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CONTENTS

Articles

Classification of Conifer Tree Species using JERS-1 OPS Data

Masato Katoh*

ABSTRACT

The Chitose region of Hokkaido, Japan was selected as the study area because of the large number of conifer plantations and old deciduous stands. Japanese Earth Resources Satellite-1 (JERS-1) data taken using the Optical Sensor (OPS) was acquired on April 17, 1993. The background and understory in the study area were still covered with snow, and the deciduous trees and shrubs had not yet opened their leaves for the approaching spring. The objectives of the research were to classify conifer tree species and to evaluate spectral differences between tree age classes and phenological stages (unopened, emerging, open) in coniferous stands. Representative conifer tree species forming closed cover were selected as sample classes. The forest cover type classification was produced with the maximum likelihood classifier. The results of the field survey and analysis indicated the following:

(1) The near infrared band (band 3) was very useful for classifying vegetation. The differences between tree species were especially important.

(2) There were spectral differences for the Japanese larch (*Lalix leptolepis*) depending on leaf phenological stage in spring time.

(3) The mean VNIR bands' values for old stands of Sakhalin spruce (*Picea glehnii*) were lower than the mean value for young stands.

(4) Bands 1 and 2, and bands 6, 7 and 8 showed a similar spectral pattern in the forest cover classes.

(5) OPS has a high potential to classify forest cover type and distinguish between tree ages and phenological stages in coniferous stands.

Keyword: remote sensing, forest resource management, forest cover classification, JERS-1, OPS

INTRODUCTION

JERS-1 was launched into orbit with an altitude of about 570km and a recurrent period of 44 days on February 11, 1992. The satellite observes the earth's surface using OPS and Synthetic Aperture Radar (SAR) sensor. OPS can observe in seven bands from the visible region to the Short Wave Infra Red (SWIR) region and is capable of stereoscopic observation. The ground resolution of OPS is 18m×24m which provides better ground resolution than the Landsat Thematic Mapper (TM) which is 30m×30m. OPS is expected to obtain data useful for monitoring the earth's resources, land survey, agriculture and forestry, and environmental protection (NASDA 1993).

The author has been carrying out research on estimation of forest resources and identifying tree species in conifer plantations using remote sensing and GIS since 1982 (Katoh 1987, 1988, 1991, 1993, 1994).

This paper will establish the classification of conifer tree species stands using optimum OPS bands.

This report involved the selection of the optimum OPS band for classifying forest cover type, distinguishing between different tree age classes and phenological stages, and forest cover types.

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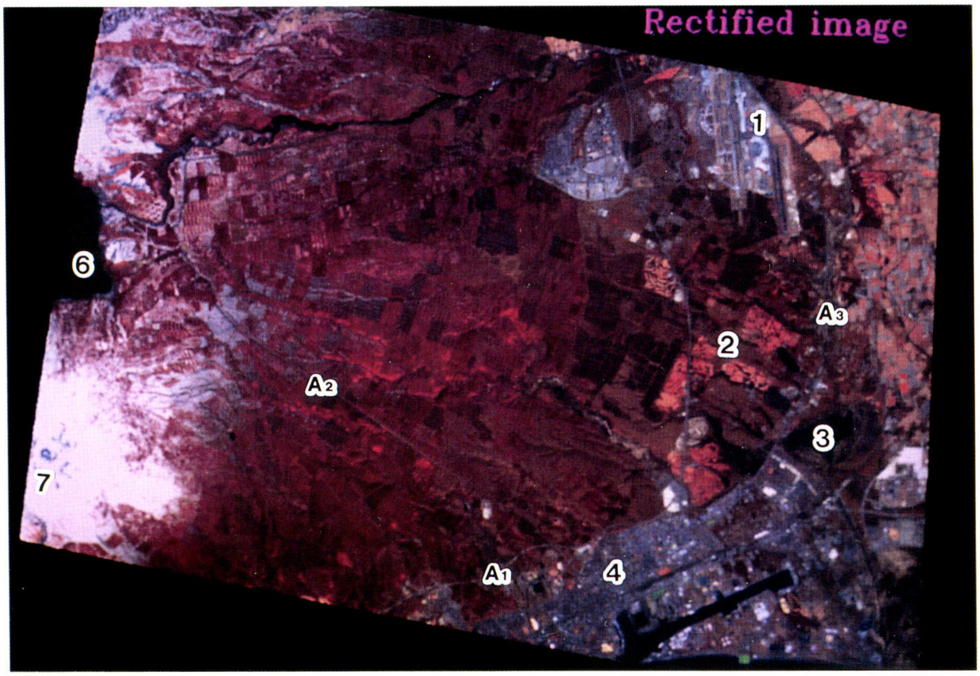

Fig. 1 A OPS false color image showing the study area which was located on the Chitose region of Hokkaido

1 : Chitose airport 2 : Golf courses 3 : Lake Utonai
4 : Tomakomai city 5 : The Chitose river 6 : Lake Shikotsu
A_1 : Express way A_2 : Route 276 A_3 : Route 36

STUDY AREA AND MATERIALS

The Chitose region of Hokkaido, Japan, was selected as the study area because of the large number of conifer plantations and old deciduous stands. A false color image of the study area with overlaid forest boundaries is shown in Fig.1. This area consists of flat land and is divided into blocks of about 45ha. These blocks are pure conifer plantations. The plantation species are Japanese larch (*Larix leptolepis*), Yezo-spruce (*Picea jezoensis*), Todo fir (*Abies sachalinensis*) and Sakhalin spruce (*Picea glehnii*).

OPS data from April 17, 1993, was acquired for the study area. A field survey was carried out to measure the Diameter of Breast Height (DBH) and tree ages of the stands, and to investigate leaf phenology and stand condition. The background and understory in the study area were still covered with snow, and the deciduous trees and shrubs had not yet opened their leaves for spring. Image processing and analysis were performed using ERDAS (ERDAS 1991).

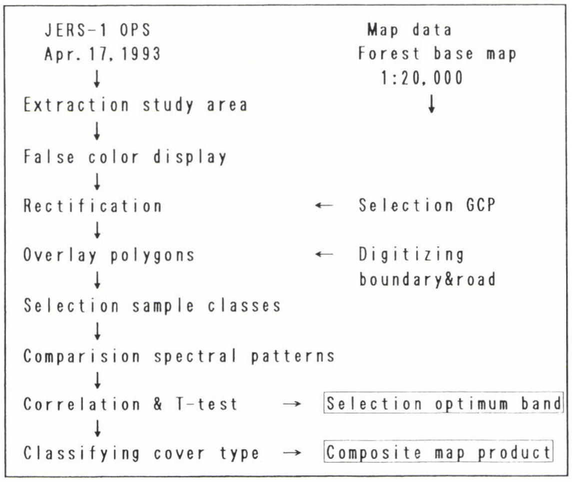

Fig. 2 Flow chart of OPS processing

METHODS

The methodology is shown in the flow chart (Fig.2). The study area was extracted from OPS scene. Ground Control Points (GCP) were then selected on the false color image corresponding to a forest base map (1:20,000 scale).

Geometric corrections were conducted in bands 1,2,3 (VNIR) and 5,6,7,8 (SWIR) using GCP. The streoscopic band (band 4) was not processed. The conversion error was kept within one pixel. Sample classes were selected for extracting spectral patterns on false color composite images. The following conditions were applied for selection:

(i) over 50 pixels per forest cover class.

(ii) the representative conifer plantation stands had closed canopy cover so as to remove the influence of ground or understory reflectance values.

Forest cover types were defined into 11 classes according to a dominant tree species, age, DBH, and stand description, as shown in Table 1. Japanese larch stands changed from those with unopened leaves to emerging leaves, and open leaf stands according to the elevation. Three different tree age classes were selected for the Sakhalin spruce and deciduous stands. The background of the deciduous stands was still covered with snow as the leaves had not opened.

Table 1 Stand condition of forest cover classes

	Age	D.B.H cm	Description
Coniferous			
Japanese Larch			
-open leaf	31	18.0	closed canopy
-intermediate	31		leaf emagency
-unopen leaf	31		covered snow
Sakhalin spruce			
-old forest	<100	45.0	closed canopy
-mature	60	23.0	
-young	34	14.0	
Ezo spruce	64	28.0	
Todo fir	34	15.0	
Deciduous			
Old-forest	<100	60.0	unopen leaf, covered snow
Second forest	30-40	16.0	
Shrub	>10	-	

RESULTS

Characteristics of Tree Species' Spectral Pattern

Sample classes were selected from the false color composite image to focus on determining differences between conifer tree species spectrals. In particular, three different classes of Japanese larch and Sakhalin spruce were selected. The Japanese larch differed phenologically and the Sakhalin spruce by age. The mean reflectance value and standard deviation for sample classes were calculated, as shown in Table 2.

Two points are important to note, the first being leaf phenology. Concerning VNIR bands, the mean reflectance value for open leaf stands in Japanese larch was lower than the mean value for stands which were unopen. The mean VNIR bands values for Sakhalin spruce and old deciduous stands were lower than for young stands. When the age increased, the reflectance value decreased. The same results have been reported using Landsat TM data (Katoh 1987, Leprieur 1988, Fiorella 1993).

The second point refers to the successional stage of the Sakhalin spruce stands in the SWIR bands. Here, an inverse relationship was shown between the VNIR and SWIR bands.

Selection of Optimum Bands

The optimum bands to improve accuracy of classification were considered using the following guidelines;

(i) the band where the range of differences between tree species reflectance values was larger than other bands was useful for classifying single and multiple bands using the clustering method.

(ii) the band where the order of tree species reflectance value was unique or different from the other bands was

Table 2 Mean value and standard deviations for classes from OPS data (Apr.17,1993).

Class name	VNIR band1	sd	VNIR band2	sd	VNIR band3	sd	SWIR band5	sd	SWIR band6	sd	SWIR band7	sd	SWIR band8	sd
Coniferous														
Japanese Larch														
-open leaf	↓ 93.4	3.6	↓ 96.9	4.4	↓ 99.2	2.9	122.5	4.3	57.1	3.1	85.4	4.2	61.0	3.6
-intermediate	93.9	3.0	97.0	3.8	105.3	3.0	132.8	3.7	59.3	2.3	87.9	3.4	61.1	2.9
-unopen leaf	141.2	7.2	157.6	9.4	142.3	5.6	98.1	3.7	44.1	2.5	65.5	3.6	47.5	3.3
Sakhalin spruce														
-old stand	↓ 86.8	3.2	↓ 75.2	5.1	↓ 102.2	3.7	↑ 96.3	6.2	↑ 29.8	3.8	↑ 47.5	4.7	↑ 36.5	3.8
-mature	88.7	3.3	76.3	4.2	105.8	2.3	92.7	5.1	25.9	3.9	43.9	5.9	32.5	4.1
-young	90.7	3.0	78.2	3.8	119.3	3.3	72.0	1.4	24.0	2.6	40.6	3.3	30.2	3.1
Ezo spruce	92.4	2.4	79.2	3.7	127.3	5.3	88.2	3.0	27.5	3.1	45.3	5.1	33.4	3.7
Todo fir	87.7	2.6	73.5	3.3	131.6	2.4	84.9	4.0	24.2	2.2	43.9	3.3	30.7	2.9
Deciduous														
Old forest	↓ 96.1	2.4	↓ 102.8	3.8	↓ 117.5	3.3	166.2	6.8	74.3	4.2	108.6	4.2	75.9	4.3
Second forest	98.0	2.7	111.6	3.7	125.5	2.9	183.8	4.7	80.2	3.9	118.4	3.4	82.4	3.3
Shrub	102.1	1.9	112.1	3.0	131.4	2.5	181.3	9.1	83.7	3.2	117.1	3.9	81.3	3.5

useful for classifying of multiple bands using the maximum likelihood classifier.

The useful bands for distinguishing tree species were band 3 in VNIR, and band 5 in SWIR (see Table 2) as they showed the greatest difference between forest cover classes. The coefficient correlation and significance test between bands in the forest area were derived as shown in Table 3. The correlations between bands 1 and 2, bands 6 and 7, bands 6 and 8, bands 7 and 8 were higher ($r > 0.92$) than those of any other bands at a significance level of 0.01. Relationships between VNIR (band 1 and band 3) and SWIR were shown to be inverse.

Table 3 OPS bands correlation matrix in the forest area

	VNIR			SWIR			
band	1	2	3	5	6	7	8
1	1.0	0.92**	0.62**	-0.12	-0.05	-0.08	-0.07
2		1.0	0.48**	0.13	0.23*	0.20*	0.21*
3			1.0	-0.21*	-0.21*	-0.25**	-0.27**
5				1.0	0.81**	0.83**	0.81**
6					1.0	0.96**	0.96**
7						1.0	0.96**
8							1.0

*:p<0.05, **:p<0.01

Forest Cover Type Classification

Bands 3 and 5 were shown to be the optimum bands as they showed the largest range between classes. However, bands 1 and 2 and bands 6, 7 and 8 showed similar spectral patterns in the forest cover classes. Forest cover classification should be classified using the optimum bands and one of the similar spectral pattern bands, as the accuracy would not have been improved, even if all bands had been included.

The study area was classified with a maximum likelihood classifier using bands 2, 3, 5 and 7 (Fig.3). The left part of the study area was covered by deciduous second forest (brown) and Japanese larch leaf open stands (yellow) and located in neighboring cities at low elevations. The center part was conifer plantations; Yezo spruce (dark green), Sakhalin spruce stands (purple) and Todo fir (moss green). The right part was composed of old deciduous forest (bright green) around Mt.Tarumae covered with snow.

Spatial resolution of OPS image was found to be higher than Landsat TM for interpreting roads, streams, etc.

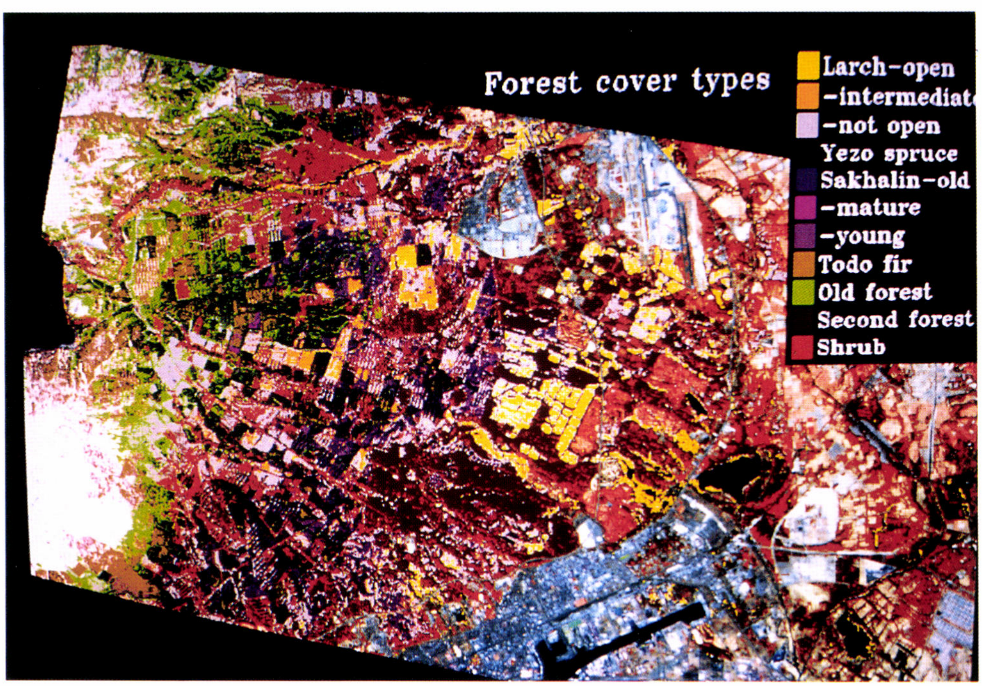

Fig. 3 Forest cover type classification composite map overlaid on false color image.

CONCLUSIONS

1 Different phenological stages (unopened, emerging, open) of Japanese larch stands could be distinguished due to different spectral patterns.

2 The mean VNIR bands values for old Sakhalin spruce stands were lower than the mean value for young stands.

3 The VNIR bands showed inverse linear relationships with the SWIR bands in forest stand area from the correlation matrix.

4 The effective bands for distinguishing tree species were band 3 in VNIR, band 5 in SWIR.

5 Bands 1 and 2, and bands 6, 7 and 8 had high correlation relationships ($r>0.92$) at 0.01 significance level.

6 Determining forest cover type was classified with useful multiple bands (2,3,5 and 7) without similar spectral pattern bands (1,6,8).

7 Spatial resolution of OPS false color image has a high potential for interpreting line data such as forest roads, streams and so on.

ACKNOWLEDGEMENT

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Forest Activity Classification System of Small Watershed Area using GIS (I)

—Classification system in case of sub-compartment—

Nobuyuki Abe*, Hisaaki Kamioka* and Ryo Benitani*

ABSTRACT

A system to evaluate and classify the forest's activity by each sub-compartment was studied. The forest's function was investigated mainly based on topographical factors. By distinguishing the stands suitable and unsuitable for cutting , based on topography, site class, stand volume and so forth, they could be evaluated by a score evaluation method. As a consequence of doing a cluster analysis of the scores, it was decided that they should be appropriately divided into 3 types such as a timber production function, on the erosion protection function and a watershed protection function. On the other hand, as for the forest function for public health and recreation, a condition was set that people could use the water for recreational use. As a result, the various functions of the forest were divided into 4 types by adding a forest function for public health and recreation. In order to determine which function each sub-compartment belongs to, a system to classify them through the use of a decision tree method, was developed by making the best of use the GIS function. As a consequence of its adoption by the Shibata District Office of the National Forestry Bureau, (to the forests within its jurisdiction) it was confirmed that an evaluation of the forest's functions by each sub-compartment could be rapidly classified.

Keyword: GIS, forest activity , watershed management,

INTRODUCTION

The forest activity plans establishing the watershed area as the subject have recently been put into effect (ZHENG and NAGUMO 1994). In this fundamental philosophy, the various functions of the forest are evaluated not only for a timber production forest, but also for a watershed protection forest, an erosion protection forest, a recreational forest and so forth, with the objective being to ensure that the forest is managed in proper accordance with its function. In the national forest, the forest functions are frequently classified mainly based on topographical factors. So, in order to analyze geographical factors, a utilization of GIS is very efficient (ABE 1993; ARONOFF 1993). In this report, by analyzing the geographical factors by making the most of the GIS function by setting the watershed areas as the subjects, and subsequently, by combining its results with the existing information in the forest inventory survey notes, a system to classify the various functions of a forest was investigated. An operation in the national forest is often performed in a small sub-compartment unitdivided by the age of the stands and the kinds of trees. Accordingly, in the first report, a classification method of the various functions in the sub-compartment unit will be reported on, followed by the second report, where a concept of the sub-compartment function classification system, has been removed.

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SMALL WATERSHED AREA AS THE SUBJECT

The subject region is the 59th compartment, the ninouji group within the jurisdiction of the Shibata National Forestry Bureau, with an area of 264ha. In this compartment, the Mizutanizawa flows through the center. It is composed of the sugi (*Cryptomeria Japonica* D.DON) man-made forest for 1/3 of its area with natural forest making up the balance. As for the stand condition of the natural forest, the down stream catchment area of the Mizutanizawa has many trees with a relatively small diameter such as the konara (*Quercus serrata* THUNB.), kuri (*Castanea crenata* SIEB. et ZUCC.), buna (*Fagus crenata* BLUME), and so forth. On the other hand, the upstream catchment area is dotted with trees with a large diameter such as the tochinoki (*Aesulus turbinata* BLUME), itaya-kaede (*Acer mono* MAXIM.) and so on. The sugi man-made forest is relatively good in terms of growth, and consequently the 80 years old splendid sugi forest still remains. Because this catchment area is only about 10 km from Shibata City, and moreover, because it is adjacent to the Tainaininouji Prefectural Natural Park, it is expected that it will be utilized as a natural recreational forest.

METHODS

Philosophy of Forest Function Evaluation by Score Evaluation Method

A forest has various compound functions. Even a man-made forest with trees for timber production, also has the watershed protection function and the erosion protection function occurring concurrently. However, in an actual activity, factors such as the topography and the distance from the forest road have a strong affect and influence. In the steep slope land, clear cutting will be impossible, and moreover, when the area is far from the forest road, cutting will be impossible from a cost point of view. Therefore, considering topographical factors and geographical conditions, evaluating the forest function is rather practical. ZEHNG already reported on the forest function evaluation using a score evaluation method (ZHENG and NAGUMO 1994). Although a function evaluation is carried out by giving the scores to the various factors, it has too many factors to be useful for practical applications.

Accordingly, a new forest function evaluation method by using a score evaluation method, was investigated. In the case of establishing the forest activity plan, the most fundamental item is cutting activity. If cutting is not conducted and the forest function of its stand might not be damaged, then there would not such a big point at stake. However, when cutting takes place, a clear and definite reason becomes necessary. Accordingly, the scores were allotted so that a stand with good cutting conditions, was given a higher score, and moreover, a stand closer to the river systems and ridges was given a lower score from the aspect of the land conservation function.

From a cutting standard aspect, the following factors were selected.

(1) Kind of forest (man-made forest or natural forest)
(2) Site class (site class for man-made forest, present accumulation for natural forest)
(3) Distance from forest road
(4) Average slope angle
(5) Distance from river system or ridge

Allotting of scores by each factor are shown in Table-1. The maximum score is given one hundred and the minimum is zero. Each category's score is given at regular intervals to each category number. A zero score is given in the case of a stand being located more than 500m from the road and 100m from a ridge and river. Zero is a condition of a no-cutting area. As for (1), the man-made forests having greater chances for cutting were given the larger scores. As for (2)～(3), the stand volumes available for cutting were given the higher scores. On the other hand, in the case of (4), along with an increase of the slope angle, cutting becomes difficult, and in the case of (5), the stand volumes closer to both the of river systems and ridges should be conserved, and therefore, based on these reasons, the lower scores were allotted. As for an allotting of scores by each factor, the site class and the accumulation of the naturalforest were made to 4 divisions from the forest inventory survey notes, the distance from the forest road was made to 6 divisions, and the slope angle was made to 4 divisions. The stands most amenable to cutting, are allotted the full scores in all 5 factors and therefore, they will get 500 points. On the other hand, the stands where the cutting should be done from the aspect of land conservation, will get 100 points.

Forest Function Classification by Cluster Analysis

Designating sub-compartment 75 as the subject, according to the standards shown in Table-1, the scores of each sub-compartment were estimated. In order to understand what kind of typology can be obtained based on the scores given, a cluster analysis wascarried out (Fig.1). As a consequence, first of all, it was divided into 8 clusters as shown in Table 2. The score distribution of this cluster in this stage is classified from 186～446 points as shown in the table, and the number belonging to each sub-compartment, greatly fluctuates, and furthermore, in the scores of each cluster, groups with similar scores such as 336, 340, 270, and 272, can be seen. Next, by squeezing the group further, it can be classified into 4 groups (Table 2). Looking at the scores by each group, the difference between the groups can be seen. Looking at the average scores by each group, they are 431,284,180 and 319 points. When it is considered that group I with the highest score is also high in the timber production function (431), as well as group III with the lowest scores, because in terms of the hillside accident

Table 1 The evaluation criterious for the forest activity

	Classification	Score
Type of forest	Natural	80
	Man-made	100
Man-mad	Site I	100
	II	70
	III	40
	IV	10
Natural	Volume I	100
	II	70
	III	40
	IV	10
Distance from the road	0~100	100
	100~200	80
	200~300	60
	300~400	40
	400~500	20
	more than 500	0
Slope degrees	0~10	100
	10~20	70
	20~30	40
	30~	10
Distance from ridge and river	0~100	0
	100~	100

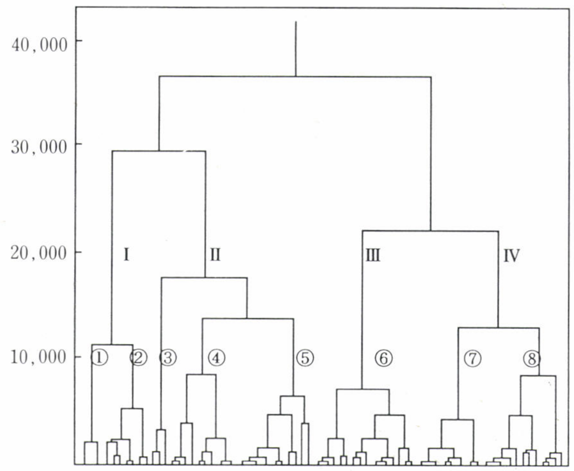

Fig. 1 Dendorogram on forest activity classification by cluster analysis (nearest neighbour method).

prevention function, the intermediate group II and IV (284, 319 points) can be selectively cut depending on the site and small watershed area, the group with the higher score was designated the selection cutting water source conservation

Table 2 Classification score using cluster analysis

Type	Ave. score	Num. of sub-com.	Type	Ave. score	Num. of sub-com.	Forest activity
①	380	4	I	431	11	→ Timber production
②	446	7				
③	270	3	II	284	25	→ Water conservation (Reserve)
④	336	10				
⑤	237	12				
⑥	180	16 →	III	180	16	→ Land conservation
⑦	340	10	IV	319	23	→ Water conservation (Selection cutting)
⑧	272	13				

function, and the group with the lower score was designated as the preservation of water source function. Accordingly, in a classification of the forest function, they were divided into a total of 3 types and 4 kinds such as a timber production forest, an erosion protection forest and a water source preservation forest, of which selection cutting is either possible or not.

