900	100	3,800	17,600	32.9
8	Fuji	86,800	25,600	2,200	41,400	300	17,300	19.9
9	Nihon Alps	174,600	5,800	145,200	16,100	0	7,500	4.3
10	Yoshino Mts. -Kumano***	52,300	5,900	800	10,300	100	35,200	67.3
11	Daisen	18,300	0	8,200	8,100	0	2,000	10.9
12	Setonaikai	2,400	0	800	400	100	1,100	45.8
13	Aso	30,800	0	4,700	24,800	0	1,300	4.2
14	Unzen	10,400	0	8,000	2,000	0	400	3.8
15	Kirishima	19,500	0	18,500	0	100	900	4.6
	Total	980,200	190,300	540,600	130,700	4,400	114,200	11.7

* New addition
** Name was changed from Noboribetsu, and the area was enlarged.
***Name was changed from Odaigahara-Ominesan.
Source: TAMURA (1932)

Home Affairs answered with a document describing the restrictions on forest management practice (THE PHYSICAL STRENGTH BUREAU 1940). The Forestry Bureau agreed to these restrictions on 20 October.

As shown in the following general principles, this document was virtually a landscape management guidelines which controlled all forests in national parks. Its general principles were as follows.

1. The maximum clear-cut area is determined by dividing the forest area with cutting period.
2. The allowed select-cut area is equivalent to the annual growth rate or 2% of the growing stock for natural forests.
3. If not harvested annually, the cut area can be enlarged by multiplying the allowed annual cut-area by the interval without cutting.
4. Clear-cut areas should be restocked within three years of harvesting.
5. Trees to be protected for esthetic reasons can be designated by the Ministry.
6. Areas for planting and the species composition can be designated by the Ministry.

In Special Areas, more detailed restrictions were made as follows:

1. Natural forests should be naturally regenerated.
2. Minimum harvesting ages are twenty years for small species and sixty years for tall species.
3. Maximum clear-cut size is 0.5ha, but it can be enlarged if there are leftover trees.
4. There should be a five to ten-year interval between clear-cutting adjoining areas. This can be shortened if landscape damage is not expected.
5. Maximum select-cut volume is one third of the growing stock, or one half in the case of evergreen species.
6. The species and forest types can be changed if they are manmade forests.
7. Harvesting methods can be specified for landscape management.
8. Special consideration can be given to private forests.

Ordinary Areas had less-tight regulations as follows:

1. Natural forests should be naturally regenerated if possible.
2. Maximum clear-cut size is 10ha, but can be enlarged if there are leftover trees.
3. The species and forest type can be changed in case of manmade regeneration.
4. Harvesting methods can be specified for landscape management.
5. Special consideration can be given to the private forests.

These guidelines became less restrictive than the original draft plan, presumably as a result of various compromises. For example, clear-cut size was enlarged from 5ha to 10ha in Ordinary Areas. Nevertheless, the guidelines were much stricter than those that applied at this time.

In addition to these guidelines, the National Park

Table 4 Landownership of the Designated National Park Areas (1938)

Number	Name	Park Area (ha)	Imperial Lands (ha)	National Lands (ha)	Public Lands (ha)	Religious Lands (ha)	Private Lands (ha)	Ratio of Private Lands (%)
1	Akan	87,498	27,263	47,591	170	0	12,474	14.3
2	Daisetsuzan	231,929	25,146	199,648	7,135	0	0	0.0
3	Towada	42,862	0	41,722	830	0	310	0.7
4	Nikko	56,923	12,976	19,865	816	466	22,800	40.1
5	Fuji-Hakone*	71,757	15,371	3,124	34,624	426	18,212	25.4
6	Chubu Sangaku**	169,768	3,667	144,221	12,870	0	9,010	5.3
7	Yoshino-Kumano	55,086	5,094	3,443	11,804	272	34,473	62.6
8	Daisen	12,403	0	6,052	5,558	83	710	5.7
9	Setonaikai***	183,100	0	173,363	1,437	300	8,000	4.4
10	Aso	67,827	0	8,943	36,271	36	22,577	33.3
11	Unzen	13,029	0	8,077	2,042	30	2,880	22.1
12	Kirishima	21,560	0	20,177	217	7	1,159	5.4
	Total	1,013,742	89,517	676,226	113,774	1,620	132,605	13.1

* Name was changed from Fuji.
** Name was changed from Nihon Alps.
***Area includes water surface as national land.
Source: The Ministry of Welfare (1948) (obvious mistakes corrected and format adjusted)

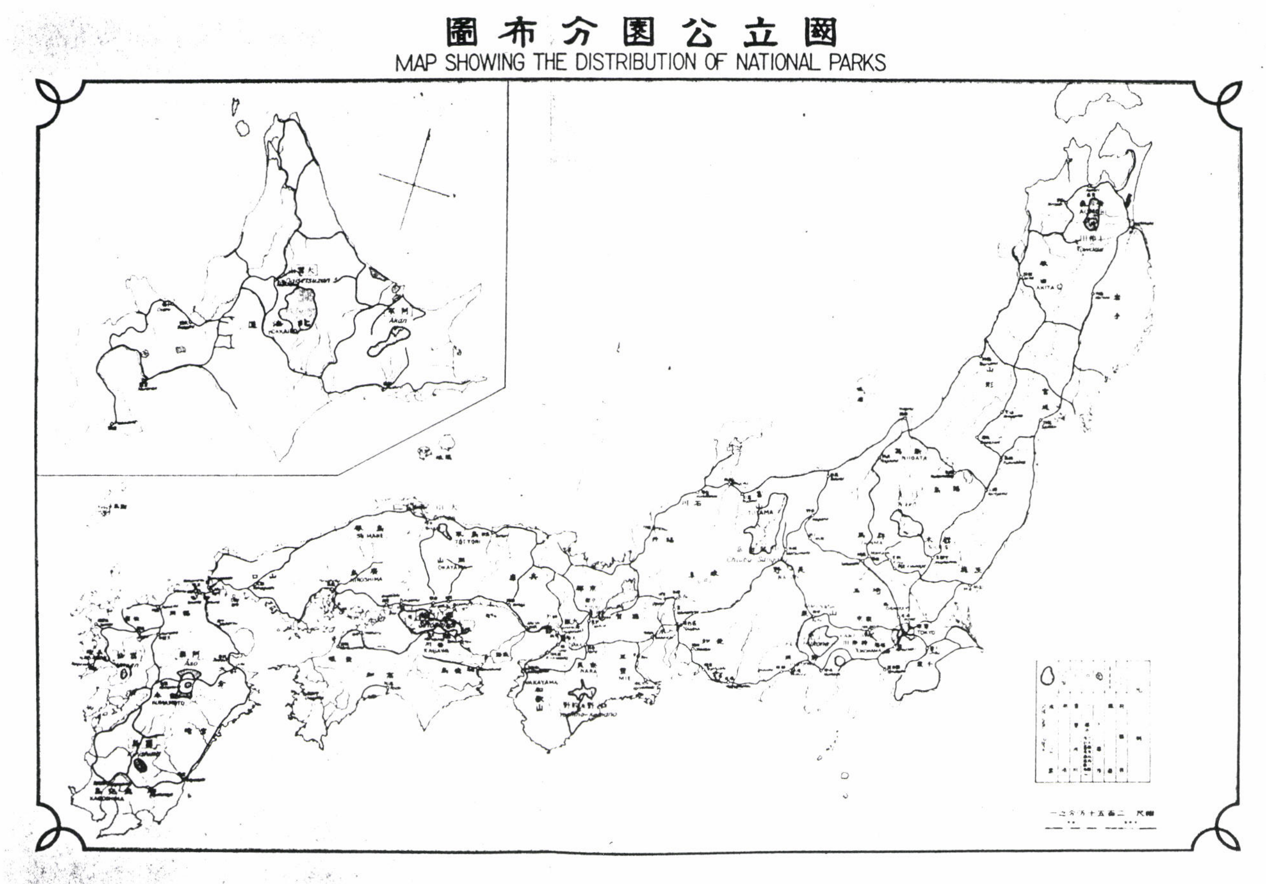

Fig. 2 Map of Original Twelve National Parks (Amishima 1938)

Planning Guidelines was established by the Ministry of Home Affairs in 1937. They say that if possible private lands should not be designated as Special Areas, and that boundaries should follow the management lines of national forests. Another interesting specification is for Special Areas along road sides. It says the width of the belt should be 100m each side of the center of the road. Such an idea must have come from the national forest management rules, which were intended to shield ugly forestry practices such as clear cutting from the road.

During the time when the forest landscape management guidelines in the parks were discussed, several articles on forestry practice in the national parks appeared. Most of them expected that the economic loss incurred by regulation would be small if select cutting was allowed, and that the benefits from accelerated road construction in the parks could exceed such loss (FUJISHIMA 1932, KURATA 1934, TOMIYA 1934). However, NAGATA pointed out the greater risk of fire hazards and the resulting rise of insurance fee (NAGATA 1934). Reflecting this view, Shioya urged allocation of sufficient budget funds to compensate private forest owners in Special Areas (SHIOYA, 1937).

After establishing the forest landscape management guidelines, boundaries of the three first-stage national parks, namely Setonaikai, Unzen, Kirishima were decided in the fourth Committee meeting on 19 December 1933, and officially designated on 16 March the following year. The fifth Committee meeting chose five second-stage parks; Akan, Daisetsuzan, Nikko, Chubu Sangaku (formerly Nihon Alps) and Aso on 9 August 1934. These parks were designated on 4 December of the same year. The decision of the final four parks was delayed until 15 January 1936 because of complicated private lands issues and the adjustment of industrial uses. For example, more than 60% of Yoshino was private land used mainly for timber production. Finally those parks were designated on February 1, 1936, and a system of twelve parks was established.

The Table 4 shows the land ownership of the twelve national parks. Comparisons with Table 1 clarify the increased portion of national land and the according decrease of private land to 13%. This was a direct result of the efforts to eliminate private lands in each park. The trend was clearly accelerated by the inclusion of Daisetsuzan in 1931, which is the largest park without private lands. As shown in the map (Fig. 2) included in an early guide book (AMISHIMA 1938), these parks seem evenly distributed over Japan and reflect a consideration of access factors.

DISCUSSION

The role of private land, especially with respect to their forest management, was a critical factor in the formation of the national park policy in Japan. To cope with this issue, national forests areas were preferred as core areas, then regulation in private forests was seriously considered. This approach was due to the following three factors.

First of all, forest was the predominant landscape in Japan, and forestry was a major industry in such areas. However, the economic demands for resources in isolated areas were weak due to the difficulty of transporting logs over steep topography. Such areas were often designated as national forests. There were some private lands even in isolated scenic areas, but forestry was small scale and machines were not introduced yet. Therefore, the human-influenced landscape was compatible with the natural one in those days, and such human influence was recognized as a positive factor which enhanced the landscape. For this reason, cultural and historic factors were included as the secondary selection requirement when the national park selection guidelines were formulated. In other words, park planners did not consider just natural landscapes.

Second, not only national parks but also national park promoters were strongly tied to forestry. Many articles related to national parks were published in the forestry magazines. Furthermore, the national park promoters like TAMURA and his advisor S. HONDA were major forestry specialists of the age. They were influential in the Forestry Bureau because they were authorities in both forestry and landscape architecture, and because their colleagues were working there.

In those days, the sustainable forestry idea from Germany was popular among foresters (YAMAHATA 1984). The sustainable management theory published by A. MÖELLER in 1922 was translated to Japanese in 1927. The forest esthetics concept of H. von SALISCH was also introduced to Japan in 1910. Under these influences, the first Japanese book on forest esthetics was published in 1918 (NIJIMA and MURAYAMA 1918). TAMURA also published several papers and a book on this topic (TAMURA 1929a). Thus, foresters were familiar with the roles of forests other than timber production, and were receptive to timber cut regulations. That explains the favorable attitudes of foresters to the restriction of forestry in national parks.

Third, there were some overseas precedents and domestic laws which the park promoters could consult as models. These models gave the national parks of Japan their start as a system. Of the overseas examples, American national parks and their cultural resources were influential. TAMURA intentionally introduced the concept of small American national parks like Hot Springs before introducing large and ideal parks like Yellowstone in his magazine articles (TAMURA 1929b). This reflects his idea that these small parks on private land could be better models for Japan. He also studied the relation between the National Park Service and the Forest Service in the United States carefully and decided that park management in Japan should be the responsibility of the Ministry of Home

Affairs.

Among the existing laws consulted during the drafting of the National Park Law, the Protection Forest system of the Forest Law and Preserved Forest by regulation of the Forestry Bureau were of great help in developing the park idea and identifying potential areas. Although the Historic Sites, Scenic Beauty and Natural Monument Preservation Law of 1911, prohibited any timber production from forests designated as Natural Monuments, the Protection Forests system allowed a specified amount of timber to be cut, and provided for compensation. The Protection Forests system as an important precedent to the National Parks Law, and many of these areas were included in the parks later.

CONCLUSION

Regulatory zoning was the essence of Japan's national park policy, and was far ahead of its time. The Special and Ordinary areas of the early national park policy are equivalent to the recent core-buffer zone concept which features in international discourse on conservation. The regulatory zoning system was included by the Sanitary Bureau as a management guideline for national forest lands within national parks. Nevertheless, TANAKA (1981) noted that the significance of the zoning regulation in the national park system was not recognized by the park planners at that time. He mentioned three reasons for this lack of recognition. First, Japanese have traditionally accepted mixtures of living space and scenic public space. Second, the proposed areas were isolated and undeveloped except for Yoshino area. Third, the proprietary rights of local farmers and mountain villagers had been ignored from feudal days, and the Ministry of Home Affairs was the center of political power in the government before the Second World War.

If such social factors are considered, the national park system based on zoning regulation was the most suitable choice for Japan in those days. However, social factors such as demand for timber and land ownership rights changed radically after the Second World War. The demand for timber in remote national forests surged, and restriction of timber harvest in private forests became more difficult. This trend was further accelerated by a power shift in the bureaucracy. While park management responsibility was transferred from the Ministry of Home Affairs to the Ministry of Welfare in 1938, then to the Environment Bureau in 1972, the national forests were put under a special self-supporting account of the Forestry Bureau in 1947.

Though the forest landscape management guidelines were an excellent way to control landscapes in the parks systematically, this remained one of the fragile rules in the government. The guidelines could be modified without public notice, and secretly changed. Indeed, these regulations were diluted as the authority of the national parks management was weakened and economic considerations became more important in the management of national forests. For instance, the maximum clear-cut allowance in the Special Areas doubled to 1ha in 1950, then to 2ha in 1959. This trend which lowered the quality of park landscapes was not stopped even the passing of the Natural Park Law in 1957. To improve landscape quality, a program to purchase private lands in Special Areas was introduced in 1972. However, the budget has always remained nominal. The double agency management and the forest landscape management guidelines were the brainchildren of the national park planners in Japan, and fitted the social conditions in those days. However, it is getting difficult to adjust park management to modern social conditions.

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Article

Forest Management and Forestry Labor

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ABSTRACT

To illustrate the features of the post-war development of a large-scale forest business and its economic characteristics, this paper focuses on the relationships between technical developments in the management of man-made forests and forestry labor. It uses Hayami Forestry of Miyama-cho, Mie prefecture as a case study. Hayami Forestry, in the course of post-war development and while coping with the changes in the timber market, has continued establishing man-made forests, created a system of comprehensive forest management, and developed new employment conditions. Based upon developments in the production of good quality timber and the relative advantage of Japanese cypress prices in the timber market, the trend of long-rotation management began in the 1970's. In the 1990's, with the establishment of new labor and employment conditions, there were increased levels of employment of new young labors and at the same time, the mechanization of forestry entered a new phase.

Keyword: large-scale forest business, forest management system, short and long rotation, good quality timber, forestry labor

INTRODUCTION

The forest area in Japan totals 25.21 million ha. In terms of administration or ownership, 31% are national forests , 11% are public forests owned by prefectures and municipalities, and the remaining 58% are privately owned. Of the total forest area, 41%, a relatively large portion, is man-made forest. As most of this these forests are the product of the massive afforestation efforts that followed World War II, the basic age-class structure is inclined towards younger forests. Also, 80% of man-made forests are now at an age where they require tending or thinning.

Most private forests are owned by forestry households. The number of such households exceeded 2.51 million in 1990, and the total forest land in private tenure was 6.75 million ha. The area of forestland owned by forestry households is, generally small. The percentage of households owning less than 5 ha is 89%. Forestry households in Japan that own more than 100 ha (these are considered large-scale owners) make up for only 0.1% of the owners. However, it should be noted that the forest area controlled by owners with more than 100 ha comprises 16% of the total forestland. (STATISTICS and INFORMATION DEPARTMENT, MINISTRY of AGRICULTURE, FORESTRY and FISHERIES 1991)

Economic conditions for forestry households are currently very difficult. The stumpage prices for Japanese cedar (*Cryptomeria Japonica*) and Japanese red pine (*Pinus Densiflora*) are now at the same level that they were in the latter half of the 1960's, and the price of Japanese cypress (*Chamaecyparis obtusa*) is where it was in the first half of 1970's. And while the total average standard of living has increased two-fold in the past 30 years, forestry wages (eg, for logging work) have increased by a factor of 15. The situation, therefore, is quite serious for large-scale private forest businesses. (KEIZAIDOUYUUKAI 1985)

The studies of large-scale forest business, only with regard to analysis in the post-war status, Kozo Uno (UNO 1954), Meitatsu Okamura (OKAMURA 1957), Kazuo Fukumoto (FUKUMOTO 1955), Seizo Fukao (FUKAO 1967, 1988), Isamu Nomura (NOMURA 1970), Michio Kuroda (KURODA 1972), and Takeshi Akaha (AKAHA 1978) discussed the economic nature of large-scale forest business, mainly in relation to capitalist theories of Japanese forestry and land use.

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This paper aims to focus on the relationship between technical developments in the management of man-made forests and forestry labor from a historical view point is used for a forest business. Hayami Forestry of Miyama-cho, Mie prefecture is used as a case study, and illustrates the features of post-war development of large-scale forest businesses and their economic characteristics.

First, the current status of forests managed by Hayami Forestry is outlined. As of 1990, the forest area under their management was 1,016 ha, of which man-made forests accounted for 76% of the total, and natural forests 24%. Of the man-made forests, 99% were planted with Japanese cypress, and these forests are representative of forestry in the Owase Region. Currently, forest estates play an important role in the forests of Hayami forestry. There are six forest estates, each around 100 ha, which in total comprise approximately 500 ha. There remaining area is composed of small-scale and widely distributed forests, which are gradually being converted into forest estates. The total stand volume is currently about 121,000m^3, and the annual volume increments is about 3,357m^3. Each year, approximately 10,000 koku (1 koku equals 0.278m^3) of Japanese cypress timber are produced.

Currently, Hayami Forestry is attempting to make a transition to long rotation management by employing modern workers and emphasising the production of fine wood, including knotless posts and wood for fine fixtures.

The Owase Forestry Region, including Miyama-cho, established a short rotation management system in the 1880's. Until the Second World War, there were no major changes made to the technical system. Consequently, Hayami Forestry's history of management in the 50 years since the war serves as a typical example of a forest business aiming to streamline and modernize management practices as short rotation management develops into long rotation management. Studying these elements and how they relate to forestry labor problems will also illustrate the changing economic nature of large-scale forest business.

MODERNIZATION OF FOREST BUSINESS AND FORESTRY PRACTICES

Prehistory

Hikimoto (formerly Hikimoto village) in Miyama-cho, where the Hayami Family lives, has long served as a site for the collection and distribution of timber produced in neighboring villages, including the once-existing villages of Soga and Funatsu. The production of timber from man-made forests in both villages began to increase during the Shoo and Meireki eras (around the 1650's). The increase in timber production also contributed to the financing of the local feudal clan, in 1818 (year 15 in the Bunka era, in the last days of Tokugawa Shogunate), the "Onshiirekata" (buying department) was set up in Funatsu village. (HORIUCHI 1932)

During this period, Hikimoto village was a famous dried bonito production site, and fishing, marine product processing, and forestry were closely linked to the local economy through fuel wood production and the building of ships.

The Hayami family is said to have engaged in commercial fishing from when they first settled in Hikimoto village in the 1790's. As part of their commercial efforts, they also invested in forestry, acquiring tracts of forestland. "Through the tending of forests beginning in the Kansei era (1801-1804), by 3rd year of the Kyowa era (1789-1801) they had already acquired 25 cho (1 cho = 2.451 acres) of forests. After "buying forest land year-after-year for more than 80 years, the land holdings were increased to about 600 cho". (FOREST AGENCY, MINISTRY of AGRICULTURE and COMMERCE 1883) By the 16th year of the Meiji era (1883), they were owners of about 600 cho of forests. These forests located only in the Hikimoto, Soga, and Funatsu areas of present-day Miyama-cho. Owning forests within in a relatively limited area was typical of the era.

Hayami Forestry is an example of a village-based, large-scale forest business. It differs greatly from the Yoshino forestry region in the Kii peninsula, where forest were controlled by forest owners who lived outside of the village. The acquisition of forests by the Hayami family was based upon their commercial fishing interests. In 1928, they stopped fishing and dedicated themselves to forestry. Their pre-war forestry techniques were dominated by the dual approach of dense planting and short rotations, and long rotation management (1/10 of area) was only sub-technique. (HAYAMI 1911-1913) Forest management based upon the dense planting of 12,000 seedlings in one cho and a 40-year short rotation management did not undergo much change during the pre-war period.

Starting point of post-war period — adjustment and improvement of age-class structure of man-made forest

After the Second World War, the Japanese economy experienced astounding levels of growth. In the first half of this period of economic growth, increasing domestic demand served as the main engine of economic growth, because Japan was then a closed economy. It is important to understand this point before studying subsequent business developments in Hayami Forestry.

As previously mentioned, Hayami Forestry, throughout the pre-war period, continued to use the man-made Japanese cypress forest management system that had been established in the 1910s. This system was village based in nature, and was characterised by dense planting and short rotations. Forestry entered a period of advanced economic growth fueled by increased levels of domestic demand. The business activities of Hayami Forestry during the post-war recovery and economic growth period, large-scale forest ownership, forest growing volume and the continuation of village-based forestry management determined the later development of the forest business to a great extent.

In 1946, immediately following Japan's defeat in the war, the total forest area was 701 cho (estimated from the payment of property taxes), of which 66% was man-made forest and 34% was broad leaf forest. Japanese cypress comprised 93% of the man-made forest. The age-class distribution of these forests is shown in Fig. 1. 27% of man-made forest was comprised of age class 1 to 2; 26%, age class 3 to 4; 31%, age class 5 to 6; 11%, age class 7 to 8; 3%, age class 9 to 10; 2%, age class 11 to 12; and 0.08%, age class 13 and above. Thus, forests less than 40-years old represented 95% of the man-made forest resource. This is a direct reflection of the dense planting and short rotation techniques noted earlier.

The post-war forest business developed from this resource base. Until the Korean war, however, the soaring living costs resulting from post-war inflation led to deficits in operations and an inability to pay for the afforestation efforts needed after clear-cutting areas. The deterioration of the man-made forest resource structure that resulted from forced cutting under the wartime regime was further accelerated by post-war inflation, which persisted until around 1950. At last, timber prices began to increase with each year as demand levels increased. As a result, the financial position of the business gradually stabilized.

In these circumstances, Hayami Forestry implemented a plan to improve the age class structure. As a result of the forced cutting during the war, stumpage sales to pay the inheritance tax of 1943 and assets tax of 1946, the age-class distribution was skewed towards the younger classes. The need to improve the age-class structure was a factor determining the change in management practices. In the five-year plan of 1950, stumpage sales based on clear cutting were discontinued and the final cutting age was extended to improve the age class structure. During this time, only thinnings sold, and the company sought to reduce afforestation expenses. Beginning in the 1950's, demand rose for small timber, and thinnings with a minimum diameter of 7 cm began to sell. Profits from such sales were immediately put back into the business for expansion and afforestation. This plan was extended for another two years.

Pruning and silvicultural operations

As a result of the market demand for and small diameter timber, silvicultural techniques also underwent major changes during this time. One change included the introduction of pruning. Also, there was a sharp decrease in the planting density. The practice of pruning, which was aimed at producing of good quality timber, began in 1950. Under the pre-war dense planting and thinning system pruning was not carried out, and trees were allowed to lose their branches naturally. By the middle of the 1950's, a system was established in which pruning was carried out four times after the eighth year following planting and six times in forests with good growth.

A decrease in planting density accompanied the introduction of pruning; densities averaged 12,000 seedlings per hectare before and about 5,000 after the middle of the 1950's. Dense planting depended on natural self-pruning, and the implementation of pruning enabled excessively dense plantings to be eliminated, thus reducing the costs associated with afforestation. The figure of 5,000 seedlings planted per hectare remained the norm for about 10 years. However, workers found that it was difficult to prune fat branches, and as a result of further studies, the current figure of 7,000 to 8,000 seedlings per hectare was settled upon.

After a 7-year period of adjustments to the age-class structure, the clear cutting of timber and stumpage sales recommenced in 1957. A system for selling timber from the final harvest, and a labor force for thinning were established, and the total volume felled in thinnings and final harvest was 2,800 to 3,000m³. Eventually, the ratio of cutting and thinning approached a stable point of 1:1. Favorable market conditions for small-diameter wood continued until around 1963. Small diameter trees felled near forest roads were bundled up where they were, while more distant trees were transported by way of a "Yaen" (a simple aerial ropeway). Later, demand for small diameter wood decreased, but thinnings of scaffolding size sold well until around 1980.