On the other hand, when the various factors for a definition of the natural recreational forest are considered, there is no clear definition for it (Kumagai 1989). When it is considered that people go to the forest for recreation, the authors pointed out 2 points as an absolute factor. For example, the firstly, that it is located close to the forest road and secondly, that it is located close to the water area paying attention to the action of playing and with, water. By considering that this time, the small watershed area is located near the city region, it was evaluated separately from the forest function by the score evaluation method. By utilizing the analytical results of these clusters, it was decided to classify the results into 4 types and 5 kinds such as (1) timber production function (2) erosion protection function (3) water source conservation function (based on the stand structure, it is classified into 2 kinds such as the stand being amenable to selective cutting and the preservation stand) and (4) Public health and recreational forest function.

Classification of Forest Function Evaluation in Sub-compartment Unit

(1) Formation of fundamental data utilizing the forest inventory survey notes

The forest data base (forest inventory survey note) within the jurisdiction of the Shibata District Office of the Forest Bureau, was formed in March 1987 (Maebashi Regional Forestry Office 1993a). On the other hand, a resources table showing the age of the stand and an accumulation per ha , has been formed as of 1994. However, the average tree height is recorded only in the forest data base. Accordingly, through the field examination, by examining a corresponding relation between the present tree height and the tree height in 1987 by each locational factor, the present tree height in each sub-compartment was presumed. By adapting a relation between the present tree height and the age of the stand to the sugi man-made forest site index table of Niigata Prefecture (1980), the site index by each sub-compartment, was established. The sugi man-made forest inside the subject catchment area, is the best at the southwestern slope with a flatter slope, and is arranged in the order of the north, east and west slope. Along with a steeper slope angle, the tree height growth drops. When compared to the distribution of the site index inside the subject region, withother site classes in Niigata Prefecture, many stands belong to a 2~3 class site. As for the stand volume and the age of the stand, the values in a the resources table were input as the attribute data.

(2) Formation of fundamental data utilizing GIS

GIS has the function of superimposing piece of each information (ARONOFF 1993). Accordingly, it is more convenient for a subsequent analysis if the files of each factor are formed beforehand and then the necessary information is picked out corresponding to the subject. Therefore, making the fundamental map as an the subject, 1. location of sub-compartment 2. location of forest road 3. location of ridge 4. location of river system 5. location of contour line (20m) interval, and each of them was input from a digitizer. As attribute data, 1. in the sub-compartment file, name of sub-compartment, age of stand, kinds of trees, 5. in the contour line file, altitude value by each contour line were input from a keyboard respectively. The slope angle, the slope azimuth angle, and the distance from the forest road, ridge and river system were inferred by using Terra Soft. Although the magnitude of the raster can be estimated by using Terra Soft, an analysis was done this time by unifying all raster at 20m×20m (Essential Planning Systems Limited 1993).

(3) Extraction method of forest function in each sub-compartment

Each sub-compartment is divided into a raster of 20 m×20m, and then the slope inclination angle, the slope

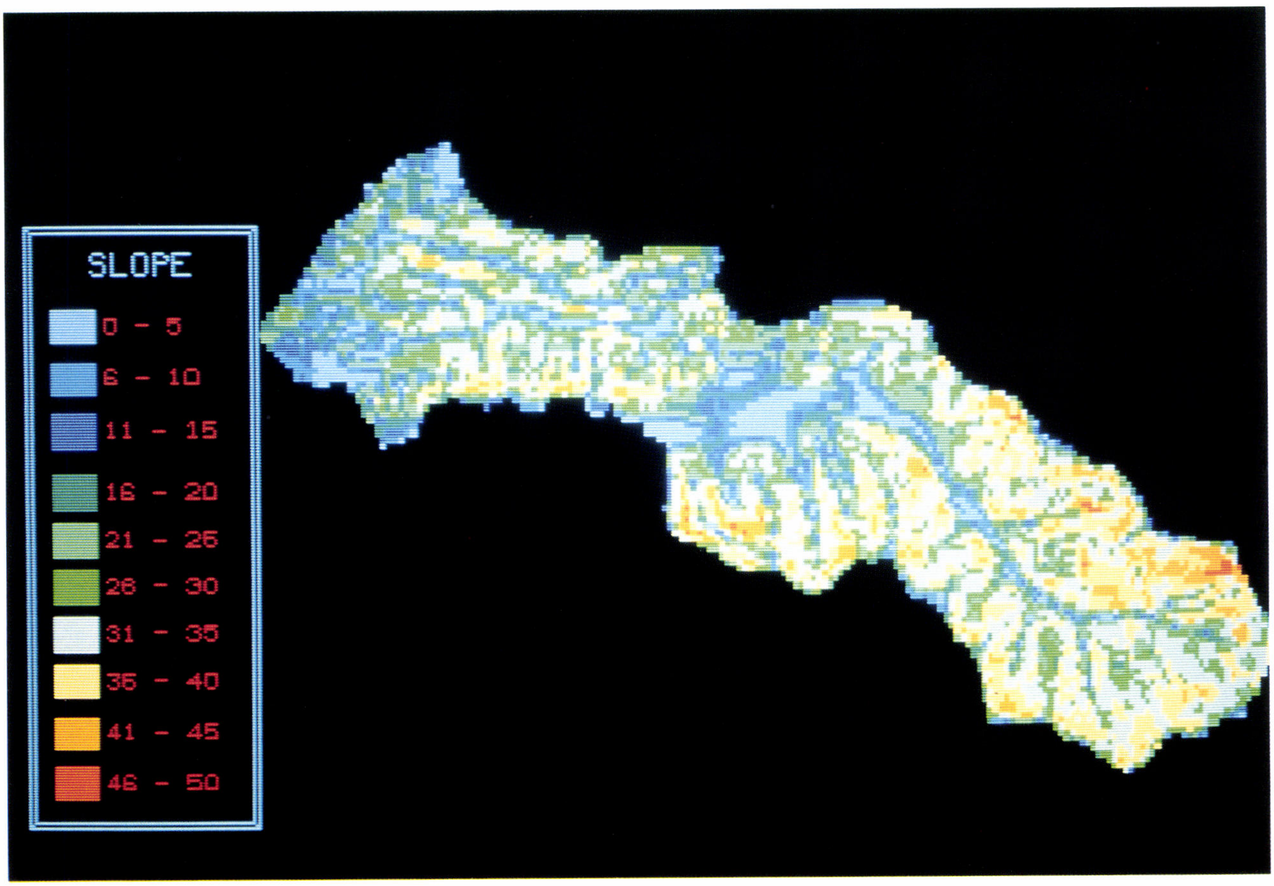

Fig. 2 Distribution of the slope degrees of small wasted area as an object.
The upper indicates north.

azimuth angle, and the distance from the forest road and river system were calculated in every raster. The average slope inclination angle is the average value of the total sum of the rasters divided by the number of rasters. The azimuth is the azimuth angle showing the mode. Fig. 2 shows the slope distribution. The distance from the ridge and water system was calculated by multiplying each of their buffers, centering around the ridge and water system and including 61% over the raster of the sub-compartment.

On the other hand, the distance from the forest road showing the geographic condition, was obtained by multiplying the buffer every 100m. By using these values, the 4 forest functions mentioned before were classified according to the standard shown below.

① Timber production forest･･･Making the man-made forest, a site class is above the III rd class. Locality class is classified into 3 groups. The 1st locality class is within 300 m of the forest road, the 2nd locality is 300～500m and the 3rd locality is above 500m. SHIRAISHI (1994) reported that the clear cutting of artificial stands was great only within one or two hundred meters widths along the forest roads. So, locality class is above the Ist class. And the timber production forest must have the advantageous point that the cutting area is to be available and if the cutting is done, it is desirable for the trees to reach a growth of more than 20m in height and to be 60 years old. So, locality class can be placed in I class and site class can be placed above the III rd class (Niigata Prefecture 1980).

② Erosion protection forest･･･Within 100m of the ridge, the average slope inclination angle is above 30. The Maebashi Regional Forestry Offices (1993b) showed that the clear and shelterwood system permitted cutting below 30°. So, above 30°is a no cutting area.

③ Water source conservation forest･･･A: If it is located within 100m of the water system, or the average slope inclination angle is below 30°and the stand volume per ha is above 150 m^3, even if it is separated from the water system above 100 m, it was classified into the water source conservation forest suitable for selective cutting. B: Reserved water source protection forest･･･If the stand volume is below 150 m^3 in the stand mentioned above, it is designated as the reserved type water source conservation forest (Maebashi Regional Forestry Office 1993b).

④ Public health and recreational forest････It is within 50 m of the water system and the average slope inclination angle is below 30°. Above 30°is not suitable for a public health and recreational forest.

It was decided that they would be classified into the

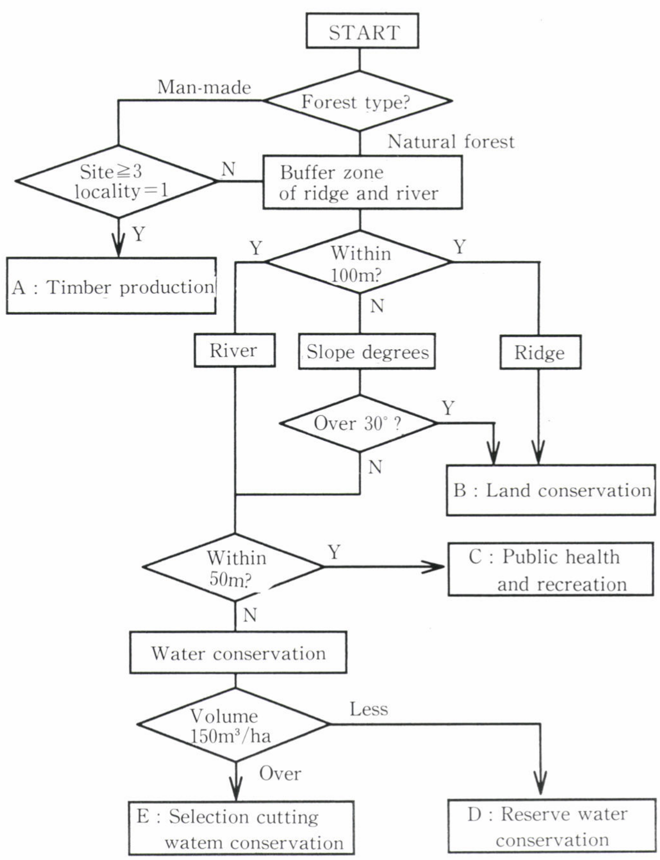

Fig. 3 Flowchart of forest classification based on function by using a decision tree method.

forest function types with 4 functions and 5 kinds as shown above. The philosophy of the public health and recreation forest is that the natural forest should be located close to the forest road and that people can play with and in the water there. Because the river flows directly by the forestry road in the 59th compartment subject area, only the distance from the water system was picked up.

RESULT

By using the decision tree method shown in Fig.3, function evaluation classification in each sub-compartment was carried out. In each sub-compartment, the rasters of 20 m×20m were generated, and then, by using the information of each raster, a topographical analysis of each sub-compartment and an analysis of geographical conditions, was executed. In the decision tree method shown in Fig.3, based on the standard mentioned above, the raster was classified into 4 forest functions. The raster is classified into either of the functions by any means.

On the other hand, the area results by each function, are shown in Table 3 and Fig. 4. The largest area is the erosion protection forest, and it occupies about 54% of the total area. The reserved type water source conservation forest is the second. It supports the notion that there are many steep slope areas in the 59 compartment. In addition, out of the production forests, 24% is production forest, and therefore, it shows that there are many sub-compartments

Table 3 Classification of forest activity

Forest activity	Area (ha)	Number of sub-com.
Timber production	20.61	10
Land conservation	143.16	27
Recreation	10.82	7
Water conservation (Selection cutting)	14.99	9
Water conservation (Reserve)	74.03	22

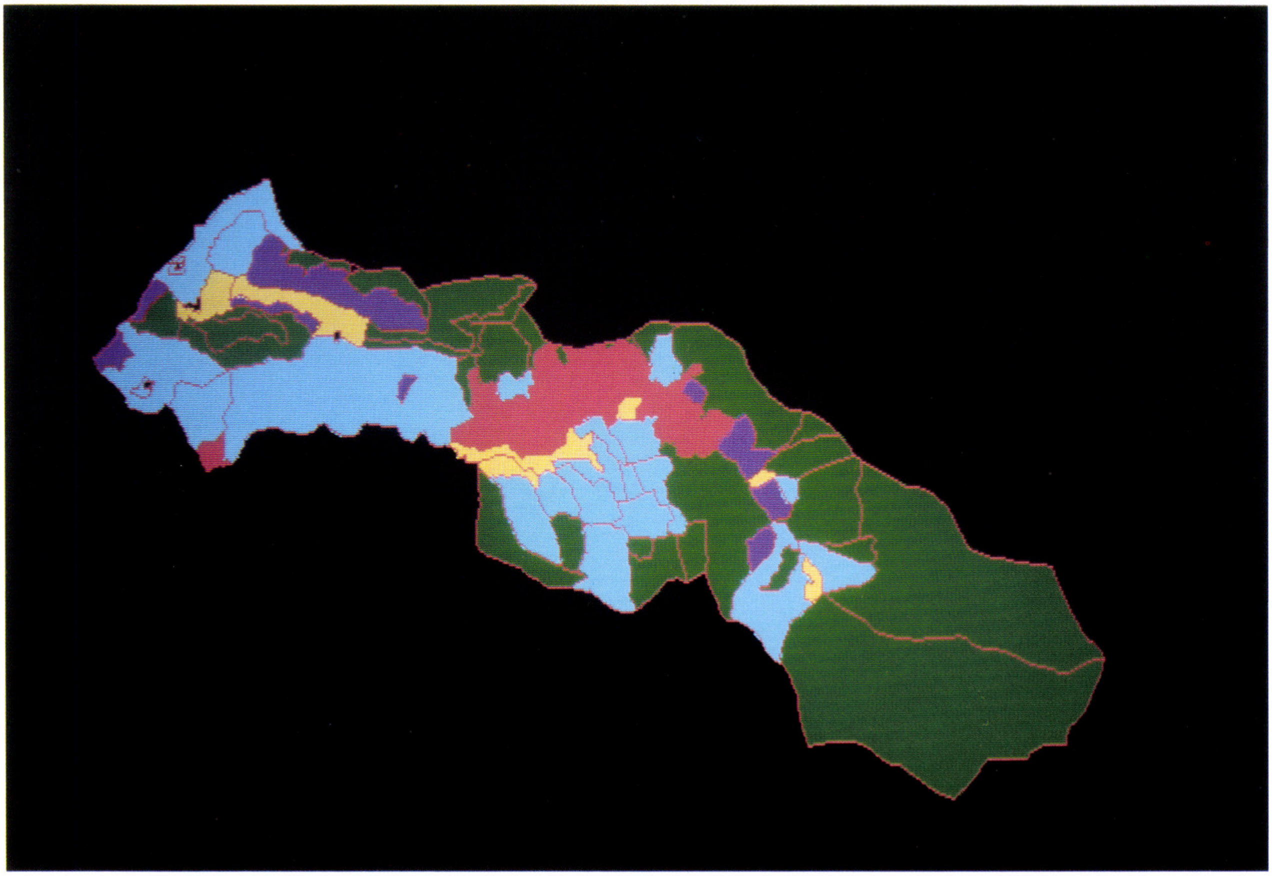

Fig. 4 Distribution of forest activity classification of sub-compartment.
Green ; Land conservation forest, Light blue ; Reserved water conservation forest, Purple ; Selection cutting water conservation forest, Red ; Timber production forest, Yellow ; Public health and recreational forest
The upper indicates north.

with a relatively good condition.

DISCUSSION

In the forests, the various kinds of functions exist in combination. By using the score evaluation method, ZHENG and NAGUMO (1994), evaluate the various kinds of functions, and then, by using the most effective function, evaluate the function in acertain sub-compartment. However, if the aim is to quantify the various functions of the forest, many items have to be assumed. At the same time, in an actual work activity, because the same work activity is conducted in a certain area, for example, when the cutting is done in a timber production function forest, it will be carried out in a sub-compartment unit. After all, its sub-compartment has to be regarded as having the same forest function. On the other hand, generally, the forest administration standard has been conventionally established in the national forests considering the topographical factor (Maebashi Regional Forestry Office 1993a). As an example, forestation should not be carried out above a certain altitude, and the cutting should not be done above a certain slope angle, etc. Accordingly, in order to establish a management plan for the sub-compartment, a work activity unit, it is rather more practical that the treatment standard of the sub-compartment would be better classified according to the function, its sub-compartment taking precedence, based on the forest data base and the topographical factor in its sub-compartment. In this report, because the rasters of each sub-compartment can be classified into either of the functions through the decision tree method utilizing GIS, by using an average value or standard value of the rasters, it demonstrates a system of classifying them into the forest functions divided beforehand. Although the rasters can not be classified by such a unified standard through a manual operation, it is easily feasible by utilizing GIS. If a standard value of each forest function is changed, the classification and area calculation corresponding to it, can be also be done easily.

The forest functions used this time are, the kinds of trees, the slope inclination angle, and the distance from the forest road and dale. So, as to standardize such factors, by executing the cluster analysis after giving the scores to each factor, its typology was examined. As a consequence (as shown in Table 2), a separation of functions could be recognized. The standards shown in Table-1 are also an important factor for the actual work activity in the present national forest. As already shown, these are the factors that can be analyzed by GIS. Accordingly, if the classification of the forest functions is possible only by using such factors, it is thought that a labor saving in the compilation might be achieved during the planingstage. KUMAGAI (1989) points out that the expected function of the forest is different in order of a favorable selection depending upon each person. It is thought that the forest activity plan will advance towards establishment by receiving public consent through the action of being asked a social request. However, as far as the forest exist in the mountainous site, needless to say, a treatment considering the topographical factors is required. Based on the technologies accumulated so far, it is thought that the establishment of the standards shown up to now based upon topographycal factors, and the distance from the ridge and water system, is also very important.

On the other hand, because the various topographical factors exist in a combined state if the sub-compartment becomes large, the same treatment can not be done even within the same sub-compartment. When the inclination sections by each raster unit are examined by making the largest sub-compartment in the small water shed as the subject, it is found that they distribute very widely from less than 5°, to 45°. In the forest data base, as only the average inclination degree is usually recorded, it is not so useful for the actual work activity plan. By utilizing GIS, it is a big advantage as well as that more detailed information concerning topography can easily be obtained.

As explained above, it can be said that the forest function classification system using GIS is effective in practical application.

CONCLUSIONS

In Japan, the Forest Law has been revised, and a new forestry planning system designating the watershed area as a unit, was inaugurated. In order to establish this plan, a united forest function evaluation is required. Because there are many uncertain factors, the forest function evaluation is very difficult. Moreover, supposing a case where a large area such as a watershed is designated as the subject, dividing the complicated forest function is impossible in practical application. Therefore, after treating the factors mechanically as much as possible by utilizing GIS, a method by which a function evaluation is possible, namely, a method to divide the functions by inputting the inclination angle, and the distance from the forest road, ridge and water system as a main body, is developed. By using GIS effectively, it could be shown that the function dividing above a certain area, can be easily executed.

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Forest Activity Classification System of Small Watershed Area using GIS (II)

—Forest activity classification system in case of raster—

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ABSTRACT

A method to evaluate the forest function in a small watershed area in every raster was shown. Concurrently, the influence of the raster size on forest function evaluation was analyzed by changing the raster size (10m, 20m, 50m). As a result of comparison with function classification in a small sub-compartment unit, from conversion accuracy of vector information and presumed result of inclination angle, it was considered that a raster size of 10m×10m is optimum for forest function evaluation in a small watershed area. As for comparison of a forest in a small sub-compartmentunit and raster unit, the areas for the timber production, public health and recreation, and selection cutting water source conservation functions increased. Conversely, a decrease in the areas for erosion production and reserved water source conservation functions was recognized.

Keyword: forest activity, raster, GIS

INTRODUCTION

In the preceding analysis, a system to evaluate forest function in a small sub-compartment unit used most widely in actual work activities was evaluated. The topographic and site merit information used for the function evaluation were calculated from DTM, and then these were averaged in each small sub-compartment and utilized. However, in a small sub-compartment, various topographic and site merit information is contained and only a standardized evaluation can be performed using the averaged information. Accordingly, by using GIS (Terra Soft), an analytical method making the best of the distinctive features of the raster type data was investigated. The raster data is a advantaged model. It has a simple structure and overlay operations are easily and efficiently implemented. (ARONOFF 1989) Accordingly, by generating the rasters, and furthermore by having the individual rasters contain information on topography, site merit and stand a method to evaluate forest function was investigated.

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SMALL WATERSHED AREA AS AN OBJECT

As in the preceding report,the 59th forest compartment (246ha) of the Nioujidake Group, under the jurisdiction of the Shibata National Forestry Bureau, was made a watershed area and used as the object of this study. The Mizutanisawa flows in the approximate center of this watershed area. About 1/3 of the stand is composed of a man-made sugi (*Cryptomeria Japonica* D.DON) forest, and the balance is composed of natural forest. As for a status of the natural forest, downstream of the Mizutanisawa, many trees with a relatively small diameter, such as the konara (*Quercus serrata* THUNB.) , kuri (*Castanea crenata* SIEB. et ZUC.), buna (*Fagus crenata* BLUME) and so forth are distributed, while the upstream area is plotted by trees with a large diameter, such as tochinoki (*Aesulus turbinata* BLUME), itayakaede (*Acer mono* MAXIM.) and so forth. Man-made sugi forest is relatively good in terms of growth, and consequently magnificent 80 years old forest still remains. In addition, because this watershed area is located at a site about 10km from Shibata City and is adjacent to the Tainai-Niouji Prefectural Natural Park, its utilization as a natural recreational forest can be expected.

METHODS

As for forest function, according to the standards shown in the preceding report, by using (Terra Soft), a function evaluation through raster was investigated. The map information input into GIS are forest sub-compartment, contour line, forest road, ridge and water system. In addition, the stand information can be obtained by superimposing the rasters on the sub-compartments, and the inclination angle is calculated by each raster size (Essential Planning Systems Limited 1992). Forest activity is evaluated using the raster information. The results are investigated, based on comparison with forest function division by preceding reports, and the difference in raster size. The flow of the analysis and investigation are shown in Fig. 1.

Investigation of Raster Size

An analysis can be done by setting the raster size freely in case of GIS. However, in a topographic analysis, raster size will be an important point at issue. Although it is anticipated that the topographic data can be expressed in more detail with a smaller raster size, when the altitude interval of the input contour line is considered, making the size smaller is not necessarily connected to an improvement in accuracy.

In this report, raster of 20m×20m utilized for calculating the average inclination angle in No. I report was set as a standard, with a smaller raster (10m×10m) and a larger raster (50m×50m) also being set. The forest function evaluation was carried out using these 3 sizes, and an optimum raster size investigated.

Forest Function Evaluation by Raster

A forest function was evaluated according to the standards shown in the preceding report.

1. Timber production forest - Man-made forest with 1st class of site merit and above 3rd class of site class.
2. Erosion protection forest - Natural forest and man-made forest whose distance from the ridge is 100m and whose inclination angle is greater than 30°, or whose inclination angle is greater than 30°.
3. Water source conservation forest - Natural forest and man-made forest whose distance from the water system is 100m, or whose distance from the ridge or water system is within 100m, and whose inclination angle is less than 30°, or with an inclination angle is less than 30°. Stands more than 50m from the water system, were classified into 2 types as described below.

3-A) Reserved water source conservation forest - In the stand mentioned above, the stand volume per ha is less than 150m3.

3-B) Selection cutting water source conservation forest - In the stand mentioned above, the stand volume is greater than 150m^3.

4. Public health and recreational forest - Natural forest and man-made forest whose distance from the water system is within 100m, or whose distance from the ridge or water system is within 100m, and inclination angle is less than 30°, or whose inclination angle is less than 30°. Of these, the distance of the stand from the water system is within 50m.

As mentioned above, through raster analysis, forest function was classified into 4 functions and 5 kinds.

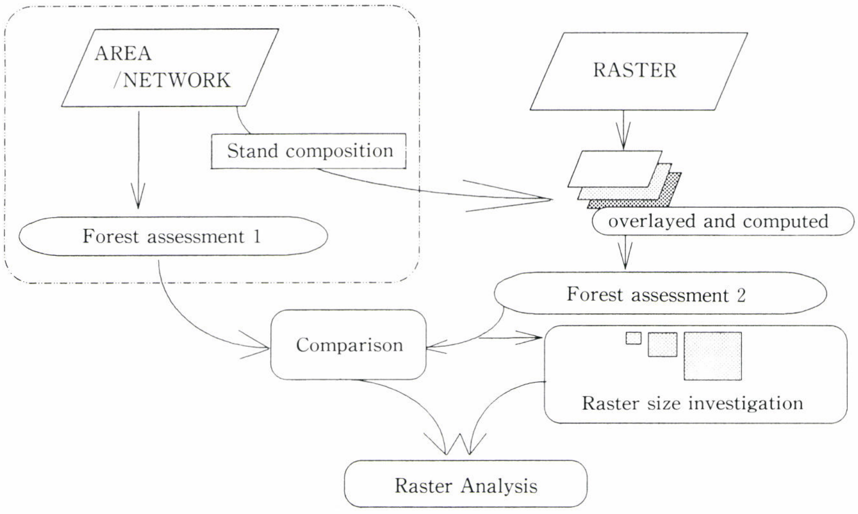


Fig. 1 Analysis flow.

RESULTS

Results of Forest Function Evaluation by Each Raster Size

According to the standards shown above, forest functions in each raster size were evaluated and the results shown in Table 1 and Fig. 2. In case of the erosion protection function, together with a larger raster size, classified areas decrease, although in the other functions it was recognized that coupled with size the areas tended to be reduced. The public health and recreational forest function showed the largest fluctuation in raster size, and in a size interval from 10m to 50m, area increased by 65%. In addition, in the erosion protection function 26% of area reduction was recognized even within the same size.

Comparison of Forest Function Division with Each Small Sub-compartment Unit

The area increase/decrease ratio to the function evaluation results by each small sub-compartment is shown in Table 2. When a respective function division is compared, the areas in the timber production function, public health and recreational function, and selection cutting water source conservation function increased, and on the contrary, a decrease of areas in the erosion protection function and the reserved water source conservation function was recognized. In the public health and recreational function, an increase from about 250% to 470% was recognized, and in the reserved water source function, a decrease from 35% to 43% was recognized.

Table 1 Classification of forest activity

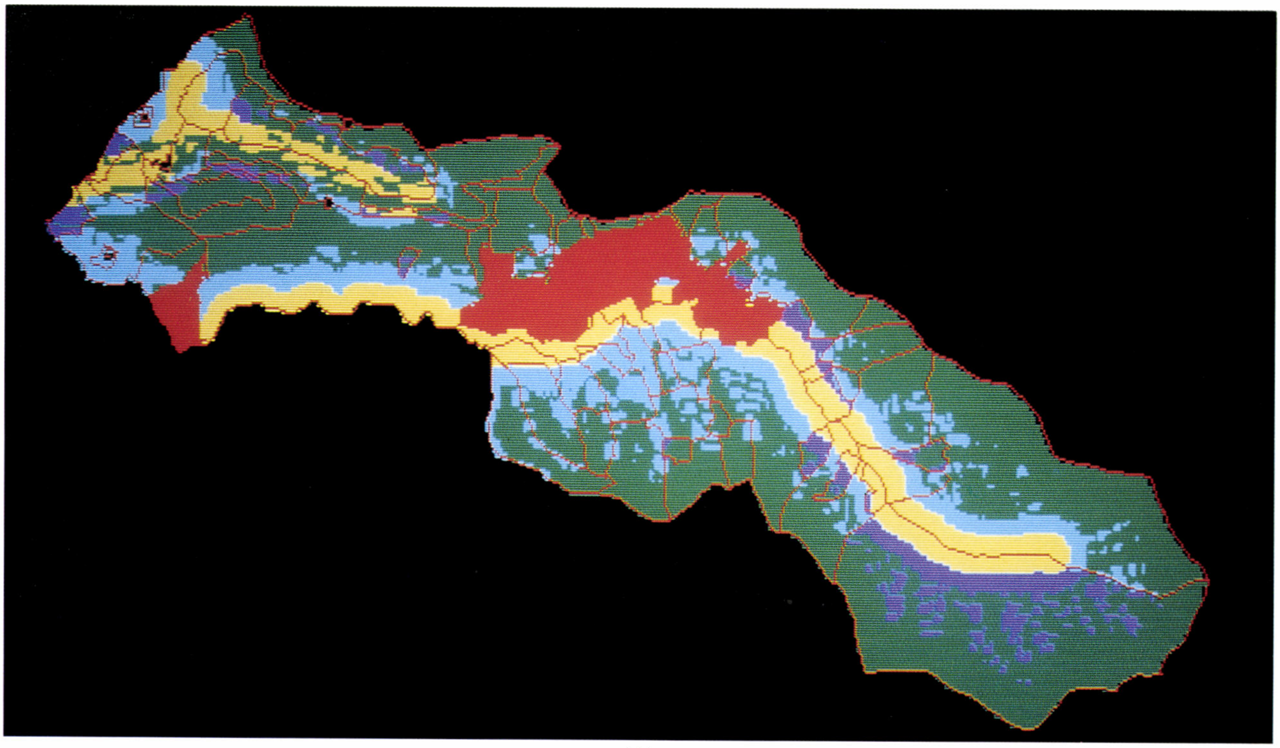
unit: (ha)

Forest activity	size 10m	size 20m	size 50m
Timber production	21.62	22.32	24.25
Land conservation	147.95	135.32	110.00
Recreation	37.36	43.48	61.75
Water conservation (Selection cutting)	14.87	16.56	18.75
Water conservation (Reserve)	41.88	46.04	48.50
non-function	0.42	0.40	0.50

Table 2 Comparison result of classification

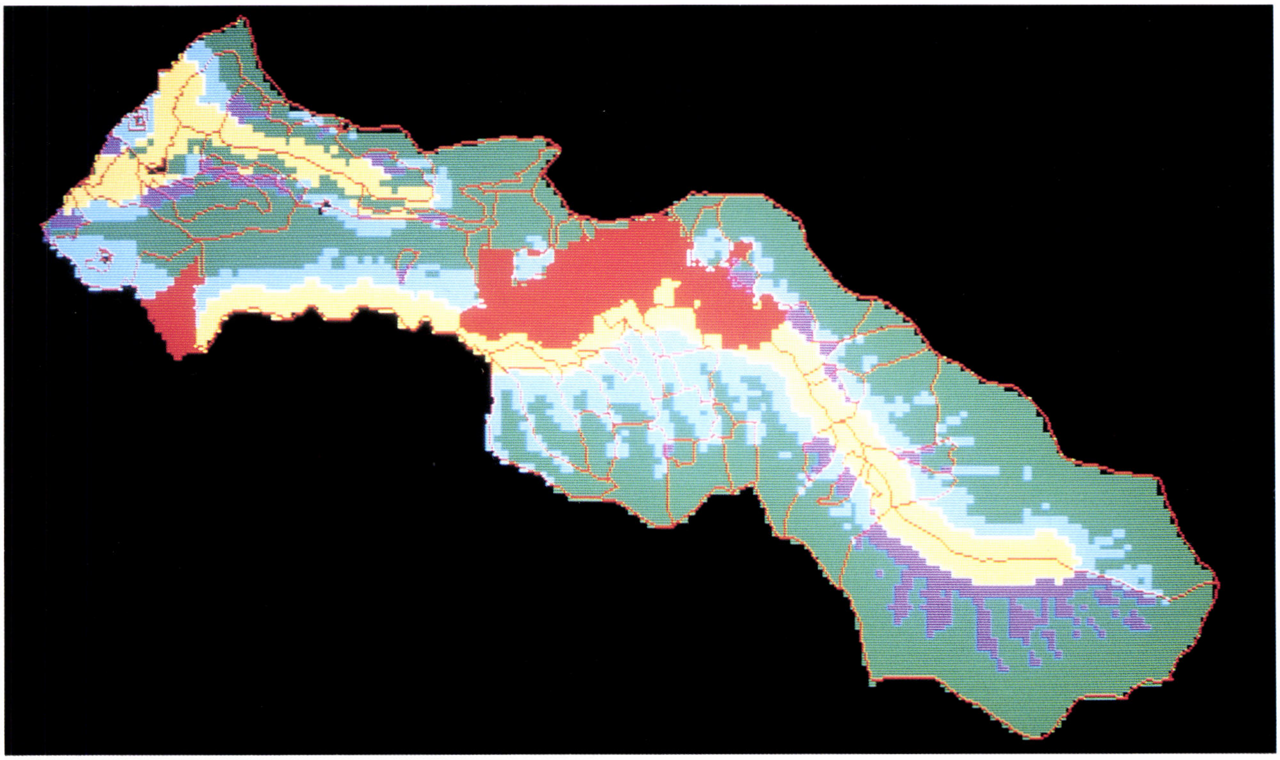
Forest activity	Result of (I)* (ha)	Ratio of increase and decrease (%)		
	area	size 10m	size 20m	size 50m
Timber production	20.61	4.90	8.30	17.66
Land conservation	143.16	3.35	-5.48	-23.16
Recreation	10.82	245.29	301.85	470.70
Water conservation (Selection cutting)	14.99	-0.80	10.47	25.08
Water conservation (Reserve)	74.03	-43.43	-37.81	-34.49

* ABE et al. (1995)

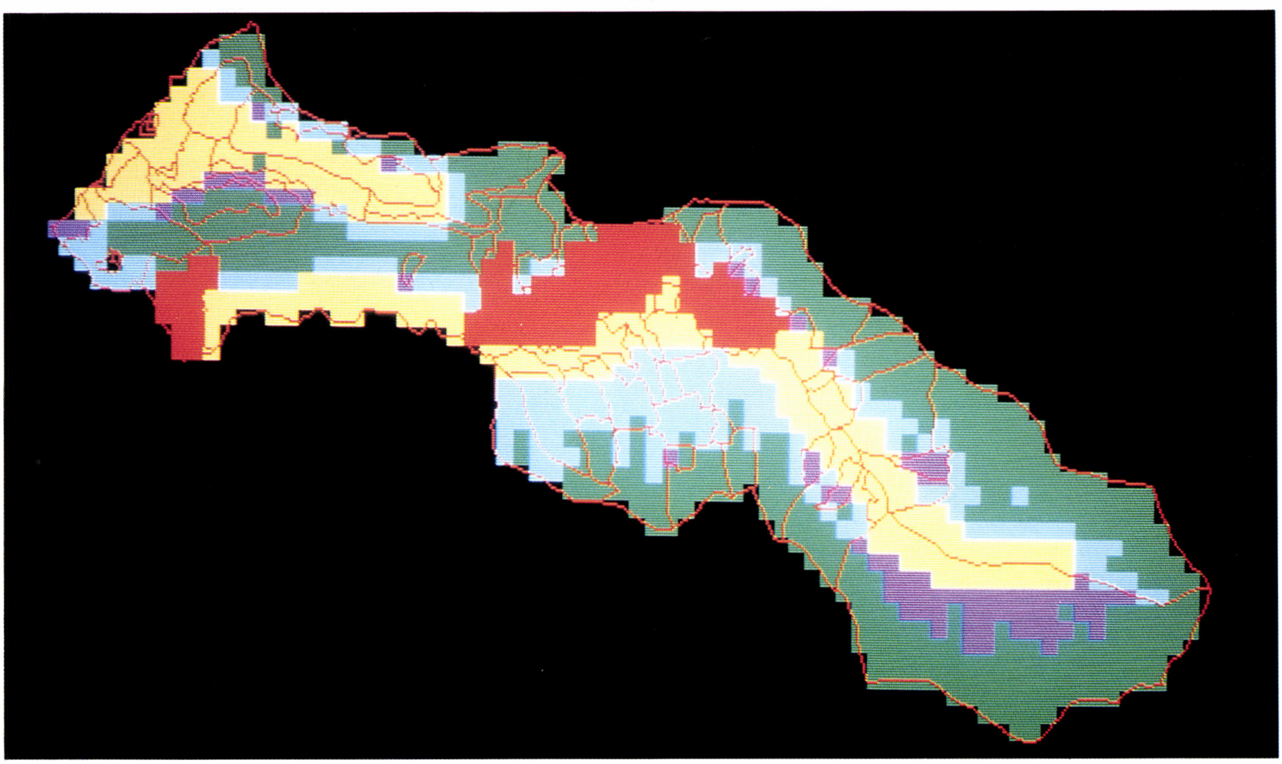


(A)

Fig. 2 Distribution of forest activity classification by each raster size.

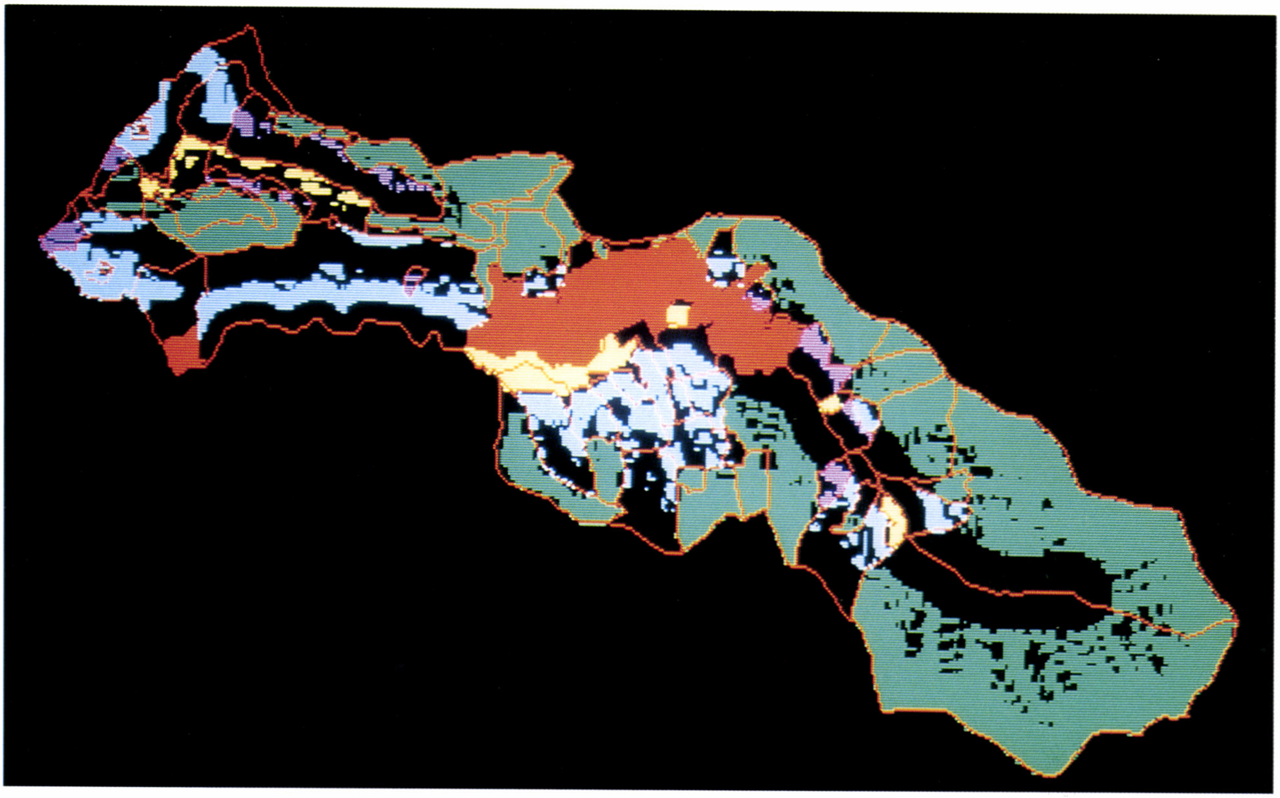


(B)

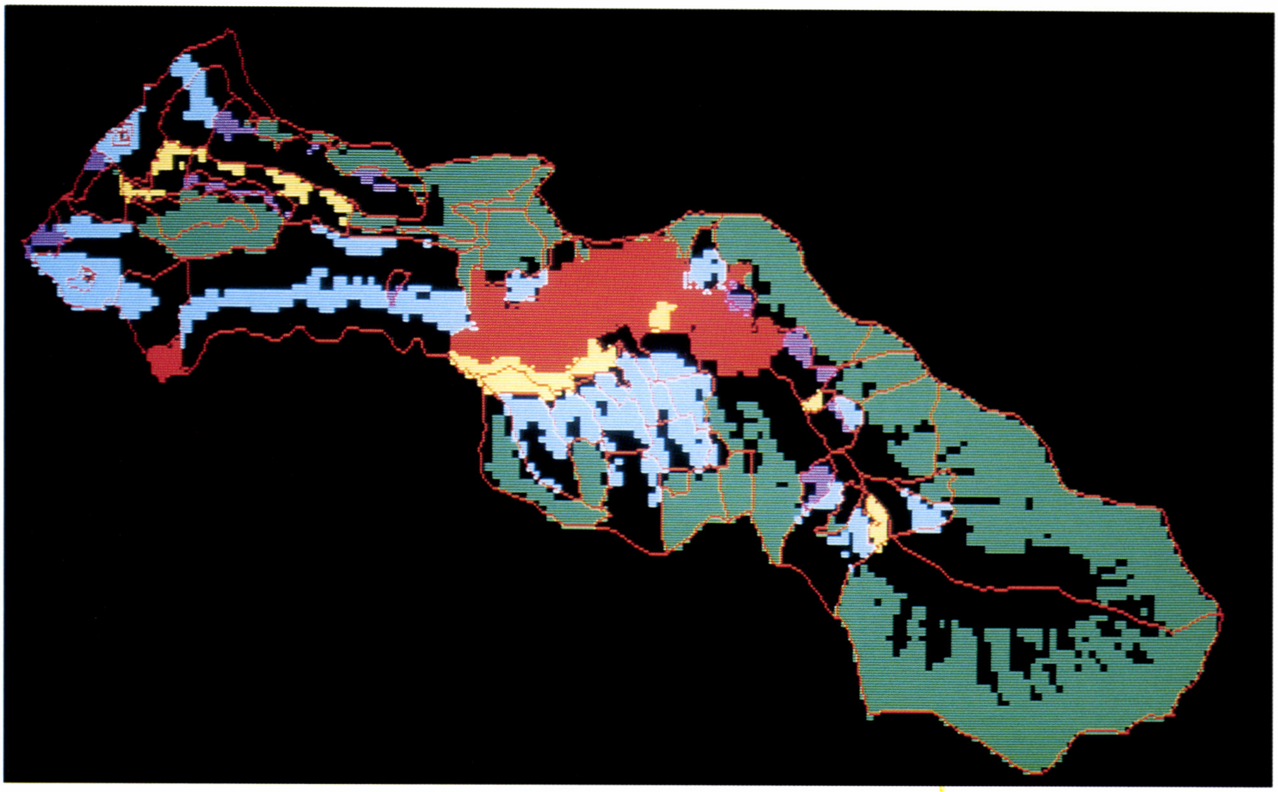


(C)

Fig. 2 Distribution of forest activity classification by each raster size.
(A) ; 10m×10m, (B) ; 20m×20m,(C) ; 50m×50m
Green ; Erosion protection forest, Light blue ; Reserved water source conservation forest, Purple ; Selection cutting water source conservation forest, Red ; Timber protection forest, Yellow ; Public and recreation forest
The upper indicates north.

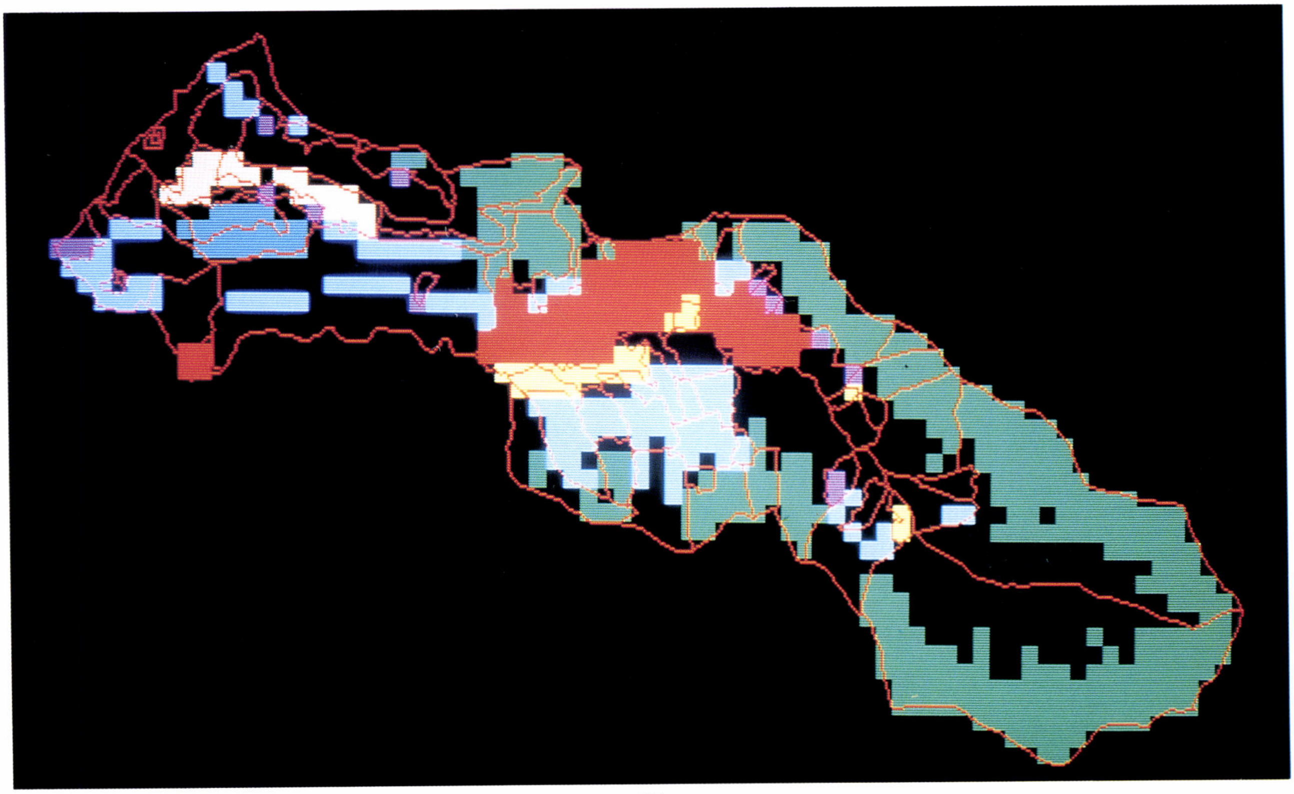


(A)



(B)

Fig. 3 Distribution of comparison with forest activity by each sub-compartment unit.



(C)

Fig. 3 Distribution of comparison with forest activity by each sub-compartment unit.
(A) ; 10m×10m, (B) ; 20m×20m,(C) ; 50m×50m
Green ; Erosion protection forest, Light blue ; Reserved water source conservation forest, Purple ; Selection cutting water source conservation forest, Red ; Timber protection forest, Yellow ; Public and recreation forest
The upper indicates north.

Table 3 Overlaid area-func with raster-func

unit: %

Forest activity	size 10m	size 20m	size 50m
Timber production	90.47	89.61	85.57
Land conservation	72.06	74.58	80.00
Recreation	16.19	16.38	17.00
Water conservation (Selection cutting)	29.12	26.33	18.67
Water conservation (Reserve)	62.30	62.38	57.73

The forest function evaluation map using the raster was laid on the function evaluation map by sub-compartment, and the parts where both functions superimpose and match were picked out and subsequently shown in Fig. 3. The area ratio superposed with the function division by each small sub-compartment unit is shown in Table 3. Although a little variation was recognized in the raster sizes, the area from 85% to 90% in the timber production function was superposed, and the area from about 55% to 80% was superposed in the erosion protection forest and the reserved water source conservation forest. Conversely, in the case of the public health and recreational forest and the selection cutting water source conservation forest, only the area from about 16% to 30% could be superposed compared with other functions, a large difference being seen in the area of function evaluation by 2 methods.