Modernization of labor organization and regular year-round employment

The introduction of pruning was accompanied by major changes in employment practices. In 1953, a daily wage system was implemented, which created regular, year-round employment. At the time, about 10 ha of afforestation, weeding, and thinning were carried out each year, and pruning had been added as work to be done during winter. However, when pruning was carried out on a contract basis, workers became careless, leading to "tragic" results. It became difficult to retain skilled workers, and therefore the employment system changed from contract basis to a daily wage system.

Until then, Hayami Forestry had organized its labor force (HAYAMI 1911-1913) under a general supervisor, a manager of a forest practice division, and a laborer system.

In 1953, a general supervisor was employed with a monthly -wage, and managers who had until then been working on a contract basis were positioned as group-leaders employed under a daily wage system. The workers were also employed under a daily-wage system to establish regular, year-round employment. (HANDA 1979)

In this way, a silvicultural system incorporating site preparation, afforestation, weeding, pruning, and thinning within a system of year-round employment was established. It is important to note that the introduction of pruning, which required additional skills to those needed for pre-war forestry (in other words, the advancement of forestry techniques), brought about the introduction of the daily-wage system and regular, year-round employment. Thereafter the number of workers stayed at about 30 people. Those in management were workers with two jobs from self-providing farms in the region's old villages of Kawachi and Mase. Many of these men were quite young at the time. The labor force continued to be organized on traditional basis of shared territory and blood bonds. This method of organization effectively used surplus labor found in the populations of the mountain villages at the time.

Increase in management scale

The area of forest at the time the current entrepreneurs inherited the business was about 800 ha. In 1990, it was 1,016 ha, an increase in area of over 200 ha. This increase was principally due to the acquisition of two forest estates of 116 ha and 59 ha, purchased between 1963 and 1965. These estates consisted of considerable areas of first generation man-made forests. In addition to purchases, small woodlots adjoining forests of Hayami Forestry were purchased, and as a result, the estate of Hayami Forestry was gradually consolidated. The development of large forest estates served as an important precondition for the introduction and subsequent expansion of dense forest road networks and forestry mechanization.

THE CONSTRUCTION OF FOREST ROAD NETWORKS AND FORESTRY MECHANIZATION

The beginnings of the self-construction of dense forest road networks

Hayami Forestry began construction of their own forest road network in 1966. This was followed immediately by mechanization of production. In 1970, the first "Forest Management Plan " based upon the Forest Law was written, and the system of man-made forestry aimed at production of knotless wood for posts was stipulated in the text. Later, the concept of long rotation management was added. Under long rotation management, the rotation length was extended beyond 40 years of age, and thinning was repeated at intervals of 10 to 15 years to retain about 600 trees per hectare at eighty-years-old , and 400 at one hundred-years-old. This system of management remains in place today.

The construction of dense forest road networks in private forests was led by the Moroto Forestry (FUKAO 1988) in Mie Prefecture. Moroto Forestry copied forest management in Austria, where forest road networks are actively constructed, regardless of the steep mountainous topography that is similar to that of Japan. Seeing these new techniques, Hayami Forestry also began construction of dense forest road networks.

Where designing the road system, the manager chose an easy method of drawing routes on a map reduced to 1/5,000, at a 10% pitch. Simple measurements were made, obstructing trees cut, and the roads developed using a bulldozers. Teams of 2-3 people constructed forest roads throughout 1966. The program was extended to the following year, although priority was given to the thinning and cutting of forest stands. Currently, the road network extends about 40,000m, and the density of roads is about 40 m/ha. In some forest estates, it has reached 80 m/ha.

Mechanization of forestry production

Following the establishment of forest roads and expansion of log production, Hayami Forestry began mechanizing forestry production. After the rapid extension of the forest roads, the manager initiated the development of new yarding machines. Referring to a photo placed in the Unimog catalog in 1970, they manufactured a tower-yarder in the local steel factory. This was used for 5 to 6 years, but wired operations and carriage operations proved difficult. While searching for new forestry machinery, a crane at a wood products auction market in Gojo city in Nara prefecture caught their eye, and the idea of upgrading it to a forestry machine was raised. In 1974, an auxiliary winch was added to the crane to improve side movement and vertical suspension, thus improving its functionality as a yarding crane. A second-hand truck purchased at a price of 3 million yen was used to complete the yarding crane. Later, in 1985 and 1992, improved models were introduced and a system of log production based upon the dense forest road network and crane yarding was established.

Developments in integrated business and the improvement of a employment environment

In 1970, at the same time as the dense road network was formed and mechanization began, the employment of the daily wage labor force was extended from thinning operations to final cutting. Cutting, yarding and transportation operations were completely absorbed into the business, and the business developed into a so-called integrated business. (HUKAO 1967, 1988; OKAMURA 1957)

Previously, trees due to for final harvest were sold through stumpage auction sales to local businesses, and the thinnings were sold through a bidding system in wood yards. This system of sales was changed so that harvesting, cutting to length and transport of logs was done by Hayami Forestry and the bidding price became the "truck load price" which included all costs. The new system combined the merits of stumpage auction sales with those of a regularly employed labor force for log production, keeping all sources of revenue within the business. The businesses to which the timber was sold were limited to lumber mills in the city.

The establishment of the road network, the expansion of log production, and mechanization also served as the basis for the formation of a business strategy for maintaining the regular year-round employment system, as stagnation of expansive afforestation projects began.

The work of forestry labor expanded and diversified into afforestation, tending, thinning and cutting, and as a result, laborers became multi-skilled. In addition, two-job labor based mainly on forestry labor strengthened, and the number of working days in a year increased. In other words, multi-skilled forestry laborers prepared to work full-time appeared. In addition, the employment environment was further improved through the application and introduction of various insurance policies such as health insurance, welfare annuity insurance, employment insurance, labor disaster insurance, and the Mie Prefecture forest worker retirement money mutual aid fund and indemnity insurance by the Mie prefectural federation of forest owner's cooperative association. Thus, there was a transition from employing surplus labor from mountain villages to employing modern forestry workers. During this time, more-or-less no workers left their jobs after being employed, and the number of workers was kept at a stable level. However, there was only a small amount of new hiring, and the population of workers inevitably aged.

TRENDS OF HIGH-QUALITY TIMBER PRODUCTION AND LONG ROTATION, AND THE PROGRESS OF MECHANIZATION

The current man-made forest resource structure and high-quality timber production, and long rotation management

As seen above, since the end of the 1950's the volume of timber produced from cutting vs. thinning has been about equal, and began a shift to long rotation management in the 1970's. Such developments in management were facilitated by pressing demands for wood during the era of the post-war era, and increasing prices for small logs and posts of Japanese cypress. Price changes that occurred with the influx of imports, such as the decrease in Japanese cedar prices and the increase of Japanese cypress prices, were of further advantage to Hayami Forestry.

However, the Japanese cypress market experienced tremendous changes around 1980, and prices began to fall steeply. In the Matsusaka timber market, prices for Japanese cypress posts peaked at 72,100 yen per m^3 in 1979, and prices for small logs peaked at 42,000 yen in 1981. By 1992, these price levels had fallen to 40,000 yen and 23,500 yen, respectively. (EDITORIAL COMMITTEE of 40 YEARS HISTORY of MATUSAKA TIMBER CO.LTD 1994) These prices are equivalent to those at the end of the 1960's.

High quality wood and aged large diameter wood suffered relatively slight decreases in market prices. For Hayami Forestry, this encouraged a great emphasis on the production of wood that would not compete with foreign wood imported in large volumes.

An important factor for the company was their resource of man-made Japanese cypress forests. The structure of this resource had changed enormously from the previously-described structure found in 1946. The man-made forest area in 1946 was 426 ha. According to the age-class structure, 95% was made up of trees below 40 years of age. This was truly short rotation management. By 1986, the area had increased to 714 ha, and the age-class structure appeared as follows: 10%, age class 1 to 2; 16%, age class 3 to 4; 16%, age class 5 to 6; 12%, age class 7 to 8; 11%, age class 9 to 10; 12%, age class 11 to 12; 15%, age class 13 to 14; 6%, age class 15 to 16; 1%, age class 17 to 18; and 2%, age class 19 and above. There had been a major shift in the age-class distribution such that trees over 55-years old now made up 36% of the total. (Fig. 1) In other words, the man-made forest resource structure continued to improve after the war. The practice of maintaining a cutting to thinning ratio of 1:1 over a long period of time had improved the man-made forest resource.

Based upon this resource, the business policies of Hayami Forestry in 1990 included the continued development of a dense system of working roads, the mechanization of forestry work, the training of workers, the production of high quality wood (knotless, rectangular Japanese cypress timbers and timber for fine fixtures), a shift to long rotation management, and the improvement of tree varieties. These practices were aimed at production of high quality wood through long rotation management.

The current production system for high quality wood (for 10.5 cm and 12 cm diameter posts over a rotation of 50 years) in the best district is as follows. The number of seedlings planted: 8,000 per hectare; weeding, twelve occasions; improvement cutting, five occasions; pruning, six occasions; and thinning, five occasions. The labor force used for work prior to the final cut totals 527 people: 370 for silviculture per hectare; 140 for thinning related work;

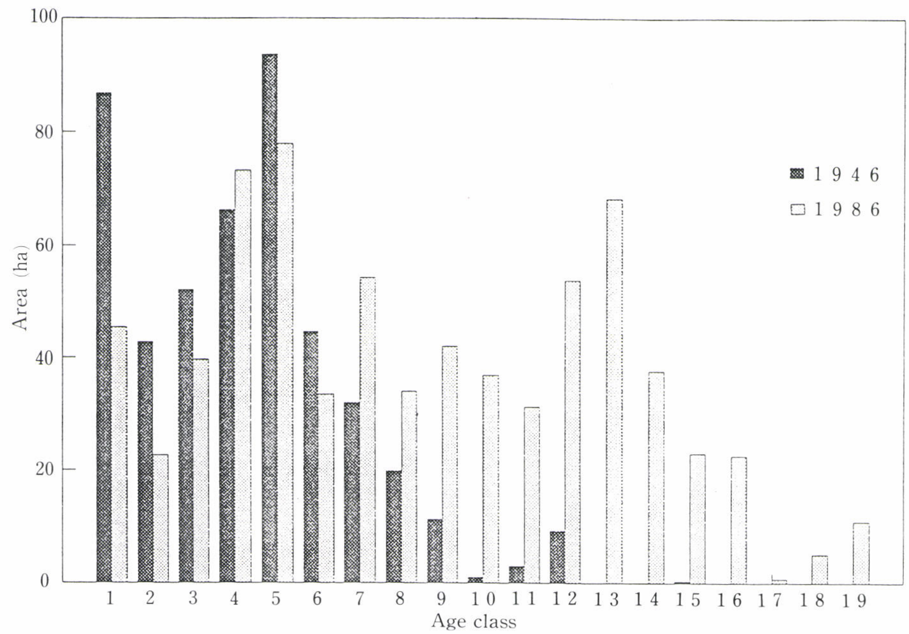

Fig. 1 Man-made forest area by age class (1946 and 1986)
Note: one age-class is 5 years

and 17 for preliminary cutting work. Today, the felling age is increasing, and is set between 60 and 150 years. This system would not have been possible without the development of good quality man-made forests over a long period of time after the war, and the establishment of highly dense forest road networks. The development of a management infrastructure and forestry mechanization has also been important.

The increase in the rates of thinning of high-age class trees and the introduction of high performance forestry machinery

During the 1980's, there was a long-term recession in the wood market, imports of foreign timber increased, and domestic wood prices further decreased. Under these circumstances, Hayami Forestry was forced to implement new management measures. Changes in harvest and timber selling methods were made with the aim of producing timber that would not compete directly with foreign timber; in other words, the commitment to production of knotless, high quality timber through long rotation management was even more clearly specified.

The first of these changes was an increase in thinning, especially of high-age class trees. In 1985, the cut volume was 2,913m^3, of which final-cut timber was 52% and thinned wood was 48%. In 1988, the rate of thinned wood rose to 66%. As a result of salvage cutting of wind damaged trees in 1990, the rate of thinned wood amongst further increased to 91% in 1993 (of a total of 3,303m^3). This resulted in further improvements in the forest resource and further facilitated long rotation management.

Harvesting techniques were also improved by introducing high performance machines, such as the "tower-yarder" and the "grapple skidder" in 1991. In the 1988 "Forestry White Paper," the construction of "new forestry machine technology systems" was proposed to enhance productivity, and the example used was the use of a tower-yarder and processor (The Forestry Agency 1988). Hayami Forestry became the pioneer of the tower-yarder. To Hayami Forestry, the introduction of high performance machines served as an extension of the technologies accumulated under the management practices implemented after the 1970's, and the combination of the "tower yarder" and "grapple skidder" matched the requirements of their production system. Prior to introducing the tower yarder, they sent two of their workers to Austria for technical training. Courses were later held at the company for all workers, and now all units are able to use the tower-yarder.

In 1993, the total number of working days was 6,012.4 man-days. Harvesting made up for 47% of this volume; silviculture, 40%, forest roads, 10%, and instructional classes, 4%. This reveals the multiplecapacities of the current forestry labor force, as well as the importance of spreading technologies inside the company. The increase in the rates of thinning of high-age class trees and the introduction of new forestry machines demands even more advanced forestry techniques.

High-quality timber production, the trend towards the development of a long rotation system, and the timber market

One aspect of the new market that must be mentioned was the change in the method for selling timber following the salvage cutting of wind damaged trees. Prior to the damage suffered in the wake of the typhoon in 1990, sales of stumpage and thinned wood were limited to businesses in the city in the interest of developing local lumber mills. After the typhoon, however, such sales practices were extended to include sales in the roundwood auction market. One reason for this was the excessive supply of logs found in the regional markets due to the large volume of wind damaged trees. In the further changes in the structure of the man-made forests and the increase in large diameter logs will be of more importance than the production of timber for posts. Local lumber mills capable of producing posts may not have adequate milling techniques to produce timber for fine fixtures, and are unable to handle the variety of timber produced by Hayami Forestry. Thus, by 1993, bidding sales of stumpage and other materials had been stopped, and sales to the roundwood auction market accounted for 92% of production. Buyers included the Miyama-cho forest union roundwood auction market, which comprised 40% of the market, and the roundwood auction market of other regions which made up 60%.

IMPROVEMENTS TO AND THE MODERNIZATION OF EMPLOYMENT PRACTICES, AND SECURING A YOUNG WORKING FORCE

Improvement to and the modernization of employment practices

When the current entrepreneurs took over management of Hayami forestry, the first surprising thing they noticed was the graying of forestry laborers and the fact that none of the children of the workers had taken over the business. The age-class structure of the employees (including clerical workers) in 1981 was one person in 10 to 19-years old range; one person in the 20 to 29-years old range; two people in the 30 to 39-years old range; eight people in the 40 to 49-years old range; twelve people in the 50 to 59-years old range; and six people in the 60 to 69-years old range. The trend of an aging work force is not limited to Hayami Forestry.

For this reason, employment conditions were improved. First, in January 1983, the "Hayami Forestry Working Rules" were developed on the basis of the working rules of the local banks. Also developed were "Wage Regulations", "Retirement Allowance Regulations", "Travel Expense Regulations", and "Hayami Forestry Mutual Aid Society Regulations". These prescribed wages, working hours, Sundays and public holiday rest days, a paid holiday system, retirement at 65, and a retirement allowance, as well as clarifying employment conditions. Furthermore, with the authorization of the Labor Standards Inspection Office, employment of new workers was pursued. Appeals were made to local high schools, public employment agencies, and those wishing to work locally were invited to change their jobs. These efforts focused on ensuring a pool of young forestry workers and the passive employment attitude of the company was changed to an active one. This involved a break from earlier methods of employment that had relied on territorial and blood connections.

To facilitate the employment of young workers, it was imperative to wipe away the image of forestry workers as being "Dangerous", "Hard", and "Dull", in both name and reality. It was also of overriding importance that forestry workers mastered advanced techniques and the working environment was improved so that workers could take pride in their work. For this reason, forestry mechanization was encouraged, as a means of making forestry labor require advanced knowledge and skills and to free it from the image of being simple, heavy labor, perceived as "dangerous", "hard" and "dull". To gain forestry skills, the acquisition of various licenses and qualifications at the expense of the employer are recommended. Workers have been asked to participate in study groups and courses sponsored by the nation, prefectures, and various groups. Forestry labor's image of being "dull" and "hard" has become something of the past for Hayami Forestry. However, the image of being "dangerous" persists , and the employer has commented that "there is a need for the entrepreneurs to pay as much money as possible to eliminate this image". Subsidies are provided to purchase of made-to-order uniforms (summer and winter), Gore-tex rainwear and foreign-made safety shoes for example. (HAYAMI 1991)

Increase in the numbers of young forestry workers

As a result of actively employing young new workers since 1980, the employee age-class structure as of July 1994 is: three people in the 10 to 19-years old range; five people, 20 to 29-years old; six people, 30 to 39-years old; five people, 40 to 49-years old; eight people, 50 to 59-years old; and five people, 60 to 69-years old, indicating that the workers have become much younger in the past 10 or more years. Between 1990 and 1993, two new workers were employed each year, and in April 1994, three new high school graduates were employed.

The new employees from the 1980's can be broadly categorized as those who changed their jobs locally, those who returned from cities, and new graduates. The employment history of the first two are varied, but most are said to have become tired of work which presses for quotas under time pressure and were drawn to the stable environment of Hayami Forestry. The number of new high school graduates employed in the recent years has also increased. Thus, Hayami Forestry is undergoing a tremendous change, evolving into a company of young people quite unlike typical forestry companies in Japan, which are forever complaining of the decreasing work force and shortage of potential employees.

The payment of wages is made on a monthly basis for office administrators and on a daily basis for on-site workers. There were attempts to change the daily-wage system to a monthly-wage system, but these attempts were opposed by the workers, indicating that they seem to prefer work that does not tie them down and which enables them to take leave freely. In particular, young people tend to prefer freelance work. The annual income of on-site workers is up to 4 million yen for those who work more than 250 days. The distribution of annual income in 1993 was: one person at less than 1 million yen; one person, 2 to 2.5 million yen; two people, 2.5 to 3 million yen; three people, 3 to 3.5 million yen; 12 people, 3.5 to 4 million yen; five people, 4 to 4.5 million yen; and one person, 4.5 to 5 million yen. The motto of the employer is to ensure a pay standard that will enable a worker to build a new home in the local area by the age of 40.

The change in the employment pattern of workers, improvements to and modernization of employment relationships, and the increase in year-round employment have changed the nature of employment of forestry workers. The "half farmer, half forestry worker" trait that once described the average worker that came out excessive labor force of mountain villages has now more-or-less disappeared. Currently, there are only 6 forestry workers who own farms and they are mainly in the elderly age group. Modern forestry workers are a new breed of workers with high skill levels. In modern societies, it is characteristic for workers to have a single-skill based upon the division of labor. This is the same in forestry and can be seen in the division between afforestation work and harvesting work, simple laborers and single-skilled workers. In these terms, forestry workers at Hayami Forestry are also varied.

CONCLUSION

In the post-war period, forest management of Hayami Forestry was characterized by dense planting and short rotation management and the forests which emerged from afforestation efforts had a complete production infrastructure.

The forest management system and the age class structure of the forests changed dramatically as domestic timber demand increased from the 1950's to the 1960's. Pruning , thinning and forest road networks were introduced as new forest techniques, and the age of final cutting was extended. With the development of highly dense forest road networks, the 1970's saw the introduction of mechanisation and the integration of all operations within the company. This led to the extension of the skills of the workers, added log production to the activities of the business, and put industrial capital in the form of profits to use; in other words, we began to see the development of integrated management. As a result, the business became modernized.

The direct employment of forestry labor and increase in forestry skills developed together and enabled the integration of silviculture, felling and forest road construction. This self-development of forestry techniques at Hayami Forestry led to the tremendous changes in the character of the business.

Developments in the production of good quality timber and the relative advantage of Japanese cypress prices in the timber market enabled the trend of long-rotation management that began in the 1970's to be expanded, not as a form of extensive forestry, but rather as a "possibility of raising forest productivity through the development of new forestry techniques" .(HANDA 1988)

The fall in stumpage prices of Japanese cypress in the 1980's led to further emphasis on the production of good quality, large diameter timber which has a relative price advantage. This forced the company to specialize in the production of aged, thinned wood in the second half of the 1980's and into the 1990's. At the same time new labor and employment conditions were established, there were increased levels of employment of new workers and the mechanization of forestry entered a new phase.

The goals and limitations of full-time, large-scale corporate management are clearly visible through this examination of the case of Hayami Forestry. The sustainable forestry management practices of Hayami Forestry were rooted in local and regional society and production is now based upon multi-skilled labor. Developments will be watched with keen interest as Hayami Forestry is looked upon as indicators of the future course of forestry in Japan.

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*1 From an analysis up to the first half of the 1970's, it was commented that "with the management in advanced forestry regions where man-made forest development is already in progress, the "streamlining" of management is seen, while in backward regions, abandonment and a reduction of business activity is progressing, and a retrogression to the forest landlord system is seen."

*2 Fukao and Okamura, in the papers, take management systems combining logs production and silviculture by forest owners to be integrated management and the creation of capitalism in forestry management

*3 In the almost same period, the dissolution of the pre-modern "Yamamori" (a general supervisor of the forests management who lived in Yoshino region) system and reorganization was progressing amongst some owners of large-scale forests in neighboring Wakayama Prefecture

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Article

Plantation Forestry of Sri Lanka
—Its Development History and the Present State—

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Jayatissa Kumara Herath*

ABSTRACT

Since very early times Sri Lanka has had many forms of forestry practices including forest plantations. The British introduced modern plantation forestry in the 19th centry. Since then the plantation forestry sector has grown and legal and institutional frameworks have developed, although the total forest cover of the country has dwindled. Today forest plantations cover about 3% of the land area and comprise exotic as well as native tree species. Primarily they supplement the nation's timber and fuelwood needs.
During the last decade several changes have taken place in the country's plantation forestry; (1) increased international funds, (2) increased awareness of forestry, (3) orientation toward the public (4) increased planting of indigenous trees and (5) a transition from government monopoly to a mix of state-owned and privately-owned plantations.
For a sustainable future of forestry, forest plantations should be planned holistically, with consideration of alternative forestry practices, and the national land use, energy and timber utilization needs.

Keyword: fuelwood, indigenous species, exotic species, government monopoly, international funds

INTRODUCTION

Sri Lanka has a long history of forest convervation. The country has one of the highest population densities in Asia and has made valiant attempts to protect her forest cover. Although the forestry sector adds a mere 1.7% to the GDP, this represents more than 8% of the overall contribution made by the agricultural sector. Presently, the agricultural sector as a whole accounts for 20.5% of the GDP. In spite of the fact that the natural forest cover has dwindled, the extent of protected areas as well as planted forests has increased steadily.

This paper examines the historical development of the plantation forestry (industrial forestry) sector and its present situation, and discusses its importance from the stand-point of future management needs.

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EARLY HISTORY OF PLANTATION FORESTRY

Sri Lanka has a long history of forest conservation. However, the early history of her planted forests remains somewhat hazy. Although there are many historical references to wildlife refuges or sanctuaries of the early monarchial period, evidence of forest plantations are less clear.

Sri Lanka has had a long history of varied forms of forestry practices from social forestry and agro-forestry practices to natural forest and plantation silviculture since the time of King Vijaya's period (543 BC) according to rock inscriptions and chronicles such as the *Mahawansa*, the *Rajaratnacari* and the *Rajavaliya*, (GUNATHILLEKE 1991).

The hydraulic civilization of Sri Lanka that flourished in the dry, north-central plain from about 200 BC through 1200s AD was based on conservation of water in numerous man-made reservoirs (called tanks) for year-round use. While the upstream areas of the rivers that fed these tanks had protected forests or forbidden forests, downstream near the villages, mixed forests were planted as a common property resource.

According to some evidence, in early days the lower area of the "Ritigala" hills in north-central Sri Lanka were planted with important medicinal trees valued in the indigenous Ayurvedic medicine. Today this is a protected archaeological site where the ruins of a Buddhist monastery and what is presumed to be a hospital can be seen. Ritigala is also one of the three 'strict nature reserves' of the country.

According to NANAYAKKARA (1987), who refers to the historical chronicle *Nahawansa* of Sri Lanka, there had been forest plantations in the country during the reign of King Butugenunu (161-137 BC). It is commonly known that, his son Prince Saliya met Asokamala, a young woman of the *Rodi* or *Chandala* outcaste society, in an 'asoka' (*Saraca indica* LINN. *Fabaceae*) forest garden and fell in love with her, relinquishing his rights to the throne.