Influence of Raster Size

In the preceding analysis, a fairly big fluctuation was recognized between the function evaluation results by each small sub-compartment unit and the forest function evaluation results by the rasters, and in addition between the raster sizes. It is presumed that this is due to the magnitude of raster sizes.

The site merit information used in this report, namely information on the forest roads, ridges, water systems and stands was obtained by converting vector data to raster data. By using a small sub-compartment, the error in the case of raster conversion was shown in Table 4 using verification statistics. Along with smaller raster size, it is recognized that a statistic approximates to 0, and conver-

Table 4 Accuracy overlaid vector with raster

	size 10m	size 20m	size 50m
max error (ha)	0.09	0.17	0.57
min error (ha)	0	0	0.01
statistic	0.028	0.124	2.451

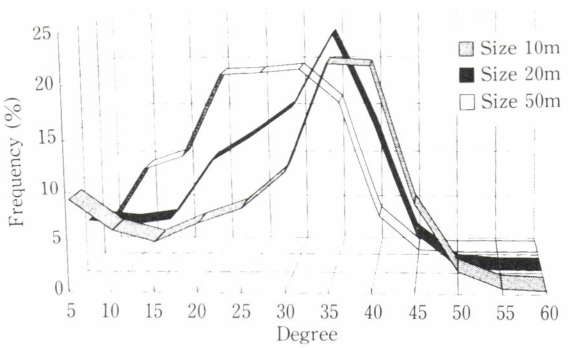


Fig. 4 Frequency distribution for slope each raster size.

sion error from the vector data become smaller. Thus, conversion of the vector data, together with a smaller raster size will increase accuracy.

Inclination angle, topographic information, and distribution of inclination angle by each raster size appears in Fig. 4. Accompanied by an increase in raster size, it is seen that distribution of the inclination angle tends to be shifted towards a flatter slope direction. The elevation value is thinned out in a constant ratio when the values are distributed at random, it is then removed and smoothed so that a large portion of slope variation is given for two points. It is thought that the variation occurs because slope based on height difference for two points is averaged and gentled (KITAGAWA 1991). By χ^2 verification, it was signified that the distributions of inclination angle between the various raster sizes are different $\{\chi^2=455.886>\chi^2_0(\phi=22,\alpha=0.05)\}$. In function classification in this report, inclination angle is an important factor. It was presumed that a cause which exerted a substantial influence on the classification results was the fluctuation of the distribution on inclination angle by each raster size.

DISCUSSION

Comparison of Forest Function Evaluation by Small Sub-compartment Unit and Raster Unit

As shown in Table 2 and Table 3, the areas of the evaluated forest function division varied greatly depending on the raster sizes. Of these, area differences of a maximum of 4.7 times especially in the public health and recreational function, and of a maximum of 0.4 times in the selection cutting water source conservation function were recognized. In addition, from Fig. 3 the plural function area seen in 1 small sub-compartment, and, consequently, a distribution difference from the evaluation results by each sub-compartment unit can be understood. These are different from the function evaluation by each small sub-compartment unit which adopted the average inclination angle, and are the results expressing in detail topographic information using rasters. Apart from the standardized function evaluation by each small sub-compartment, it is shown that function evaluation corresponding to a topography is possible after considering the information of the stand, site merit and topography.

Function Evaluation by Raster

In the function evaluation by each small sub-compartment unit and the function evaluation by raster, the evaluation results were different depending on the functions, and in addition, coupled with an increase in raster size, the areas of function evaluation division by raster increased and decreased. The functions with little variation in area are the timber production forest and selection cutting water source conservation function. These functions are strongly affected by the factors except for the topographic factors in the function classification process. Therefore, an increase/decrease difference compared with the function evaluation by each small sub-compartment unit will become minimum in a 10m size raster with little conversion error in vector data. As for the timber productin function, it can be judged that distribution will not change from Fig. 3. As for the erosion protection function, the fact that there was a significant difference between function evaluation by each small sub-compartment unit and vector information in function evaluation by raster, may be given as a reason. Since the degree of dependence on the vector is high in the case of the 3 functions mentioned above, it is thought that many vector conversion errors are contained in the variations between rasters. On the contrary, in the public health and recreational function and reserved water source conservation function, because the classification is performed depending on topographic data rather than vector data, the area difference from the evaluation by each small sub-compartment unit increased. Therefore, it is considered that conversion of the vector data has an important significance in function evaluation by raster unit.

As for the variations between rasters, in addition to the conversion errors of vector data, the inclination angle distribution by the raster sizes also exerts an influence. This affects each function, except the timber production function. In the erosion protection function, classified as having an inclination angle exceeding 30°, a division area decreases accompanied by an increased size, and it increases in the other functions classified as less than 30°. This is the same tendency shown by inclination distribution by raster size (Fig. 4). This means that forest function evaluation corresponding to topography is possible using the detailed raster type data.

Optimum Raster Size in Function Evaluation

Based on the function evaluation results by the raster sizes, it was considered that an increase/decrease of each function division area is caused by a loss of vector information (Table 4) by a change of sizes, as well as the influence of increasing distribution of the flatter slopes (Fig. 4) proportional to the raster sizes. Accordingly, the raster size will be a big point at issue in function evaluation. Concerning the conversion accuracy of vector information, a convenient rule of thumb, based on statistical sampling theory, is to use a raster cell half the length (or one-fourth the area) of the smallest feature one wishes to record. A more conservative suggestion would be to use a raster size one-third or one-fourth the length of the smallest desired feature (STAR and ESTES 1990). As for the optimum raster size for function evaluation, based on the conversion accuracy of vector information, estimated results of inclination angle and so on, it was considered that a size of 10m×10m was suitable for forest function evaluation corresponding to topography at this stage.

CONCLUSIONS

The purpose of this report was to evaluate forest function by raster unit. When forest function in one small sub-compartment was evaluated by raster unit, it separated into many forest functions. This shows that a function evaluation corresponding to more detailed topography which could not be expressed by a small sub-compartment unit is possible. In future, it is necessary to investigate further methods of deciding raster size corresponding to the various topographies.

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Detecting Changes in Forest Vegetation using Multitemporal Landsat TM Data

—A case study in the Shibata Forest, Niigata Prefecture—

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ABSTRACT

This paper outlines three change detection methods, i.e., (1) direct multidate classification (MDC), (2) 12-dimensional multitemporal principal component (MPC) and (3) 2-dimensional multitemporal principal component, to detect specific changes in forest cover due to new artificial regeneration, natural growth and forest cutting. Of these 3 techniques, the MDC technique which simply classifies the multidate bands directly consistently provided better delineation of forest change. In the selection of band dimensionality, the 12-dimensional MPC is the most effective. Not only this technique can reduce the dimensionality of the original data, but also effectively picks up the change of interest and provides nearly as the first technique. For all date-pairs (3- to 7-year intervals) the changes due to forest cutting and new artificial regeneration and tree height growth of young plantations were detected; however, the height growth of the larger trees, i.e., S1-S2/3, P1-P2 and P2-P3, could not be detected. As indicated in this study, as the time interval increases, the ability of multidate TM to detect forest cover change increases. Within the young forest plantation, differences in the density of under-story vegetation of Japanese cedar seedlings sometimes led to misclassification.

Keyword: change detection, forest cover change, direct multidate classification, 12- and 2-dimensional multitemporal principal components.

INTRODUCTION

The increasing number of new and improved sensors with finer resolution capabilities of remotely-sensed data acquired by land-observation satellites, such as Landsat, SPOT, ERS-1, RADARSAT and JERS-1, has been accompanied by increasing interest in evaluating their capability to delineate forest cover, particularly in documenting the rate and distribution of forest cover change. Monitoring forest change using conventional methods is often inconsistent among analysts because these methods are based solely on the interpreter's skill. Although there have been numerous studies using remotely-sensed data for detecting land cover changes (e.g., ADENIYI 1985; ALWASHE and BOKHARI 1993; AWAYA et al. 1994; EKSTRAND 1990; FORAN 1987; FUNG 1990; HALLUM 1993; JENSEN et al. 1993; NELSON 1983; PYLON et al. 1988; and WEISMILLER et al. 1977), the change detection of detailed forest classes has not been fully documented. This paper emphasizes upon strategies for identifying appropriate change detection logic and detecting forest cover changes, particularly changes due to natural growth, artificial regeneration and forest cutting, between two points in time. A more sophisticated change detection method to diagnose forest growth stages based on an image data base consisting of multitemporal satellite data has been described by SENOO (1994).

Our earlier study (JAYA and KOBAYASHI 1995) showed that detailed forest cover types, such as hardwoods, bush/shrub, mixed forest, tree-height classes of Japanese cedar and pine etc., were reliably classified using single-date TM data. From the monitoring point of view, multidate TM data should be useful for detecting forest changes between two or more dates. Since it would be more desirable for implementation reasons, this study applied a simpler approach without employing atmospheric and topographic

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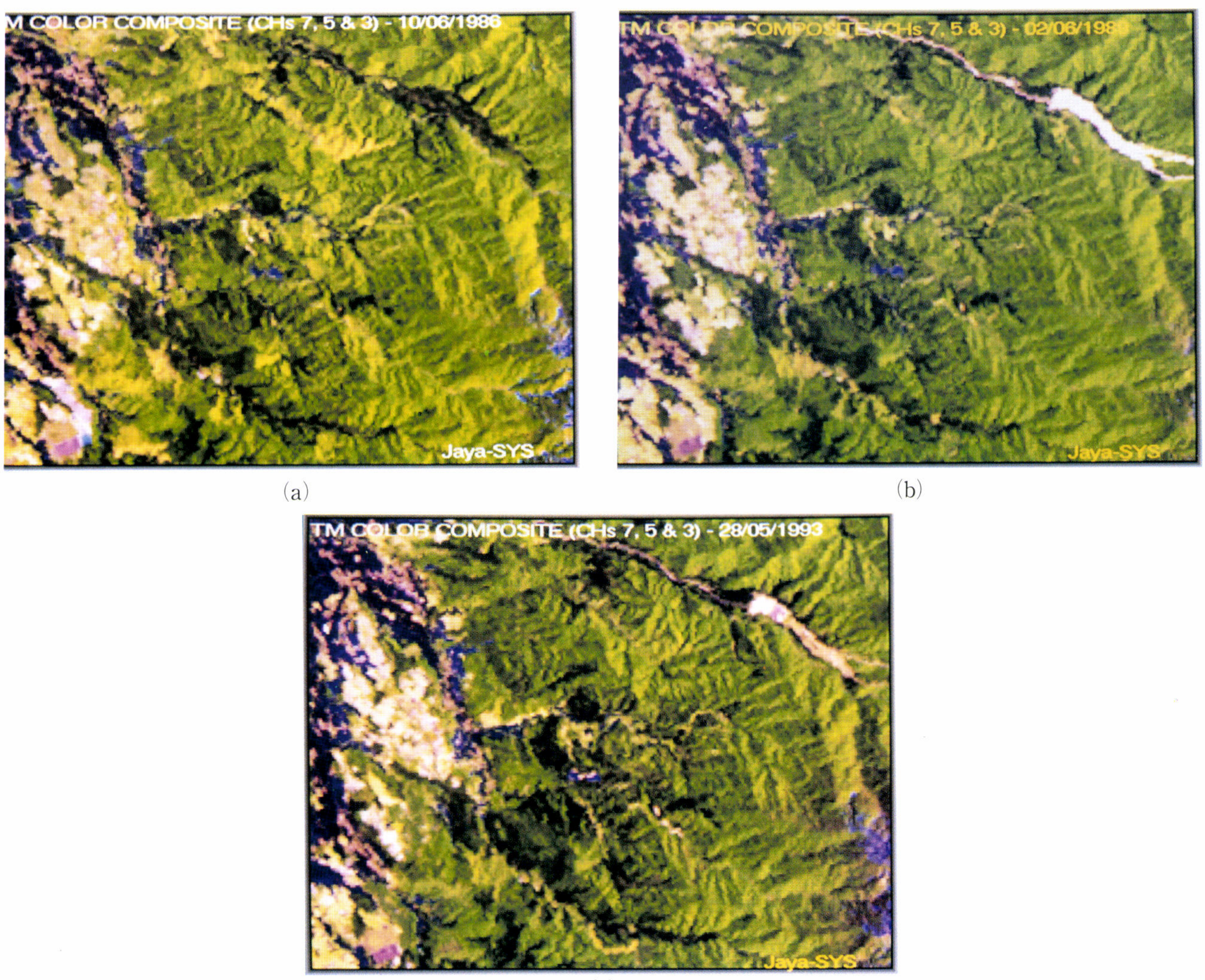
correction. More complex methods usually require more carefully drawn data inputs together with more thorough user understanding to achieve acceptable results.

The objective of this study is to evaluate how well forest cover changes could be detected between certain dates with TM data using computer-assisted analysis techniques. A quantitative approach was selected to avoid a completely subjective assessment. An additional objective of this study is to evaluate the three change detection methods applied here.

STUDY SITE AND IMAGE PROCESSING

Study Site

The main study site of the forest change detection was in Shibata, Niigata Prefecture, between latitudes 37°52' and 37°58' N and longitudes 139°22' and 139°31' E. This area was chosen because it contains a variety of forest cover conditions such as clearcuts and various stages of growth following artificial regeneration of both Japanese cedar and pine. Further information concerning the site, single-date category description, and its classification results including the evaluation of the forest class separability can be found in our previous study (JAYA and KOBAYASHI 1995).



(a) (b) (c)

Fig. 1 Portion of the Landsat TM color composite images (band 7 as red, band 5 as green and band 3 as blue) over the study area acquired on (a) 10 June 1986, (b) 2 June 1989 and (c) 28 May 1993. The areas shown are approximately 7.3 km × 5.7 km.

Image and Supporting Data

Multidate Landsat TM images acquired on 10 June 1986, 2 June 1989, and 28 May 1993 (Fig. 1) were used for analysis, assuming no atmospheric and/or phenological differences occurred between these dates. No clouds were present at each date at the time of overpass. The availability of aerial photographs obtained in 1988, 1990 and 1993, 1: 25,000 scale topographic maps, and other ancillary data, coupled with ground observation data allowed the authors to perform this change detection study. The TM 10 June 1986 data were supported by 1:20,000 forest compartment maps and forest inventory documents containing species, diameter at breast height and height information. In addition, valuable information concerning the relationship between tree height and age was obtained from the Shibata Forest Service and ground verification. An extensive effort was made to get data and information representing the actual conditions at each date through field observation, study maps and interviews.

Image Processing Hardware and Software

The so-called JAYA-SYSTEM software, which had been developed and coded using Quick-C programming language by the authors was used for the analysis. The ability to rectify, register and overlay data from different dates, to create either standardized or unstandardized principal component (PC) images, to classify them using maximum likelihood classifier, to generate image enhancements and filtering, to compute divergence and its transformation (TD) and to evaluate the significance of several confusion matrices based on Kappa statistics is an essential attribute of the software needed for this study. The mathematical concepts and terminologies that constitute the software referred to the descriptions of CONGALTON et al. (1983), JENSEN (1986), RICHARDS (1993), and HUDSON and RAMM (1987). The analysis was carried out on a personal computer of the NEC PC-9821 series.

CHANGE DETECTION METHODS

Geometric Correction and Registration

Prior to any other analysis, "image-to-map" rectification and "image-to-image" registration were conducted. The rectification of TM 02 June 1989 images followed by the registration of the remaining TM 1986 and 1989 had been done by JAYA and KOBAYASHI in previous studies (1994, 1995).

Image Smoothing

The anticipated registration errors that are often compounded by the complexity of forest cover patterns and topography may cause significant overestimates of change, particularly that occurs with boundary pixels. To reduce this source of error, the images were smoothed using a 3×3 size median filter. Many authors (e.g. CHUSNIE and ATKINSON 1985; GONZALEZ and WINTZ 1988; NARENDRA 1983; and RICHARDS 1993) proved that a median filter was effective for smoothing images without blurring the sharp edges or details in the image as much as the equivalent linear low-pass filter. We also used the median filter because it does not alter the pixel brightness values during filtering.

Change Detection Methods

Of the various available change detection methods (HOWARTH and WICKWARE 1981; and SINGH 1989, we examined forest change detection using the following methods.

(1) Direct multidate classification

In this method, the two-date original TM data of the same bands were classified simultaneously using training data sets representing specific types of change and no-change. The classification was based on the multidate TM bands which consisted of the same original TM bands of different dates. This method is quite simple and requires only a single classification, but it requires many bands. Since a full band set may be redundant in information content, classification using a reduced multidate band was then examined. The input images were comprised of spatially-filtered images. This method was used as a standard to evaluate the effectiveness of the change detection techniques that will be described further.

(2) Principal component

Principal component transformation was performed as a preprocessing procedure prior to automated classification. This transformation should be able to increase computational efficiency of the classification because it may reduce the dimensionality of the original data. The purpose of using principal component analysis is to create a combination of given TM bands that generate significant dimensionality indices for detecting forest cover change. Since TM bands 3 and 4 are highly correlated with the amount of vegetation cover, the eigenvector weights and algebraic signs of these bands were examined. Theoretically, this method could lead to greater separability between two classes along the new major components. The two-date TM data were put together and then processed using standardized principal components analysis to produce new synthetic bands. Hereafter, this technique will be called the multitemporal principal component (MPC) technique. The analysis was done using two techniques: (1) 12-dimensional MPC and (2) 2-dimensional MPC. Other applications of MPC for change detection have been examined by BYRNE et al. (1980), RICHARDS (1984), FUNG and LEDREW (1988), INGEBRITSEN and LYON (1985) and JIAU (1988).

In the 12-dimensional MPC technique, two different dates of six non-thermal bands were superimposed and treated as a single data set (six-plus-six). To select the PC image that summarize unchanged and changed areas, we applied the concepts of stable greenness (SG), stable brightness (SB), delta greenness (DG) and delta brightness (DB) by examining the characteristics of the eigenvector of each component (INGEBRITSEN and LYON 1985). Finally, the selected PC images referred to as SB, SG, DB and DG were classified to delineate the areas undergoing change by means of the maximum likelihood classifier using training areas as used in the direct multidate classification method.

In the 2-dimensional MPC, two TM data sets of the same bands from different dates were put together and analyzed at one time. Furthermore, in the same way, all of the second components (PC2), i.e. six PC2s, were classified based on the maximum likelihood classifier using the same training areas used in the earlier techniques.

Change Detection Category

Forest cover change categories described in this paper were formulated based on the forest categories developed in the single date classification in our previous

Table 1 The initial "from-to" change categories of the study site of all date-pairs.

"from-to" change category	from: 1986 to: 1989	from: 1986 to: 1993	from: 1989 to: 1993
a. Forest Area			
(1) P3,S2/3-OC: from large size of pine (P3) or J. cedar (S2/3) to overcuts area (OC);	x	x	x
(2) OC-S0: from overcuts area (OC) to seedling stage of pine and J. cedar (S0);	x	x	–
(3) S0s-S0d: from seedling stage of J. cedar whose underlayer vegetation sparsely developed (S0s) to seedling stage whose underlayer vegetation fully developed (S0 d);	x	x	x
(4) S0-S1: from seedling stage (S0) to small size of J. cedar (S1);	x	x	x
(5) S1-S2/3: from small size (S1) to medium/large size of J. cedar (S2/3);	x	x	x
(6) P1-P2: from small size (P1) to medium size of pine (P2);	x	x	x
(7) P2-P3: from medium size (P2) to large size of pine (P3);	x	x	x
b. Non-forest area			
(8) B-S: from bare land (B) to shrubby area (S);	x	x	x
(9) DV-B/C/E: from dense vegetation (DV) to bare land (B), construction (C) or exposed area (E);	x	x	x
(10) PF/DC-B/C/E: from paddy field (PF) or dry-crop vegetation (DC) to bare land (B), construction (C) or exposed areas (E);	x	x	x
(11) SV-DV: from sparse vegetation (SV) to dense vegetation (DV);	x	x	x
(12) NC: no-change area	x	x	x

Note: x = present and – = not present. Because the lack of representative pixels, the category of change from P0 to P1 was not defined. When the study undertaken, the OC-S0 change category of 1989-1993 date pair was not found.

study (JAYA and KOBAYASHI 1995). To describe what the changes have been for a specific class from one date to another, the class is defined in a "from-to" category. Then, to show where the changes took place, the class of change is displayed in a "from-to" change detection image. In our earlier study, attempts to differentiate tree height classes, i. e., small, medium and large, have shown that between P1 (small size of pine) and MF (mixed forest), and between S2 (medium size of J.cedar) and S3 (large size of J.cedar) are spectrally inseparable. These categories were then merged and called the P1 and S2/3, respectively. Based on map analysis, aerial-photo interpretation, forest inventory documents representing actual conditions at each date, analysis of the relationship between tree height and age, and ground verification, the initial "from-to" change detection categories of all date-pairs that shown in Table 1 were created.

Training data sets representing specific types of change and no-change were then derived from the original and synthetic bands of both the selected 12-dimensional MPC images and the PC2 images of the 2-dimensional MPC. Conventionally, to facilitate in setting the change detection training area, the raw images from two different dates were simply superimposed and displayed in red and green guns. However, we found a difficulty to appreciate visually all of the change and no-change information using only two original multidate TM bands. Furthermore, since the MPC effectively summarized the 12 original TM bands in the first few components, the PC images representing the areas of change were then used and superimposed to select training areas. Any areas that have changed will be highlighted in one of the colors. The greater the change in tone, e.g., from dark to light, between the two dates, the more dominant one of the color (green or red) will appear on the monitor. The red and green colors reveal the locations of where the changes took place. When possible, coincident training areas were selected for all possible date-pairs, i.e., 1986-1989, 1986-1993 and 1989-1993.

Accuracy Measures

In this study, we sought to evaluate the accuracy (degree of agreement) of automatic change detection based on statistical approaches. The evaluated accuracy measures were: (1) overall accuracy, (2) producer's accuracy (omission error), (3) user's accuracy (commission error) and (4) Kappa accuracy. Because only the Kappa accuracy can take into account all cells of the confusion matrix elements, the change detection accuracies were then determined on the basis of the highest Kappa accuracy. This measure had been found to be consistent to either the user's or producer's accuracy measures (FUNG and LEDREW 1988). Detailed descriptions of these accuracy measures can be found in CONGALTON *et al.* (1983), and ROSENFIELD and FITZPATRICK-LINS (1986), while the exact equation of the Kappa accuracy and its variance has been described by HUDSON and RAMM (1987).

Separability Analysis

To evaluate whether any types of change were significantly detected or not, individual separability analyses was performed. As indicated in our earlier study (JAYA and KOBAYASHI 1995) and by other researchers, since the Transformed Divergence (TD) provided good estimates for both the interclass separability and accuracy assessment, the TD measure was then applied. On the basis of the separability and accuracy analyses obtained above, change detection images of both 12-dimensional and 2-dimensional MPC were then created using a maximum likelihood classifier.

Smoothing of the Classified Image

The rounding-off which is associated with the computation involved in MPC technique can produce some noise in images. Because the software encodes the PC score values in an 8-bit integer format (values from 0 to 255), it's believed that the rounding of intermediate results, either up or down, can produce noise whether in the PC image or in the final classification. To filter out this noise, the final change detection map was again smoothed with a 3x3 size median filter. This smoothing should be able to reduce errors that associated with misclassification and reduce overestimation of change at one time. This filtering process can eliminate small size and scattered areas of change. A flowchart of the general change detection procedure used in this study is depicted in Fig. 2.

RESULTS AND DISCUSSION

Direct Multidate Classification

The Kappa and overall accuracies of classifying both the original and the merged categories using direct multidate classification (DMC) are listed in Table 2. We can see that the change detection using only six raw TM bands, which consisted of two bands 3s, two bands 4s and two bands 5s from two different dates produced optimal results. Statistically, it appears that their Kappa values have no significant difference with the Kappa values derived from a higher number of multidate bands. That's why the change detection image based on the DMC method was then created using this combination. This shows that the full multidate band sets (12 bands) can be reduced without any significant reduction in accuracy. This in turn increases classification speed.