The *talawa* grasslands/savannas of the eastern part of the 'central hill country' (Fig.1) of Sri Lanka are tree-savannas dominated by scattered trees of species such as *Terminalia chebula* RETZ. and *Terminalia belerica* ROXB. (*Combretaceae*), *Phyllanthus emblica* LINN. (*Euphor-*

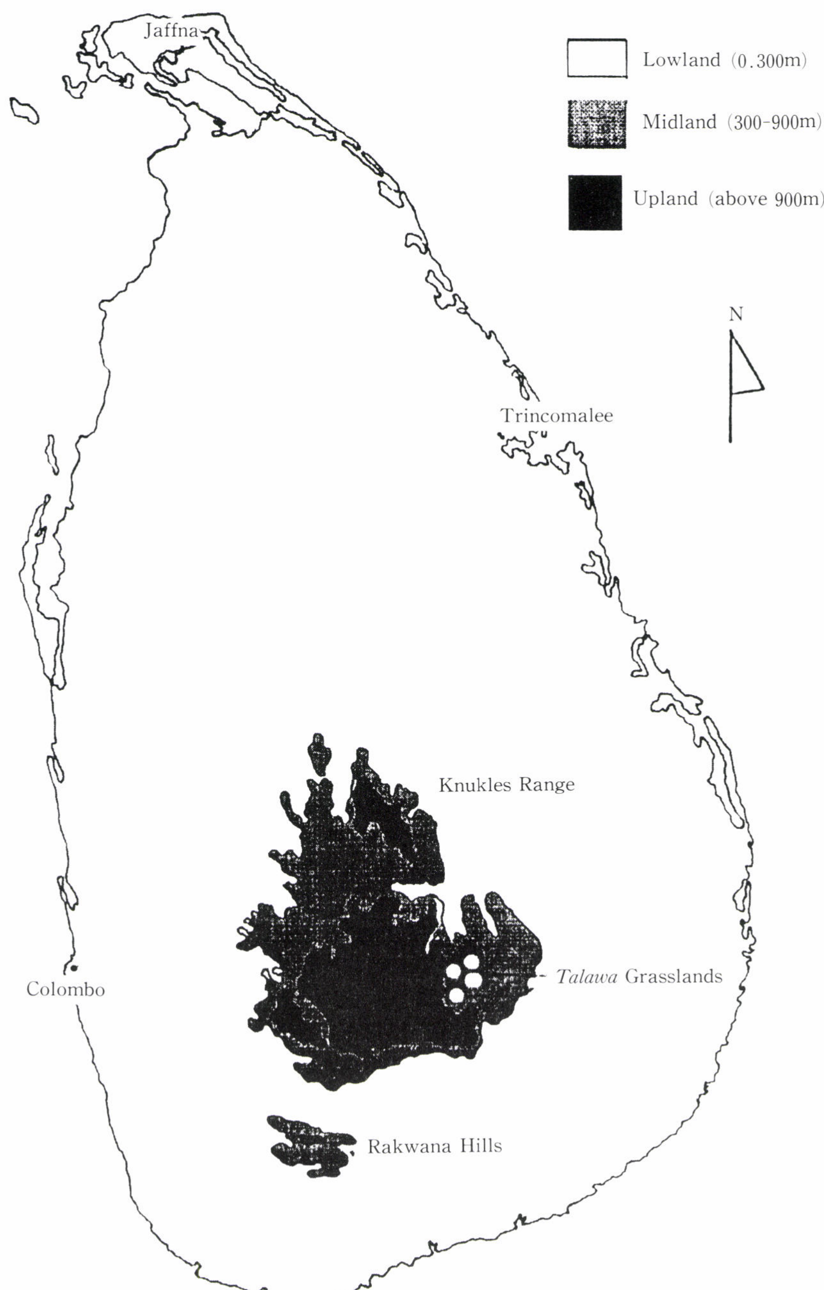

Fig. 1 Relief map of Sri Lanka

biaceae), *Pterocarpus marsupium* ROXB. (*Leguminosae*) and *Careya arborea* ROXB. (*Lecythidaceae*). These species are used in the indigenous medicine, and some people suspect that these areas were royal medicinal parks sometime in history. It is noteworthy that King Buddhadasa (362-409 AD) was a patron as well as a practitioner of the indigenous medicine.

Leaves for the traditional palm or ola manuscripts were provided by the talipot palm (*Corypha umbreculifera* LINN. *Arecaceae*) groves of the village Galatara, according to PERERA and JAIN (1992). The place name of Tal-aramba, in southern Sri Lanka also, translates as palm grove, where, there could have been palmyra palms (*Borassus flabellifer* LINN.), a naturalized species common in the 'dry zone' of Sri Lanka. There are many other names of localities that literally mean clusters of various important trees such as Kosgoda (*Artocarpus heterophyllus* LAM. woodlot), Meegoda (*Madhuca longifolia* LINN. woodlot), Nagoda (*Mesua nagasarium* KOSTERM. woodlot) and Thimbirigasyaya (*Diospyros malabarica* KOSTEL. tract). However, presumably these places did not have monocultures of trees.

Sri Lanka also has a long history of introducing exotic tree species, and controversial exotic trees are part of modern forest plantations of the country. The first recorded example of this is the planting of a branch of the sacred Bo-tree, *Ficus religiosa* LINN. (*Moraceae*), under which Prince Siddhartha Gauthama attained enlightenment. This branch, which was brought from India during the reign of King Tissa (250-210 BC according to de Silva 1987) and planted in the City of Anuradhapura (Fig.2), still exists. Even the coconut palm (*Cocos nucifera* LINN. *Arecaceae*) is not indigenous to Sri Lanka. Although it is not exactly known when this palm was introduced to the island, 'in the sixth century AD the first mention occurs in the native chronicles of coconut plantations...' (ARUNACHALAM 1906), credited to King Agrabodhi. Another early introduction was the Baobab tree or *Adansonia degitata* LINN. (*Bombacaceae*) to the Mannar area in the northwest by Arab traders around the 10th century AD. Even such

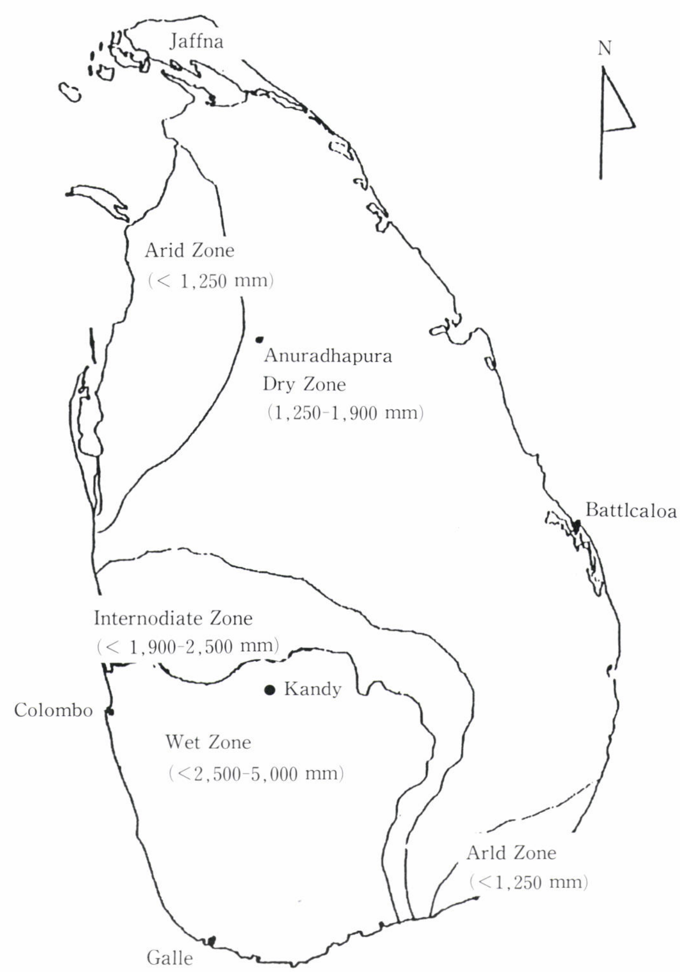

Fig. 2 Climatic divisions

naturalized trees as beli (*Aegle marmelos* CORR. *Rutaceae*), cashew (*Anacardium occidentale* LINN. *Anacardiaceae*), margosa or neem (*Azadirachta indica* A. JUSS. *Meliaceae*) frangipani (*Plumeria* spp. LINN. *Apocynaceae*), have been introduced at some point in the history.

Likewise, tree-planting and conservation is embedded in Sri Lankan culture. According to one commonly known anecdote, once, while an old man was planting a mango seedling, a young boy came and asked him what he was doing. The man replied "As you can see I am planting this mango seedling." The boy was surprised and remarked "But you won't live long enough to see that plant grows and bears fruits". "No", the man replied. "But, I ate what my forefathers had grown. This is for people like you".

The transition from the early history of forestry to the modern era began with the arrival of western people since the 16th century. First came the Portuguese in the early 1500s who began to exploit the forest resource. They were succeeded by the Dutch in the mid-1600s.

MODERN HISTORY OF PLANTATION FORESTRY

Early attempts at commercial plantation forestry in Sri Lanka were made during the Dutch period, when teak (*Tectona grandis* LINN. *Verbenaceae*) was introduced in 1680 and some plantations were attempted (PERERA 1962). More extensive and systematic forest plantations were begun by the British who arrived in the country since 1796 and took control of the entire nation in 1815. In 1870, teak planting began in abandoned *hena* or *chena* (shifting cultivation) lands in the dry zone by the *taungya* co-operative method. In addition, some naturalized species (e.g. *Artocarpus heterophyllus* LAM. *Moraceae*) and indigenous species (e.g. *Melia dubia* CAV. *Meliaceae*) were planted, also in similar lands. Moreover, around this time they also planted Acacia trees in the hill country. After the Forest Department was established in 1887 following the 1885 Forest Ordinance, more systematic plantations were attempted. In 1888 *Eucalyptus* was first planted in deforested areas and patana grasslands of the hill country (PERERA 1961). Also initiated around this time was enrichment-planting in natural forest areas, of mahogany (*Swietenia macrophylla* LINN. *Meliaceae*), introduced from the Honduras. In 1921 planting of teak completely stopped, but was resumed after 1931.

In 1929 the emergence of the country's first forest policy was very important, as its stated first objective was 'to make the island self-supporting in timber and other forest products' (PUSHPARAJA 1985). It has since been amended several times. The establishment of the Silvicultural Research Unit in the Forest Department in 1937 was the next important development, as subsequently more attention was paid to the plantation forestry sector. Thus, by the time Sri Lanka (then Ceylon) got her independence in 1948, there was some 10,000 ha. of forest plantations in the country.

In 1949 the Timber Utilization Research Branch was set up in the Forest Department.

From the mid-1960s plantations of tropical pines (e.g. *Pinus caribaea*, *P. patula* and *P. insularis*) were established, although earlier trials of planting pines had been carried out in the 1930s and 1950s. These plantations have been mainly for timber, but in the late 1960s the exotic bamboo *Dendrocalamus strictus* (*Bambusaceae*) from India was planted in the eastern province with the principal objective of providing pulp for paper. Table 1 lists out principal exotic tree species grown in forest plantations and tea estates.

Another major institutional development of this period was the creation of the State Timber Corporation in 1968 to handle the activities of extracting, processing and marketing of timber, fuelwood and other forest products.

Before 1977 reforestation was done with local funds. This changed after a new government came to power in the second half of 1977. The first reforestation funded by the World Bank was undertaken by the Forest Department under the sponsorship of NADSA (National Agricultural Diversification and Settlement Authority) in the Kandy District. This project covered four watersheds.

Since the amendment of the National Forest Policy in 1980 the Forest Department has intensified its activities. Undoubtedly the increasing national awareness and politi-

Table 1 Exotic trees grown in forest plantations, tea estates and other areas in Sri Lanka.

Species	Family
Acacia decurrens	*Fabaceae*
A. mangium	〃
A. melanoxylon	〃
A. molisima	〃
Albizzia moluccana	〃
Casuarina equisetifolia	*Casuarinaceae*
Cedrella toona	*Meliaceae*
Cupressus macrocarpa	*Cupressaceae*
Dendrocalamus stricticus	*Bambusaceae*
Eucalyptus camaldulensis	*Myrtaceae*
E. globulus	〃
E. grandis	〃
Grevilea robusta	*Proteaceae*
Pinus caribaea	*Pinaceae*
P. insularis	〃
P. patula	〃
P. oocarpa	〃
Swetenia macrophylla	*Meliaceae*
Tectona grandis	*Verbenaceae*

cal interest in environmental matters after the National Environment Act of 1980 has also been important. The Community Forestry Project, initiated by ADB funds was something new. Another development of this period was the emergence of fuelwood plantations owned by both the state and provate companies. These will be discussed in the next section. In 1981 the government abolished the previously mentioned *taungya* reforestation scheme practised in the dry zone.

Thus, the extent of forest plantations has increased sharply since the 1970s. Data presented in Table 2 on the growth of forest plantations in the last century clarify this. These data show marked increases in 1953 and 1985. The first one indicates the increased attention reforestation received after the independence of 1948. The increase of 1985 reflects the awareness of forestry that grew after 1980. The Forestry Master Plan (1986) is noteworthy. Whilst addressing all aspects of forestry, this plan emphasized planning for timber supply for the next 30-35 years. Due to heavy criticisms from many concerned people it is being revised. In spite all its shortcomings and deficiencies, it meets a long-awaited need.

THE PRESENT STATE AND DISCUSSION

Presently the plantation forestry sector of Sri Lanka comprises the following components:

1. Pure stands of monocultures
2. Mixed stands enriched with mahogany
3. Community/social forestry component
4. Energy forests (other than community forests)

Forests of categories 1 and 2 are owned by the Forest Department and timber extraction in such forests is carried out by the State Timber Corporation.

Community forestry (category 3) was undertaken by the Forest Department in five districts in 1982. Its main objective was the involvement of people in planting, managing and protecting trees. According to the Sri Lanka National Report To The UN Conference On The Environment And Development (1991) 26,000 ha of fuelwood plantations were established under this scheme. This includes farmers' woodlots, community woodlots, fuelwood blocks, homestead woodlots, avenue planting etc., and the expected benefits include the extraction of fuelwood, timber, green manure, fodder, fruits and edible leaves and spices plus environmental conservation and beautification. It has been acceptable to the rural peasant communities (De Zoysa and Nagata 1994), although the degree of success so far has not been up to the very ambitious nature of the project.

Energy forests (category 4) are managed by the state agencies of the plantation sector such as the Sri Lanka State Plantations Corporation (SLSPC) and the Janatha Estate Development Board (JEDB), and private estate companies. The state agencies own about 17,000 ha. while the total extent managed by more than 20 private tea-estate companies and the Ceylon Tobacco Company is around 6,000 ha. (Forestry Planning Unit, Sri Lanka). The species grown are mostly exotics.

The latter company sector is an important novelty, as previously virtually all plantation forests and natural forests were owned by the state.

These forest plantations, which now cover roughly 3% of the total area of the island, are of tremendous importance to the country and need to meet the increasing demand for forest products. The increasing population (annual growth rate =1.4%) and rising living standards will demand more fuelwood, timber and other forest products toward the next century and thus, these forest plantations are crucial for the future survival of the protected (conservation forestry) areas.

In this context it is essential to address the energy situation of the country in relation to forestry. Sri Lanka has no endowments of fossil fuel and is heavily dependent on biomass fuel. Approximately 70% of the gross energy used in the country comes from biomass fuel while about 20% is provided by imported petroleum. About 10% of the energy needs are met by hydro-electricity. There is some direct use of solar energy (e.g. in the drying of fish, agricultural products and pottery, bricks and tiles) as well as animate energy (e.g. elephants in lumbering, water buffaloes and neat cattle in ploughing rice fields and threshing harvested paddy, oxen in pulling carts). Nearly 80% of the biomass fuel needs are met by agricultural plantations and homegardens while forests provide the balance presently (Fig.3). Over 80% of the biomass fuel is consumed by households while industries use the remaining amount (or

Table 2 Extent of forest plantations in Sri Lanka (1890-1990).

Year	Cumulative extent (ha. approx.)
1890	367
1900	569
1953	10,530
1960	27,135
1972	53,865
1985	144,000
1986	174,729
1987	184,540
1988	189,533
1989	192,694
1900	193,992

(Not included: Extent of Community Forestry projects and other fuelwood blocks)

—Compiled with data from Statistical Abstracts and several other sources—

roughly 1/6 of household consumption). As the use of biomass fuel is growing at about 1.4% per year (NATIONAL ENVIRONMENTAL ACTION PLAN 1991:65), this exerts some partial pressure on the forests too, in spite of the fact that recently the use of LPG has been increasing (Table 3).

The main non-forest sources of biomass fuel are rubber plantations and coconut plantations, followed by home gardens, tea estates and crop wastes, e.g. paddy husks. As the potential for using treated rubber wood as timber increases, forest plantations will have to provide more fuelwood to fill the gap. Sri Lanka's hydro-electricity potential will be fully harnessed by 2000. All large sources are now being used but medium and small sources of hydro-power remain to be tapped. Future development of these sources will need more protected forests in the watershed areas at the expense of plantation forests or other types of land use.

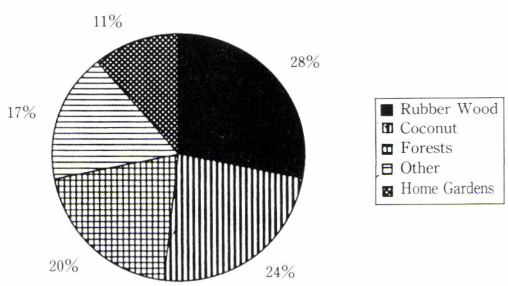

Fig. 3 Composition of biomass fuel used in Sri Lanka

Table 3 Trends in the production of LP Gas

Year	1978	1991	1992	1993	1994
Amount	5.0	37.5	44.7	52.9	64.3

(metric tons × 1,000)

Source: Sri Lanka Socio-economic Data 1995 Central Bank of Sri Lanka.

As for timber supply, non-forest sources supply 50%-60% of the sawn timber. These sources are rubber plantations, coconut plantations, home gardens and tea estates. About 18% of the sawn timber comes from forest plantations. Natural forests and (semi-)natural forests enriched with mahogany also provide up to 17%. Unknown sources, non-point sources and imports also add a small amount (MUNAWEERA and BELL 1994). However, this situation may change especially with the possible decline of timber supply from non-forest sources. Hence it will be necessary for the forestry sector to increase its timber output. In such a situation the role of plantation forestry will become of prime importance because there is a negative balance in the supply of timber against demand (Table 4).

Increasing the timber output from forest plantations can be echieved by (a) expanding the extent and (b) improving the production from existing forest plantations.

(a) In Sri Lanka there is still room for increasing the extent of forest plantations as degraded land is available. Most of these lands are found in the midland wet zone and are abandoned tea lands. The Forestry Master Plan envisages the annual establishment of 10,000 ha of new forest plantations for timber production which seems to be practicable. In addition, logged over areas can be reforested.

When addressing the possibilities of afforestation of degraded lands and reforestation of logged over areas the controversy of exotic species versus native species arises. As in mány tropical countries, the planting of exotic species in forest plantations in Sri Lanka has been the subject of debate. Many environmentalists are opposed to exotic tree plantations and mostly their objections are against monocultures of such trees. Yet, exotic tree plantations have proven to be far superior in timber production. Moreover, the success of most of the exotic tree species in secondary succession on degraded land is proven. Although there is no straight-forward answer to this controversy of

Table 4 Demand and supply of industrial wood (1986-2020)

	1986-90	1991-95	1996-2000	2001-10	2011-20
Timber Supply					
Forest Plantations	135	130	178	408	341
Natural Forests	350	335	320	297	172
Sub-Total	485	465	498	705	513
Non-forest sources	267	287	350	403	455
Plantation Agriculture	278	363	414	475	585
Total	1,030	1,115	1,262	1,583	1,552
Demand	1,050	1,230	1,390	1,680	2,050
Balance	-20	-115	-128	-97	-498

(Data sources: Forestry Master Plan (1986), Jayasekera (1987)) exotics vs. indigenous species, the recent trend has been to plant more indigenous species while concurrently reducing the proportion of exotic species in new plantations (Table 5). In the past five years, about 39% of the replanted trees have been indigenous hardwood species. There has also been an increase in acacias (*A. acuriculiformis*), and decrease in eucalyptus and the cessation of planting pines. Fig. 4 depicts a time-series of the extent of major species in plantations and illustrates this trend. It shows an increase in the extent of indigenous species, a decrease in the extent of pine-bamboo, and a stable level of teak, mahogany and eucalyptus which reflects a balance between harvesting and replanting.

The improvement of existing plantations requires the introduction of appropriate silvicultural practices. For instance, selection of species suitable to different geographic areas is very important. If exotic species are to be selected due consideration should be given to naturalized exotic species e.g. hevea rubber (*Hevea brasiliensis* KUNTH. *Euphorbiaceae*, *Alstonia macrophylla* WALL. *Apocynaceae*).

Another need is the improvement of nursery techniques and practices. Malpractices such as the use of substandard seeds and keeping of seedlings in pots for too long are reported in literature.

Once forest plantations are established many perennial problems are encountered. for instance, tree damage by animals, especially elephants in the dry zone is considerable. In the hill country where patana grasslands have been afforested, fire hazard is severe. Such fires are mostly deliberately lit by villagers. In forest plantations of other parts, fire hazards are also important. On average, 15,000 ha of forest plantations are damaged by fire annually. As for thinnings the State Timber Corporation has rarely complied with the thinnings or fellings prescribed by the Forest Department. Possible remedies to such problems must to be found.

Table 5 Species composition in past and present forest plantations.

Past		Recent	
Teak	47%	Teak	7%
Pine	21%	Pine	2%
Eucalyptus	28%	Eucalyptus	35%
Other softwood spp.	1%	Other softwood spp.	17%
Indigenous spp.	2%	Indigenous spp.	39%

(Source: Munaweera and Bell 1994)

CONCLUSION

When considering the future of plantation forestry of Sri Lanka one needs to look at the overall forestry situation holistically. Although forest plantations are far more productive than natural or semi-natural forests, their benefits should be compared with alternative forestry practices such as agroforestry and natural forest management.

For instance, forest plantations are best for producing fuel wood and timber but are poor in sustaining the environment and biodiversity. One the other hand agroforestry systems also yield extractable fuelwood and timber but are far more compatible with community needs. The remaining natural and semi-natural forests of Sri Lanka should be declared protected areas and not managed for timber. a combination of the other two forestry types can be allowed and the future extent of plantation forestry should be decided.

It is also important to note that a slow 'energy revolution' is taking place in Sri Lanka now, with people switching to electricity and LP gas. Thus, if the demand for fuelwood levels-off toward the next century, forest plantations could provide more timber for the slowly, but steadily expanding industrial and services sectors. It is also important to consider the future timber and energy supply from non-forestry agriculture (i.e. rubber, coconut and tea plantations).

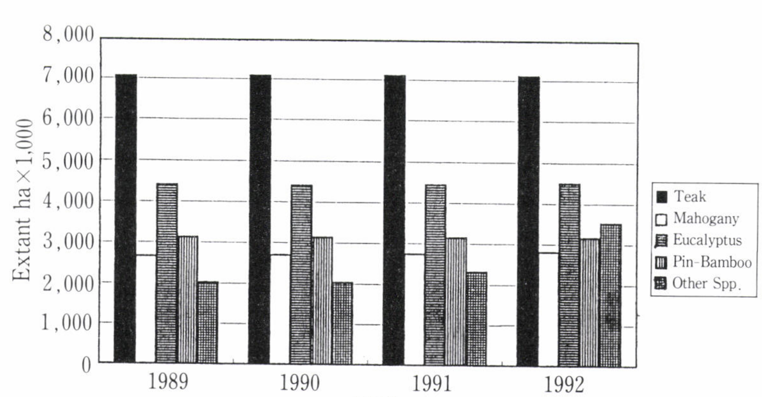

Fig. 4 Extent under major species in forest plantations

The total landuse mosaic of the country has to be planned, including agricultural landuse as a component. Such a wide approach will allow the extent and species composition of future forest plantations to be determined, and will allow conflicting agricultural and non-agricultural landuses to be reconciled.

Future forest plantations will need to be of multiple character, with native as well as suitable exotic tree plantations, located in selected terrain to serve the needs of the country.

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Article

DBH-Height Relationship for Japanese Red Pine (*Pinus densiflora*) in Extensive Natural Forests in Southern Japan.

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ABSTRACT

The diameter at breast height (DBH)-tree height relationship for Japanese red pine (*Pinus densiflora*) in an extensive natural forest (27.86ha) was studied at the Kyushu University Forest in Miyazaki (UFM), southern Japan. DBH-height allometry and the shape of height distribution based on DBH class were analyzed using a generalized allometric equation and the Weibull distribution function, respectively, and a height estimation model based on DBH (HEMD) was constructed. The slope of the DBH-mean height curve at a forest level was steeper than that for *Pinus densiflora* stands at a plot level. The height distributions based on DBH class were positively-skewed and the degree of skewness was stronger at sizes <20cm and>50cm. HEMD described height distribution and DBH class-volume distribution well at a forest level. The effects of stand structure on size diversity and the DBH-height relationship of *Pinus densiflora* in the UFM were discussed.

Keyword: DBH-height allometry, height distribution, size diversity, *Pinus densiflora*, extensive forest

INTRODUCTION

In yield inventory of mixed species natural forests of 10 ha or more in area, it is often difficult for foresters to select sample trees to derive diameter-height curves for each tree species, because of the complexity of the species composition and the structure of the natural forest. In such situations, the forester would have to measure diameter at breast height (DBH) and height of all target trees within the forest, if DBH-stem volume tables for each species or species group have not been constructed for the region. However, to accomplish large-scale forest inventory with limited time and resources, it is essential to simplify the inventory, especially height mensuration, as much as possible.

In addition, even if yield inventory data were obtained after investing much time, money and labor, these data would probably not be used again after calculating standing volume. However, used yield inventory data represent a great deal of information about the forest and can be used for forest operation planning (YAMAMOTO 1990) and forestry and ecological research (SUZUKI 1984; KUNISAKI *et al*. 1996).

In consideration of these viewpoints, we studied species-specific DBH-height curves for some tall hardwood and softwood trees established in the Kyushu University Forest in Miyazaki prefecture (UFM), southern Japan, using yield inventory data from an extensive natural forest in UFM (KUNISAKI *et al*. unpublished; KUNISAKI and IMADA 1996a). We found that the variance of the DBH-height curve data was greater than that of a small-scale stand of about 0.01-0.1ha. Therefore, in order to construct a precise and accurate height estimation model based on DBH for extensive forest, we concluded that not only the DBH-height curve, but also height variation based on DBH class should be analyzed (KUNISAKI and IMADA 1996a)

Extensive natural forests in the study area comprise a number of small-scale stands with different species composition and structure (ARAGAMI 1987; MASUTANI *et al*. 1992; ITO and ARAGAMI 1993). Such a complex structure in extensive forests may increase the size diversity in DBH-height relationship in any species. The species-specific size diversity probably results from differences in developmental stage and such environmental factors as altitude, topography and wind between the component stands.