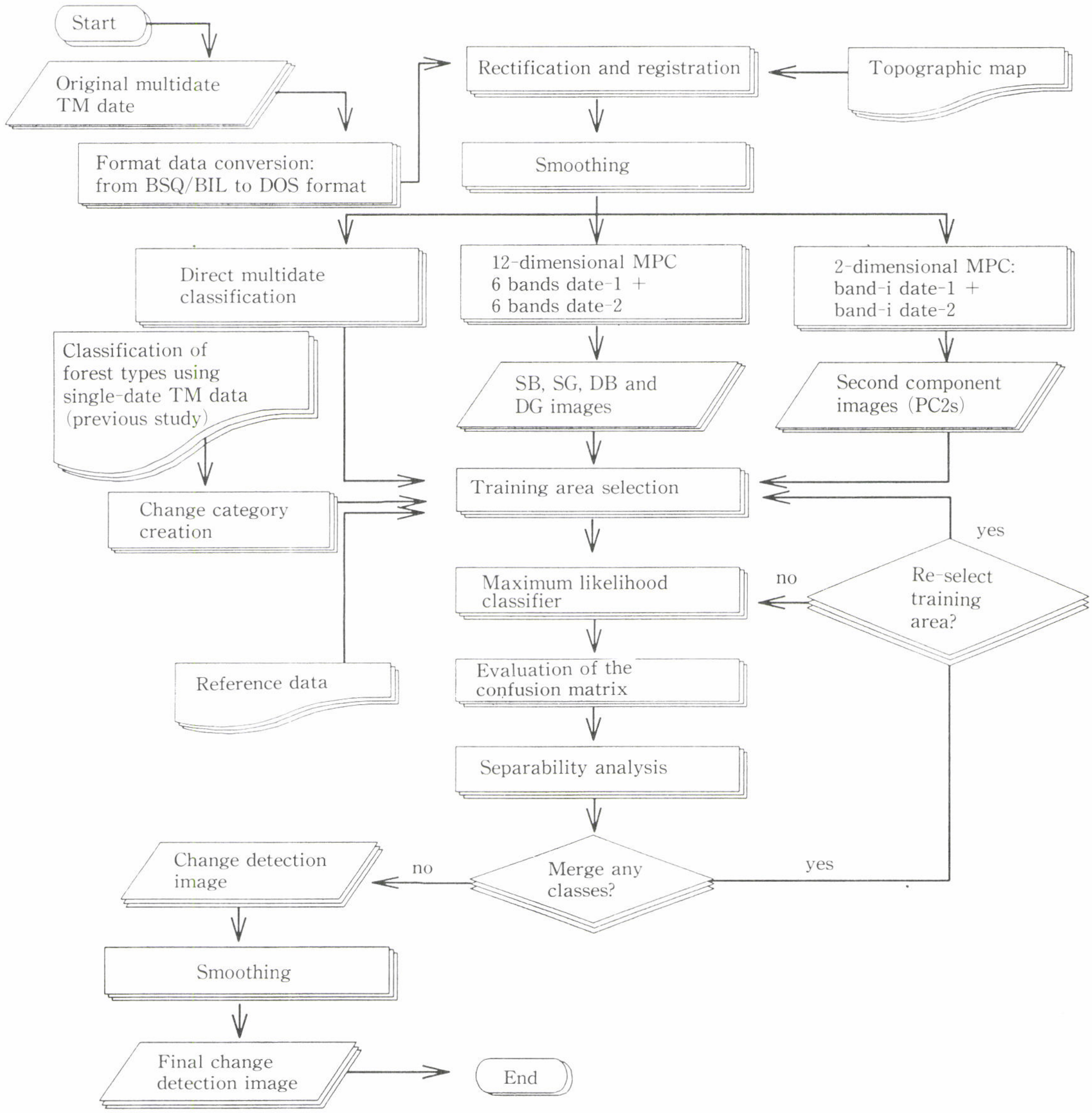


Fig. 2 Flow-chart of the change detection taken in this study.

(1) The forest change from 10 June 1986 to 2 June 1989

The evaluation of the original "from-to" change categories as determined using the transformed divergence and confusion matrix for the merged TM 10 June 1986 and TM 2 June 1989 (hereafter referred to as the 1986-1989 date-pair) showed that the OC-S0, S0s-S0d and S0-S1 categories are poorly separated from each other, while the S1-S2/3, P1-P2 and P2-P3 change categories were statistically inseparable from the no-change category. In the initial confusion matrix examined, the last three change categories mentioned above produced substantial confusion with the no-change category. The results from this classification attempt clearly showed that natural growth from S1 to S2/3, from P1 to P2 and from P2 to P3 was difficult to be detected during this 3-year period. In the final classification, using six multidate TM bands which consisted of two band 3s, two band 4s and two band 5s, these categories were then merged into a no-change category producing considerably high overall accuracy, i.e. 94.4% (Table 2). Also during this 3-year period, both the producer's and user's accuracies of the change and no-change categories were encouraging, ranging from 82.7% to 100% (Table 3a). Unmelted and wet snow that still covered part of the top of Mt. Ninouji caused some problems in forest change detection.

(2) The forest change from 10 June 1986 to 28 May 1993

Between 10 June 1986 and 28 May 1993 (1986-1993 date-pair), both the changes from forested area to clearcut area (P3,S2/3-OC) and from clearcut area to new artificial

Table 2 The Kappa and overall accuracies of change detection using direct multidate classification

Number of band	multidate of original TM band	Original category Kappa	Original category Accuracy Overall	Original category Accuracy TDavg	Merged category Kappa	Merged category Accuracy Overall	Merged category Accuracy TDavg
	from 10 June 1986 to 2 June 1989						
12	1 2 3 4 5 7	67.71	70.70	2000.0	97.02	97.72	2000.0
10	1 2 3 4 5	66.46	69.52	1999.3	94.40	96.48	2000.0
8	2 3 4 5	65.55	68.90	1997.4	94.96	96.13	2000.0
6	3 4 5	61.57	65.03	1995.9	94.42	95.72	2000.0
4	3 4	53.31	60.60	1990.0	85.82	89.01	1999.9
	from 10 June 1986 to 28 May 1993						
12	1 2 3 4 5 7	70.92	73.79	2000.0	90.18	92.40	2000.0
10	1 2 3 4 5	69.99	72.87	1999.8	90.40	92.57	1999.5
8	2 3 4 5	64.03	67.03	1999.4	89.88	92.15	1998.9
6	3 4 5	62.96	66.03	1998.8	90.63	92.74	1997.8
4	3 4	56.87	60.60	1993.0	78.46	83.39	1985.4
	from 2 June 1989 to 28 May 1993						
12	1 2 3 4 5 7	72.88	78.67	2000.0	94.30	96.22	2000.0
10	2 3 4 5 7	67.10	73.49	2000.0	94.95	96.66	2000.0
8	2 3 4 5	61.40	67.78	1997.4	94.96	96.66	2000.0
6	3 4 5	57.93	64.18	1993.4	93.66	95.79	1991.1
4	3 4	54.67	61.55	1982.3	83.38	90.25	1996.4

Note: The vertical lines that connect the Kappa values express that those values are not significantly different at 95% confidence level.

regeneration (OC-S0) were accurately detected. By examining the final confusion matrix (Table 3b), we can see that S0s-S0d exhibits little confusion with the S0-S1 category, producing only 76.4% and 70% user's accuracy. Based on ground observations, and studies of maps, aerial-photo interpretations, and forest inventory documents, some areas of S0 (defined in TM 10 June 1986) were approaching the S1 category and had been densely invaded by shrub vegetation. During this 7-year period, the S0 category had developed considerably into the S1 category, so the accuracy of the change detection from the seedling stage of J. cedar to the medium size of J. cedar (S0-S1) was encouraging. The confusion between the change from S0 whose understory vegetation sparsely developed to S0 whose understory had fully developed (S0s-S0d) with S0-S1 may be related to the fact that the changes in reflectance due to tree height growth and the invasion of shrub vegetation produced similar delta greenness. Actually, the ground condition of the S0d was at any point within the development sequence between S0 and S1 categories. These facts were supported by the results obtained by RICHARDSON and WIEGAND 1977, and TUCKER and MAXWELL 1976 in which reflectance of red and near-infrared (TM bands 3 and 4) were correlated closely with plant height and vegetation density.

During this period, cutting activity within the forest bounds (P3,S2/3-OC) is difficult to be distinguished from the transformation from paddy or dry-crop fields to barren land/construction/exposed area (PF/DC-B/C/E), producing only 72.7% user's accuracy. The changes due to new artificial regeneration (OC-S0) were clearly identified. As a result of the separability. analysis and examination of the confusion matrix, the changes from S1 to S2/3, P1 to P2, and P2 to P3 during this 7-year period, could not be detected because of their similarity to the no-change category. Therefore, these types of changes were finally grouped into the no-change category.

(3) The forest change from 10 June 1989 to 28 May 1993

During this period, there were the same difficulties in distinguishing between S0s-S0d and S0-S1 as occurred in the 1986-1989 date-pair. However, during this 4-year period, the changes due to harvesting activities (P3, S2/3-OC), agricultural land conversion (B-S, PF/DC-B/C/E, DV-B/C/E) and SV-DV were considerably detected, as indicated by both the producer's and user's accuracies that fell between 83.1% and 100% (Table 3c). The changes detected in the dry crop fields, might have been due to differences in water content (and thus soil background reflectance) between the two dates, differences in seasonal crop types, or conversion from cropped area to harvested area. The changes that were detected in agricultural areas might be the norm as farmers practice crop rotation, e.g., change crop types, fallow periods etc.). Urban areas that consisted of various small-size features such as paved areas, residential roofs, area with scattered trees or woods, were poten-

Table 3 Confusion matrix of the final change detection category based on direct multidate classification using six multidate TM bands that consisted of two band 3s, two band 4s and two band 5s.

(*a*) *from 10 June 1986 to 2 June 1989*

Class	Number of pixel	C1	C2	C3	C4	C5	C6	C7	Producer's accuracy
C1	132	126	0	0	6	0	0	0	95.45
C2	294	0	293	0	0	0	0	1	99.66
C3	97	0	0	94	0	0	3	0	96.91
C4	81	11	0	2	67	0	0	1	82.72
C5	121	0	5	0	0	116	0	0	95.87
C6	139	0	0	0	0	0	139	0	100.00
C7	583	0	33	0	0	0	0	550	94.34
User's accuracy		92.0	88.5	97.9	91.8	100.0	97.9	99.6	

Change categories: C1:P3,S2/3-OC; C2:OC-S0/S0s-S0d/S0-S1; C3:B-S; C4:PF/DC-B/C/E ;C5:SV-DV; C6:DV-B/C/E; and C7:NC

(*b*) *from 10 June 1986 to 28 May 1993*

Class	Number of pixel	C1	C2	C3	C4	C5	C6	C7	C8	Producer's accuracy
C1	97	96	0	0	0	0	0	0	1	98.97
C2	91	0	73	18	0	0	0	0	0	80.22
C3	56	0	6	50	0	0	0	0	0	89.29
C4	50	0	1	0	49	0	0	0	0	98.00
C5	99	0	0	0	1	98	0	0	0	98.99
C6	204	36	3	1	0	0	161	0	3	78.92
C7	109	0	7	2	2	0	0	98	0	89.91
C8	492	0	6	0	0	0	0	0	486	98.78
User's accuracy		72.7	76.0	70.4	94.2	100.0	100.0	100.0	99.2	

Change categories: C1:P3,S2/3-OC; C2:S0s-S0d; C3:S0-S1; C4:OC-S0; C5:B-S; C6:PF/DC-B/C/E; C7:SV-DV; and C8:NC.

(*C*) *from 2 June 1989 to 28 May 1993*

Class	Number of pixel	C1	C2	C3	C4	C5	C6	C7	Producer's accuracy
C1	25	25	0	0	0	0	0	0	100.00
C2	123	0	118	0	0	0	0	5	95.38
C3	69	0	0	69	0	0	0	0	100.00
C4	50	2	0	0	43	0	5	0	86.00
C5	102	0	0	3	0	99	0	0	97.06
C6	141	0	0	0	0	1	140	0	99.29
C7	629	0	24	8	0	0	0	597	94.91
User's accuracy		92.6	83.1	86.3	100.0	99.0	96.6	99.2	

Change categories: C1:P3,S2/3-OC; C2:S0s-S0d/S0-S1; C3:B-S; C4:PF/DC-B/C/E; C5:SV-DV; C6:DV-B/C/E; and C7:NC

Table 4 Eigenvector patterns of the first five 12-dimensional MPCs

(a) Merged TM 10 June 1986 and 2 June 1989

Year	Band	PC1	PC2	PC3	PC4	PC5
TM 10	1	0.30749	-0.25662	-0.12274	-0.16762	-0.10008
June	2	0.29685	-0.29132	-0.15947	-0.32602	0.14992
1986	3	0.26341	-0.37757	-0.08312	-0.42188	0.28992
	4	0.28166	0.26959	-0.48335	-0.09779	-0.05393
	5	0.27187	0.37989	-0.02482	-0.19859	-0.36333
	7	0.28364	0.25234	0.37916	-0.37526	-0.43441
TM 2	1	0.31071	-0.17846	0.03390	0.47885	-0.35069
June	2	0.31732	-0.20304	0.02725	0.35730	-0.13950
1989	3	0.28448	-0.33520	0.01536	0.22795	-0.02891
	4	0.27029	0.31093	-0.43304	0.26466	0.26185
	5	0.28572	0.33976	0.09473	0.13133	0.39203
	7	0.28530	0.16884	0.59380	0.03981	0.44078
Eigenvalue:		8.4859	2.2964	0.5812	0.3441	0.1577
Proportion:		70.72	19.14	4.84	2.87	1.31
Cumulative:		70.72	89.85	94.70	97.56	98.88
Description:		stable brightness	stable greenness	—	delta brightness	delta greenness

(b) Merged TM 10 June 1986 and 28 May 1993

Year	Band	PC1	PC2	PC3	PC4	PC5
TM 10	1	0.32104	-0.20363	0.00676	-0.21257	0.31425
June	2	0.31540	-0.24504	-0.00223	-0.21492	0.35359
1986	3	0.28536	-0.32620	0.08564	-0.17179	0.38317
	4	0.28719	0.24112	-0.46674	-0.27706	-0.00091
	5	0.26928	0.36133	-0.03950	-0.36105	-0.26297
	7	0.28167	0.26396	0.39484	-0.39794	-0.33614
TM 28	1	0.31678	-0.23049	-0.01605	0.21170	-0.28733
May	2	0.31546	-0.24538	-0.04882	0.24185	-0.30667
1993	3	0.28070	-0.33777	0.06616	0.20531	-0.38492
	4	0.27817	0.23744	-0.53255	0.34808	0.07118
	5	0.24538	0.40780	0.04863	0.35338	0.27255
	7	0.25583	0.28912	0.56948	0.34948	0.20771
Eigenvalue:		8.0275	2.7756	0.5839	0.3008	0.1386
Proportion:		66.90	23.13	4.87	2.51	1.16
Cumulative:		66.90	90.03	94.89	97.40	98.55
Description:		stable brightness	stable greenness	stable greenness	delta brightness	delta greenness

(c) Merged TM 2 June 1989 and 28 May 1993

Year	Band	PC1	PC2	PC3	PC4	PC5
TM 2	1	0.31703	-0.16119	0.03086	-0.50386	0.25901
June	2	0.32334	-0.18943	0.03464	-0.37731	0.11341
1986	3	. 0.29161	-0.31359	0.16324	-0.24355	0.10969
	4	0.27245	0.28947	-0.44880	-0.19782	-0.26685
	5	0.28917	0.33052	0.01637	-0.08973	-0.45549
	7	0.29130	0.17975	0.48587	-0.02247	-0.48674
TM 28	1	0.30756	-0.27815	-0.09833	0.18595	0.02404
May	2	0.30220	-0.28564	-0.13842	0.33157	-0.06815
1993	3	0.26291	-0.37885	-0.04111	0.46373	-0.19575
	4	0.27636	0.24502	-0.52045	0.14503	0.20536
	5	0.25508	0.41638	0.02424	0.15082	0.41571
	7	0.26594	0.28030	0.48111	0.30565	0.36591
Eigenvalue:		8.216	2.4032	0.6873	0.3392	0.2028
Proportion:		68.47	20.03	5.73	2.83	1.69
Cumulative:		68.47	88.49	94.22	97.05	98.74
Description:		stable brightness	stable greenness	—	delta brightness	delta greenness

Source: JAYA and KOBAYASHI (1994)

tial sources of much confusion. As mentioned earlier, the registration errors that are often compounded by the complexity of land cover patterns may cause overestimation of change.

Multitemporal Principal Component

(1) 12-dimensional MPC

Table 4 summarizes the eigenvectors of the first five components of all date-pairs derived by JAYA and KOBAYASHI (1994) when they carried out a qualitative evaluation of the MPC images. Here we were tempted to create a change detection map using automated classification. This automated approach was based solely on reflectance (i.e. digital number) range and ignored the basic diagnostic interpretation elements such as tone/color, shape, size, texture, shadow, pattern, location and association of the objects that are usually used in visual image analysis. As indicated by the proportion of their eigenvalues, the first five components accounted for 98.9%, 98.6% and 98.7% of the total variance for 1986-1989, 1986-1993 and 1989-1993 date-pairs, respectively, while the rest accounted for only less than 1.5%. In addition, the eigenvector characteristics of the remaining last seven components did not show any specific pattern that would be useful for forest change detection. Therefor, the discussion and analysis were focused within these components. As shown, the eigenvector loadings of the first principal components (PC1s) are all positive and very similar in magnitude, indicating a stable brightness (SB) component. In the PC2 image the changed areas were not readily apparent. Its eigenvector loadings express the stable greenness (SG) where the visible bands are always negatively loaded, while near- and mid-infrared bands are positively loaded in both earlier and latter dates. This PC2 characteristic closely matches the theoretical spectral response of vegetation as mentioned earlier. As indicated by its eigenvector, particularly, bands 3 and 4, the PC3 of the 1986-1993 date-pair also summarizes the stable greenness, however, the PC3s of the other date-pairs do not explain any specific feature. The PC4s obviously represent change in brightness (delta brightness/DB) where the eigenvector loadings are always negative on the data from earlier date but positive on the data from the other date counterpart. The fifth component (PC5) images for all date-pairs measured the change in greenness (delta greenness/DG) as indicated by their eigenvector characteristics that are always positively loaded in the visible bands (except band 1) and negatively loaded in the near- and mid-infrared (bands 4, 5 and 7) from the earlier date and inverted sign in the latter date. In these components any forest covers with an increase in greenness were bright, while those where the greenness decrease were dark.

Summarizing all of the above, the SB, SG, DB and DG for all date-pairs were mapped consistently within the first five components, i.e. in the first (PC1), second (PC2), fourth (PC4) and fifth (PC5) components, respectively. Particularly for 1986-1993 date-pair, the SG was also mapped in third components (Table 4b). This may depend on the nature of change between dates. These components appear to be useful for both qualitative and quantitative analyses. JAYA and KOBAYASHI (1994) made some trial and error to superimpose three or two of the selected components for visual interpretation. They found that the principal component images representing the change are more interpretable than the original data. The color composite images created using the PC images representing the change of interest depicted the areas of change in unique color tones which were easier to interpret than the individual black-and-white images. As with the quantitative change detection carried out here, the automated classification appears to discriminate the areas of change clearly than that could be obtained from visual interpretation.

(2) 2-dimensional MPC

Table 5 clearly shows that the magnitude and sign of the eigenvector loading values of second components from one date is perfectly inverted from the other date counterpart (Table 5). As expected, the second components of the 2-dimensional MPC picked up the change of interest. Furthermore, the change detection image using an optimal combination of all possible PC2 combination was performed. The composite image formed by displaying three of the six second components of these 2-dimensional images also highlighted the forest cover changes of interest. These results agree with the study results obtained by RICHARDS (1984).

Forest Cover Change Accuracy

Instead of using multidate original TM bands, the synthetic bands referred to as stable-brightness, delta-brightness and delta-greenness obtained previously were applied. Using the same way and the same categories, the produced Kappa and overall accuracies using the 12-dimensional and 2-dimensional MPC techniques are listed in Table 6. These methods also identified the same separable and inseparable class-pairs as were identified using direct multidate classification. This table clearly shows that inclusion of the SB, SG, DB and DG images in classifying the original categories always gave the highest rank of both overall and Kappa accuracies. A similar tendency was also seen when classifying the merged categories. As depicted, the accuracies using only the DB and DG components are ranked in the lower order. Exclusion of SB and SG caused loss of no-change information (static cover change). In other words, this study suggests that due to the characteristics of their eigenvector loadings, the SB, SG,

Table 5 Engenvectors of the two-dimesional multitemporal principal component

	TM 10 June 1986 and TM 2 June 1989			TM 10 June 1986 and TM 28 May 1993			TM 2 June 1989 and TM 28 May 1993		
Band	Year	PC1	PC2	Year	PC1	PC2	Year	PC1	PC2
1	1986	0.7071	0.7071	1986	0.7071	0.7071	1989	0.7071	0.7071
1	1989	0.7071	-0.7071	1993	0.7071	-0.7071	1993	0.7071	-0.7071
Proportion		95.06	4.94		97.08	2.92		94.36	5.64
2	1986	0.7071	-0.7071	1986	0.7071	0.7071	1989	0.7071	0.7071
2	1989	0.7071	0.7071	1993	0.7071	-0.7071	1993	0.7071	-0.7071
Proportion		94.49	5.51		96.79	3.21		94.28	5.72
3	1986	0.7071	0.7071	1986	0.7071	0.7071	1989	0.7071	-0.7071
3	1989	0.7071	-0.7071	1993	0.7071	-0.7071	1993	0.7071	0.7071
Proportion		94.38	5.62		96.53	3.47		93.64	6.36
4	1986	0.7071	0.7071	1986	0.7071	0.7071	1989	0.7071	0.7071
4	1989	0.7071	-0.7071	1993	0.7071	-0.7071	1993	0.7071	-0.7071
Proportion		96.79	3.21		94.90	5.10		95.44	4.56
5	1986	0.7071	0.7071	1986	0.7071	0.7071	1989	0.7071	0.7071
5	1989	0.7071	-0.7071	1993	0.7071	-0.7071	1993	0.7071	-0.7071
Proportion		96.14	3.86		94.56	5.44		94.75	5.25
7	1986	0.7071	0.7071	1986	0.7071	0.7071	1989	0.7071	0.7071
7	1989	0.7071	-0.7071	1993	0.7071	-0.7071	1993	0.7071	-0.7071
Proportion		93.70	6.30		93.02	6.98		93.45	6.55

Source: JAYA and KOBAYASHI (1994)

DB and DG must be included in the change detection using the 12-dimensional MPC technique.

In comparison with the accuracies of the 2-dimensional MPC, change detection accuracies produced using the SB, SG, DB and DG are higher than the accuracies produced using all six of the 2-dimensional MPC images. In addition, the 12-dimensional MPC provided better delineation of forest cover change than that produced using 2-dimensional MPC. The final confusion matrices of 12-dimensional MPC are shown in Table 7.

Comparing the accuracy of the three change detection techniques examined here, we see that except for the 1989-1993 date pair, both the DMC using 6 multidate bands and the 12-dimensional MPC using SB, SG, DB and DG (Table 4) provided very close Kappa accuracy, i.e., 94.4% and 94.2% for the 1986-1989 date pair, and 90.6% and 90.8% for the 1986-1993 date pair (see Tables 2 and 6). Unfortunately, for the 1989-1993 date pair, the change detection map derived using the 12-dimensional MPC (map is not displayed here) appears to overestimate the areas of forest cover change. The change detection image using direct multidate classification provided better accuracy. The overestimates of change assessed by MPC technique might have been greatly affected by the large part of the area that was covered by unmelted and wet snow indicating change. According to RICHARDS (1984), this MPC technique would be useful when the area includes a substantial area of relatively no-change, Final change detection maps created for all date pairs are depicted in Fig. 3. The 1986-1989 and 1986-1993 date pairs were created using 12-dimensional, while the 1989-1993 date pair was created using the DMC technique (Fig. 3c).

In this study site, a particular finding was the changes in the young forest plantation within the forest service territory, on the center of the image. These forest plantation changes are revegetations from the 1986 or from earlier date. In general, the DMC method provided consistent better results in delineating forest cover change. This indicates that the original pixel values contain an important information of forest change. The combination of red, near infra-red and middle infra-red bands makes all the difference when discriminating one type of change versus another.