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However, the effects of developmental stage and environmental factors on the DBH-height relationship for a given species are still not clear.

The principal aims of this study were to: (1) describe species-specific allometric relationships between DBH class and minimum, mean and maximum tree heights based on DBH class; (2) describe the shape of height distribution based on DBH class; (3) construct and the reproducibility of a height estimation model; (4) examine size diversity in the DBH-height relationship for a sample species, in relation to population structure and environmental factors. In this study, we selected Japanese red pine (*Pinus densiflora*) as a sample species for the following reasons.

First, *Pinus densiflora* is one of the most representative coniferous species in the UFM (THE KYUSHU UNIVERSITY FORESTS 1996). There are many large-sized trees of *P. densiflora* (MASUTANI *et al.* 1992), and forestry researchers have been examining the possibility applying a forest working system to *P. densiflora* natural forests in the UFM (MASUTANI *et al.* 1992; OTA *et al.* 1994; KUNISAKI and IMADA 1996b).

Second, *P. densiflora* is a remarkably shade-intolerant species and it is extremely difficult for seedlings to regenerate within a stand, except in large-sized gaps resulting from clear cutting or landslides (INOUE 1960). Also, *P. densiflora* generally forms cohorts and develops in a similar way to plantation species such conifer as *Cryptomeria japonica* and *Chamaecyparis obtusa* which are two of the most widely planted species in Japan. Therefore, it is possible to develop DBH-height relationships for *Pinus densiflora* with an extensive forest by referring to information about the structure and dynamics of coniferous plantations.

Third, since data for several *P. densiflora* stands with different structures in the UFM (MASUTANI *et al.* 1992; OTA *et al.* 1994; KUNISAKI *et al.* this paper) are stored in our laboratory, we could compare DBH-height relationships from the extensive forest level with those from the small-scale plot level.

STUDY SITE

The UFM is located in Miyazaki prefecture in southern Kyushu, Japan (2,916ha; 32° 22'10"N, 131°10'40"E) and is within the cool-temperate deciduous forest zone. The altitudinal range is from 700-1,476m a.s.l.. Annual precipitation is about 3319mm and this region is one of the most rainy regions in Japan. Therefore, debris flow, landslips and landslides induced by heavy rain have often occurred in the UFM (THE KYUSHU UNIVERSITY FORESTS 1996). The average annual temperature is 13.1℃ at an elevation of 600 m; the mean monthly maximum temperature is greatest in August (23.6℃) and the mean monthly minimum temperature is lowest in January (2.7℃). The soils are mainly brown forest soils. Also, since UFM is located at central mountainous district of Kyushu, strong winds usually blow and there are a lot of wind-damaged trees on W- to N-facing slopes and ridges (THE KYUSHU UNIVERSITY FORESTS 1996).

The vegetation is regarded as a part of the *Fagus crenata-Sasa borealis* association (THE KYUSHU UNIVERSITY FORESTS 1996). Hardwood species such as *Fagus crenata, Quercus mongolica* var. *grosseserrata* and *Betula grossa* and softwood species such as *Abies firma, Tsuga sieboldii* and *Pinus densiflora* generally dominate the overstorey. The understorey is generally characterized by shade-tolerant low trees such as *Clethra barbinervis, Lindera triloba, Illicium religiosum* and *Pieris japonica* and bamboo grass, *Sasa borealis*.

P. densiflora natural forests in the UFM are generally located along ridges and next to forest roads (KUNISAKI personal observation), and might have established after severe clear cutting or natural disturbances during the years 1910-1920 (KUNISAKI *et al.* 1996).

DATA

During 1985-1987, 9 cutting blocks of natural forest (a total area of 27.86ha) in the Oyabu river basin of the UFM were investigated and each tree>10cm in DBH was measured (Table 1). Species or species group name, DBH and tree height were recorded in the inventory. The total number of *P. densiflora* was 813 trees varying from 10-70 cm in DBH, and the average DBH and height of sample trees were 34.28cm and 15.02m, respectively. DBH distribution was positively-skewed (2.10 of Weibull parameter *c*; see "Methods"), while height distribution was a weakly negatively-skewed with a parameter *c* of 3.71. In this paper, hereafter, the term of "forest level" indicates the combination of the cutting blocks, and "block level" indicates each cutting block.

During the years 1991-1996, 6 plots of *P. densiflora* natural populations in the Oyabu river basin were investigated (Table 2). P1 (0.06ha) is an unclosed stand established on flat ground at 1080m a.s.l. (MASUTANI *et al.*, 1992). P2-P5 (0.08-0.40ha) are closed stands with differing ages and density (OTA *et al.*, 1994; KUNISAKI and IMADA, 1996b). These stands are located on gentle slopes, except for P4 where the inclination ranges from 15-25 degree, at 1,050-1,100m a.s.l.. P6 (615m of line) is a population of single trees established along a ridge from 1,150-1,245m a.s.l.. Hereafter, the data of P1-P6 are referred to as "plot level".

Table 1 General description of each cutting block (for trees with 10cm or more in DBH).

Cutting block	Area (ha)	Altitudinal range (m a. s. l.)	Stand volume (m^3/ha)	Stand density (no./ha)	*Pinus densiflora* Mean DBH (cm)	Mean H (m)	Volume (m^3/ha)	Density (no./ha)
1	1.76	1,040-1,080	206.1	710	33.78	16.48	102.23	138
2	1.56	1,050-1,090	180.4	874	33.79	15.57	74.69	106
3	2.53	1,050-1,130	134.5	856	34.32	13.52	6.59	10
4	1.57	1,040-1,130	122.5	930	26.00	11.65	4.04	11
5	4.65	1,050-1,190	125.7	932	25.16	11.39	4.53	12
6	5.38	1,060-1,200	171.4	1,136	28.62	12.46	4.46	10
7	2.51	1,070-1,150	166.6	890	38.75	13.51	39.48	33
8	3.40	1,060-1,120	152.4	917	37.59	14.57	28.50	32
9	4.50	1,050-1,130	282.9	1,317	43.13	17.95	16.69	14
Total	27.86		175.62	1,004	34.28	15.02	22.81	29

Table 2 Attributes of each plot.

Plot stand	P1	P2	P3	P4	P5	P6
Compartment	25	29	25	29	33	28
Stand age* (year)	nc	39	50	70	71	nc
Topographic position	Flat	Lower slope	Flat	Middle slope	Upper slope	Ridge
Altitude (m a. s. l.)	1,080	1,050	1,065	1,060-1,080	1,100	1,150-1,245
Slope direction	W	S	SW	SE	NW	E-SE
Slope inclination (°)	0-5	0-5	0-5	15-25	0-5	5-15
Canopy condition	Unclosed	Closed	Closed	Closed	Closed	Open
Mean DBH (cm)	45.33	21.04	34.39	36.85	45.77	62.31
Mean height (m)	18.28	14.24	18.13	18.44	20.80	16.52

*: Age in the year when each stand was investigated. nc: not clear

METHODS

We used the generalized allometric equation (OGAWA 1969) to describe the relationships between DBH class (cm) and minimum (H_{min}), mean (H_{mean}) and maximum (H_{max}) heights (m) based on the DBH class at forest level:

$$1/H = 1/AD^h + 1/H^*, \quad (1)$$

where A (cm/m), h and H^* (m) are positive parameters. An iterative nonlinear-least-square method was used to obtain the parameters of eq. (1).

We used the Weibull distribution function, a probability density function, to describe height distribution based on DBH class at the forest level:

$$f(H) = (c/b)((H - H_{min})/b)^{c-1}\mathrm{EXP}(-((H - H_{min})/b)^c), \quad (2)$$

where b (m) is the positive parameter for cumulative distribution at the 63% point, and c is the positive parameter of the shape of distribution (NISHIZAWA 1978; KAKIHARA 1995). This function can express the shape of any unimodal distribution (BAILEY and DELL 1973). The values of c reflect the shape of the distribution curve: $c \leqq 1$ indicate an inverse-J shape, $1 < c < 3.6$ a positively-skewed shape, $c = 3.6$ approximately a bell-shape, and $c > 3.6$ a negatively-skewed shape. The parameters of eq. (2) were obtained using a simple method developed by NISHIZAWA (1978) which uses the mean and standard deviation of the size distribution, and the values of the gamma function.

A species-specific height estimation model for extensive forests, based on DBH, was constructed using eqs. (1) and (2). To verify the reproducibility of this model, height distribution and DBH class-volume distribution at forest level were estimated using the model, and compared with the actual distributions.

The DBH-height relationship at the forest level was compared with those at the block and plot levels and the size diversity of *P. densiflora* in the UFM was discussed.

RESULTS

The coefficients of determination (r^2) of eq. (1) for DBH-height allometry were all high, ranging from 0.94 (DBH-H_{max}) to 0.98 (DBH-H_{mean}) (Table 3). Thus, eq.

(1) was well suited to all three DBH-height allometries at the forest level.

For DBH-H_{min} curve, the parameter A was the greatest (1.01) and h the lowest (0.75) of the three allometric curves (Table 3). Since h indicates the slope of the curve for small values of DBH, the slope for small-sized trees (<20cm) was gentlest of the three curves (Fig. 1). On the other hand, the slope for large-sized trees (>30 cm) was steepest in three curves, since H^*, which indicates maximum value for infinite DBH, was greatest (48.93). In the DBH-H_{max} curve, A was the lowest (0.36), and h the greatest (1.62), and the slope at small-sizes was steepest in three curves (Fig. 1). On the other hand, the slope at large-size was the most gentle, as the size difference between the value of height at DBH=30cm (18.63) and H^* (23.56) was the lowest of the three curves. For the DBH-H_{mean} curve, the values of parameters A (0.42), h (1.42) and the slope at small-sizes were between those of the other two curves (Table 3; Fig. 1). The slope at large-sizes was similar to that of the DBH-H_{max} curve, as the size difference between the value of height at DBH=30cm (15.00) and H^* (20.62) was almost the same.

Fig. 2 shows the relationships between DBH class and the indices of height distribution based on DBH class. Height range based on DBH class increased with DBH until 30cm, and then decreased (Fig. 2a). Although similar tendencies were shown for six tall trees of deciduous hardwood (KUNISAKI and IMADA 1996a), the height range of large-sized *P. densiflora* was significantly greater than that of these hardwoods. Parameter c of eq. (2) was lower than 3.6 for all DBH classes and the height distributions based on DBH class showed positively-skewed shapes, that is, the modes of height distributions were below the DBH-H_{mean} curve. Parameter c increased with DBH until 40cm,

Table 3 Parameters of eq. (1).

Dependent variable	A	h	H^*	r^2
H_{min}	1.01	0.75	48.93	0.96
H_{mean}	0.42	1.43	20.62	0.98
H_{max}	0.36	1.62	23.56	0.94

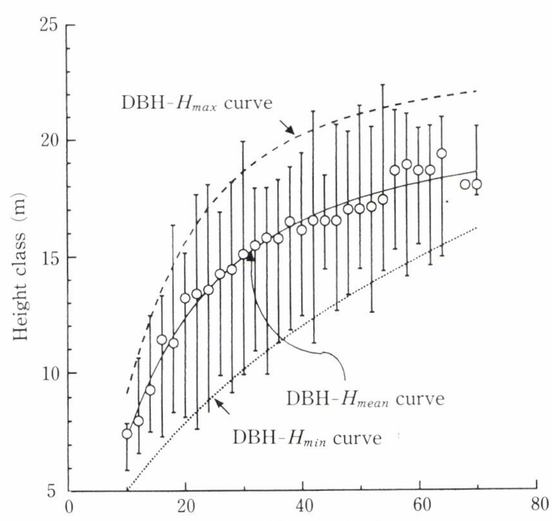

Fig. 1 DBH-Height relationship for *Pinus densiflora* at a forest level.
Open circles, upper and lower bars represent the mean, maximum and minimun height based on DBH class, respectively.

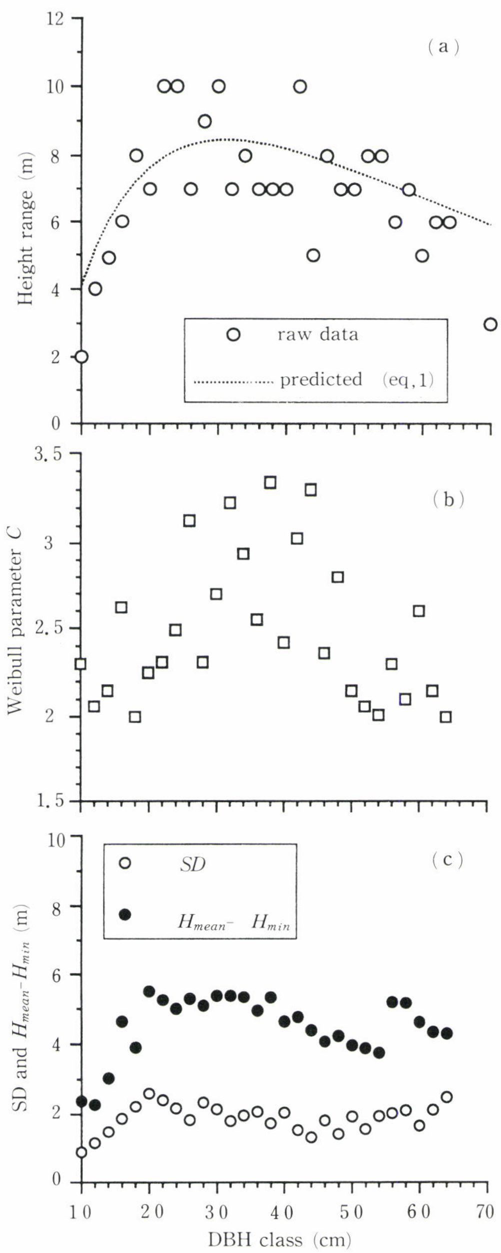

Fig. 2 Relationships between DBH class and indices of height distribution.

and then decreased (Fig. 2b).

The coefficient of variation (CV_x) is closely connected with parameter c (KAKIHARA 1995):

$$CV_x = SD_H / (H_{mean} - H_{min}), \quad (3)$$

where SD_H is the standard deviation of the height distribution based on DBH class. We examined the changes in SD_H and $H_{mean} - H_{min}$ with increasing DBH class (Fig. 2c). SD_H increased with DBH at small-sizes, decreased gently until 44cm and then increased gently. On the other hand, $H_{mean} - H_{min}$ increased with DBH at small-sizes, was approximately constant between 20-38cm and then decreased. The changes in $H_{mean} - H_{min}$ were significantly greater than those of SD_H, indicating that the change in parameter c with DBH class was strongly influenced by the changes in $H_{mean} - H_{min}$ rather than changes in SD_H.

Based on the above results, we constructed a height estimation model based on DBH (called "HEMD" hereafter). HEMD was constructed using four sub-models: (a) DBH-H_{mean} curve model, (b) DBH-H_{min} curve model, (c) DBH-Weibull c curve model, and (d) height distribution model. Models (a) and (b) were described by eq. (1), model (c) by a third order polynomial expression, and model (d) by eq. (2). Although the DBH-Weibull b curve model was not determined, the parameter b can be calculated using models (a), (b) and (c) and the gamma function (NISHIZAWA 1978; KAKIHARA 1995).

Actual and estimated height distributions at the forest level are shown in Fig. 3. The general shape of the height distribution was described well by HEMD, although the frequencies of the 16 and 18m height classes were underestimated and that of 19m overestimated. Actual and estimated total volumes were 600.52m^3/27.86ha and 606.90 m^3/27.86ha, respectively, and the difference between two values was very small (error ratio=1.06%). Further, the error ratio based on DBH class was lower than 5%, except for DBH classes 16, 20 and>64cm, which ranged from 5-9% (Fig. 4).

We compared the DBH-height relationship at a forest level with that at a block level (Fig. 5). The distribution of block stand data on the forest-level DBH-height relationship differed between blocks. Block 1 was mostly distributed above the DBH-H_{mean} curve irrespective of DBH class. Blocks 3-7 were distributed below the DBH-H_{mean} curve, and Blocks 2, 8 and 9 were similar to the DBH-height relationship at the forest level. Blocks 3-7, where data was distributed below the DBH-H_{mean} curve, had relatively high maximum elevation, and Block 1, where data was distributed above the DBH-H_{mean} curve, had a relatively low maximum elevation (Table 1).

Fig. 6 showed DBH-height relationships at plot level. Data for the closed stands of P2-P5 were distributed above the DBH-H_{mean} curve or DBH-H_{max} curve except for data from small- and middle-size trees (<30cm), and there were no large-size trees below the DBH-H_{mean} curve in P2-P5. On the other hand, most data for the unclosed stand of P1 and open-grown population of P6 were distributed below the DBH-H_{mean} curve.

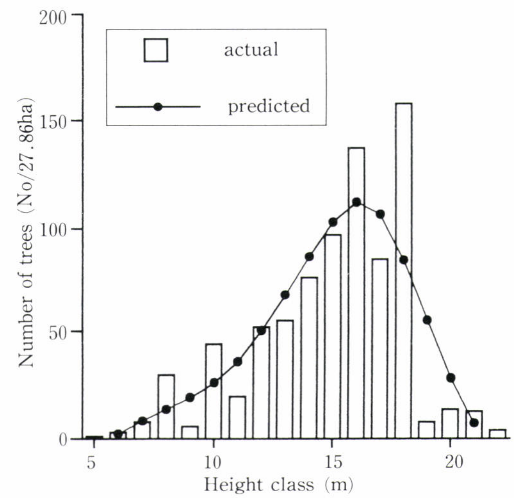

Fig. 3 Predicted and actual height distribution.

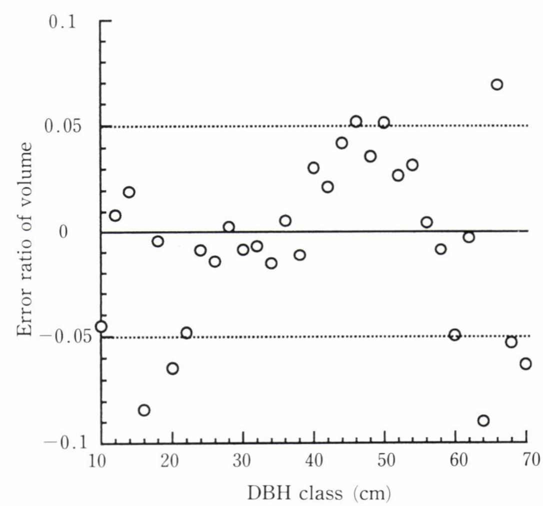

Fig. 4 Error ratio of predicted volume for each DBH class.

DISCUSSION

DBH-height allometry for *P. densiflora* at a forest level

In general, h of the DBH-height curve is approximately equal to 1 in mature forests (OGAWA 1969; SANO 1986) and for climax species (OGINO 1975; KOMIYAMA 1977; KOHYAMA *et al.* 1990; AIBA and KOHYAMA 1996), and greater than 1 in secondary forests (OGAWA 1969). In this paper, the parameter h of DBH-H_{mean} curve for *P. densi-*

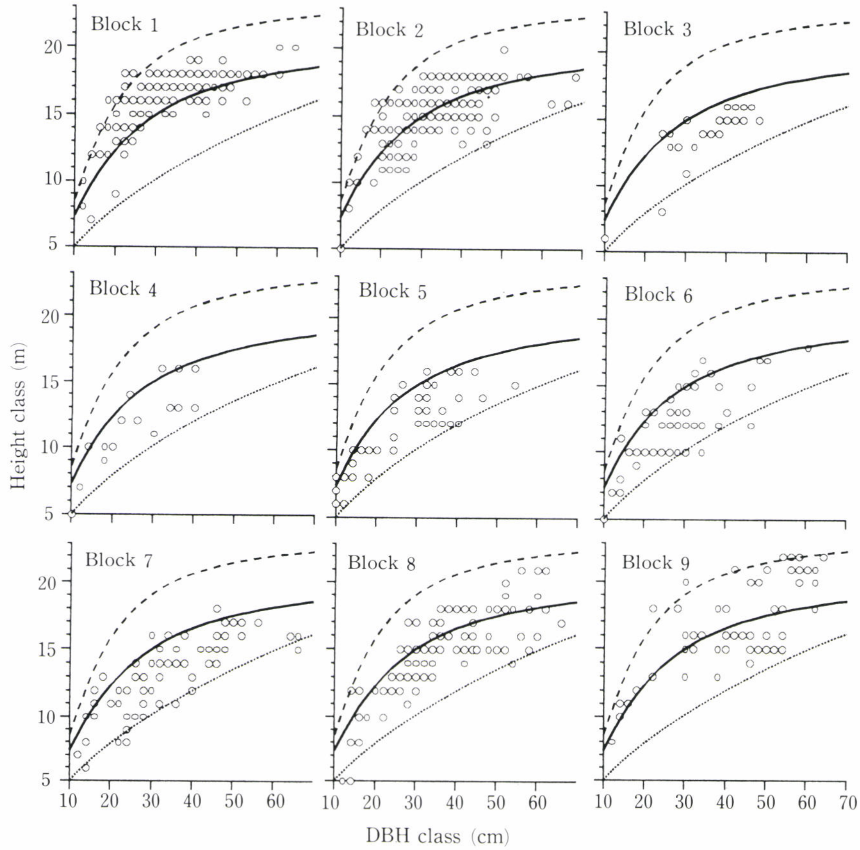

Fig. 5 Comparison of DBH-height relationships at a block level with those at a forest level.
The three curves represent the same parameters as in Fig. 1

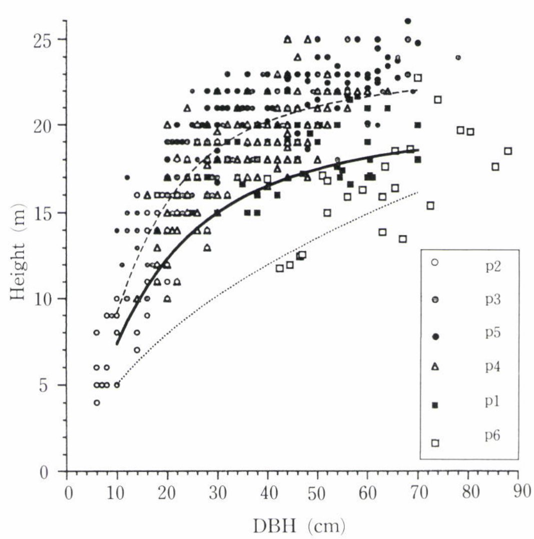

Fig. 6 Comparison of the DBH-height relationship at a plot level with the forest level.

flora at forest level was greater than 1. FUJIHARA *et al.* (1992) suggested that h for *P. densiflora* populations at plot level in Hiroshima city could be approximated to 1, although they used trunk diameter at $H/10$ instead of DBH. KUNISAKI and IMADA (1996b) also reported that h for DBH-height curve of *P. densiflora* stands, containing understorey trees of other species>6cm in DBH in the UFM, could be approximated to 1. KOHYAMA *et al.* (1990) suggested that the slope of the DBH-height trajectory was significantly steeper than that of the DBH-height curves for *Abies* even-aged stands, and showed that A and h for the trajectory were 0.48 and 1.42, respectively. These values of the parameters were similar to those of the DBH-H_{mean} curve (Table 3). The *P. densiflora* population at the forest level in the UFM might be organized as small-scale populations with different ages and structures (see Fig. 6). Therefore, we concluded that the DBH-H_{mean} curve at the forest level also indicated the DBH-H_{mean} trajectory at the forest level in the UFM.

A height estimation model based on DBH (HEMD)

HEMD described the height distribution and DBH class-volume distribution at a forest level well (Fig. 3 and 4). This suggested that HEMD is useful for large-scale forest inventory, although more sample data should be collected to determine the precision and accuracy of the model (see Fig. 6).

Size diversity for *P. densiflora* in the UFM

DBH-height relationships for *P. densiflora* stands were stand-specific in relation to stand age, environment and spatial scale (Fig. 5 and 6). Data for blocks with relatively high maximum elevation (1,130-1,200m a.s.l.) were below the DBH-H_{mean} curve, and data for a block with relatively low maximum elevation (1,080m a.s.l.) was above the DBH-H_{mean} curve irrespective of DBH class (Table 1, Fig. 5). Data for closed stands P2-P5 were above the DBH-H_{mean} curve at large-sizes (Fig. 6). These stands were located from 1,050-1,100m a.s.l. (Table 2), and are regarded as stands where trees have developed under intense competition for light (KUNISAKI *et al*. 1996). On the other hand, data for the unclosed stand (P1) and the population of P6 were below the DBH-H_{mean} curve at large-sizes (Fig. 6). *P. densiflora* trees within open stands in the UFM tend to have greater crown diameter than those within closed stands for a given DBH (KUNISAKI personal observation). Further, the data for P6 was distributed lower than those of P1 on the DBH-height coordinate (Fig. 6). P1 was located on the flat at 1080m a.s.l. and P6 along a ridge from 1,150-1,245m a.s.l. (Table 2).

From these results, we propose three hypotheses about size diversity of *P. densiflora* in the UFM.

First, the effects of wind-exposure can reduce tree height and increase DBH. In region often exposed to strong winds, canopy trees are more susceptible to wind damage, because of high probability of wind exposure (BREWER and MERRITT 1978; NAKA 1982; PUTZ *et al*. 1983; AIBA and KOHYAMA 1996). In such regions, canopy trees often suffer tip-up and/or stem bending from wind exposure and the *H*/DBH of the stems is reduced (KING 1986; SAKAMOTO 1990; MUNISHI and CHANMSHAMA 1994). In addition, trees under wind stress change the stem form autonomically. Wind-exposed trees have pronounced growth on the lower stem, at the expense of upper stem development, to prevent the physical damage of stem following wind sway (JACOBS 1954; LARSON 1965; TAKAHASHI 1978; LONG *et al*. 1981; KING 1981, 1986; HOLBROOK and PUTZ 1989). The study sites were located in a windy area (THE KYUSHU UNIVERSITY FORESTS 1996) and there are many *P. densiflora* trees along ridges where strong winds blow (ISHIZUKA 1977). Further, *P. densiflora* is a remarkably shade-intolerant species and establish as canopy trees or open-grown trees. Hence, we concluded that many the *P. densiflora* trees established along ridges in the UFM may suffer wind-exposure and have changed stem form.

Second, size diversity may be affected by stand density. When coniferous trees are at a low stand density, the crown generally expands to gain more light. Thus, the crown diameter of trees within sparse stands is greater than those of trees within dense stands at a given age and DBH (ANDO *et al*. 1962; HARMS and LANGDON 1975; STRUB *et al*. 1975; KOBAYASHI 1978; LAROCQUE and MARSHALL 1994). However, height growth is insensitive to stand density (ANDO 1968; HARMS and LANGDON 1975; LANNER 1985). Hence, the *H*/DBH of trees within sparse stands is lower than that of trees within dense stands. Lone trees often have greater crown diameter and DBH and lower height than trees within a stand of the same age (HARMANN and PETERSEN 1969; STRUB *et al*. 1975). IWASA *et al*. (1984) simulated the crown shape and height of trees in a community using a game theory. They suggested that a lone tree should have a hemispherical crown and low height as the optimum, because there is no competition with other trees for light and the lone tree receives no benefit due to a high crown (IWASA *et al*. 1984).

Third, the availability of water and nutrients may affect size diversity. On a site with low water and nutrient availability, the height growth of coniferous trees is often inhibited relative to crown diameter and DBH growth, although the mechanism is obscure (ANDO *et al*. 1985; MOROTO *et al*. 1987; FUJIHARA *et al*. 1992; KUNISAKI *et al*. in press). Soils along ridges generally have low water and nutrient availability (ISHIZUKA 1977), and therefore, the *H*/DBH of *P. densiflora* trees established along ridges may be low.

In addition, we suggest that these three factors often act in combination. For example, a ridge is usually blown by strong winds and the soils are poor in terms of water and nutrients (ISHIZUKA 1977). Since this severe environment is assumed to seriously stress established *P. densiflora* trees, some of the trees may die and the population density and canopy crowding decrease.

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Article

Estimation of Relative Illuminance in Forests using Hemispherical Photographs

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ABSTRACT

We compared sky factor, which is used in the field of architecture, and openness grade with measured relative illuminance. Sky factor and openness grade were measured on hemispherical photographs taken with an equidistant formula fisheye lens. The measurements were conducted under uniformly overcast skies at 20 points in a hinoki (*Chamaecyparis obtusa*) stand. Sky factor corresponded well with relative illuminance and the errors were ranged from −0.96 to 0.98 (%). By contrast, openness grade was lower than relative illuminance, and the regression coefficient between them was 0.62. The difference between sky factor and openness grade was due to the effect of the projection formula of the fisheye lens. In conclusion, sky factor was a better estimator of relative illuminance than openness grade. Furthermore, it was shown that it is important to state clearly the kind of fisheye lens used when measuring sky factor or openness grade.

Keyword: sky factor, relative illuminance, openness grade, hemispherical photograph, projection formula

INTRODUCTION

Light is essential to growth of forest trees and herbs, and it is very important to know the light conditions within forests to understand the growth of under-storey trees in multi-storied forest (FUJIMORI 1989) and the dynamics of under-storey vegetation as related to water and soil conservation (SHIMIZU *et al*. 1984; KIYONO 1990). Therefore, the development of a simple and reliable method for the measurement of light condition is required. Relative illuminance is the ratio between the illuminance (lux) at a target point in the forest and that measured simultaneously in an open place where the illuminance is not obstructed by trees or other vegetation. Relative illuminance has been used mainly as an index of light condition in forests, since its measurement is comparatively simple and it provides much ecological information. However, relative illuminance in forests changes greatly with various factors ; e.g. season, time of day and weather (FUJIMORI 1989). Furthermore, in practice, it is very difficult to measure illuminance at a fully open place. Therefore, measurement of light conditions in forests using hemispherical photographs has been tried.

TAMAI and SHIDEI (1972) compared relative illuminance estimated from hemispherical photographs with measured data. They used an empirical formula for calculating luminance distribution with a uniform overcast sky (MOON and SPENCER 1942). The hemispherical photograph was divided into 1,000 segments, and each segment classified into one of five categories. The ratio of open area (segments unobstructed by trees or other vegetation) to the total area of other segments was an estimate of relative illuminance (ANDERSON 1964). Since this is a manual method, there is a risk of human error which can not be avoided, and as the number of photographs to be assessed increases, time and labor increase.

To avoid this problem, ANDO (1983) and WASEDA (1983) devised a method for measuring the openness grade using image analysis equipment and compared it with

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relative irradiance and relative illuminance. Openness grade is the ratio of the open area to all area of the hemispherical photograph. The development of this method made estimation simple, but although the correlation between openness grade and relative irradiance or relative illuminance was high, the openness grade differed from both relative irradiance and relative illuminance.

OKAMURA *et al.* (1995) used the sky factor (YAMADA 1989), from the field of architecture, as an index of light conditions in forests, and using hemispherical photographs, developed a method to measure it on a personal computer. However, the sky factor has never been compared with relative illuminance or openness grade. This paper tests the validity of sky factor and openness grade as estimators of relative illuminance in forests. We compare the sky factor and openness grade measured on hemispherical photographs with measured relative illuminance and discuss the differences between sky factor and openness grade.

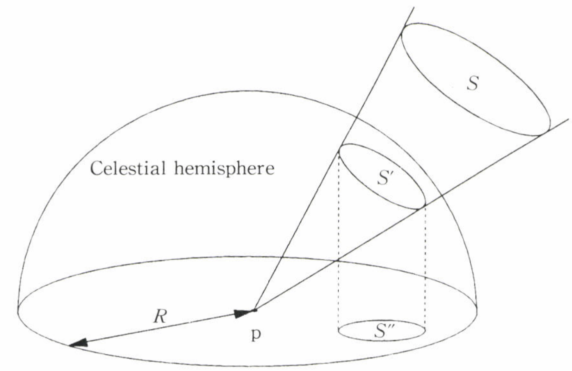

Fig. 1 Explanation of sky factor
Note: p is the measurement point. R is radius of the celestial hemisphere. S, S' and S'' are the open areas observed from measurement point p, the celestial hemisphere and the orthogonal projection image, respectively.

EXPLANATION OF SKY FACTOR

Daylight factor is used in the field of the architecture as an index of the light condition and is defined by equation (1) (YAMADA 1989).

$$\text{Daylight factor } (\%) = (E / E_s) \times 100 = \{(E_d + E_r) / E_s\} \times 100 = D_d + D_r \quad (1)$$

Where E is the illuminance at the target point, E_s is the illuminance on the open place at the same time, E_d is the direct illuminance from the open area (direct light) and E_r is the indirect illuminance caused by the diffuse light, i.e. light transmitted through foliage and reflected in the forest. D_d and D_r are called the direct daylight factor and indirect daylight factor, respectively (YAMADA 1989). Equation (1) indicates that daylight factor equals relative illuminance.

Sky factor is explained as follows : As Fig.1 indicates, the open area observed from the measurement point, p, is S. When a celestial hemisphere with radius R is drawn with p at the center, S' is the area projected by S onto the celestial hemisphere. S'' is the area projected orthogonally by S' onto the base circle of the celestial hemisphere. The ratio of S'' to the base area of the celestial hemisphere, πR^2, is called the sky factor, and is expressed by equation (2) (YAMADA 1989).

$$\text{Sky factor } (\%) = (S'' / \pi R^2) \times 100 \quad (2)$$

In a forest, the open area S is interspersed with foliage. Thus, sky factor at the measured point is the total of the ratios of each open area when projected orthogonally onto the base circle (OKAMURA *et al.* 1995). If it is assumed that the sky is a perfect diffusing surface (ELECTRICITY SOCIETY 1975) which has a uniform luminance regardless of zenith angle θ, then the sky factor corresponds with D_d (YAMADA 1989).

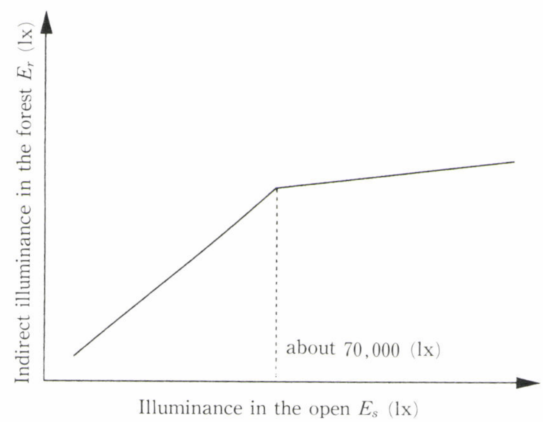

Fig. 2 Relationship between illuminance in the open E_s and indirect illuminance in the forest E_r (FUJIMORI 1989)

SASAKI and MORI (1981) and FUJIMORI (1989) showed that E_r is proportional to E_s under cloudy conditions, i.e. when illuminance in the open is below about 70,000 (lx). As E_s decreases, E_r also decreases, as shown in Fig.2. Therefore, under cloudy conditions, we can assume that the daylight factor is close to the direct daylight factor D_d, because the indirect daylight factor D_r decreases. Thus we can assume that the sky factor is close to relative illuminance.

MATERIALS AND METHODS

Study Area

The study site was a hinoki (*Chamaecyparis obtusa*) stand in the Kyushu University Forest in Fukuoka, Japan. The stand age was 38 (year), average tree height was 13.2 (m), average diameter at breast height was 15.8 (cm), average clear length was 10.7 (m), average crown width was 1.1 (m) and stand density was 2,368 (number / ha) in November 1994. This study site was almost flat.

Measurement of sky factor and openness grade

Hemispherical photographs were taken at 20 points in the hinoki stand in December 1995. The camera used was a Nikon F3 (high eye appoint body), the lens was a fisheye Nikkor 8mm f/2.8 and the film was negative color film for color print (Super G ACE100, Fuji Color). The lens was an equidistant projection formula lens. A L1BC filter was attached to the lens. Hemispherical photographs were taken with the camera and lens mounted about 1.2 (m) off the ground (TERAOKA 1995). A spirit level was used to ensure the camera was horizontal. To prevent fluttering and halation, photographs were taken under cloudy, still conditions (TAMAI and SHIDEI 1972; ANDO 1983; WASEDA 1983). The aperture was F=8 (TERAOKA 1995) and the shutter speed was determined automatically. The size of all printed photographs was 8.9 (cm) × 12.8 (cm).

The printed photographs were digitized on a personal computer (Apple Macintosh Quadra 800) with a resolution of 200 dpi (dots per inch) and a 256 color scale, using an image scanner (GT6000, Epson). The digitized images were converted to circular gray images using Photoshop 3.0J software (Adobe). The resulting diameter on the display was 725 pixels. Using the thresholding method (CHAZDON and FIELD 1987), the circular gray image was then converted so that open areas became black pixels, and areas obstructed by trees or other vegetation became white pixels.

The sky factor for each photograph was calculated as follows : When hemispherical photographs are taken using an equidistant projection formula lens, as shown in Fig.3, then the open area on the celestial sphere (*DSC*) is projected equidistantly as *DSE* on the photograph. As the sky factor is the ratio of the open area projected " orthogonally " (*DSO*), not " equidistantly " (*DSE*) onto the circular image area, we need to transform the equidistant projection image into the orthogonal one. The transformation equation, when *DSC* is infinitely small, is as follows (OKAMURA *et al.* 1995) :

$$DSC = \{\pi R \sin(\pi r/2R)\}/2r \times DSE \quad (3)$$

$$DSO = \sin[\{\pi(R-r)\}/2R] \times DSC \quad (4)$$

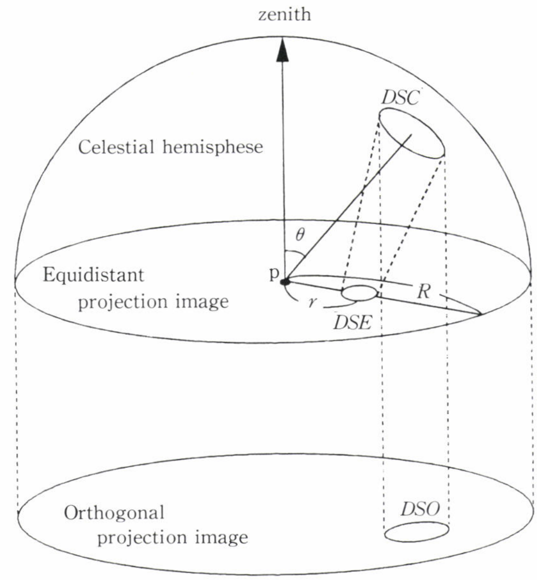

Fig. 3 Calculation method of sky factor
Note: p is the center of equidistant projection image. *DSC*, *DSE* and *DSO* are the open area on the celestial hemisphere, equidistant and the orthogonal projection image, respectively. *R* and *r* are the radius of the celestial hemisphere and the distance from the center of image (p) to *DSE*, respectively. θ is the zenith angle.

In this study, *R* is 362.5 (the radius of the circular image) and *r* is the distance from the image center p to *DSE*. The circular image is composed of about 410,000 ($=725\times725\times\pi/4$) pixels. If one pixel is considered to be infinitely small, each pixel of open area *DSE* can be converted to *DSO* by applying equation (5).

$$DSO = \sin[\{\pi(R-r)\}/2R] \times\{\pi R \sin(\pi r/2R)\}/2r \times DSE = (\pi R/4r) \times \sin(\pi r/R) \times DSE \quad (5)$$

Then, sky factor is the ratio of the sum of each *DSO* to the total number of pixel in the image (equation (6)) :

$$\text{Sky factor } (\%) = (\Sigma\, DSO/\pi R^2) \times 100 \quad (6)$$

The above procedures were followed using NIH image 1.59, which is public domain image processing software made by Rasband in the National Institutes of Health.

Openness grade is the ratio of the number of open pixels to the total number of pixels in a circular image, regardless of the projection formula of the used fisheye lens (ANDO 1983; WASEDA 1983). In this study, the equidistant projection formula lens was similar to those used in other studies (ANDERSON 1964; TAMAI and SHIDEI 1972; OKAMURA *et al.* 1995; TERAOKA 1995), and the openness grade was calculated as:

$$\text{Openness grade } (\%) = (\Sigma\, DSE/\pi R^2) \times 100 \quad (7)$$

Measurement of relative illuminance

Illuminance was measured using two of the same lux meters (T1-H, Minolta). Illuminance was measured at the measurement point in the forest immediately after taking the photograph, and at an open area about 600(m) away from the hinoki stand. Illuminance was measured five times at each measurement point and averaged. The measured illuminance in the open area ranged between 9,500 and 23,000 (lx).

RESULTS AND DISCUSSION

The relationships between relative illuminance and sky factor and openness grade are shown in Fig.4. The broken line in this figure indicates the 1 : 1 line. Errors between sky factor and relative illuminance ranged from −0.96 (%) to 0.98 (%), and the regression line was almost the same as the 1 : 1 line. Thus, the sky factor corresponded almost exactly with relative illuminance. This is probably because relative illuminance was measured when illuminance in the open (E_s) was below 23,000 (lx). Since diffuse light in the stand Er was very low (SASAKI and MORI 1981, FUJIMORI 1989), it had little effect on the relationship between sky factor and relative illuminance.

On the other hand, openness grade was lower than relative illuminance, and the regression coefficient between openness grade and relative illuminance was 0.62. This underestimation is due to the effect of the projection formula of the fisheye lens, as follows : When using the equidistant projection formula lens, any point on the celestial hemisphere with zenith angle θ (*DSC*) is projected to a point on the hemispherical photograph, where the distance from the center of the image p is proportional to θ as shown in Fig.3. Therefore, the relationship between r and θ can be expressed by equation (8).

$$r = c\ \theta \quad (8)$$

where c is a constant. When θ is 90 (°), then, r correspond with R. Thus, c is $R/90$. From equations (3), (4) and (8), changes in *DSE* and *DSO* with θ were expressed by :

$$DSO = \cos(\pi\theta/180) \times DSC \quad (9)$$

$$DSE = \theta/45\ \pi \sin(\pi\theta/180) \times DSC \quad (10)$$

When *DSC* is 1, *DSO* and *DSE* change with θ as shown in Fig.5. As the figure indicates, *DSE* is smaller than *DSO* when θ is smaller than 60 (°). When θ is larger than 60 (°), *DSE* is larger than *DSO*. Fig.6 is one of the hemispherical photographs used in this study. This photograph shows that much of the open area is projected around the center of the photograph, where θ is small, and much of the obstructed area is projected around the edge of the photograph, where θ is large. When calculating the openness grade, much of the open area (where θ is small) is underestimated, and much of the obstructed area (where θ is large) is overestimated. Thus, openness grade is smaller than the sky factor.

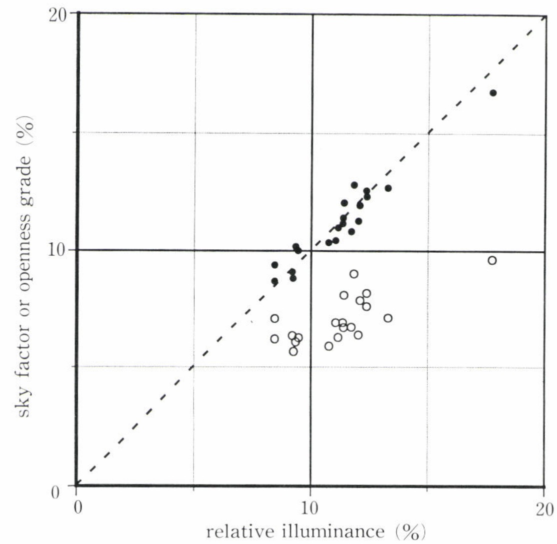

Fig. 4 Relationships between sky factor (●), openness grade (○) and relative illuminance

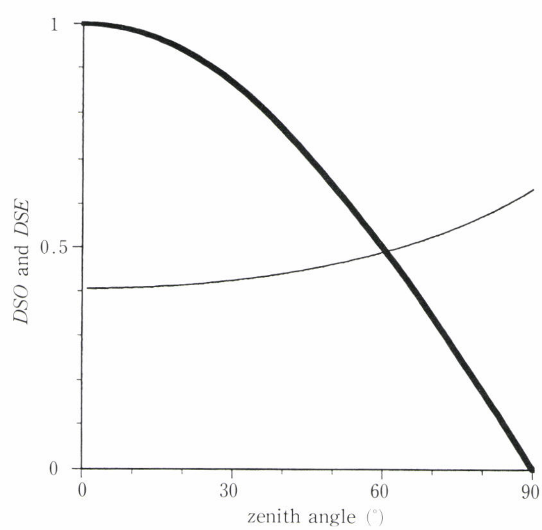

Fig. 5 Relationships between the zenith angle θ and *DSO* (thick line), and *DSE* (thin line) when *DSC*=1.

In conclusion, under cloudy conditions, sky factor is a better estimator of relative illuminance than openness grade. Since the equidistant formula fisheye lens has been widely used, measurements should be converted from the equidistant projection image to the orthogonal one to measure sky factor. However, when using an orthogonal formula lens, the photograph is an image of what is orthogonally projected, so the openness grade equals the sky factor, and the conversion is not needed. Thus, to measure sky factor or openness grade, it is important to clearly

Fig. 6 One of hemispherical photographs used in this study
Sky factor and openness grade are 10.36(%) and 5.80(%) in this hemispherical photograph, respectively.

state what kind of fisheye lens is being used.

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Article

Stochastic Forest Management and Risk Aversion

Ken-ichi Akao*

ABSTRACT

This paper considers the timing of timber harvesting under uncertainty. The decision of a forest manager who maximizes the expected utility is formalized using a form of the closed loop control model. The stochastic optimization problem derived is very similar to the deterministic single stand problem known as the classical Faustmann formula, but there is a notable difference. Whilst optimal rotation periods are certain in the deterministic world, they are random variables in stochastic circumstances. Stochastic optimal rotation periods are difficult to include in forest economic analyses. Fortunately, under some technical assumptions, we can find a non-stochastic variable named "barrier" which corresponds to the optimal cutting stock size in the deterministic world. This paper shows that the von Neumann-Morgenstern forest manager cuts his/her trees when the stochastic stumpage values reach a certain amount, that is the barrier. Comparative statics on the barrier were conducted to evaluate the effect of planting costs and the degree of the manager's risk aversion. The results show that the barrier rises as planting costs increase or as the Arrow-Pratt index of absolute risk aversion becomes smaller.

Keywords: stochastic Faustmann formula, barrier, risk aversion, comparative statics

INTRODUCTION

For a forest manager, it is important to consider the uncertainties surrounding the forest, because there is a long period between planting and harvest. Literature in the field of forest economics has tried to explicitly introduce uncertainty into forest management models. The models used in the literature are classified into two categories: the open loop control model and the closed loop control model. In the former model, the harvest age is determined before harvesting, possibly at the time of planting. We can find this kind of model in REED (1984), AKAO (1987), BHATTACHARYYA and SNYDER (1988), CAULFIELD (1988) and KUROKAWA (1991). In contrast, the closed loop control model allows the cutting age to be changed, depending on future states which vary. The closed loop control model is found in MILLER and VOLTAIRE (1980, 1983), MALLIARIS and BROCK (1982, pp.194-205), JOHANSSON and LÖFGREN (1985, pp.261-264), BRAZEE and MENDELSOHN (1988), CLARKE and REED (1989), REED and CLARKE (1990) and THOMSON (1992).

Intuitively, in a stochastic model, decision making about a harvest is contingent upon the known present state as well as uncertain future states. Tomorrow provides new information which updates the decision maker's knowledge of the current state, and improves his/her knowledge about future states. Forest management models which incorporate uncertainty should allow some flexibility in decision making and be able to use new information coming in the future. Thus, closed loop control models are more appropriate than open loop control models for forest management under uncertainty. The open loop control model does not consider information which reaches the decision maker with the passage of time, whereas the closed loop control model does. Also the open loop control model may cause time inconsistency, which means that today's decision is inconsistent with tomorrow's one. AKAO (1987) observed this inconsistency in a feedback open loop control model. In general, the results from open loop control models do notcoincide with ones from closed loop control models, although exceptions could exist, as shown by CLARKE and REED (1989). Furthermore, the differences between them

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may be great. BRAZEE and MENDELSOHN (1988) showed in a numerical example that the optimal expected reward from a closed loop control model is two or more times that of an open loop control model.

In this paper, we use the closed loop control model to formalize a timber harvesting problem. It is a simple version of the models developed by MALLIARIS and BROCK (1982) and by MILLER and VOLTAIRE (1983). The difference is that they constructed the model in terms of money, whereas the model proposed here is constructed in terms of utility, so that we can examine the effects of the forest manager's attitude towards risk. The remainder of this paper is constructed as follows. Section II gives the assumptions and formulates the model. Section III shows the results of comparative statics (sensitivity analysis) with respect to planting costs, the degree of risk aversion, and other parameters. Section IV discusses applications of the results to forest economics.

THE MODEL

Notation and Assumptions

Suppose an even-aged forest whose current stumpage value is denoted by $x_t \in R$ (the set of real numbers), where t stands for the time. Denote by $t=0$ the present time and let $t \in R_+$ (the set of non negative real numbers). At time t, a certain stumpage value x_t is known, but until the time t comes, the value is uncertain. Denote by X_t the uncertain stumpage value to distinguish it from the realized certain value x_t. Suppose that X_t is a random variable defined on a probability space and that the probability process $\{X_t, t \geqq 0\}$ is given by the Ito stochastic differential equation,

$$dX_t = f(x_t)\,dt + \sigma(x_t)\,dz, \quad dz = \varepsilon\sqrt{dt}, \quad \varepsilon \sim \mathrm{N}(0,1), \tag{1}$$

where f expresses the instantaneous mean growth rate of x_t, called the shift coefficient, and σ is the instantaneous standard deviation of x_t, called the diffusion coefficient. To ensure that the sample paths following (1) are continuous, we assume that

[A.1] f and σ are bounded and continuos functions defined on R,

and

[A.2] f is non negative over R.

For simplicity, we restricted revenue to clear cutting and ignored thinning. Also we assumed that the costs for planting and silviculture are non-stochastic variables and constants. The total discounted cost evaluated at planting time is denoted by c.

Put the function $u: R \to R$. If the manager harvests the trees whose current value is x_t at time t, the present value of the utility is denoted by $u(x_t)\exp(-rt)$, where r is his/her time discount rate. The current value monetary utility $u(x)$ might be interpreted as the value function of some dynamic optimization problem for the consumption schedule derived from the manager's instantaneous utility function under constraint of the budget including x. As for $u(x)$, we assumed that:

[A.3] $u(x)$ is at least twice continuously differentiable, strictly increasing, and concave.

[A.4] $u(0)=0$.

Finally, we supposed that the aim of the forest manager is to maximize the sum of all future series of expected utilities evaluated at the present time. More exactly,

[A.5] The manager has additively separable utility and follows the VON NEUMANN-MORGENSTERN's expected utility hypotheses. The time horizon is infinite.

One rotation problem

We begin with the one rotation problem, called the Fisherian problem or the wine aging problem, which considers only the optimal harvest of the initial forest and ignores the costs of regeneration or revenues from harvests thereafter. This problem is preliminary to the infinite rotations problem considered later.