From the dimensionality standpoint, using only SB, SG, DB and DG could effectively reduce number of bands and provide considerably close accuracy with the DMC technique. However, this gain in efficiency comes with a little loss in accuracy. This shows that 12-dimensional MPC

Table 6 The Kappa and overall accuracies of change detection using multitemporal principal component technique

Synthetic bands	Original Kappa	category Accuracy Overall	TDavg	Merged Kappa	category Accruacy Overall	TDavg
(a) from 10 June 1986 to 2 June 1989						
12-dimensional MPC						
PC1,PC2,PC3,PC4 &PC5	62.1	65.2	1990.9	93.8	95.3	2000.0
PC1,PC2,PC4 & PC5	64.5	65.3	1982.0	94.2	95.3	1999.9
PC4 & PC5	56.0	59.2	1854.9	92.9	94.5	1926.9
2-dimensional MPC						
PC2 of CHs 1,2,3,4,5 & 7	60.0	63.8	1954.5	83.9	87.8	1981.2
PC2 of CHs 1,2,3,4 & 7	57.7	61.4	1940.2	84.0	87.8	1965.8
PC2 of CHs 2,3,4 & 7	52.9	56.7	1917.7	85.1	88.1	1963.6
PC2 of CHs 3,4 & 7	53.5	57.4	1890.4	84.9	88.7	1957.1
PC2 of CHs 3 & 4	40.4	44.6	1821.3	62.0	70.5	1852.3
(b) from 10 June 1986 to 28 May 1993						
12-dimensional MPC						
PC1,PC2,PC3,PC4 & PC5	60.5	63.4	1996.6	90.8	92.9	1995.3
PC1,PC2,PC4 & PC5	57.5	60.7	1984.4	82.8	86.5	1973.3
PC4 & PC5	51.6	56.9	1794.3	67.8	74.4	1826.2
2-dimensional MPC						
PC2 of CHs 1,2,3,4,5 & 7	60.1	64.4	1964.4	80.8	85.1	1978.8
PC2 of CHs 1,2,3,4 & 7	59.3	63.7	1953.5	80.5	84.9	1971.8
PC2 of CHs 2,3,4 & 5	59.6	63.8	1943.2	80.5	84.9	1948.4
PC2 of CHs 3,4 & 5	59.7	63.9	1928.3	79.3	84.3	1935.5
PC2 of CHs 3 & 4	46.7	52.3	1846.9	63.3	71.7	1793.6
(c) from 2 June 1989 to 28 May 1993						
12-dimensional MPC						
PC1,PC2,PC3,PC4 & PC5	56.2	61.8	1995.8	91.3	94.4	1997.6
PC1,PC2,PC4 & PC5	54.7	60.4	1938.2	91.8	94.5	1996.6
PC4 & PC5	52.5	59.1	1950.4	83.3	88.5	1965.9
2-dimensional MPC						
PC2 of CHs 1,2,3,4,5 & 7	60.0	67.2	1972.6	86.8	91.2	1991.4
PC2 of CHs 1,2,3,4 & 7	57.7	65.1	1963.8	84.9	89.9	1987.2
PC2 of CHs 2,3,4 & 7	55.0	62.3	1940.4	84.3	89.5	1982.9
PC2 of CHs 3,4 & 7	52.7	60.2	1917.1	83.6	89.0	1977.6
PC2 of CHs 3 & 4	41.0	49.4	1850.5	68.7	78.8	1893.0

technique has an important advantage to summarize dynamic information of change within image over a period. Even though the MPC needs some extra computing time, it would be compensated by saving classification time. Besides, direct multidate classification needs too many bands, so that it needs many trial-and-errors to select the best multidate band combination. To use the MPC technique based on quantitative approach as described here, it's advisable first to superimpose the delta brightness and delta greenness that displayed in red and green guns respectively. Areas of no-change will appears mid-yellow, the increasing amount of vegetation (natural growth and new artificial regeneration) appears green, while forest cutting appears red or very bright yellow. If the tone or reflectance difference between the areas of change and no-change is not clearly shown, it's better to ignore quantitative classification using MPC. As also suggested by many other authors, this study shows that the visual inspection of the final change detection map could not be absolutely ignored to fill in the within-field gaps of automated classification

Table 7 Confusion matrix of the final change detection category based on 12-dimensional MPC using the synthetic bands defined as delta brightness, delta grenness, stable brightness and stable greenness components.

(c) from 10 June 1986 to 2 June 1989

Class	Number of pixel	C1	C2	C3	C4	C5	C6	C7	Producer's accuracy
C1	134	126	0	0	8	0	0	0	94.03
C2	294	0	294	0	0	0	0	0	100.00
C3	97	0	0	92	0	0	5	0	94.85
C4	81	11	0	2	65	0	1	2	80.25
C5	121	0	0	0	0	121	0	0	100.00
C6	139	0	0	0	0	0	139	0	100.00
C7	583	0	35	0	0	0	0	548	94.00
User's accuracy		92.0	89.4	97.9	89.0	100.0	95.9	99.6	

Change categories: C1:P3,S2/3-OC; C2:OC-S0/S0s-S0d/S0-S1; C3:B-S; C4:PF/DC-B/C/E; C5:SV-DV; C6: DV-B/C/E; and C7:NC

(b) from 10 June 1986 to 28 May 1993

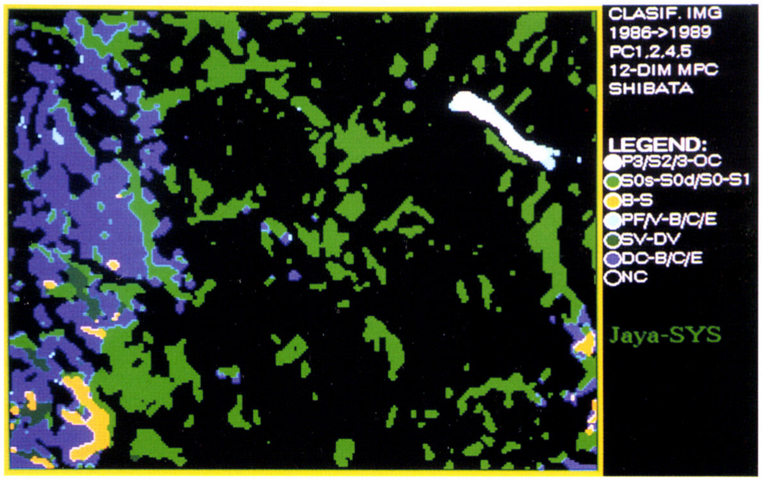
Class	Number of pixel	C1	C2	C3	C4	C5	C6	C7	C8	Producer's accuracy
C1	97	94	0	0	0	0	0	0	3	96.91
C2	91	0	85	6	0	0	0	0	0	93.41
C3	56	0	5	51	0	0	0	0	0	91.07
C4	50	0	4	0	46	0	0	0	0	92.00
C5	99	0	0	0	0	99	0	0	0	100.00
C6	204	38	0	0	3	1	157	0	5	76.96
C7	109	0	6	5	3	0	0	95	0	87.16
C8	492	0	3	3	0	0	0	0	486	98.78
User's accuracy		71.2	82.5	78.5	88.5	99.0	100.0	100.0	98.4	

Change categories: C1:P3,S2/3-OC; C2:S0s-S0d; C3:S0-S1; C4:OC-S0; C5:B-S; C6:PF/DC-B/C/E; C7:SV-DV; and C8:NC

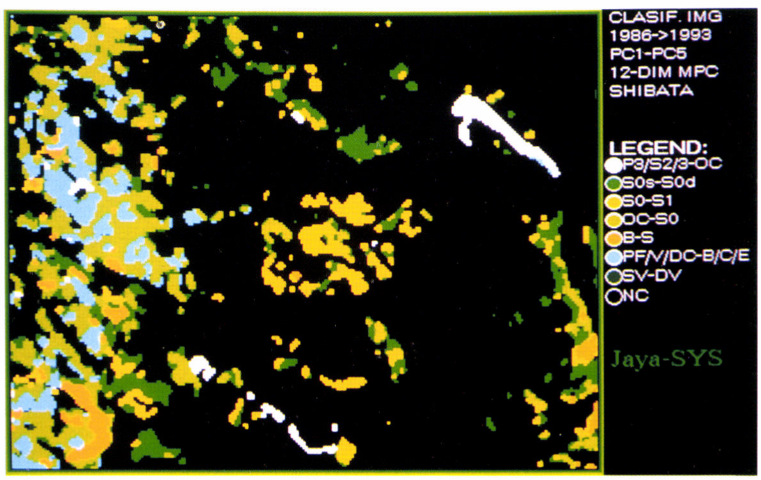
(c) from 2 June 1989 to 28 May 1993

Class	Number of pixel	C1	C2	C3	C4	C5	C6	C7	Producer's accuracy
C1	25	25	0	0	0	0	0	0	100.00
C2	123	0	120	0	0	0	0	3	97.56
C3	69	0	0	69	0	0	0	0	100.00
C4	50	1	0	0	45	0	4	0	90.00
C5	102	0	0	6	6	96	0	0	94.12
C6	141	0	0	2	2	0	139	0	98.58
C7	629	0	47	0	0	0	0	582	92.53
User's accuracy		96.2	71.9	89.6	100.0	100.0	97.2	99.5	

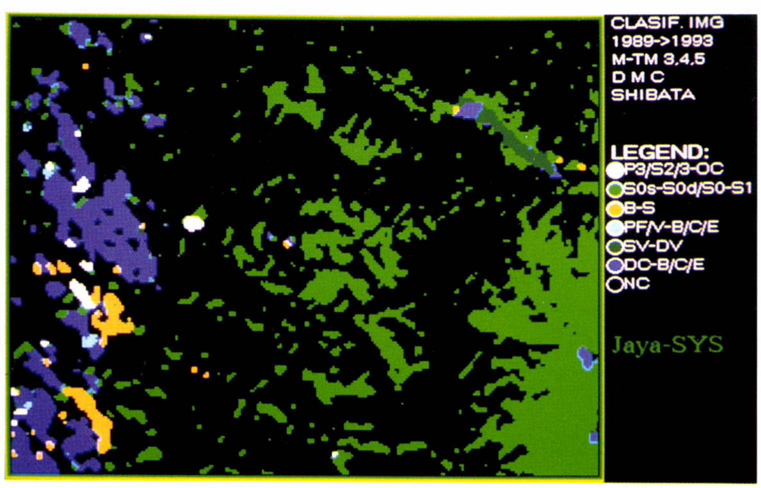
Change categories: C1:P3,S2/3-OC; C2:S0s-S0d/S0S1; C3:B-S; C4:PF/DC-B/C/E; C5:SV-DV; C6:DV-B/C/E; and C7:NC



(a)



(b)



(c)

Fig. 3 The final change detection maps: (a) from 10 June 1986 to 2 June 1989, (b) from 10 June 1986 to 28 May 1993 and (c) from 2 June 1989 to 28 May 1993. The areas shown are approximately 7.3 km × 5.7 km.

that misclassified into no-change category and remove the small areas of overestimate change.

For future requirements of forest monitoring within this area, it is suggested that a time series of TM data from another month or season when uninterested objects, e.g., unmelted snow is absent (for example, September or October) is required to reduce this considerable confusion.

CONCLUSION

From the results of this study, the following conclusions were derived:

1) The study reemphasized the fact that TM data can be used to accurately monitor the distribution and types of forest cover change, especially the natural growth of young forest plantations and artificial regeneration activity. Specifically for the study area, differences in the density of understory vegetation that invades the seedling stage of J. cedar are factors which influence the misclassification between $S0_S$-$S0_d$ and S0-S1. Although these results provided an insufficient basis for broad generalization, the TM data and quantitative approach using the MPC technique have shown promising results for monitoring forest plantation change. As time intervals become longer, the ability to detect forest cover change due to natural growth increases. The fact that during longer time intervals, i.e. between 1986 and 1993 (7 years) beside detecting the recent clearcuts or forest conversion, the changes from clearcuts to artificial regeneration (OC-S0) and growth from S0 to S1 were monitored. The ability to detect S0-S1 was due to the accumulation of a large amount of standing green foliage during the time interval as tree growth.

2) Of the three change detection techniques examined in this study, the DMC consistently provided high accuracy. For the 1986-1989 and 1986-1993 date pairs, the 12-dimensional MPC is preferable because it can: (1) reduce the dimensionality of data, (2) effectively pick up the change of interest which is mapped in several components and (3) provide a relatively high accuracy.

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An Appraisal of the Practice of Improvement Cutting to Enhance In-stand Scenic View in A Broad-leaf Secondary Forest

— A case study done in Gifu city —

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ABSTRACT

In this paper, improvement cutting done in a broad-leaf secondary forest for recreational use, was appraised by a standard presented in this paper. This improvement cutting was done by the 'Forest for Safeguarding Living Environment Project (FSLEP)' in Gifu City. This standard, based on data collected in two plots of the study forest, shows correlations among the average DBHs of the trees remaining after cutting and other parameters of stand structure, when trees having a larger DBH in the descending order are given preference for saving over cutting. The other parameters are the STD of DBH, stand density, the number of species, the diversity index and the spatial pattern of trees. The average DBHs of the two plots after improvement cutting, were 8.7cm and 10.0cm respectively. The parameters of actual stands after cutting - except stand density - were bigger than those simulated by standards. Therefore, it may be concluded that this kind of improvement cutting enhances the variety of in-stand scenic view variation. Nevertheless, the spatial patter of remaining trees belonged to the Ca_1 type, both in the actual stands and the standard.

Keyword: broad-leaf secondary forest, improvement cutting, stand structure, larger DBH, in-stand scenic beauty.

INTRODUCTION

The demand for non-extractive forest utilization shows an increasing trend. Therefore, the Japanese Forestry Agency created the Forest for Safeguarding of Living Environment Project (hereafter referred to as FSLEP) in 1971, and 394 projects had been completed by 1989. There has been some work done on the management or policy of FSLEP or other similar programs e.g. KOJIMA et al. (1990), SUZUKI et al. (1976), TANAKA et al. (1993), YAMANE et al. (1990) etc.. Moreover, psychological studies have also been done on recreational forest utilization (MIURA et al. 1993). However, only a few papers deal with the importance of the relationship of forest stand structure to such uses (ITOH et al. 1984).

In the future, discussions on the management or psychological aspects of forests which are not used for extractive purposes will have to be further developed (NODA 1986). At the same time, such forests should also be appraised in relation to stand structure, which is an objective indicator. In other words, non-extractive forests should be understood on the basis of information about them. Studies of stand structure, when considered with studies of mental aspects of utilization will contribute to recreational planning. KATAOKA (1974) wrote a paper on techniques to enhance the scenic views of forests inclusively. Therefore, this paper presents a very simple standard, applicable to improvement cutting for enhancing the scenic views of forests. This standard was based on the diameter at breast height (DBH) measured in actual forest stands used for in-stand view by FSLEP. The standard deviation of DBH, the number of species, the diversity index, and the stand density, are the other factors considered in this standard.

Specifically, broad-leaf secondary forests located in suburban areas of cities in Japan, are no longer felled for timber, fuelwood and other industrial uses. As a result, the

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forests are not managed under specialized purposes for sustainable forest management controlled by economic interests. These broad-leaf secondary forests have a complex stand structure (TSUKAMOTO 1989), therefore, treatment methods applied to given utilization purposes such as recreational use will also be complex. It is hard to predict future stand structure. Nevertheless, a complex stand structure provides many possibilities in terms of forest utilization.

STUDY SITE AND METHOD

The study site of this paper is an forest of FSLEP established in Akutami, Gifu City (Fig.1). This forest is a secondary mixed stand, consisting of conifers, broad-leaf evergreens and deciduous species. The utilization of this forest in the past has not been clarified. The area of this FSLEP is ca.16.5 ha. Improvement cutting was carried out to meet the recreational demands of the citizens living in a residential area close to this forest.

Two plots of 20 m×20 m size were set up in the forest. In these plots, the DBH and the spatial patterns of all the trees over 2 m in height were recorded, followed by the species identification.

There is no standard treatment method (salvage cutting, improvement cutting etc.) which is applied to broad-leaf secondary forests used for recreational purposes. In recreational forests, it is important that the users get many different in-stand views. But it is also important, that the standard for improvement cutting is simple. Because these forests occupy wide areas in the suburban zones of many cities, it is essential to improve the status of forest vegetation in order to maintain the forests potential for renewal. Generally, the DBH is treated as one indicator. Thus, the standard that trees with larger DBHs are preferably left intact, can be considered. However, if they choose the method in which the larger DBH trees are given preference to be saved during actual cutting, this method may contribute to lower species diversity, which can subsequently reduce in-stand view. In this paper, MDI (MORISHITA's diversity index) in the equation (1) is used to express species diversity (MORISHITA 1967).

$$MDI = \frac{N(N-1)}{\Sigma n_i(n_i-1)} \qquad (1)$$

where MDI : Index of diversity

N: Total number of individuals

n_i: Number of individual of i-th species

The number of species and diversity index are computed for the remaining trees on the basis of the descending order of their average DBHs. Another aspect which is important for a scenic view is the spatial pattern of trees, which is examined in this study by means of the Iδ index developed by MORISHITA (1959). The stand structure shown by this simple standard was compared with the actual results of improvement cutting in the study area.

The total number of trees recorded in plot 1 was 311, belonging to 17 species in 16 genera within 13 families. There were 269 individual trees representing 27 species within 16 genera belonging to 14 families in plot 2. At first, the STD of the DBH, the stand density, the number and the diversity of species were measured. The actual practice of cutting conducted in the surveyed forest was appraised, comparing the differences in stand structure between the actual stand after cutting and the expected stand, on the standard explained above. The average DBHs of the two plots after cutting were 8.72cm (plot 1) and 9.97cm (plot 2). This cutting was done by forest workers who have no quantitative standards.

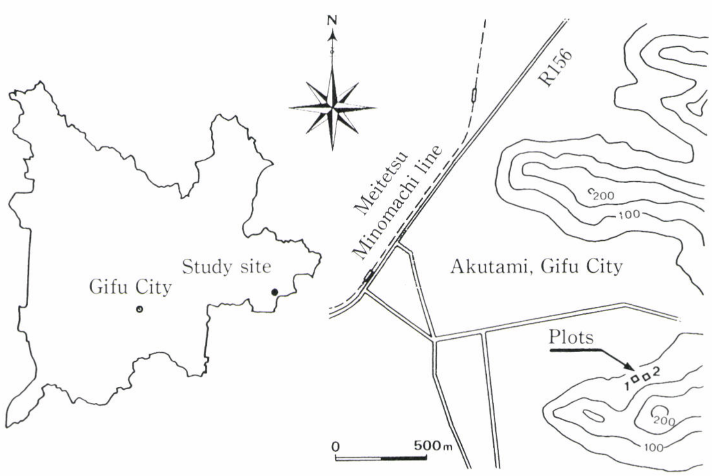

Fig. 1 Location and topography of study area.

RESULTS

The Standard for Cutting

Following the method discussed in the previous section, the measured DBH values of trees were averaged additionally in the descending order. The total number of species, MDI as, standard deviation (STD) of DBH and stand density, are presented in the Fig.2, with respect to the average of the remaining trees after the improvement cutting. The average DBH of the remaining trees is on the X axis. The stand density was defined as the average distance among the remaining trees.

For instance, in plot 1,if the average DBH of the remaining trees after cutting is 20cm, then the computed parameters will be as follows:

STD of DBH 4.9, the stand density 350 stems/ha (i.e. the average distance among trees is 5.3m), the number of species 6, MDI 6.1 (e.g. if there are 100 stems consisting of 5 species, MDI will be 5.2, the species abundance uniform, in other words, each species has 20 individual trees. If one species has 96 individual trees, while the other four species have only one individual tree, then the MDI will be reduced to 1.1(KIMOTO and TAKEDA 1989)).

If the average DBH of 20cm and the STD of DBH 0.9 are desired, then all the trees less than 15cm in diameter have to be removed. This 15cm DBH limit is decided by subtracting the STD of the desired 20cm DBH from that DBH (e.g. 20cm−4.9 cm). Although this method is not very accurate, it is sufficient for approximate calculations.

The aggregate number of species becomes highest when no trees are removed. In plot 1, MDI reaches its peak when the average DBH of the remaining trees is ca.25cm. Another peak of the MDI appears when the average DBH is ca.11cm. Similarly in plot 2, one peak of MDI can be seen when the average DBH is ca.12cm. In other words, when these stands are cut to make the average DBH 11-12cm, species diversity becomes highest. A decrease of the MDI when the average DBH is less than 11 cm, is due to the domination of the smaller DBH classes by one species (*Eurya japonica*). The MDI decreases according to increases in the number of individual trees of a given species.

In this manner, the correlation among some parameters, reflects the stand structure at the average DBH of the remaining trees. The reason for treating the average the DBH as a first parameter (explanatory indicator) is that DBH is easy to measure in actual investigations for cutting planning. Although trees of low height are removed during the actual cutting, in order to ensure an unobstructed view in stand, the measurement of tree height prior to cutting is a time consuming task.

Comparison between Standard and Actual Stand Structure after Cutting

For the two average DBHs of plots 1 and 2 given before, the respective stand densities are 2,525 and 2,175 stems/ha as shown in Fig.2 and Table 1. The actual stand density after cutting was 1,475 stems/ha in each plot, which is a coincidence. An observer in this forest can find a tree at every 5.3m on the average (calculated by stand density). Users of recreational forest prefer lower stand

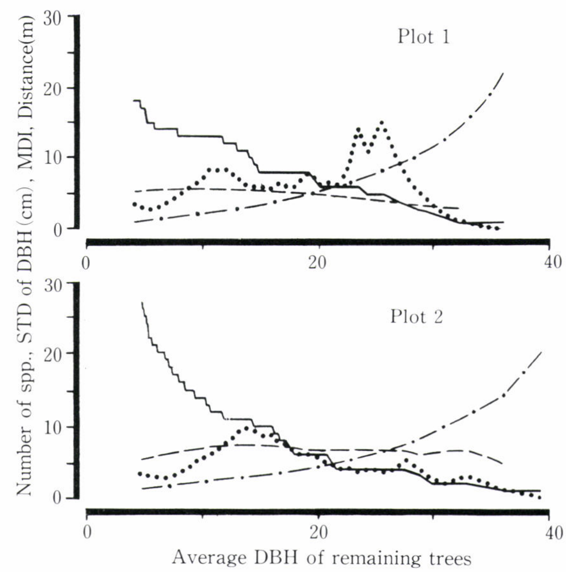

Fig. 2 Standards of cutting : Stand structure in case of average DBH of remaining trees after cutting is given.
Legend : ——— : Number of species.
- - - - : STD of DBH.
·········· : MORISHITA's diversity index.
—·—·— : Average distance among remaining trees after cutting (stand density).

Table 1 Comparison of stand structure.

	plot 1		plot 2	
	Expected	Actual	Expected	Actual
STD(DBH) (cm)	5.5	7.2	6.9	8.7
Density (stem/ha)	2525	1475	2175	1475
Species	13	14	14	21
MDI	5.7	8.8	5.3	17.1

1. These are values in case of average DBHs are 8.7cm (plot 1) and 10.0cm (plot2) in the stands after actual cutting.
2. MDI is MORISHITA's diversity index.

density (FUJIMOTO 1978). In addition, stand in which the density of small DBH (<13cm) trees are lower, is preferred (ARTHUR 1978). Based on their results, improvement cutting which was done in this study's plots was propriety. However, the best stand density for recreational use, or in-stand scenic beauty, is not known. The mental reaction of users in a forest does not vary greatly, when the stand density is greater than 1000 stems/ha (OISHI et al.1994). Therefore, if the stem proportion of the tree which will be cut by additional cutting is less than ca.50 % (to 1475 stems/ha; ca. 500 stems) in the plots, then the mental reaction of the forest users will not be changed. However, higher stand density of larger DBH (>40cm) trees has more positive effects for scenic beauty (Schroeder et al., 1981). In this view point, this study's forest has not matured because there are no trees with a DBH greater than 40cm.

The STDs of DBHs of actual stands are greater than those of the standards. Although the STDs of DBHs on the standards are 5.5 (plot 1) and 6.9 (plot 2), those of actual stands after cutting are 7.2 and 8.7 respectively. Thus, it may be stated that the DBHs of the remaining trees in actual stands after cutting, reflect a distribution from smaller to larger, than those of standards.