The manager must decide when it is the best time, T, to sell the trees. At any time, whether he/she should sell them depends on the current stumpage value. Since the value varies randomly, the best time T must also be a random variable. The manager's strategy is to choose a contingent time T, which is called the stopping time. If x_0 is the present stumpage value, the manager's strategy is formulated as:

$$\left.\begin{aligned} W(x_0) = \sup_{T \in [0,\infty)} E\,[u(X_T)\exp(-rT)], \\ \text{subject to } dX_t = f(x_t)\,dt + \sigma(x_t)\,dz, \text{ with } X_0 = x_0, \end{aligned}\right\} \tag{2}$$

where E is the expectation operator and the supremum is taken over the set of measurable stopping time T. Note that if the supremum were taken over R_+, the problem is the choice of a certain optimal cutting time and becomes the open loop control model.

Although solving this problem looks complicated, MIROSHINICHENKO (1975, Lemma 1.) and MALLIARIS and BROCK (1982, Theorem 18.2.) showed that, under some conditions, the problem can be transformed into a more simple one as follows.

The real line of current stumpage values is divided conceptually into two sets called the continuation region and the stopping region. If x_t falls into the stopping region, it is optimal to harvest the trees. If x_t remains in the continuation region, then it is optimal to keep the trees. Since the Ito process $\{X_t, t \geqq 0\}$ used here is time independent, these two sets must be independent of time. Also since the decision making depends only on the realized current stumpage value at each time, the two sets are independent of the initial state x_0. Therefore we can denote the stopping region by $\gamma = \{x \mid W(x) \leqq u(x)\}$ and the continuation region by $C = \{x \mid W(x) > u(x)\}$.

If $x \in \gamma$, then if dt is small enough,

$$u(x) \geqq E[u(X(dt))\exp(-rdt)]$$

holds. Expanding the right hand side by invoking ITO's lemma, we have

$$u(x) \geqq u(x) + [-ru(x) + u'(x)f(x) + (1/2)u''(x)\sigma^2(x)]\,dt.$$

Therefore, if $x \in \gamma$,

$$-ru(x) + u'(x)f(x) + (1/2)u''(x)\sigma^2(x) \leqq 0.$$

This implies that the set

$$A = \{x \mid -ru(x) + u'(x)f(x) + (1/2)u''(x)\sigma^2(x) > 0\}$$

must be contained in C. Furthermore if A is connected, then C must be connected. Otherwise, a connected component of C must exists such that the intersection of the component and A is an empty set. Denote this connected component of C by C_1 and let the stopping time for $x \in C_1$ be $T(x)$. $A \cap C_1 = \phi$ implies

$$-ru(x_t) + u'(x_t)f(x_t) + (1/2)u''(x_t)\sigma^2(x_t) \leqq 0$$

for every feasible x_t from x at $t \in (0, T(x))$. Thus, we have

$$\begin{aligned} W(x) &= E[u\{X[T(x)]\}\exp(-rT(x))] \\ &= E[\textstyle\int_0^{T(x)}\{-ru(x_t) + u'(x_t)f(x_t) + (1/2)u''(x_t)\sigma^2(x_t)\}dt + u(x)] \end{aligned}$$

However, $x \in C_1 \subset C$ implies $W(x) > u(x)$. A contradiction appears.

Thus, if a unique real number x^* exists such that $A = (-\infty, x^*)$ and $A^c = [x^*, \infty)$, then the boundary between the stopping region and the continuation region is unique. Then the problem (2) can be transformed into

$$W(x_0) = \max_x u(x)E[\exp(-r\,S(x_0, x))],$$

where $S(x_0, x)$ is the first hitting time from x_0 to x. This is a stochastic Fisherian problem.

Notice that the solution is the boundary between the continuation region and the stopping region. If the initial stumpage value is less than the boundary, the harvest occurs when the stumpage value touches the boundary. This is the reason why the solution is called "barrier". Also notice that the problem is to choose the non-stochastic optimal stumpage value. It is much easier to handle than the problem (2).

The FAUSTMANN problem

Now consider the infinite rotations problem. Let X_{T_i} ($T \geqq 0$, $i = 1, 2, \ldots$) be the stumpage value for the trees planted at ith whose age is T_i. Suppose that so far, the manager has iterated planting and cutting, and now he/she stands on the just planted land. The problem is to determine the contingent cutting ages ($T_1, T_2, \ldots$). Let x_{01} be the stumpage value at the present time and denote by $W(x_{01})$ the sum of infinite series of the present value of expected utilities attained in the optimal strategy. In order to apply the foregoing results to the infinite rotations problem, let us assume that

[A.6] There exists $W(x_{01}) < \infty$.

In the stochastic but time independent circumstances supposed here, at the time when the first harvest just has been done, the problem must be the same as one at the present time. Therefore $x_{01} = x_{02}$ and the harvest strategy T_2 must be same to T_1. Put $x_0 = x_{01}$ $(= x_{02} = \cdots = x_{0i} = \cdots)$. Then we have the stochastic Bellman equation.

$$\left.\begin{aligned} &W(x_0) = \sup_{T_1 \in [0,\infty)} E[\{u(X_{T_1} - c) + W(x_0)\}\exp(-rT_1)], \\ &\text{subject to } dX_{T_1} = f(x_{T_1})\,dt + \sigma(x_{T_1})\,dz, \text{ with } X_{01} = x_0, \end{aligned}\right\} \quad (3)$$

where the supremum is taken over the set of measurable stopping times. In order to apply the previous results, let us assume that

[A.7] There exists a continuation region and a stopping region for problem (3) and the boundary is unique.

Then (3) can be transformed into

$$W(x_0) = \max_x [u(x - c) + W(x_0)]\,\Phi(x), \quad (4)$$

where $\Phi(x) = E[\exp(-rS(x_0, x))]$.

Let $p(s; x_0, x)$ be the probability density with which the first hitting time from x_0 to x is s. Then $\Phi(x)$ can be expressed as the LAPLACE transformation of $p(s; x_0, x)$, that is

$$\Phi(x) = \int_0^\infty \exp(-rs)\,p(s; x_0, x)\,ds. \quad (5)$$

Notice that both of $exp(\cdot)$ and $p(\cdot)$ in the right hand side in (5) are nonnegative. Also notice that $\int_0^\infty p(\cdot)\,ds \leqq 1$ for any $x \in R$ and $exp(\cdot) \geqq 1$ for any $s \in R_+$. From these observations, we know $\Phi(x) \in [0, 1]$. Let x^* be the solution of (4). $\Phi(x^*) = 0$ implies that the optimal strategy is to keep the trees eternally with probability one. On the other hand, $\Phi(x^*)=1$ implies that the optimal strategy is to cut the trees at the moment the land is planted. Since both of these polar cases are non realistic, we assume that

[A. 8] $\Phi(x^*) \in (0,1)$.

From (4), the following inequality holds.
$W(x_0) \geqq [u(x-c)+W(x_0)]\ \Phi(x)$, any $x \in R$.
Equality holds if and only if $x=x^*$. [A.8] implies that $W(x_0) > [u(x_0-c)+W(x_0)]\Phi(x_0)$. Since $\Phi(x_0)=1$, $u(x_0-c)$ must be negative. Therefore we can rearrange above inequality to

$$W(x_0) \geqq u(x-c)\Phi(x)/[1-\Phi(x)], \text{ any } x \in R.$$

Equality holds if and only if $x=x^*$. As a result, we can rewrite the problem (4) to

$$\max_x \ u(x-c)\Phi(x)/[1-\Phi(x)], \qquad (6)$$

which is the stochastic FAUSTMANN formula.

There are two important points about this formula. First, when $\Phi(x)$ is displaced by $exp[-rT(x)]$ where T is the function which maps the stumpage values to the age of trees in a deterministic model, we get the deterministic FAUSTMANN formula. Therefore the stochastic FAUSTMANN formula is very similar to the deterministic one. Second, for any sample path starting from x_0, the principle of optimality must be satisfied. Therefore if x^* is the solution for the stochastic FAUSTMANN formula starting from x_0, then x^* also must be the solution for the problem starting from any initial forest whose stumpage value is less than x^*.

COMPARATIVE STATICS

The first order condition

In this section, we conduct comparative statics on the barrier x^*, i.e. the solution of (6), with respect to planting costs, the degree of forest manager's risk aversion, and other parameters. To do this, let us assume the differentiability of $\Phi(x)$. That is, for $p(s;x_0,x)$ (the probability density with which the first hitting time from x_0 to x is s), we assume that

[A.9] $p(s;x_0,x)$ is twice continuously differentiable in x.

Under [A.9], we can have at the optimal barrier x^*,

$$d\{u(x^*-c)\Phi(x^*)/[1-\Phi(x^*)]\}/dx=0.$$

From this equation, the first order condition for the optimal barrier x^* are derived as

$$u_x(x^*-c)\Phi(x^*)+\Phi_x(x^*)\ [u(x^*-c)+W(x_0)]=0,$$

where $u_x=u'$ and $\Phi_x(x^*)=\partial\Phi(x^*)/\partial x$.

$u(x^*-c)<(>)\ 0$ implies $W(x_0)<(>)\ 0$ since $W(x_0)=u(x^*-c)\Phi(x^*)/[1-\Phi(x^*)]$ and $0<\Phi(x^*)<1$. Note that if $u(x^*-c)<0$, the manager would cease management of the forest after the first harvest because regeneration costs exceed revenue from the first harvest. As a result, the problem is reduced to the one rotation problem. The case that $u(x^*-c)=0$ is the same. Therefore so long as we can consider the FAUSTMANN problem, $u(x^*-c)$ must be positive. That is,

$$u(x^*-c)>0. \qquad (7)$$

Then,

$$\Phi_x(x^*)=-u_x(x^*-c)\Phi(x^*)/[u(x^*-c)+W(x_0)]$$
$$=-[1-\Phi(x^*)]\Phi(x^*)u_x(x^*-c)/u(x^*-c)<0. \qquad (8)$$

In order to conduct comparative statics simply, we define the function for problem (6) as

$$w(x(a),a)=\max_x \ u(x-c)\Phi(x)/[1-\Phi(x)]. \qquad (9)$$

Here a stands for a shift parameter in what follows (e.g. planting costs c) and $x(a)=x^*$ (the solution for (6)). The total differential of the first order condition

$$\partial w(x(a),a)/\partial x=0$$

gives

$$w_{xx}(x(a),a)\,dx+w_{xa}(x(a),a)\,da=0.$$

From [A.7], the solution $x(a)$ is unique. This implies $w_{xx}(x(a),a)<0$. Hence we have

$$dx(a)/da=-w_{xa}(x(a),a)/w_{xx}(x(a),a)$$

and

$$\text{sign}[dx(a)/da]=\text{sign}[w_{xa}(x(a),a)].$$

This result shows that for comparative statics we only have to examine the sign of $w_{xa}(x(a),a)$.

The effect of planting costs

For planting costs, calculate $w_{xc}(x(c),c)$ to get

$$w_{xc}(x(c),c)=[-u_{xx}\Phi(1-\Phi)-u_x\Phi_x]/(1-\Phi)^2.$$

Substituting (8) into the numerator, we have

$$w_{xc}(x(c),c)=[u_x\Phi(1-\Phi)][(-u_{xx}/u_x)+u_x/u]/(1-\Phi)^2>0. \qquad (10)$$

The strict inequality follows from [A.3], [A.8], and (7)

Thus we can conclude that as the planting costs rise, the barrier also rises. Even if the manager is a risk lover, this inequality holds as long as the Arrow-Pratt index of absolute risk aversion $(-u_{xx}/u_x)$ is less than u_x/u.

The effect of degree of risk aversion

One measure of a manager's attitude towards risk is the Arrow-Pratt index of absolute risk aversion $-u_{xx}(x)/u_x(x)$. This index depends on both the first and second order derivatives of the utility function. However, the first order condition (8) is concerned only with the first order derivative of the utility function. In order to use the Arrow-Pratt index of absolute risk aversion, we must restrict the utility functions considered here to those in which the second order derivative of the utility function is uniquely determined by the first order derivative.

Using some real number $\lambda \in (0,1)$ and some function $v: R \rightarrow R$, let us express the utility function as

$$u(x) = \lambda x + (1-\lambda) v(x). \qquad (11)$$

Note that $v(x)$ is (strictly) concave if $u(x)$ is (strictly) concave. We use λ as the shift parameter for comparative statics. It is easily verified that as λ increases, the Arrow-Pratt index of absolute risk aversion approaches zero monotonically. In other words, as λ increases, the manager's attitude towards risk becomes more neutral.

By calculating $w_{x\lambda}$, we get

$$w_{x\lambda} = \{[1-v_x(x^*-c)]\Phi(1-\Phi) + [x^*-c-v(x^*-c)]\Phi_x\}/(1-\Phi)^2.$$

Substituting (8) into the numerator of right hand side and rearranging it, we have

$$w_{x\lambda} = \{[\Phi(1-\Phi)/u]/(1-\Phi)^2\}[v(x^*-c)-(x^*-c)\times v_x(x^*-c)].$$

Notice that $\{[\Phi(1-\Phi)/u]/(1-\Phi)^2\}>0$. Then we check the sign of $[v(x^*-c)-(x^*-c)\times v_x(x^*-c)]$.

We know that $x^*-c>0$ from [A.4] and (7), otherwise, the problem is reduced to the Fisherian problem. Also we know that v is concave and $v(0)=0$ since u is concave and $u(0)=0$. Thus from the property of concave functions,

$$v(x^*-c)-v(0) = v(x^*-c) \geqq (x^*-c)\times v_x(x^*-c), \qquad (12)$$

holds. From the inequality (12), we conclude $w_{x\lambda} \geqq 0$. In particular, if u is a strictly concave function, v is also strictly concave and then (12) holds with strict inequality. In this case, we can claim that as the Arrow-Pratt index of absolute risk aversion approaches zero from the right side, i.e. as the attitude towards risk becomes more neutral, the barrier rises. If the manager is a risk lover, with a strictly convex utility function, the barrier falls as his/her attitude towards risk becomes more risk neutral.

The effects of other parameters

There remain three parameters to examine. They are discount rates r, shift coefficients f, and diffusion coefficients σ. All of them are in Φ. Thus we rewrite Φ to $\Phi(x, a)$ where a stands for a shift parameter. Take the partial derivative of $w(x(a), a)$ with respect to a to get

$$\begin{aligned} w_a &= [u\Phi_a + u\Phi_a\Phi/(1-\Phi)]/(1-\Phi) \\ &= (\Phi_a/\Phi)w + [\Phi_a/(1-\Phi)]\,w \\ &= \{\Phi_a/[\Phi(1-\Phi)]\}\;w. \end{aligned} \qquad (13)$$

Taking the partial derivative of (13) with respect to x and substituting the first order condition, we have

$$w_{ax} = [\partial\{\Phi_a/[\Phi(1-\Phi)]\}/\partial x]\;w. \qquad (14)$$

This equation shows that the effect of the shift parameter a on the optimal barrier is only because of its effect on Φ and not on w, and thus it is independent of the manager's attitude towards risk.

In general, it is difficult to analyze the bracket [・] in the right hand side in (14). Here we show the results for a special case which was analyzed by MILLER and VOLTAIRE (1983). They considered the model where the shift coefficient f and the diffusion coefficient σ are constants and strictly positive. In this case, we can reduce Φ to

$$\Phi = exp\,[-\eta(x-x_0)],$$

where $\eta = \sigma^{-2}\,[f + (f^2 + 2r\sigma^2)^{(1/2)}]$.

Calculate $w_{\eta x}$ to get

$$w_{\eta x} = -\{\exp[-\eta(x-x_0)]-1-\eta(x-x_0)\}\exp[-\eta(x-x_0)]/\{1-\exp[-\eta(x-x_0)]\}<0.$$

The inequality is derived by using the MACLAURIN series of $\exp[\eta(x-x_0)]$. Taking the partial derivatives of η with respect to r, f, and σ, respectively, we have

$$\begin{aligned} \partial\eta/\partial r &= (f^2+2r\sigma^2)^{(-1/2)} > 0, \\ \partial\eta/\partial f &= \sigma^{-2}\,[1 + f(f^2+2r\sigma^2)^{(-1/2)}] > 0, \\ \partial\eta/\partial\sigma &= \eta^2\sigma/(f-\eta\sigma^2) < 0. \end{aligned}$$

(The inequality of last line follows from $f-\eta\sigma^2 = -(f^2+2r\sigma^2)^{(1/2)} < 0$.)

From these inequalities, we conclude that in this special case, the optimal barrier rises if discount rates decrease, or shift coefficients decrease, or diffusion coefficients increase.

Although these results are similar to results from the deterministic Faustmann formula, this special case is not very realistic for forest management problems. Therefore, further analysis under more appropriate assumptions for the probability process is required.

DISCUSSION

Under some technical assumptions, this paper derived a stochastic Faustmann formula and investigated the properties of the optimal barrier under uncertainty. The results imply that most of the properties of the deterministic Faustmann formula for determining optimal cutting stock size, i.e. the optimal barrier, are carried over in stochastic circumstances. This suggests that forest economic analyses conducted under deterministic settings such as the assumption of perfect foresight are reliable.

By introducing uncertainty into a forest management model explicitly, we found that a forest manager's propensity for risk aversion promotes harvest in early stages. It is often observed in Japan that a manager who owns large forests tends to adopt longer rotation periods than a small forest owner. This might be explained by differences of their attitudes towards risk. It seems plausible that a small forest owner is more risk averse for his/her forest than a large forest owner since a large forest owner has several stands and could make a better portfolio than a small forest owner. Another aspect of forestry in Japan is that the cutting ages have become older since about 1965. The deterministic Faustmann formula suggests that this phenomena has been caused by the rise of wage rates of forestry and the stagnation of timber prices, which accompanied the economic growth in Japan. Our analysis of the effect of planting costs indicates that this would still hold under uncertainty. Besides this analysis, the tendency might be explained partly by the manager's attitude towards risk. As the economy in Japan has developed, the money, asset, and insurance markets have matured. As a result, forest managers have been able to make better portfolios than previously. This indicates that forest managers in Japan have become less risk averse for their forests. If so, our results show that a change in the forest manager's propensity for risk aversion causes the optimal cutting stock size of the forest to rise.

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Article

Comparison of the Accuracies of Four Ground-Survey Methods Used for Estimating Forest Stand Values on Two Occasions

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ABSTRACT

This paper presents a comparison of the accuracies of four ground-survey methods; point sampling (PS), line sampling (LS), circular plot (CP), and concentric circular plot (CCP), when used to estimate the current values of number of stems, basal area and volume per hectare. The comparison was conducted to evaluate the utility of the four methods for continuous forest inventory (CFI) for forest management. Data were gathered on two occasions from a sugi (*Cryptomeria japonica* D. Don) stand in the Takakuma Experimental Forest, Kagoshima Prefecture, Japan. After entering the data of the entire study area in a file, the sample-trees of each ground-survey sampling methods were selected by a BASIC program. For PS and LS, basal area factor 4 was used. For LS, the line length was 10 m, and stems on both sides of the line were selected. For CP, the radius was 6 m, corresponding to 0.011 ha; for CCP, the radii were 5 and 10 m, corresponding to 0.008 and 0.031 ha respectively. The sampling intensity was 12 samples, and the systematic sampling process was applied 10 times for each method. The accuracy of each method varied according to the variable. On both occasions, CCP was slightly superior to the other three methods for the estimation of basal area and volume, and CP was slightly superior for estimating the number of stems. However, there were no marked differences in sampling error between the four methods. Therefore, the most appropriate method cannot be selected solely on the basis of sampling error.

Keyword: point sampling (PS), line sampling (LS), circular plot (CP), concentric circular plot (CCP), comparisons

INTRODUCTION

Sampling theory allows us, by measuring just part of a population, to draw inferences as to the whole with an acceptable accuracy, within a specified probability level.

In forestry, sampling theory has been applied to forest inventory for the collection of basic information for commercial purposes or for the support of forest management, such as forest structure, growing stock, site index, increment, and yield estimation.

Desirable properties of a sampling design include an absence of bias, precision, cost-effectiveness, and ease of application. A resource survey planner has a host of options when choosing a sampling design (Scott 1984).

In this study we compared the accuracy of four ground-survey methods in estimating the current values of number of stems, basal area and volume. Data were collected from a sugi (*Cryptomeria japonica* D. Don) stand in the Takakuma Experimental Forest in Kagoshima Prefecture. The four ground-survey methods of point sampling (PS), line sampling (LS), circular plot (CP), and concentric circular plot (CCP), were compared to evaluate their potential utility for continuous forest inventory for forest management. In an earlier study the authors (Nakajima *et*

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al. 1995) compared the same four methods using data from a sugi stand in the Shiragadake Experimental Forest in Kagoshima Prefecture, but these data were acquired on only one occasion. In this study, the objective was to compare values obtained on two occasions.

STUDY AREA AND METHODS

Study area

The study area is situated within the jurisdiction of Tarumizu City in Kagoshima Prefecture, Japan, at latitude 31°32'35" north and longitude 130°47'23" east.

Takakuma Experimental Forest is owned by Kagoshima University, and the study area was 2.8ha. The terrain is broken, with slopes, and the gradient ranges from 5 to 50 degrees. The altitude ranges from 550 to 620 m (Fig. 1).

The soil is derived from sandstone and clay-slate of a mesozoic formation, and is covered with volcanic soil and sand.

In 1926, a sugi (*Cryptomeria japonica* D. DON) forest was established with an initial spacing of about 2m × 2m. In 1981, when the stand was 55 years old, the first measurement of the entire study area was conducted, and the second was conducted in 1991. Both were carried out by the authors and students at the Kagoshima University Laboratory of Forest Management. The homogeneous stand, then 65 years old, had never been thinned.

Method of forest survey (YOSHIDA 1984)

For the survey of the forest, strings were used for dividing the entire study area into plots of 10m × 10m (Fig. 1). After that, a stake was driven on one corner of each plot, which were utilized as reference points in the measurement of individual trees with diameters at breast height of 4cm or more (*dbh* ≧ 4cm). Tree location coordinates, dbh, and height data were collected. Diameters were measured using a diameter tape with 1mm increments, and tree height was measured with a Blume-Leiss hypsometer.

(1) Height, stem volume, and stand parameter calculations

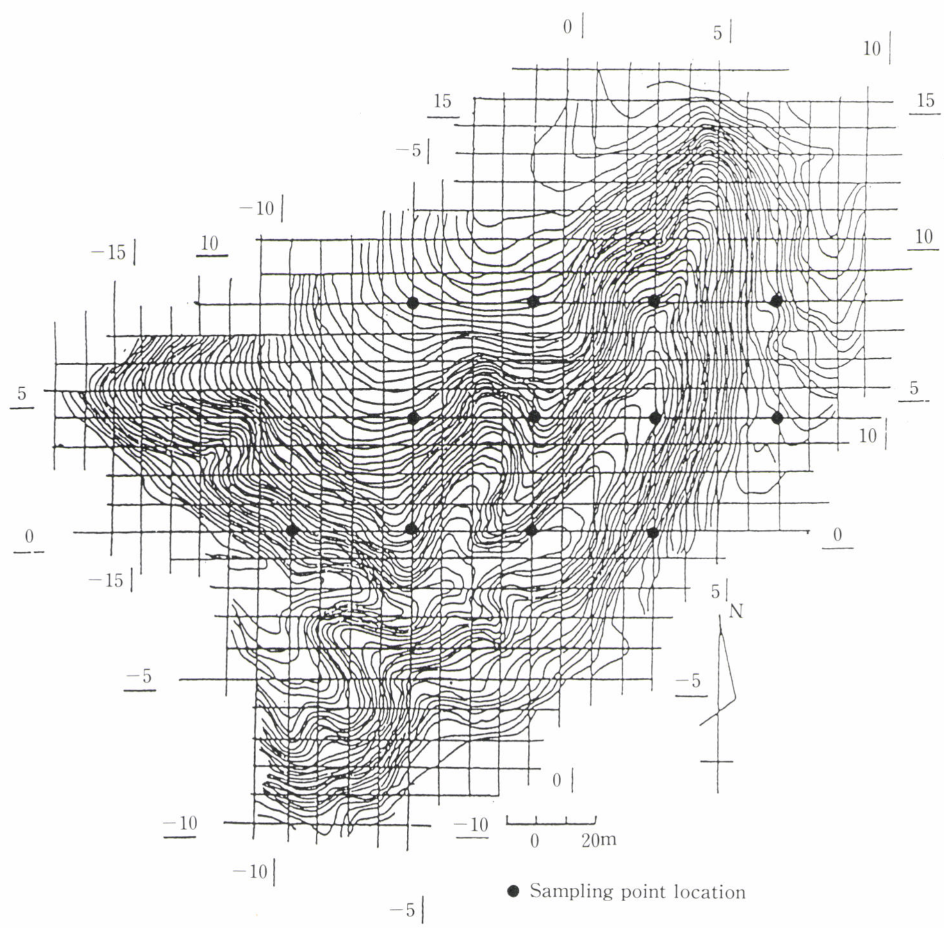

Fig. 1 Scheme of forest survey (Source: YOSHIDA 1984)

The volumes of individual stems were determined by diameter class, height class, and species using the Japanese Forestry Volume Table (THE FORESTRY AGENCY 1970).

On the second occasion, the height of only 59 % of the trees was measured, so the heights of the remaining 41 % of the trees had to be estimated. Heights were estimated using the following NESRUND equation model after fitting, as described by YAMANAKA (1992):

$$h=1.20+[dbh/(2.726+0.161\times dbh)]^2$$

The actual values of stand variables on both occasions were then calculated, and used as references to compare the ground-survey methods.

(2) Sampling process and ground-survey methods

A systematic sampling process was used to define the ground-survey sampling points: the first sampling point was randomly selected at the intersection of lines of the grid defining the 10m × 10m plots, and subsequent sampling points were selected systematically, keeping a distance of 40m between plots to avoid the overlapping of plots. For PS with basal area factor 4, the minimum distances which assured the independence of sampling points was 34.0 and 39.5m in 1981 (maximum *dbh* of 68cm) and 1991 (maximum *dbh* of 79cm), respectively (PELLICO-NETTO and BRENA 1993). The sampling intensity was 12 samples for each method, that is, the maximum number of plots allowed for the entire area. The systematic sampling process was applied 10 times for each method. For selecting the sample-trees in each method, after entering all of the data in a file (tree location coordinates, dbhs and heights), a BASIC program designed for each method was used. As the coordinates x and y were recorded, the location of each tree on the study area was known. Then, the programs for PS and LS calculated the distance (D) from sampling point to sample tree based on diameter at breast height (dbh) and basal area factor (k), by means of the following formula: $D < (dbh/k)$. For CP and CCP, the programs for selecting the sample-trees were based on their respective radii.

As PS and LS are plotless sampling methods lacking a defined area, while CP is a fixed-radius plot and CCP a combination of circles with two different radii, one way of transforming the samples to a common basis was to adjust the sample sizes of the four methods to have, on average, a uniform number of stems. For this, PS was used as the reference method; the average number of stems at each point was first counted and the other three methods were then adjusted to have the same number of stems as for PS. On both occasions (1981 and 1991) the same sample-plot characteristics (basal area factor, line length and radius) and sampling point locations for the four methods were used.

Point sampling (PS)

In practice, this method consists of using an instrument such as a relaskop to count trees, which have diameters (*dbh*) larger than the sighting angle, making a rotation of 360 degrees. Trees are selected with a probability proportional to basal area. In this study the basal area factor 4 was chosen.

Line sampling (LS)

In this method, a line of constant length is defined as a plot, and by using an instrument such as a relaskop, all trees whose *dbh* are larger than the sighting angle are counted. The trees are selected with a probability proportional to diameter. In this method, the basal area factor 4 was also used. The line length was 10m, and trees on both sides of the line were selected.

Circular plot (CP)

The CP method is a variant of the standard method, in which the shape of the sample plot is circular with a fixed-radius. In this method, all trees with $dbh \geqq$ 4cm inside the plot were selected. The trees on the plot boundary are selected if the center of the tree is located inside the plot. In this study, the radius was 6m, corresponding to 0.011ha.

Concentric circular plot (CCP)

In the CCP method, two concentric circles are used. The radii of the smaller and larger circle were 5 and 10m, which correspond to 0.008 and 0.031ha, respectively. The criterion for the selection of trees on the plot boundary was the same as that for CP. In the smaller circle, all trees between 4cm $\leqq dbh <$ 30cm were selected, and in the larger circle all trees with $dbh \geqq$ 30cm.

As this method offers several possible combinations of the larger and smaller circles, the most appropriate combination was determined using the radius of the CP as a reference, such that the inner circle in CCP was smaller than the radius of the CP. The outer circle was then selected so that the total number of stems (on average) was the same as for PS.

The authors have given the formulae for statistical analyses and for estimating the variable values of the four methods in an earlier paper (NAKAJIMA *et al*. 1995). For each of the four methods, the population was considered infinite, and the level of confidence was set at 95 %.

RESULTS AND DISCUSSION

Stand parameters

The study area was 2.8ha and the number of trees surveyed at the first and second occasions was 3,433 and 3,037 trees, respectively. The stand parameters and the diameter distributions obtained at each occasion are presented in Table 1 and Fig.2.

Comparison among the four ground-survey methods

The number of stems sampled at each of the 10 measurements, on each occasion and the overall mean number for each method are shown in Table 2.

In spite of the use of the same samples on the two occasions, the mean number of trees sampled on the second occasion differed from the number sampled on the first occasion. When PS or CCP was used, the number of trees increased (ingrowth), when LS was used the number stayed the same, and when CP was used it decreased. These differences may be due some trees having grown in and others having died in the intervening 10 years. In PS, the sampling probability is proportional to basal area, and with increasing basal area (i.e., dbh) the likelihood increases that a given tree will be sampled. In CCP, only trees with *dbh* ≧ 30cm are measured in the outer plot, and some trees would have grown sufficiently to be included in the second measurement. In CP, the sample-plot area is fixed, so the growth of trees would have had no influence, but the death of trees would result in fewer trees being sampled on the second than on the first occasion.

Fig.3 and 4 show, for each of the four ground-survey methods, the estimated values and the sampling errors, respectively, for the number of stems (stems/ha), basal

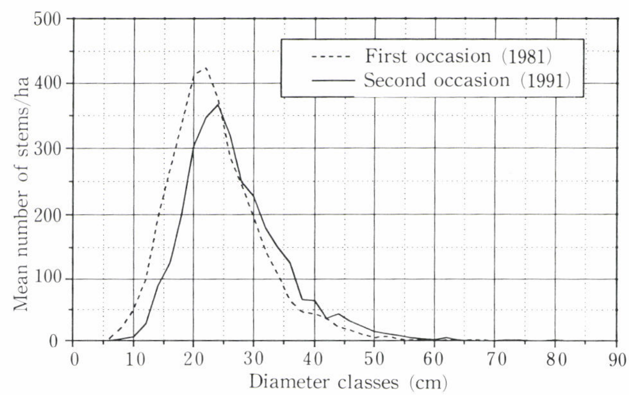

Fig. 2 Diameter distribution at each measurement occasion

Table 1 Stand parameters at each measurement occasion as determined by the complete survey

Variables	First occasion	Second occasion
number of stems (stems/ha)	1,226	1,085
Mean diameter (cm)	23.5	26.7
Mean total height (m)	13.1	15.8*
basal area (m^2/ha)	58.8	66.5
volume (m^3/ha)	409.2	525.3

* At this occasion the mean total height was based on 59% of the total trees.

Table 2 Mean number of stems sampled by each survey method at each repetition

First occasion					Second occasion				
Rep.	PS	LS	CP	CCP	Rep.	PS	LS	CP	CCP
1	13	13	12	13	1	14	13	11	15
2	15	15	14	14	2	16	14	13	15
3	14	14	15	13	3	15	14	13	14
4	14	15	15	15	4	17	16	13	16
5	15	15	13	15	5	16	15	12	16
6	14	14	13	13	6	16	14	11	16
7	12	12	13	11	7	14	12	11	14
8	15	16	16	16	8	17	15	13	17
9	14	15	14	14	9	16	14	13	15
10	13	14	14	13	10	15	14	13	14
Mean	14	14	14	14	Mean	16	14	12	15

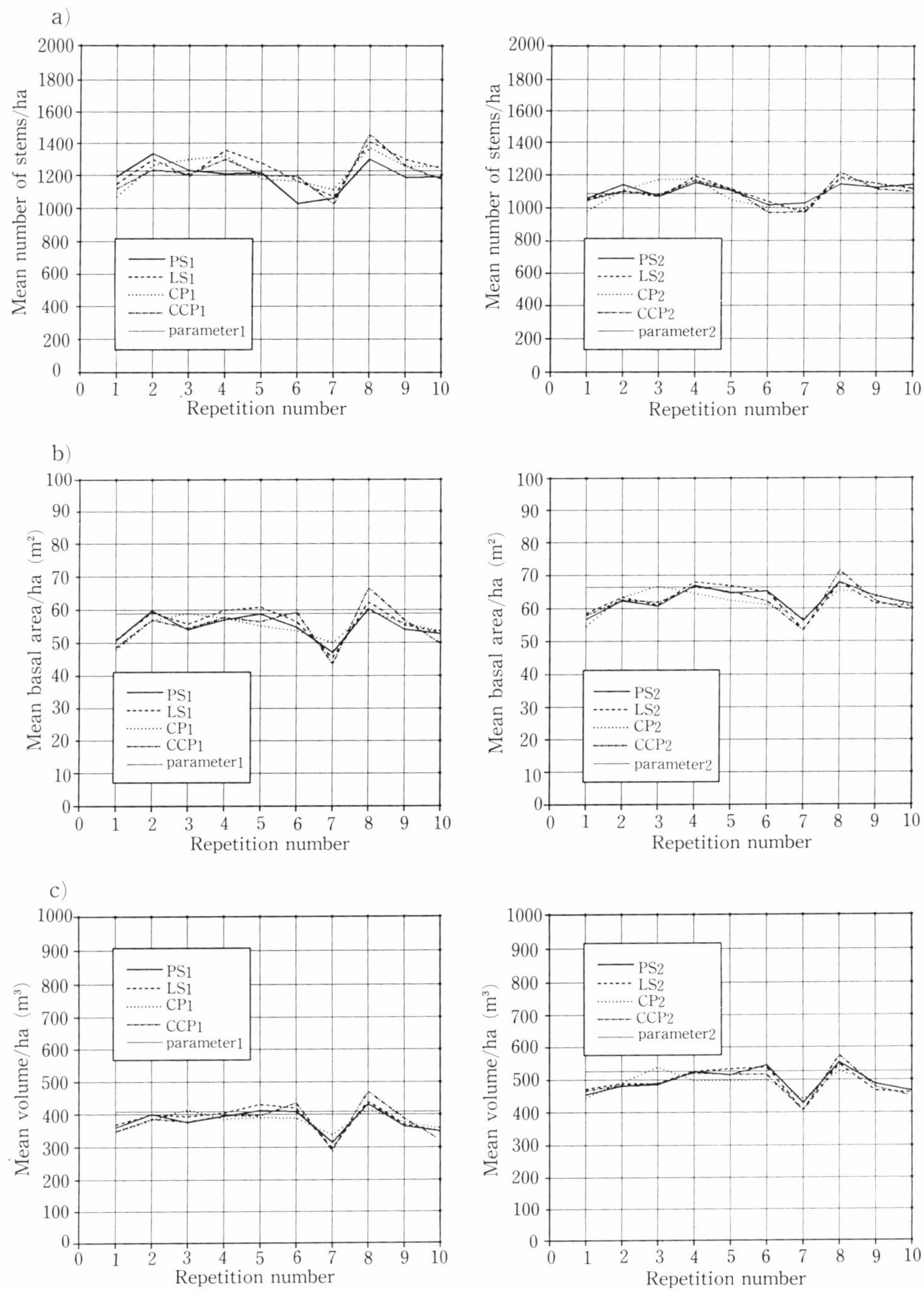

Fig. 3 Comparison of estimated variable values between the four methods. the Figures at the first and second occasions are presented in the left and right column, respectively, and the known value for each variable is shown as a single line a) number of stems/ha; b) basal area/ha; c) volume/ha

area (m^2/ha), and volume (m^3/ha), on the two occasions.

Compared with the measured stand parameters, all four sampling methods underestimated the variable values on both occasions, except for the number of stems. There were no marked differences in sampling errors between the four methods.

Table 3 shows the mean values and summary statistics for each variable at each occasion, compared with the known value.

On both occasions, CCP showed the least error for the

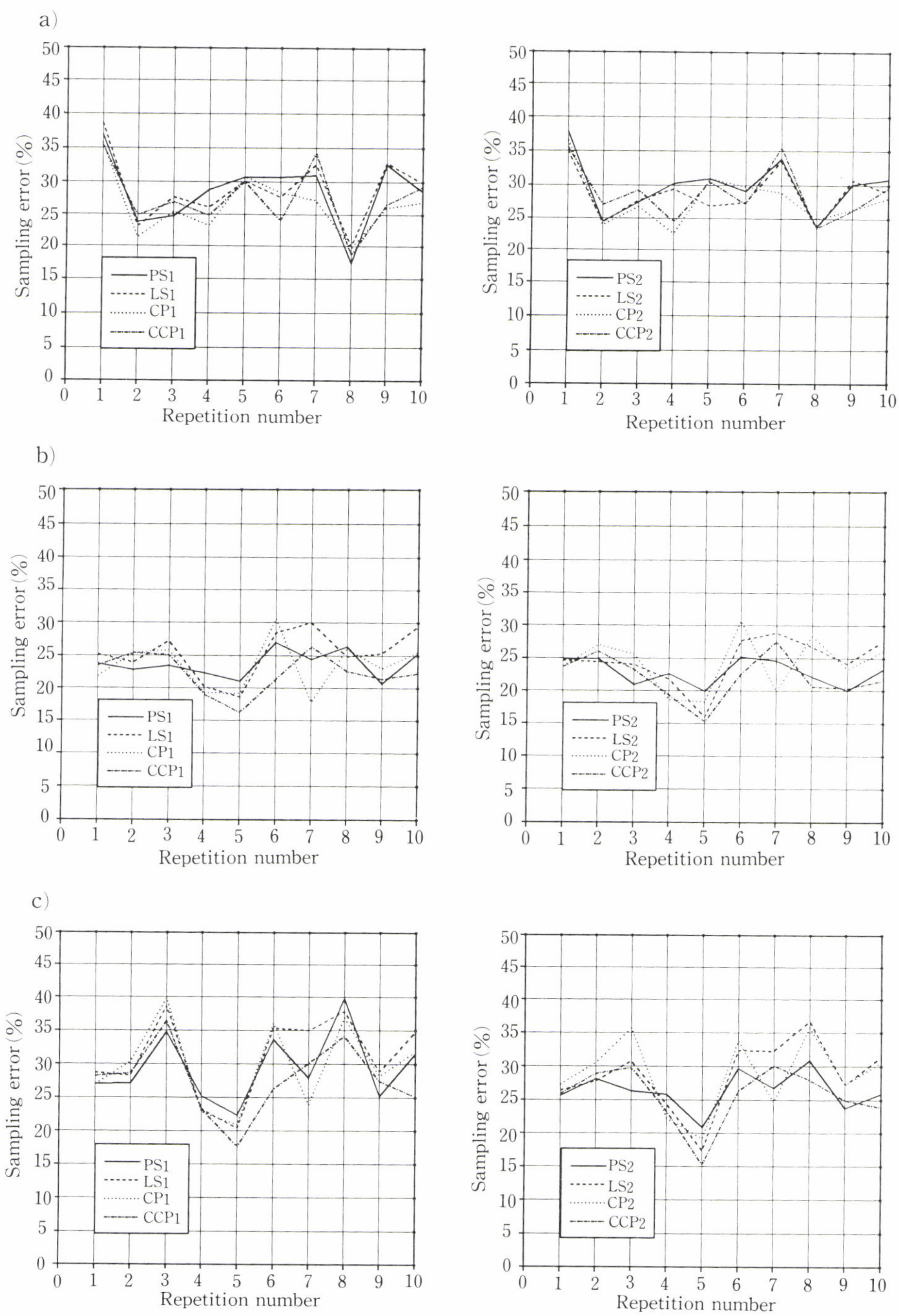

Fig. 4 Comparison of sampling errors between the four methods. The Figures at the first and second occasions are presented in the left and right column. respectively a) number of stems/ha; b) basal area/ha; c) volume/ha.

estimation of basal area and volume per hectare, followed by CP on the first occasion and PS on the second.

Despite sharing the plotless nature of PS, LS was inferior to PS for basal area and volume estimation, on both occasions. This may be because PS is proportional to the basal area of the trees, while the LS sampling is proportional to the diameter. CP was the most accurate method for estimating the number of stems per hectare, and PS the least. According to LOETSCH *et al.* (1973), CP can be regarded as sampling with the probability proportional to frequency. Hence, the number of stems is more effectively estimated by CP than by PS.

Table 3 Estimates and statistical summary of some parameters for each survey method and occasion. The known value for each parameter is shown in brackets.

First occasion					Second occasion				
Method	PS	LS	CP	CCP	Method	PS	LS	CP	CCP
Number of stems (1,226 stems/ha)					Number of stems (1,085 stems/ha)				
N	1,194	1,244	1,227	1,215	N	1,097	1,098	1,089	1,087
StD	532.2	560.6	506.3	519.0	StD	515.1	496.0	475.1	491.9
StE	153.6	161.8	146.2	149.8	StE	148.7	143.2	137.1	142.0
CV	44.9	45.5	41.7	43.3	CV	47.1	45.3	43.9	45.5
SE	28.5	28.9	26.5	27.5	SE	29.9	28.8	27.9	28.9
CI	856-153	888-1,600	905-1,549	885-1,545	CI	770-1,424	783-1,413	787-1,391	775-1,399
Basal area ($58.8m^2/ha$)					Basal area ($66.5m^2/ha$)				
G	54.9	55.9	54.9	55.0	G	62.6	62.6	62.0	62.2
StD	20.5	22.1	20.3	19.2	StD	22.4	24.1	23.6	21.4
StE	5.9	6.4	5.9	5.5	StE	6.5	7.0	6.8	6.2
CV	37.3	39.9	36.9	35.1	CV	35.9	38.7	38.0	34.6
SE	23.7	25.3	23.4	22.3	SE	22.8	24.6	24.1	22.0
CI	41.9-67.9	41.9-69.9	42.0-67.8	42.8-67.2	CI	48.3-76.9	47.3-77.9	47.0-77.0	48.6-75.8
Volume ($409.2m^3/ha$)					Volume ($525.3m^3/ha$)				
V	381.1	386.8	379.5	380.7	V	493.7	492.4	488.2	489.6
StD	177.5	188.8	179.2	166.2	StD	205.4	221.7	221.7	196.9
StE	51.3	54.5	51.7	48.0	StE	59.3	64.0	64.0	56.8
CV	46.4	49.0	46.9	43.6	CV	41.5	45.1	45.2	40.4
SE	29.5	31.1	29.8	27.7	SE	26.4	28.7	28.7	25.6
CI	268.3-493.9	266.9-506.7	265.7-493.3	275.1-486.3	CI	363.3-624.1	351.6-633.2	347.4-629.0	364.6-614.6

StD=standard deviation, StE=standard error, CV=coefficient of variation, SE=sampling error (%), CI=confidence interval (lower and upper limits), N=number of stems (stems/ha), G=basal area (m^2/ha), and V=volume (m^3/ha).

The authors (NAKAJIMA *et al.* 1995) compared these same four methods in a stand of *C. japonica* 43 years old mixed with pines (*Pinus* spp.) and diverse species of broad-leaved trees in Kagoshima Prefecture, Japan, and obtained the following results: for the number of stems per hectare, the least sampling error was found in CP, followed by CCP, and that for basal area and volume per hectare, the least error was found in PS, followed by CCP, LS, and CP. However, we concluded that there were no marked differences among the four methods for any estimated stand variable or sampling error. In this study, the same conclusion was obtained when the accuracies of these four methods were compared on two occasions. Therefore, the choice of the most appropriate ground-survey method should not be based solely on the sampling error.

CONCLUSIONS

This serial comparative study of four ground-survey methods revealed that, under the conditions of the study area, the accuracy of each method varied according to the variable: for estimating the number of stems per hectare, CP presented the least error on both occasions, followed by CCP; for basal area and volume per hectare, CCP presented the least error, followed by PS and CP.

In terms of accuracy, we can say that CCP was generally slightly superior to the other three methods. However, there were no marked differences between them. Therefore, the selection of the most appropriate ground-survey method should also consider cost, which is directly related to the amount of time spent in plot establishment and data surveys.

When choosing a ground-survey method, one should also take into consideration the individual stand conditions such as stand structure, topography, and undergrowth.

In our next study, we intend to compare the same four methods by evaluating the accuracy in terms of changes and the amount of time spent in plot establishment and data surveys. Based on those results, we hope to identify the most appropriate ground-survey method for use in continuous forest inventory (CFI) for forest management.

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Article

Comparison of Change Estimation between Four Ground-Survey Methods for Use in a Continuous Forest Inventory System

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ABSTRACT

In this study we compare the accuracy with which four ground-survey techniques estimate change. The methods compared are; point sampling (PS), line sampling (LS), circular plot (CP), and concentric circular plot (CCP), which can all be used as permanent samples in a continuous forest inventory system. Data were collected on two occasions from a sugi (*Cryptomeria japonica* D. DON) stand in the Takakuma Experimental Forest, Kagoshima Prefecture, Japan. For the PS and LS methods a basal area factor of 4 was used. For the LS method, the line length was 10 m, and the stems on both sides of the line were selected. For the CP method, the radius was 6 m, corresponding to 0.011 ha; and for the CCP method, the radii were 5 and 10 m, corresponding to 0.008 and 0.031 ha respectively. Twelve samples were systematically sampled and the process repeated 10 times for each method. The CP method was the most accurate for estimating the change in the number of stems per hectare, but there were no significant differences between the four methods for estimating basal area or volume.

Keyword: point sampling (PS), line sampling (LS), circular plot (CP), concentric circular plot (CCP), change estimation

INTRODUCTION

Change, or growth, may be estimated from differences between independent plots measured on two occasions, from remeasured plots, or from a combination of both (SCOTT and KOHL 1994).

According to HUSCH *et al.* (1982) successive sampling in forest inventory has three objectives: to estimate the quantities and characteristics of the forest at the first inventory; to estimate the quantities and characteristics of the forest at the second inventory; and to estimate changes in the forest during the intervening period. Sample units measured on the first occasion and remeasured on the second and all succeeding inventories are referred to as permanent sample plots and are the basis of continuous forest inventory (CFI). Permanent sample plots may be selected randomly or systematically to represent the entire forest population.

SCHMID-HAAS *et al.* (1993) recommend that permanent sample plots should be unmarked to ensure that management activities in the sample plots are as uniform as those applied to the entire population. But one of the difficulties of continuous forest inventory has been the exact relocation of the plots in subsequent measurements. Other disadvantages of permanent plots are that plots in distinct strata or regions may be lost, samples may not be representative over time, or the number of samples can become too low for some units of reference (KOHL *et al* 1995). WEST (1995) recommends that, because variability in forests is generally high, it is important to maximize the sampling intensity. VANCLAY *et al.* (1995) recommend that

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permanent sample plots should include a wide range of sites (all climatic zones and soil types) and stand conditions to ensure valid inferences.

Inventory on successive occasions is the basis of forest management decisions, silvicultural guidelines, yield tables, yield prediction, health monitoring, long-term productivity monitoring and analysis of the socio-economic influences of forests (VANCLAY *et al*. 1995; ADLARD 1995).

In forestry, the term "growth" is often used synonymously with "change", despite the former's implication of positive change. Among forest scientists and practitioners there is long-standing disagreement about the merits of growth estimation from sample designs which use fixed-area plots versus those which use horizontal points or variable radius plots (GREGOIRE 1993).

BICKFORD et al. (1963), cited by KOHL *et al*. (1995), reported that despite the use of sampling with partial replacement (SPR) since the 1960s, there are only a few instances when SPR has been used on more than two occasions. The tendency has been to abandon SPR and move back to CFI or to other techniques such as updating techniques based on growth projection models (HAHN and HANSEN 1983, cited by KOHL *et al*. 1995). SCOTT (1986), cited by KOHL *et al*. (1995) recommends simplification by returning to CFI particularly now that change is at least as important as current values. The CFI design is less efficient, but due to its simplicity, is more appropriate for most practical applications and continuous surveys over more than two occasions (KOHL *et al*. 1995).

The objective of this study was to compare the accuracy with which four ground-survey methods estimate change. Each method can be used for permanent samples for CFI, and are; point sampling (PS), line sampling (LS), circular plot (CP), and concentric circular plot (CCP).

STUDY AREA AND METHODS

Study area

The study was conducted in the Takakuma Experimental Forest, situated within the jurisdiction of Tarumizu City in Kagoshima Prefecture, on an area of 2.8ha. The terrain is broken and the gradient ranges from 5 to 50 degrees. In 1926, a sugi (*Cryptomeria japonica* D. DON) forest was established with an initial spacing of about 2 m × 2m. In 1981, when the stand was 55 years old, the first measurement of the entire study area was performed, and the second was conducted in 1991. The homogeneous even-aged stand, then 65 years old, had never been thinned.

Forest survey, sampling process and ground-survey methods

For the complete survey of the forest, the entire study area was divided into plots of 10m × 10m, and a stake was driven on one corner of each plot. These stakes were used as reference points in the measurement of individual trees with diameters at breast height of 4cm or more (dbh 4cm). The data collected were tree location coordinates, dbh, and height (YOSHIDA 1984).

Sampling of the forest was simulated using the data collected from the complete enumeration of the forest. The maximum number of plots allowed for the entire area was 12, so 12 samples were systematically selected for each survey method. Sampling was conducted 10 times for each method. To avoid bias, a minimum distance between the stand boundary and the sample-plots was observed. The data from the complete forest survey (tree location coordinates, dbhs and heights) was entered into a computer and a BASIC program written to select the sample trees of each method was used.

PS and LS are plotless sampling methods without a defined area, the CP method is a fixed-radius plot with a defined area, and the CCP method a combination of circles with two different radii. To compare the plots fairly, the plot sizes of the four methods were adjusted so that each plot had a uniform number of stems, using the PS method as a reference. The average number of stems in PS method was first counted and the other three methods were then adjusted to have the same number of stems as the PS method.

For the PS and LS methods, a basal area factor of 4 was chosen; in the LS method the line length was 10m, and the sample trees on both sides of the line were selected. For the CP method the radius was 6m, corresponding to 0.011 ha, and all trees with dbh 4cm and whose center was located inside the plot were selected. For the CCP method, the radii of the smaller and larger circles were 5 and 10m, corresponding to 0.008 and 0.031ha, respectively. The criteria for the selection of borderline trees was the same as for the CP method. In the smaller circle, all trees between $4 \leqq$ dbh <30cm were selected, and in the larger circle all trees with dbh $\geqq 30$cm were selected. On both occasions (1981 and 1991) the same sample-plot characteristics (basal area factor, line length and radius) and sampling point locations for the four methods were used. For each of the four methods, the population was considered infinite, and the level of confidence was set at 95%.

The authors have given the formulae for estimating current values and the statistical analyses of the four methods in an earlier paper (NAKAJIMA *et al*. 1995).