There were 13 species in plot 1, and 14 in plot 2 in standard. But the number of species in actual stands after cutting, was 14 (plot 1) and 21 (plot 2). This situation helps raise the MDI. The MDI indices are 5.7 and 5.3 for the respective two plots in standard. However, the actual values of the MDI indices were 8.8 and 17.1. Then, the species compositions before and after cutting were compared in each plot, which is shown in Fig.3. The stem proportions (%) of respective species before and after cutting are presented in Fig.3. One remarkable feature is that almost all of the *Eurya japonica* trees had been cut. The DBH of this species, which dominates the low-tree layer in the stands, is small. The high foliage density of this species intercepts sunlight,resulting in shady conditions underneath.

Species that appear in low frequencies in these stands remained mostly uncut. The species diversity had not been reduced in these stands. In brief, quantitative parameters of stand structure are higher in actual stands than in standards except stand density. Forest users do not recognize species diversity as scenic beauty (ARTHUR 1977; BUHYOFF 1984). Therefore, it is not important that rare species in plots were not removed, for scenic beauty. However, even if forest users can not distinguish species, it can be stated that high-diversity stands have more applications for utilization than low-diversity stands. High-diversity is important in many ways (ITOH et al. 1994; AKAI et al.1989). And high ' naturality ' is suitable for scenic beauty (AKAI et al. 1986; ICHIHARA et al. 1995). It can be said that high naturality corresponds to high diversity. Thus, to leave many species in actual forest stands by improvement cutting is important.

Next, the spatial pattern of trees in two plots were examined, the results of which are presented in Fig.4. These figures indicate a correlation between I_δ and area of which the plot is sub-divided into quadrats of several varying sizes. In these figures, the hand line with marks indicates the value of the actual stand after cutting in plot 1, and the dotted line with 'O' marks indicates the value for the standard in the case of the average DBH size of 8.72 cm. The 'Δ' mark in plot 2 is similar to plot 1, in the case of the

Fig. 3 Proportion of stem of each species in the plots before and after cutting.

1. Each species names are not revealed.
2. ○ : plot 1, □ : plot 2.

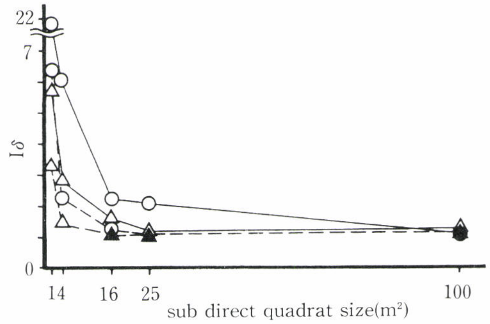

Fig. 4 I_δ-area curve of the remaining trees after cutting in actual stand and standard.

○ : Plot 1, △ : Plot 2

———: in actual stand. ---- in standard

Shaded marks indicate that these values do not deveate from 1.0 at 1.0% level of significance in F-value test.

higher average DBH 9.97cm. The shaded marks indicate that these values do not deviate from 1.0 at a 1 % level of significance in this F-value test.

The explanations of $I\delta$ index are as follows:

$I\delta > 1.0$:Aggregated distribution of trees

$I\delta = 1.0$:Random distribution of trees

$0 < I\delta < 1.0$:Regular distribution of trees

The $I\delta$-area curves show that tree distributions after cutting are aggregated, (Ca_1-type:MORISHITA 1959) both in the actual stand after cutting and the standard. However, The $I\delta$s which have to be considered are those of sub-divided quadrat size of more than 6.8 m^2 (2.6 sq.m), because stand densities are 1475 stems/ha in both. In plot 1, $I\delta$ indices show that the spatial pattern of trees is random in the case of the sub-divided quadrat size of 5m ($F = 2.00$ at $p > 0.01$: The same level of significance will be applied hereafter) in the standard. However, the distribution is not random in the case of the sub-divided plot size of 5m in the actual stand, after cutting. The same conditions are applicable to plot 2. In short, the tree's spatial pattern is random in the case of sub-divided quadrat sizes of ; 4 and 5 m ($F =$ 1.31 and 1.49 respectively). The spatial pattern of remaining trees is aggregated.

We consider that larger DBH trees are aggregately distributed and smaller trees are distributed among groups of larger trees. Therefore, if remaining trees are selected by DBH in descending order, the distribution pattern of trees becomes aggregated as in the situation mentioned above.

Although spatial patterns are mentioned above, it can not be judged that these spatial patterns are good or bad for scenic beauty. AKAI et al.(1986) considered scenic beauty with an $I\delta$ index in a mixed stand of *Pinus densiflora* and *Chamaecyparis obtusa*. Their consideration stands on regeneration or regulation of stem number in understory. If a forest stand does not have an extremely aggregated distribution of trees, perhaps undergrowth which occurs after cutting will be distributed ubiquitously. If a higher coverage of the forest floor by vegetation is better for scenic beauty (SCHROEDER and DANIEL 1981), ubiquitous distribution of undergrowth is important.

DISCUSSION

The appreciation of a given stand structure varies depending on the user's occupation, frequency of visits to forests in the past and perception etc.. Therefore, it is difficult to decide upon the best stand structure suitable for recreational use. The management of forests for recreational uses must conform to the levels of forest users' attributes. Because of this, the appraisal of stand structure from the view point of recreational use, and thus in-stand scenic view, is important. In the appraisal of surveyed stands, it is noteworthy that species diversity has not been reduced, in order to often save rare species in these stands. On the other hand, most abundant species such as *E. japonica* were almost completely cut. The greater DBHs in actual stands after cutting were greater than in the standards, due to the non-uniformity of DBH in real stands.

In view of the above, it can be said that the improvement cutting practiced in the surveyed actual stands is favorable for maintaining species diversity as well as variable DBH of trees in order to have a varied in-stand scene. As such, the forest studies will not be boring to the users. However, forest users who less frequently visit the recreational forests, generally prefer artificial forests, which are orderly (KAJIGAESHI et al. 1985).

This condition may be applicable to the spatial pattern of trees in a stand. In other words, in the actual stands studied, having aggregated or random distributions of trees might not greatly impress the infrequent visitors. There is a housing scheme close to the forest of this study. Although they live near the forest, it maybe assumed that some of these residents do not go to the forest or any other forested area frequently. Thus, this group will not appreciate the forest very much. This problem will be investigated in a subsequent study.

It is expected that the management of in-stand view can be done on the basis of parameters of forest structure, because the objective appraisal of different forests could be based on stand as evidenced in this study. The planners of FSLEP in the Prefectural Office are aware of this problem. Because psychological indicators of users are of special importance in the recreational utilization of forests, there is a growing need for further studies of this nature. Another aspect is the growth of remaining trees after improvement cutting. In this regard, the growth process of each of the same stands studied for this paper, have been investigated in another paper (HAYASHI et al. 1995). A study of the canopy structure of the same stands were presented at the IUFRO Furano Symposium in 1994 (TSUKAMOTO et al. in press).

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The Natural Resource Base and Industrialization in Asia

—In assessing phenomenal deforestation and industrialization of Thailand—

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Adisorn Noochdumrong*[4] and Emmanuel Rhodantes G. Abraham*[5]

ABSTRACT

In pre-industrial societies, forests provide most daily necessities, ranging from fuelwood to construction material and from supplementary food to fertilizer. Forest resources become even more important as the firsthand source of energy and materials for both industrial and household uses when the society tries to industrialize itself, thus making the availability of forest resources one of the key factors for successful industrialization. In this paper, the present endowment of forest resources in the countries of South and Southeast Asia is analyzed in a historical and geophysical perspective so as to assess their potential for industrialization from a natural resources point of view, with a special emphasis on Thailand. Though at the heavy cost of deforestation, Thailand seems to have been one of the successful forerunners in the post-World War II Asian effort of industrialization, and its experience in the ordeal of deforestation and associated socioeconomic conflict should provide a good lesson for the rest of the countries in the region.

Keyword: natural resource base, industrialization, civilization center, peripheral region, hinterland region

INTRODUCTION

Deforestation in tropical and sub-tropical countries has been one of the major issues of global concern for the past few decades. The warning evoked by the Club of Rome (MEADOWS et al. 1972, MESAROVIC and PESTE 1974) against unchecked economic growth at the expense of natural resources, both renewable and non-renewable, may be the one of the earliest, while this view has since been strengthened and more widely acknowledged by such succeeding reports as those from the U.S. Presidential Committee (BARNEY 1980a, 1980b, 1980c), FAO (LANLY 1982) etc..

The rise of a civilization and the accociated increase in human population have always been made possible at the expense of forests since ancient times. Even discounting the climate changes that have occurred since the days of ancient civilizations, the shrubby and denuded lands of Central China, Indus Valley, Hindustan Plains, Mesopotamia and Egypt, all tell of the long-lasting impacts of the great ancient civilizations. The same is true of the modern civilization of European countries. It was wood as fuel, and as building, industrial and shipbuilding material that enabled the early industrial renovations of the 16th and 17th Centuries to occur, which in turn nursed the real industrial revolution to come (NEF 1932), as well as the subsequent continuation and rise of modern Western civilization. As a result, the forests that predominantly covered European countries shrank to the present coverage of some 30 percent or less of the total land area.

Of course, forest resources can not be exploited for nothing. Deforestation causes a wide variety of problems. It starts with such very localized problems as the loss of fertile topsoil and landslides in the limited area where deforestation took place, but its consequences expand

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downstream in the form of silting, flooding, shortage and irregularity of water supply etc. This has been true in ancient as well as in modern civilizations.

The industrialized nations of today, which include most of Europe, North America and some countries in the Pacific Basin have also suffered from these problems in their respective course of industrialization in the relatively recent past. However, in view of the developing countries of the tropical and sub-tropical regions today, the already industrialized nations were happy since their difficulties and responsibilities were limited to the more-or-less localized problems mentioned above. In other words, even when their forests were depleted and exhausted at home, innumerable forests were still remeining in the other regions of the globe from where raw woody materials could be extracted in exchange for industrial products as did the British from North America for ship-building material throughout the 18th and 19th centuries (JAMES 1981), and Japan from Southeast Asia for industrial wood in its recovery from the exhaustive defeat in World War II (WWII).

Furthermore, the already-industrialized nations were happy in that the innumerable forests in other regions of the globe than the land of their own held down such global environmental problems as climate change for which current global deforestation is considered to be part of the cause by altering the global albedo and depleting the carbon dioxide reservoir (BOLIN et al. 1986).

In this regard, the currently developing countries in the tropics and subtropics which are in desperate need of forest resources as fuel, industrial material, fertilizer and so on in their efforts to industrialize, are triply burdened, i.e. the exploitation of their own forests evokes not only resource shortages and evnironmental problems at home, but also grave danger to the global environment.

The long-range objective of our work is to find narrow pathways for the industrialization of developing countries through these labyrinth of problems that the exploitation of forest resources cause, locally, nationally and internationally. The reason Asia and Thailand were chosen above others, was that they are respectively the region and the country in which the rate of deforestation has been most pronounced in association with economic development, and therefore, the conflict between the forest exploitation and the resultant socioeconomic problems are considered to be the most pronounced, intensive and telltale of the rest of the developing world. In this paper, the present state of the Asian forests is discussed in a broad historical perspective to identify where Thailand and its forests stand in the geographical/historical frame of the region, followed by an examination of Thailand's socioeconomic problems resulting from the deforestation and degradation of its forests.

FORESTS OF ASIA

Effects of Ancient Civilizations upon the Forests of Asia

From the ancient civilization point of view, Asia east of Pakistan, can be classified into three categories, i.e. the central region of major civilizations, the peripheral region to those major civilizations, and the hinterland region that stretches behind the peripheral region. Although these bounds of the ancient civilizations and the boundaries between the present political units do not necessarily coincide, the central region of civilizations undoubetedly includes China and India. The second region may include such countries as Thailand, Korea, Viet Nam, etc., which lie directly neighboring the centers. The third region, which may includes Japan, Indonesia, Malaysia, etc., were doubly segregated from the direct influence of the central civilizations by the peripheral countries of the second group, as well as by the surrounding seas.

Although they have been obscured to a certain extent by the influence of more recent civilizations brought to Asia along with such successive religious philosophies as Hinduism, Moslem, Catholicism and then Protestantism to a varying degree depending on the country involved, the effects of these ancient civilization are still strongly felt in the present status of forests.

In a way, human civilization can be defined as a complex of technological, political and social systems which enables more human population to be supported in a more luxurious way. Thus, the establishment of a civilization means the establishment of technological, political and social systems which exploit natural resources more effectively than before. Until the late phase of industrial revolution, when considerable bioresources were replaced by mineral resources as the source of energy and raw materials, the former, originating almost exclusively from forests, was the major source of energy and material to support civilizations. The iron output from charcoal-burning smelters was surpassed by that from coke smelters so late as the 1790's even in Great Britain (NEF 1932).

Thus it is no wonder that in the region where ancient civilizations flourished and were subsequently passed down over thousands of years, the lands and forests had been exhausted and depleted long before the arrival of modern civilization by supporting a huge mass of population almost continuously to the point where today, any further exploitation is almost impossible.

In the region of the other extreme, i.e. in the hinterland region of the ancient civilizations, both forests and land fertility have been very well preserved until recently due to the scarce population for forests to support. Even after the massive extraction of timber by modern means of heavy machinery in the last couple of decades, in order to meet post-WWII industrial demands as well as to support rapidly increasing local population, the thick and lush forest cover of this region is no comparison with the impoverished shrubby forests of the ancient civilization centers.

In the peripheral regions, the history and present status of demography and forests are just midway between the above two extremes. In this region, local civilizations such as Sukhotai (ca. 1230-1440), Ayuthaya (ca. 1350-1770), and Chakri (1782-present) Dynasties of Thailand, Pagan (ca. 1040-1330) and Toungu (ca. 1500-1750) Dynasties of Burma, and so on, flourished under the direct or indirect influences of, and on-and-off contact with the major civilizations of China or India or both. Being younger, smaller, less-lasting and thus less populous than the major ones, these local civilizations exploited land and forests less intensively and extensively than did the major civilizations. As a result, the forests of this region have been better preserved than those of the civilization centers, but not as well as those of the hinterland region. The effects of the ancient and medieval civilizations upon forests discussed above, are shown schematically in Fig. 1.

Interestingly enough, the above classification of countries by the distance from the ancient civilization centers, roughly corresponds with the natural geographical zoning of Asia by continentality or oceanicity. The region of the central civilizations is situated right in the continental part of Asia, while much of the peripheral region consists of countries in coastal Asia, and the hinterland region covers most of insular and peninsular Asia. In view of this correspondence, the terms "civilization centers", "peripheral regions" and "hinterland" are used henceforth interchangeably with the terms "continental", "coastal" and "insular/peninsular" Asia.

Before closing this section, it would be fair to note that another important factor that makes the civilization centers less forested than the peripheral region, which in turn is less forested than the hinterland, is their difference in continentality, or conversely oceanicity. The ocean is the very source of precipitation which is essential to tree growth and formation of forests. Thus, being surrounded by the sea, insular/peninsular Asia is more naturally endowed than coastal Asia, and much more so than continental Asia in terms of potential for tree growth and forest cover as well as for recovery of vegetation from devastation.

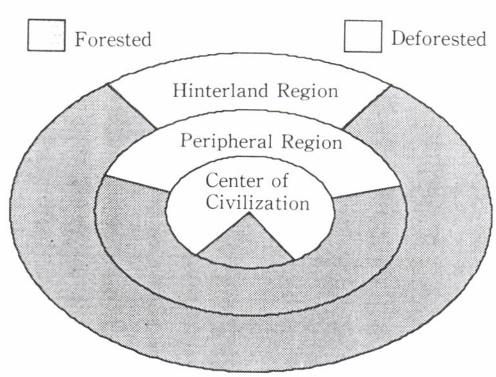

Fig. 1 Effects of ancient and medieval civilization upon present forest cover

Present State of Forests of South-Southeast Asia

To provide the above discussion with some statistical evidence, and to show the state of Thai forests in comparison with those of neighboring nations as well, forest cover statistics for 16 nations in South and Southeast Asia are given in Tables 1 through 3. For statistical consistency, all the original data in the Tables was derived from the Tropical Forest Resources Assessment Project of the United Nations' Food and Agriculture Organization (FAO 1981). As the name of the original data source indicates, the countries involved are exclusively from South and Southeast Asia. Tables 1 and 2 respectively, show estimates of natural woody vegetation at the end of 1980 and 1985, while Table 3 shows the difference between them, i.e. the trend of deforestation and forest degradation in the five years.

In accordance with the notion of remoteness from the great ancient civilizations, the 16 countries involved were classified into three groups, i.e. civilization center (CC), peripheral region (PF) and hinterland region (HL). Most of the countries involved can be easily classified. There is not much room to debate in classifying India as civilization center, Thailand as peripheral and Papua New Guinea as hinterland, whereas a few of them, like countries such as Nepal and Lao, may need more rigorous historical and cultural examination before their classification is firmly established. For the present analysis, however, the tentative classification given in Table 1 through 3 should suffice.

The original FAO data is far more complicated, with the natural woody vegetation being classified into great detail by such multiple of criteria as species composition, stand density, production capacity, management status, past logging history etc., but they were aggregated here so that each given breakdown would stand out to a reasonable degree by itself. By the same token, fallow area which was originally given for each vegetation type, is also put together under the column heading "Fallows", so as to include all those resulting from harvesting of all forms of closed and open forests.

As has been mentioned in the preceding section, the most striking difference between the three regions is the existing forested area. In 1980 (Table 1), natural woody vegetation covers only about 20 percent on average, of the total land area in the countries of the civilization center, whereas it covers 60 percent in the peripheral region and 80 percent in the hinterland region. Similarly, closed forests

Table 1 Area of natural woody vegetation at the end of 1980 as estimated by FAO (in thousand ha)

Classi-fica-tion	Country	Total Land Area	Natural Woody Vegetation										
			Total	Tree Formation									Shrub
				Total	Closed Forest						Open Forest	Fallows	
					Total	Broadleave			Coni-fer	Bam-boo			
						Total	Prod'v	Unprod.					
CC	Nepal	14,080	2,461	2,231	2,051	1,610	1.055	555	330	1	180	110	230
CC	Pakistan	80,394	3,585	2,480	2,185	860	220	640	1,325	0	295	0	1,105
CC	India	328,759	72,082	66,704	61,311	46,044	38,358	7,686	4,357	1,440	5,393	9,470	5,378
CC	Bangladesh	14,400	1,242	1,242	1,242	927	850	77	0	0	0	315	0
HL	P. New Guinea	46,169	39,705	39,620	35,610	33,710	14,035	19,675	520	0	4,010	1,445	85
HL	Philippines	30,000	13,030	13,030	13,030	9,320	6,700	2,620	190	0	0	3,520	0
HL	Malaysia	32,975	25,820	25,820	25,820	20,995	15,552	5,443	0	0	0	4,825	0
HL	Indonesia	190,435	158,155	134,255	127,355	113,575	73,575	40,000	320	0	6,900	17,360	23,900
HL	Brunei	577	560	560	560	323	287	36	0	0	0	237	0
PF	Kampucea	18,104	13,273	12,873	7,748	7,150	5,120	2,030	18	380	5,125	225	400
PF	Thailand	51,400	16,975	16,475	10,035	8,135	3,915	4,220	200	900	6,440	800	500
PF	Lao	23,680	19,360	18,625	13,410	7,560	2,880	4,680	250	600	5,215	5,000	735
PF	Bhutan	4,700	2,370	2,345	2,305	1,490	1,315	175	610	0	40	205	25
PF	Sri Lanka	6,561	2,727	2,512	2,512	1,659	1,226	433	0	0	0	853	215
PF	Viet Nam	32,956	21,190	20,860	19,520	7,400	3,670	3,730	170	1,200	1,340	10,750	330
PF	Burma	67,655	52,641	50,041	50,041	31,193	23,116	8,077	116	632	0	18,100	2,600
	Total	942,843	445,176	409,673	374,735	291,951	191,874	100,077	8,406	5,153	34,938	73,215	35,503
Civilization		437,633	79,370	72,657	66,789	49,441	40,483	8,958	6,012	1,441	5,868	9,895	6,713
Peripheral		205,055	128,536	123,731	105,571	64,587	41,242	23,345	1,364	3,712	18,160	35,933	4,805
Hinterland		300,155	237,270	213,285	202,375	177,923	110,149	67,774	1,030	0	10,910	27,387	23,985

Table 2 Area of natural woody vegetation at the end of 1985 as estimated by FAO (in thousand ha)

Classi-fica-tion	Country	Total Land Area	Natural Woody Vegetation										
			Total	Tree Formation									Shrub
				Total	Closed Forest						Open Forest	Fallows	
					Total	Broadleave			Coni-fer	Bam-boo			
						Total	Prod'v	Unprod.					
CC	Nepal	14,080	2,046	1,816	1,636	1,210	730	480	310	1	180	115	230
CC	Pakistan	80,394	3,860	2,435	2,150	855	215	640	1,295	0	285	0	1,425
CC	India	328,759	72,531	67,153	61,760	45,384	37,758	7,626	4,302	1,420	5,393	10,654	5,378
CC	Bangladesh	14,400	1,227	1,227	1,227	887	825	62	0	0	0	340	0
HL	P. New Guinea	4,617	39,595	39,510	35,500	33,600	13,920	19,680	520	0	4,010	1,450	85
HL	Philippines	30,000	11,570	11,570	11,570	8,865	6,250	2,615	185	0	0	2,520	0
HL	Malaysia	32,975	25,191	25,191	25,191	19,721	14,378	5,343	0	0	0	5,470	0
HL	Indonesia	190,435	157,160	133,260	126,360	110,580	67,540	43,040	320	0	6,900	19,460	23,900
HL	Brunei	577	560	560	560	298	262	36	0	0	0	262	0
PF	Kampucea	18,104	13,203	12,788	7,683	7,025	5,005	2,020	18	380	5,105	290	415
PF	Thailand	51,400	15,280	14,780	8,975	6,915	2,880	4,035	195	865	5,805	1,000	500
PF	Lao	23,680	19,085	13,310	7,060	2,455	4,605	250	600	5,040	5,400	735	
PF	Bhutan	4,700	2,360	2,335	2,295	1,485	1,310	175	605	0	40	205	25
PF	Sri Lanka	6,561	2,371	2,156	2,156	1,368	1,000	368	0	0	0	788	215
PF	Viet Nam	32,956	21,415	21,085	19,745	7,100	3,470	3,630	145	1,200	1,340	11,300	330
PF	Bruma	67,655	52,590	49,990	30,685	22,608	8,077	113	617	0	18,575	2,600	
	Total	901,291	440,044	404,206	370,108	283,038	180,606	102,432	8,258	5,083	34,098	77,829	35,838
Civilization		437,633	79,664	72,631	66,773	48,336	39,528	8,808	5,907	1,421	5,858	11,109	7,033
Peripheral		205,055	126,304	121,484	104,154	61,638	38,728	22,910	1,326	3,662	17,330	37,558	4,820
Hinterland		258,603	234,076	210,091	199,181	173,064	102,350	70,714	1,025	0	10,910	29,162	23,985

Table 3 Deforestation and degradation of natural woody vegetation between 1980-1985 (in thousand ha)

Classi-fica-tion	Country	Total Land Area	Natural Woody Vegetation										
			Total	Tree Formation									Shrub
				Total	Closed Forest						Open Forest	Fallows	
					Total	Broadleave			Coni-fer	Bam-boo			
						Total	Prod'v	Unprod.					
CC	Nepal	14,080	415	415	415	400	325	75	20	0	0	-5	0
CC	Pakistan	80,394	-275	45	35	5	5	0	30	0	10	0	-320
CC	India	328,759	-449	-449	-449	660	600	60	55	20	0	-1,184	0
CC	Bangladesh	14,400	15	15	15	40	25	15	0	0	0	-25	0
HL	P. New Guinea	4,617	110	110	110	110	115	-5	0	0	0	-5	0
HL	Philippines	30,000	1,460	1,460	1,460	455	5	5	0	0	1,000	0	
HL	Malaysia	32,975	629	629	629	1,274	1,174	100	0	0	0	-645	0
HL	Indonesia	190,435	995	995	995	2,995	6,035	-3,040	0	0	0	-2,100	0
HL	Brunei	577	0	0	0	25	25	0	0	0	0	-25	0
PF	Kampucea	18,104	70	85	65	125	115	10	0	0	20	-65	-15
PF	Thailand	51,400	1,695	1,695	1,060	1,220	1,035	185	5	35	635	-200	0
PF	Lao	23,680	275	275	100	500	425	75	0	0	175	-400	0
PF	Bhutan	4,700	10	10	10	5	5	0	5	0	0	0	0
PF	Sri Lanka	6,561	356	356	356	291	226	65	0	0	0	65	0
PF	Veit Nam	32,956	-225	-225	-225	300	200	100	25	0	0	-550	0
PF	Burma	67,655	51	51	51	508	508	0	3	15	0	-475	0
	Total	901,291	5,132	5,467	4,627	8,913	11,268	-2,355	148	70	840	-4,614	-335
Civilization		437,633	-294	26	16	1,105	955	150	105	20	10	-1,214	-320
Peripheral		205,055	2,232	2,247	1,417	2,949	2,514	435	38	50	830	-1,625	-15
Hinterland		258,603	3,194	3,194	3,194	4,859	7,799	-2,940	5	0	0	-1,775	0

cover 15, 50 and 70 percent of the respective total land area. There is no doubt that this marked difference between the three regions is a reflection of differences in the duration of human activities since the days of ancient civilizations.