Change estimation and statistical analysis formulae

The estimation of the current values, and statistical analyses at each inventory were conducted as in the case of two separate inventories. Differences between means at each inventory represent the changes in the forest. However, because the same sampling units are used on both occasions, the standard error of the difference is calculated as for paired plots (HUSCH *et al.* 1982). This calculation should take into account any removed trees on both occasions.

The change estimation and statistical analyses were conducted using the following formulae (PELLICO-NETTO and BRENA 1993):

$d_m = (y - x)$ (there was no thinning),

$s_d^2 = [(s_x^2 + s_y^2 - 2s_{xy})]/m,$

$s_d = \mathrm{sqr}(s_d^2)$, and

$se = (t \times s_d/d_m) \times 100,$

where:

d_m = mean change or growth of the estimated variable

y = mean of the estimated variable at the second occasion

x = mean of the estimated variable at the first occasion

s_d^2 = variance of the change or growth

s_x^2 = variance of the estimated variable at the first occasion

s_y^2 = variance of the estimated variable at the second occasion

s_{xy} = covariance between the first (x) and second (y) occasions

m = number of samples measured at the first occasion and remeasured at the second occasion

s_d = standard deviation

se = sampling error as percentage

t = student table value $[t_{(0.05,22)} = 2.07]$

Further details about the study area and methods can be found in NAKAJIMA *et al.* (1996).

RESULTS AND DISCUSSION

Stand parameters

The study area was 2.8ha, and the number of trees surveyed at the first and second occasions were 3,433 and 3,037 trees respectively. Table 1 shows the stand parameters on both occasions and their change.

Details of the diameter distribution, statistical analyses, and the accuracy of the estimations for each survey method are presented in a former paper (NAKAJIMA *et al.* 1996).

Comparison of the accuracy of the estimation of change between the four methods

On the first occasion the sample plot size of each method was adjusted to have, on average, the same number of stems (14 stems per sample). But, on the second occasion (10 years later), despite the use of the same sample plots, the mean number of trees sampled was different from the first occasion, because there were ingrowth trees. For the PS and CCP methods, the average number of stems per sample plot increased to 16 and 15 stems, respectively. HRADETZKY (1995) reports that in forest inventories using PS as permanent samples, the composition of samples from successive measurements change due to sample trees being selected with a probability proportional to basal area. For this reason, the variance of estimators of growth based on this type of data tends to be very high.

In the LS method, the number of stems measured on the second occasion stayed the same (14 stems). For the CP method, the number of stems per plot decreased to 12 stems. In this method, the sample-plot area is fixed and the growth of trees had no influence (i.e., there were no ingrowth trees), but the death of trees resulted in fewer stems being sampled on the second than on the first occasion.

Fig. 1 shows, for each of the four ground-survey methods, the estimated change values (left column) and respective sampling errors (right column), for the number of stems per hectare (stems/ha), basal area per hectare (m^2/ha), and volume per hectare (m^3/ha).

Table 1 Stand parameters on each occasion and their change

Parameter	First occasion	Second occasion	Change
Mean number of stems/ha	1,226	1,085	141
Mean dbh (cm)	23.5	26.7	3.2
Diameter range (cm)	4-68	6-79	-
Mean total height (m)	13.1	15.8	2.7
Mean basal area (m^2/ha)	58.8	66.5	7.7
Mean volume (m^3/ha)	409.2	525.3	116.1

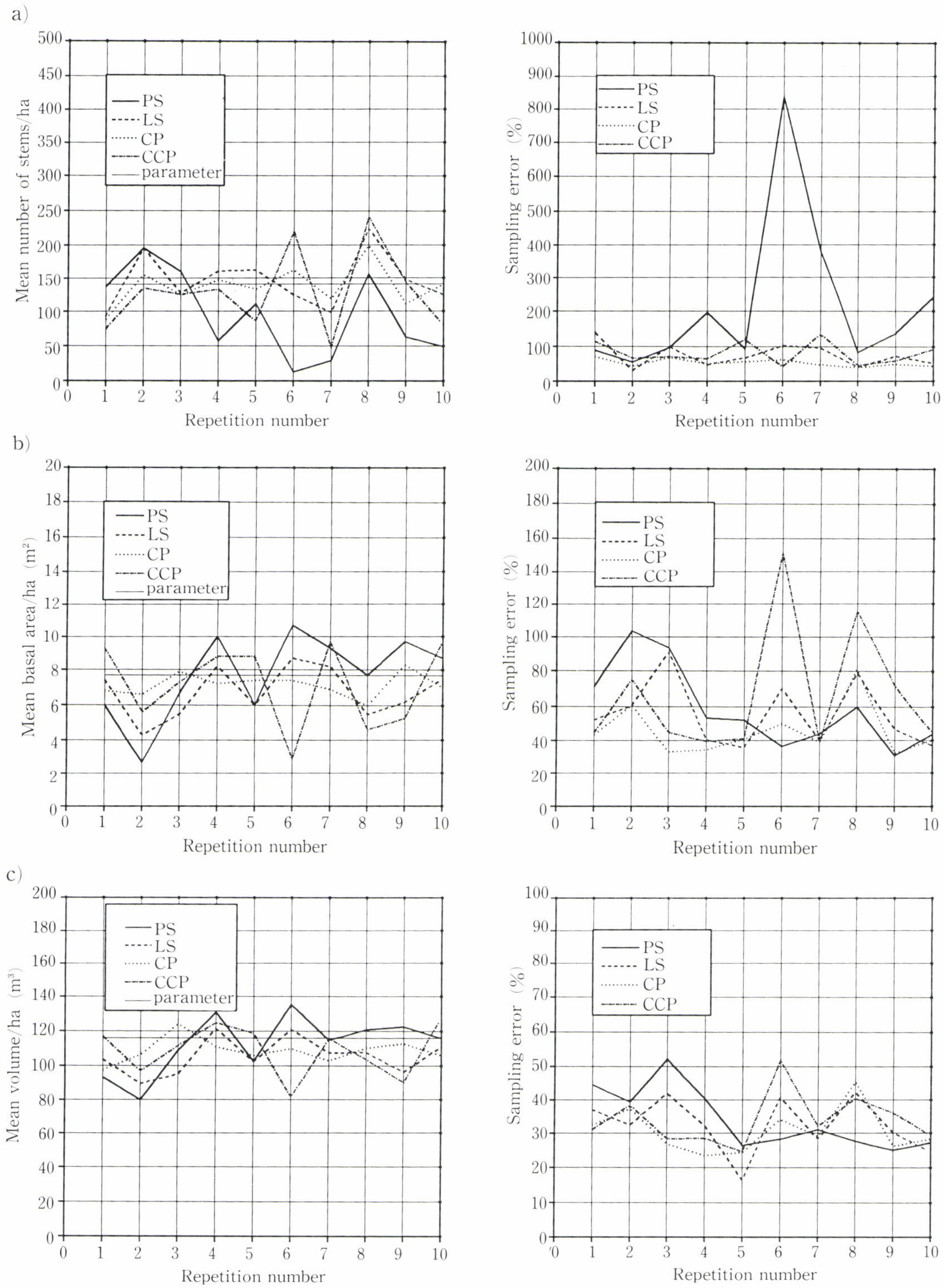

Fig. 1 Comparison of the estimated changes (left column) and sampling errors (right column) among the four ground-survey methods. a) number of stems/ha; b) basal area/ha; c) volume/ha.

Over the 10 repetitions, the CP method gave the closest estimation of the change in each stand parameter the most number of times. The CP method also had the lowest average sampling error for each stand parameter, followed by the LS method. The sampling error for the change in the number of stems was lower for the CP method than the other three methods. However, for volume and basal area change there were no significant differences between the 4 methods, at a confidence level of 95 % (test of hypothesis, t - distribution). According to HRADETZKY (1995), the variance of the calculated growth is reduced in CFI, because the covariance between the first and second occasion is positive and the degree of covariance is higher if the same trees are measured at both inventories, as in the CP method. LOETSCH *et al.* (1973) state that simple plots (e.g. CP) are superior to combined and Bitterlich plots (PS) for CFI, because in simple plots the same trees are remeasured at every mensuration. SCHMID-HAAS *et al.* (1993) recommend that after defining a plot size, it should stay the same as long as possible.

In the PS, LS and CCP methods, the plot size varies with tree size and they are therefore less appropriate than the CP method for CFI.

Tables 2 and 3 show the tests of comparisons between sampling errors of the four methods, and the means of the estimated change values from 10 repetitions, as well as the results of statistical analyses, respectively.

YANG and WANG (1987) report that permanent horizontal line sampling (LS) for forest growth estimation is problematic, because ingrowth trees which were originally out of the plot are suddenly included at the next measurement period even though there was little diameter growth. This can sometimes cause an abrupt change in the estimated volume per hectare, and YANG and WANG (1987) assert that this is caused by the estimation technique rather than actual growth. In this study, the LS method did not show an abrupt change in volume between measurements.

CONCLUSIONS

In prior papers we (NAKAJIMA *et al.* 1995, 1996) compared the accuracy of the same four ground-survey methods for the estimation of current values of two distinct experimental forests. We found that when estimating basal area and volume in a stand where the tree distribution was almost random (Shiragadake Experimental Forest), the PS method was the most accurate, followed by the CCP method (see NAKAJIMA *et al.* 1995). In a stand where the tree distribution was approximately a square lattice pattern (Takakuma Experimental Forest), the CCP method was the most accurate (see NAKAJIMA *et al.* 1996). For estimating the number of stems the CP method was the most accurate in both stands. However, we concluded that

Table 2 Comparisons between sampling errors of the four methods

Variable	PS vs LS	PS vs CP	PS vs CCP	LS vs CP	LS vs CCP	CP vs CCP
Number of stems	2.00^{ns}	2.24^{ns}	1.79^{ns}	2.72*	0.52^{ns}	2.71*
Basal area	0.50^{ns}	1.70^{ns}	0.52^{ns}	1.66^{ns}	1.11^{ns}	2.15^{ns}
Volume	0.56^{ns}	0.91^{ns}	0.04^{ns}	0.83^{ns}	0.62^{ns}	1.65^{ns}

*: differences were significant at $t_{cal} \geqq t_{tab(9;\ 0.05)} = 2.26$.
ns: no significant

Table 3 Estimated change and statistical analyses

Statistical analyses	PS	LS	CP	CCP
For number of stems (N = 141 stems/ha)				
Mean num. of stem/ha	97	146	138	129
Standard deviation	55.7	48.1	35.0	42.8
Sampling error	220.8	75.6	53.9	81.6
For basal area (G = 7.7 m^2/ha)				
Mean basal area/ha (m^2)	7.7	6.8	7.1	7.2
Standard deviation	2.0	1.8	1.5	2.0
Sampling error	58.9	55.4	45.5	66.8
For volume (V = 116.1 m^3/ha)				
Mean volume/ha (m^3)	112.6	105.6	108.8	108.9
Standard deviation	18.3	16.6	16.1	17.5
Sampling error	34.2	32.6	30.7	34.1

there were no marked differences between the sampling techniques in the accuracy of their estimates.

In this paper we compared the accuracy of the four ground-survey methods for estimating changes in the number of stems, basal area, and volume. Under the conditions of the study area, the CP method was the most accurate, especially for estimating the number of stems. However, for estimation of the change in volume or basal area, there were no significant differences between the sampling methods.

Based on the estimation of current values and change, we conclude that among the four ground-survey methods compared, there is no single method which is unanimously best for estimating both current values and change. Generally speaking, for estimating current values, there were no marked differences between the four methods, but for estimating change the CP method was the best. However, it is also desirable that the ground-survey method used to estimate current values and change is efficient. An efficient ground-survey method should not only be accurate, but should also be cost-effective and easy to apply, as this directly affects the amount of time spent in plot establishment and data surveys. Therefore, our next study will compare the amount of time spent in plot establishment and data surveys for each of the same four methods. We hope we will then be able to select the most appropriate ground-survey method for use in CFI for forest management.

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Short communication

Characteristics of Young Stands Regenerated Naturally on Cutting Areas in Siberia

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ABSTRACT

Variations in successions following commercial (industrial) cutting of pine forests in the eastern Siberia were studied. The dimensional hierarchy of trees in the stands were determined by morphometric methods. Structure and biomass of aboveground vegetation were studied. The greatest aboveground biomass was found to be near 70 ton/ha (100% dry matter). This biomass accumulation rate is close to natural coniferous forest with about the same growing stock in Hokkaido, Japan. Maximum average annual biomass increment was found to be 1.9 ton/ha.

Keyword: cutting area, forest succession, structure, biomass, Siberia

INTRODUCTION

In Siberia a considerable part of the stocked forest land is covered nowadays by young stands naturally regenerated on previously areas (DANILIN 1995). Lack of understanding of their structure and growth dynamics makes forest management in the region difficult, necessitating more detailed forest inventory. Management requires criteria for forest ecosystem stability to be developed. Improved forest resource it is therefore important to determine complex biometric characteristics of forest stands of different ages and thoroughly study their structure and biological productivity. This information is vital for understanding geographic variations in the forest succession process in disturbed vegetation communities of the boreal zone (DANILIN 1994). Information about structural and functional mechanisms in forest biogeocenoses and their anthropogenic dynamics is also valuable for management purposes and studyng the global carbon balance of forest biomes (KOL'CHUGINA *et al.* 1993).

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MATERIALS AND METHODS

Characteristic of young stands of commercial (industrial) clear cutting areas of eastern Siberia (Krasnoyarsk territory, Chuna River cutting area) (Fig. 1) were measured. The sample plots are described in Table 1. The sample plots were established using conventional forest inventory techniques (MOISEEV 1971; NIKITIN and SHVIDENKO 1978; SUKHIH *et al.* 1977). All trees in the sample plots were measured and mapped to establish their size-dependent position in the phytocenosis and to determine the structure of the aboveground biomass. Parameters were measured as follows. Trees for stem analysis were selected from each diameter class, and their stems and crowns were measured in detail. Then the trees were divided into fractions to be weighed (weighting errors were +- 1g and +- 100g for up to 10kg and above 10kg fraction weight, respectively). Samples for determination of moisture content were taken from each fraction and oven-dried (t = 105 C) to a 100% dry condition. Total moisture content calculated, summed by diameter class and reduced to a 1 ha unit area value. The approximation accuracy was not less than 0.97 ($r^2 > 0.97$) (UTKIN 1975). To estimate ground vegetation, fifty 20 × 25 cm miniplots were established on every sample plot. Ground plants were identified and grouped in species according to their classification (BUSIK *et al.* 1979). Samplings was performed in the second half of July,

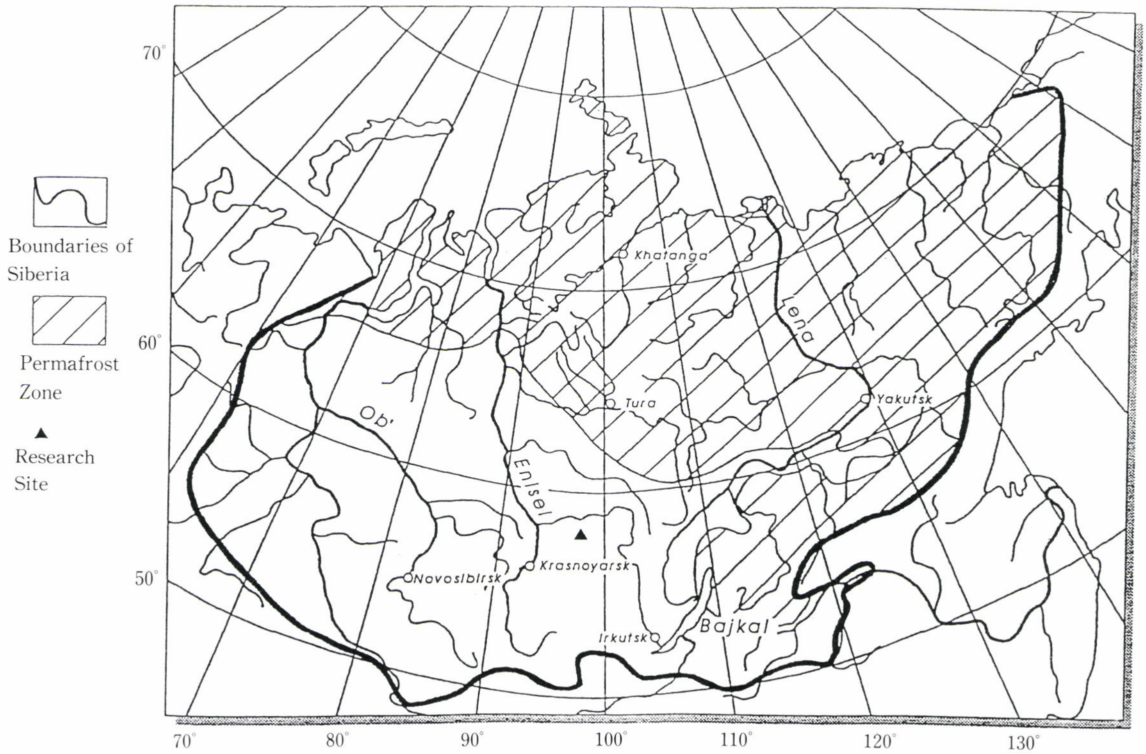

Fig. 1 Location of the research site

Table 1 Description of the sample plots

Sample plot number	Species composition	Dominant ground plants	Species	Stand age (years)	Average DBH (cm)	Average Height (m)	Density (thousand trees/ha)	Growing stock (m^3/ha)
1	100%Pine	Bearberry, Lichens	Pine	12	1.1	1.2	94.6	23.1
2	100%Pine	Red bilberry, Green mosses	Pine	15	2.4	2.6	6.8	7.6
3	60%Pine	Herbaceous	Pine	15	3.6	5.5	3.8	13.0
	40%Aspen		Aspen	15	3.2	6.2	2.3	7.0
	+Birch		Birch	15	2.8	5.7		0.7
4	60%Pine	Herbaceous	Pine	28	6.5	8.4	4.8	69.0
	20%Aspen		Aspen	30	4.7	8.8	3.3	27.0
	20%Birch		Birch	25	6.9	11.2	0.8	17.0
5	80%Pine	Herbaceous	Pine	36	5.3	6.2	10.4	86.0
	20%Birch		Birch	30	8.2	9.0	0.8	21.0
6	100%Pine	Red bilberry, Green mosses	Pine	36	5.8	8.8	10.3	126.0
7	100%Aspen	Herbaceous	Aspen	15	4.4	8.5	4.7	30.0
	+Pine		Pine	15	5.3	6.0	3.2	0.8
	single Birch		Birch	15	2.8	5.0	0.2	0.5
8	80%Aspen	Herbaceous	Aspen	15	3.6	6.9	8.1	34.0
	20%Birch		Birch	15	5.0	7.6	1.1	9.0
	single Pine		Pine	15	2.3	2.9	0.8	1.0

which is close to the end of the period of active vegetation growth in the experimental area.

RESULTS AND DISCUSSION

The forest cover of the experimental area was even-aged young pine and aspen stands, both pure and mixed, belonging to different forest types and natural formation patterns (series). Pure young pine stands occurred mostly on the Chuna river terraces and belong to the pine-bearberry-lichen (*Pinus sylvestris* -*Arctostaphylos uva-ursi*-*Cladina sylvatica*) and pine-red bilberry-green moss (*P. sylvestris*-*Vaccinium vitis idaea*-*Pleurozium schreberii*) forest types. The tree density in these stands varied from 6.8 to 94.6 thousand trees per hectare. Tree mortality was maderate. Mixed pine, aspen and aspen-birch stands were common on flat interfluves with loamy soils. These belong to the pine-aspen -birch-red bilberry-herbaceous (*Pinus sylvestris*-*Populus tremula*-*Betula pendula*- *Vaccinium vitis idaea*-*Calamagrostis arundinacea*-*Carex macroura*-*Pulsatilla patens*-*Trifolium lupinaster*-*Bupleurum aureum*-*Geranium sylvaticum*) forest type and the density of these stands varied from 6.4 to 11.2 thousand trees per hectare.

The frequency distributions of morphometric parameters were compact, with high excess and right-side asymmetry. Empirical curves of frequency distribution by stem diameter, height, crown length and crown diameter became less steep with increasing average stand age; i.e. they became smoother, but the range increased. Changes in distribution for each parameter occurred spontaneously. Coefficients of variation were in the range of 40 to 70%.

The horizontal stand structure of these forests was distinctive; trees spread over the area in groups, canopy closure was very high (>100%) and suppressed and well-growing trees could be easily distinguished by their vitality (morphometric parameters). Although tree growth was significantly hampered due to intense competition, even the most suppressed trees maintained their viability and showed increment. Natural thinning was moderate, with dead trees not exceeding 15% of the total tree number. The highest mortality was observed in trees of the lower height and diameter classes.

Morphometric parameters of tree stems and crowns correlated strongly (r^2=0.83-0.98). Correlation between morphometric and biomass parameters was also very high (r^2 = 0.85-0.99), and relationships between the amounts of some biomass fractions approached the functional level ($r^2 > 0.99$). The correlation between biomass components and stem diameter was higher than with tree height or crown length. This can be attributed to the non-uniform vertical stand structure and differences in tree height common in dense young stands (MOISEEV 1971).

The aboveground tree biomass is given in Table 2. The greatest biomass was found in sample plot 6, a 36-year-old pure pine stand with 126 m^3/ha growing stock, and 53.7 ton/ha dry matter in stems and 7.0 ton/ha in needles. This is comparable with a Japanese natural coniferous forest of *Picea glehnii* (70%), *Picea jezoensis* (22%) and *Abies sachalinensis* (8%) in Hokkaido, which had 141 m^3/ha growing stock and 52.7 and 7.5 ton/ha of stems and needles, respectively (SIDEI *et al.* 1961).

The structural relationships between biomass fractions changed with increasing average stand age and density. In dense stands, tree crowns were best developed. (Sample plot 1). Consequently, the total crown biomass of dense, young stands was greater than in older stands with lower tree density. This may be due to the fact that trees, at early development stages, make maximum use of their assimilation apparatus and branches, and there is intraspecific (coenopopulation) competition for light, nutrients, and water (ZLOBIN 1980).

Biomass increment is a more objective index for the production process than total biomass (UTKIN 1975). Over the last 5 years, the current annual increment of diameter and height increased consistently with increasing tree size. Trees with the best developed crowns and stems showed the greatest increment, but in underdeveloped trees, these values were the lowest. The maximum average annual biomass increment was found to be 1.9 t/ha (100% dry matter) at sample plot 6 (Table 2).

CONCLUSION

If the process of succession follows its natural cource and the existing rate of biomass increment is maintained, these forests could be expected to regain their original state (i.e., a relatively stable climax forest ecosystem whose components are in balance with the environment) in about 100 years for the pure pine and mixed stands, and about 50 years for the aspen phytocenosis (ATKIN *et al.* 1993). However, this time period would become much longer if disturbances occured, such as fire or insect outbreaks. In this case, if a phytocenosis is partly or completely destroyed, succession would take the form of replacement of coenopopulations: secondary aspen and birch stands on flat interfluves with loamy soils; or the native edificator tree species on river terraces with sands and loamy sands.

Specific forest management activities, such as thinning, can considerably reduce the time necessary for a native phytocenosis to fully recover. From the biological viewpoint, thinning is useful because about 50% of wood dies by the stand age of maturity (SOKOLOV *et al.* 1994). Extraction of some part of dead and injured trees changes the insolation and temperature conditions, as well as those of air humidity and soil moisture and the decomposition

Table 2 Aboveground biomass of the stands

Sample plot number	Stand age (years)	Species	Aboveground biomass (ton/ha, 100% dry matter)					
			Stems	Branches Live	Branches Dead	Needles foliage	Sum total	Annual increment
1	12	Pine	7.2	1.3	0.4	2.0	10.9	0.9
2	15	Pine	3.5	0.6	0.1	0.8	5.0	0.3
3	15	Pine	4.4	0.8	0.2	0.9	6.3	0.4
	15	Aspen	2.7	0.2	0.1	0.4	3.4	0.2
	15	Birch	0.7	0.07	0.01	0.12	0.9	0.06
4	28	Pine	33.0	4.7	0.9	3.7	42.3	1.5
	30	Aspen	13.7	1.8	0.3	0.7	16.5	0.6
	25	Birch	8.0	1.6	0.2	0.4	10.2	0.4
5	36	Pine	31.1	4.5	0.8	4.0	40.4	1.1
	30	Birch	10.7	2.0	0.3	0.5	13.5	0.5
6	36	Pine	5.37	7.7	1.4	7.0	69.8	1.9
7	15	Aspen	11.5	1.0	0.1	1.7	13.8	0.9
	15	Pine	0.27	0.05	0.01	0.06	0.39	0.03
	15	Birch	0.22	0.02	0.003	0.027	0.27	0.02
8	15	Aspen	15.9	1.4	0.2	2.4	19.9	1.3
	15	Birch	4.2	0.9	0.1	0.2	5.4	0.4
	15	Pine	0.21	0.04	0.01	0.01	0.27	0.02

rate of the forest floor organic layer increases. The condition of vegetation then improves, as conditions for tree growth and development improve and trees drop their dead branches and accumulate timber. These factors apparently facilitate better productivity and consequently induce higher resistance in the phytocenosis. Moreover, the increased yield of valuable conifer wood results in high economic returns and decreases the conifer cultivation period.

Thinning, however, is a complex biotechnical measure that needs planning. Before thinning, account should be taken of the biological characteristics of the stand, i.e. its composition, age, density and productivity, as well as site conditions, such as topography, soils, climate, the rate and character of anthropogenic disturbance, wildfire dynamics, etc.

In the event of phytocenosis succession controlled by man (anthropogenic succession) it is preferable for the forest ecosystem to regenerate through the native edificator species to form the original pine coenopopulation.

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