Another marked contrast between the three regions is the rate of deforestation (Table 3). While the area of natural woody vegetation disappeared by a couple of million of hectares in the peripheral and hinterland regions during the five years, it even increased (negative signs) in the region of ancient civilization centers. This means that with the area of natural woody vegetation at less than one fifth of the total land area, there is virtually no forest left to be exploited in the latter region.

Regional Characteristics

(1) Region of ancient civilizations

As has been mentioned above the characteristic of the region of ancient civilization is the naked scarcity of the remaining natural woody vegetation to such an extreme as to make any further exploitation virtually impossible, even where there is desperate need of wood as fuel and industrial material. Even at this extreme of scarcity, the area of natural woody vegetation varies by country, ranging from 4.46 percent of the total land area in Pakistan to 21.93 percent in India. There is no doubt that in addition to population pressure, dry continental climate makes it more difficult for depleted forests to recover in Pakistan, but equally scarce natural woody vegetation (8.63 percent) in Bangladesh, where more than enough moisture is provided by heavy monsoon rain and two great rivers originating in the Himalayas, tells the magnitude of population pressure in this region in general.

The use of animal dung, widely practiced throughout South Asian countries as a domestic source of energy for cooking and other daily needs of heat, indicates that forests of this region had long been in a similar state of depletion even prior to the explosive population growth after WWII. To make matters worse, the increased demand for energy and raw materials resulting primarily from this increase in population, has also been directed to forests due to a chronic lack of foreign currency to buy alternative energy sources and raw materials from abroad.

This remains the same today. Although the area of natural woody vegetation, as a whole, is increasing (negative values in Table 3), the deterioration in forest inventory is still continuing, as indicated by the decrease in highly-stocked closed broadleaved forests and the corresponding increase in the area of much more poorly stocked fallows and shrubs.

(2) Hinterland region

From the historical point of view, exactly the opposite explanation holds for the forests of the hinterland region, i.e. the less population to be supported means much forest preserved. Thus from a vegetation point of view, the thick and lush forests of this region are no comparison to the exhausted shrubby forests of continental Asia. From an industrial timber resources point of view, however, a considerable part of these insular and peninsular forests has been depleted.

Due to the relatively rich forest resources still remaining, forests are most rapidly exploited volume-wise in this region at present, mainly for industrial timber, and subsequently by shifting cultivation. Areas of virgin forests logged-over annually and areas of secondary forests subjected to second logging, are also greatest in this region. However, relatively abundant forest resources, relatively intact soil fertility and lower population pressure in this region combine to prevent logging to result directly in deforestation.

In this region too, differences exist between the countries, and they are greater than between the countries of the ancient civilization centers. While natural woody vegetation covers nearly 80 percent or more of the total land area in Papua New Guinea, Malaysia, Indonesia and Brunei, it is only slightly more than 40 percent in the Philippines. This may be explained partly by the relatively early penetration of the country by modern Western civilization, which is more productive and thus more destructive than the traditional Oriental civilization, and partly by the extensive and intensive logging operations after WWII, mainly for export to Japan.

(3) Peripheral region

In this region as a whole, the natural woody vegetation accounts for slightly less than 50 percent of the land area, a coverage well below that of the hinterland region, but significantly better than that of the civilization centers. The younger and more modest local civilizations of this region had demanded less sacrifice, and thus, although forests had been exploited, forest deterioration was neither as intensive nor extensive as it was in the major civilization centers.

In comparison with the other regions, the countries of this region are much more differentiated from each other in such aspects as degree of political and military disturbance after WWII, political system, geographical location and cultural strain. These differences show themselves in the area of natural woody vegetation, which is highest in Lao at 82 percent of the total land area, and lowest in Thailand at 33 percent. Generally, the forests are better preserved in the countries involved in military disturbances after WWII, than in the countries relatively free from them. Interestingly enough, the latter nations are much better off economically than the former.

This fact indicates the significant dependence of economic development upon forest resources. The difference in the percentage of forested area between the war-plagued and war-free countries, may thus be taken as an indication of the toll that economic growth placed on the latter in the last 40 years or so following WWII. This difference, amounting to some 30 percent of the given land area on average, might look like too much for the cost of 40 years of economic build-up, but it should be remenbered that the post-WWII means of forest harvesting is much more effective, and thus destructive, than its prewar counterparts. Another important factor responsible for the rapid deforestation, is the relatively unthrifty habit of forest exploitation in this region. Due to the relative abundance of forest resources in the past, the people of this region failed to developed a thrifty culture to cope with limited forest resources as did the direct descendants of the major civilizations. As a consequence of all these factors combined, the forests of the region, which were already at a certain level of exhaustion, are easily giving way as we see today.

FACTORS AFFECTING DEFORESTATION IN THAILAND

Overview

It has already been shown that with forest cover at only one third of the nation's land, Thailand is the least forested nation in the peripheral region. Fig. 2, compiled from Table 3, shows that it is also the nation with the highest rate of deforestation. In no other country of the entire region under consideration, are forests disappearing at such a staggering rate of over 300,000 ha annually. As has been suggested earlier, this rapid rate of deforestation coincides very well with the rapid rate of economic growth of Thailand. The postwar gross domestic production (GDP) of the country expanded at a mean annual rate of

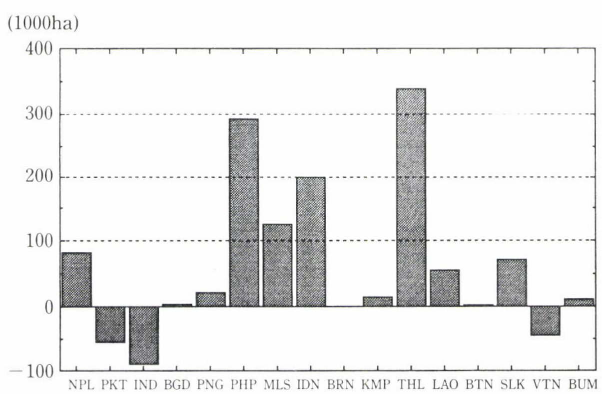

Fig. 2 Annual rate of deforestation by country

seven percent by the late 1980s. Discounting the somewhat dampened growth in this decade, the mean growth by the beginning of the '80s was even higher.

This parallelism between deforestation and economic growth not only indicates the heavy dependence of economic development upon the availability of forest resources, but also reminds us of RICHARDSON's (1966) remark on forest and economic development in China. Shortly after WWII, when the best bet for economic and social development was considered to be China and India by the majority of observers, Richardson, on his invited trip to China, showed an opposite view, reasoning that the exhausted forests of China wouldn't match its expected growth. The Thailand case gives another proof to Richardson's far-sighted inference.

Besides economic growth, there are many other factors responsible for the rapid postwar deforestation in Thailand either directly by themselves or indirectly through contribution to economic growth. The important factors and the relationship between them are shown in Fig. 3. The three most basic factors that eventually affect the rate of deforestation are the country's long period of peace since the late 18th Century, the sustained independence throughout the times of colonialism and imperialism of the 19th and 20th centuries, and the climate. The first two factors are interdependent, and the way they contribute to deforestation through economic growth and other factors has already been discussed in general terms in the preceding section.

The climatic control of vegetation and deforestation is mainly through precipitation. Precipitation in Thailand is not distributed evenly throughout the year, but concentrated in the monsoon months of June through September. During the monsoon, prevailing southwesterlies bring moist air from the Andaman Sea, but the country is parched for the rest of the year by the dry northeasterlies from Central Asia and the strong solar radiation of subtropics. What makes the country drier is the Bilauktaung Range which, stretching along the Burmese border on the west, puts much of Thailand, including the most populous Chao

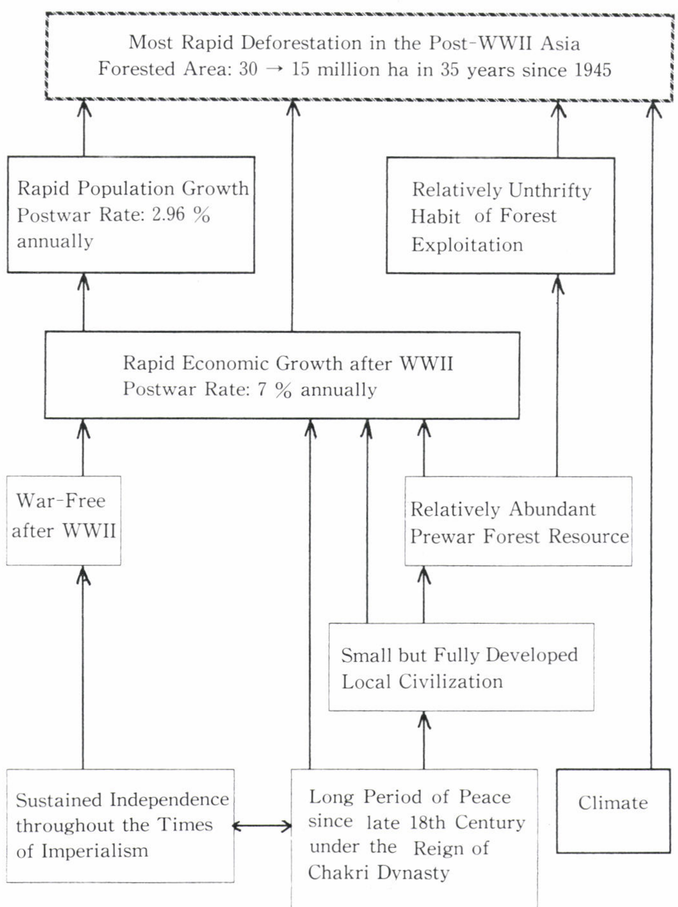

Fig. 3 Significant factors and their relationship leading to rapid deforestation in the postwar Thailand

Phraya Basin and the large Northeast Region, in the rain shadow of the moist southwesterlies. Thus, except for the southern peninsular part of the country, dry teak and dipterocarpus forests predominate, which are relatively vulnerable to exploitation and difficult to return once exploited.

Of the four factors which are directly associated with deforestation in Fig. 3, climate is beyond human control, thus, the measures against deforestation should be taken on the rest of the factors. Although either way doesn't look straightforward, as discussed in the next section, what makes the future bright is the discovery of natural gas in the Gulf of Siam in 1973 and the beginning of production in 1983. The shift of industrial and domestic sources of energy from fuel wood and charcoal to natural gas, will certainly ease the burden on the forests.

Socioeconomic Problems Evoked by Deforestation

Along the same line as what has been mentioned above, the rapid deforestation in the northern and northeastern part of the country has been continually observed since the end of WWII. On the one hand, logging industries partly financed the development of other light industries during 1960-1975, through earning from export of teak and other wood products in various forms. On the other hand, logging industries were both the push-and-pull factors towards deforestation. The push factor, led by the people in the industry themselves, was shown in the form of extraction of wood from once natural forests, while the pull factor was shown in the form of agricultural plantation and opening up of new cultivated land by rural-rural migration stemming mainly from economic factors. The latter was further aggravated by the habit of shifting cultivation by the minority tribes in the north and along the Laos and Burmese borders. One realizes immediately that Thailand has reached the deforestation frontier once he travels along the border of northeast Thailand and Laos.

Unlike the north, where teaks were such precious wood to be eagerly exploited, in the northeast, scant leftover timber of lesser market value in the paddy field (mostly glutinous rice and cultivated once in a year) were enormously cut down during the last decade. This rapid rate of depletion came after the deforestation had come nearer to the frontier in the 1980's.

The socioeconomic consequences of the country-wide deforestation came in the forms of drought and flood, and from time to time resulted in insufficient rice stock even for self-consumption in the northeast. Many northeast villages fell below the poverty level of the country. This caused rural-urban migrations, especially to Bangkok. Sussangkan (1987) estimates that approximately 60 percent of rural labor (roughly 2.4 million workers) are potential migrants actively seeking jobs. A considerable number of farm workers remaining in the agriculture sector are those who are not able to migrate due to a lack of skills and education.

In the north, where cultivating areas were insufficient relative to the population pressure, the socioeconomic conflicts came in different forms. For example disputes between timber profiteers vis-a-vis villagers over the source of the water supply for agriculture.

In the south, the timber industry was a late comer as compared with the other regions. Interestingly enough, logging occurred when the deforestation reached nearer to its frontier. It seems that deforestation was moving southward. The rapid rate of depletion resulted in a striking flood during the rainy season of 1988.

The disaster brought about by this flood may be regarded as the sequential peak of the deforestation in Thailand. The government (the Ministry of Agriculture and Cooperatives) initiated an indefinite prohibition on logging. The public at large seemed to have approved of this proposal. We should regard this public reaction as a sign of "recognition of the deforestation frontier" in Thailand. The demand for timber by the logging and wood product industries is presently met by import from Malaysia, Burma, Cambodia and Lao. The price of wood and wood products has returned to the normal market level.

The central region where the center of economic growth is located, still remains the country's most valuable rice bowl. It should be noted here that the Chao Praya River and its four major tributaries, namely the Ping, Wang, Yom and Nan, were the crucial routes down which logs were transported to the central region for domestic consumption and export.

While the government is obviously the most responsible for failing to protect natural forests, trespassers are sometimes blamed as the main culprit of deforestation. An eviction plan has been undertaken from time to time. Yet at present it is estimated that there are about 1.5 million families or nearly 10 million people living illegally in the forest reserve area. However, the government can not find places for them to move to and earn a living. One of the possible solutions is to grant them land rights and let them be the caretakers of forests i.e., legislation of the community forest.

Some scholar dated the existence of the community forest back to the Sukothai Dynasty of over 700 years ago. Others have argued that the existing community forests in many regions of the country give proof that villagers are competent forest managers. For instance in Huay Donsai village of the northern province of Lampoon, villagers have taken care of the community forest for generations. As a matter of fact, the community forest has expanded from 60 rai (1rai = 0.16ha) 70 years ago, to more than 1600 rai at present. For a comparison, a research study showed that one forestry official has to look after about 30,000 rai of forest area with a budget of 3 Baht per rai for conservation (1U.S.$ = approx. 26 Bahts).

One of the major targets of the Sixth Economic and Social Development Plan is to bring the forest area back to 40 percent of the country's total land area (it was 66 percent in 1950 and 28 percent or even less in 1989) comprising 15 percent for conservation area and 25 percent for production. The 25 percent is mostly in the hands of private owners who are likely to plant such fast-growing trees as *Eucalyptus* for paper and furniture industries in degraded forest areas. They are given a 30 year concession in the forest reserve land at the price of 10 Baht per rai per year.

The socioeconomic impact of the deforestation in Thailand is not limited within its borders, but has an international dimension of both cost and benefit. The total logging ban in Thailand will benefit the ecological system of the country, but at the cost of forest depletion in Burma, Lao and perhaps Sarawak, since the thirsty demand for lumber in Thailand must be fulfilled in one way or another. In view of the sacrifice of humanity resulting from the loss of forests, as well as the cost of recovering them in the long run, the present market price of timber seems too low. The decision of whether or not to cut a forest is not a national matter anymore, but a matter of optimum management of a limited global asset.

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Reconstructing Past Stand Structures using Tree Ring Data

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ABSTRACT

We developed a method to reconstruct past stand structures especially diameter distribution, by data obtained by investigations of present stands. On the assumption that regeneration takes place in gaps when upper-story trees die, we reconstructed past upper-story trees in past gaps. Past gaps were estimated from tree ring analysis and spatial distribution analysis of present trees. Past lower-story trees were reconstructed according to shading of the forest floor. It became possible to reconstruct past diameter distributions by repeating this procedure. We applied this method to a broad-leaved secondary forest stand in Tochigi Prefecture, Japan, and obtained apparently satisfactory results in reconstruction.

Keywords: diameter distribution, gap model, tree ring data, spatial distribution, stand structure

INTRODUCTION

In developing a management plan, it is necessary to predict stand growth. In many cases with natural forests, however, there are not enough data on stand growth to determine the parameters of a stand growth model. Although there are methods to reconstruct past stand structures from present data (KAMITANI and MARUYAMA 1978; KOOP 1989; KOHYAMA and FUJITA 1981), they require detailed investigations and are not practical for formulating forest management plans. Therefore, a method that enables us to reconstruct past stand structure with less detailed investigation should be developed.

If past stand structures can be reconstructed, it will become possible both to predict stand yield (ISHIBASHI 1989a, 1989b, 1990; WADA et al. 1990; KOBAYASHI et al. 1991) and develop management plans with a cutting course planning method (IMAZEKI et al. 1991; TANAKA and ISHIBASHI 1993).

In this paper, we discuss a method to reconstruct past stand structure from data obtained from the investigation of present stand. With this method, we can reconstruct past stand structure and predict future stand yield.

STUDY AREA

We applied this method to a broad-leaved forest stand in the Karasawa-yama University experimental forest in the southern part of Tochigi Prefecture, Japan (Fig. 1). This was originally a plantation of *Pinus densiflora*. The pines were gradually killed off over several decades by pine nematoda. About 10 years ago, the dead pines were cut and

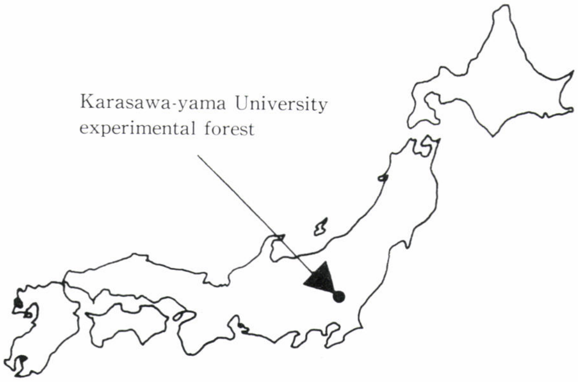

Fig. 1 Study area

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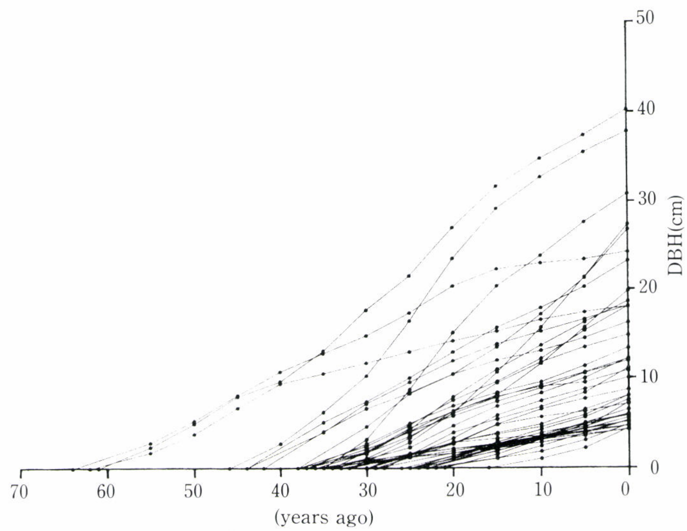

Fig. 2 The diameter growth of present trees

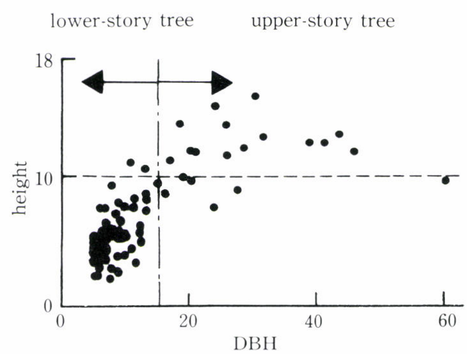

Fig. 3 Relationship between DBH and height (classification of upper-story tree and lower-story tree)

removed. Now the forest is dominated by such broad-leaved species as *Quercus serrata, Acer* spp., *Prunus* spp. and *Carpinus* spp..

We established a 20m×20m plot in the stand and examined the species, DBH, height and position of trees with DBH of 5cm or more. Breast height diameter (DBH) increment was measured from tree rings on a disk taken from each tree (Fig. 2). The DBH and the crown radius of trees were measured around the plot. We classified each tree as either upper-story or lower-story by DBH (Fig. 3).

RECONSTRUCTION OF PAST STAND STRUCTURES

Figs. 4 and 5 outline the method used to reconstruct past stand structure. In this method, past stand structure was reconstructed from diameter distribution, spatial distribution, species component ratio and tree ring data of a present stand.

First, the stand structure of 5 years ago was reconstructed from that of the present, then this was used to reconstruct the stand structure of 10 years ago. In this way, past diameter distributions were reconstructed. This method is an application of the gap model (SHUGART 1984). Lower-story trees were reconstructed from the relationship between the distribution of lower-story trees and the shaded ratio of the forest floor.

Reconstruction of Upper-story Trees

First, the ground plan of 5 years ago was plotted using the present ground plan and crown projection of upper-story trees and the average diameter growth curves for each species (Fig. 6). For upper-story trees, the crown projections were estimated from the relationship between DBH and the crown radius of present trees (Fig. 7). As the study area was steep and center of crown was shifted from position of tree stem, we draw the crown projection shifted lower-side of slope 2.4m for broad-leaved trees and 1.8m for *Pinus densiflora* from center of tree stem. The positions of ingrowth under-story trees "next term ingrowth" were marked. "Next term ingrowth" refers to trees that had appeared in the previous 5 years (the symbol '×' in Fig. 5).

Second, circles that included groups in the next term ingrowth were drawn (Fig. 5). We named these "gap circles" because we estimate that they reflect the gaps that were present 5 years ago. We set the radii of each gap circle for 1m longer than that of circle area that included one group of the next ingrowth trees. The range of gap circle size was the same as the range of upper-story trees crown size. If a gap size was larger than the largest crown size, two or more gap circles were fitted. If a gap size was

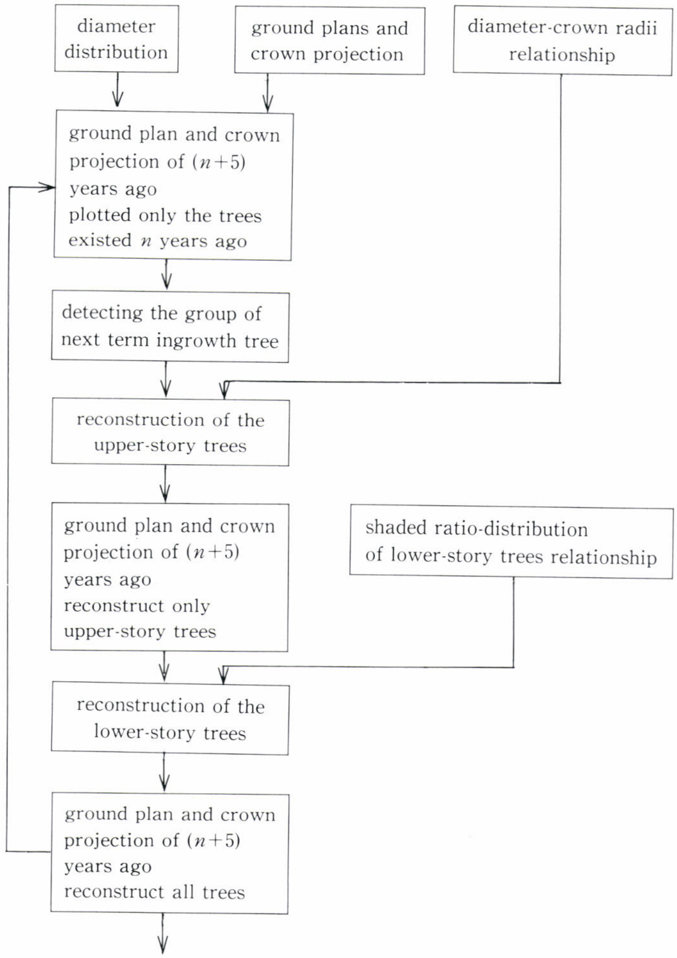

Fig. 4 Flowchart of the method to reconstract past stand structure.

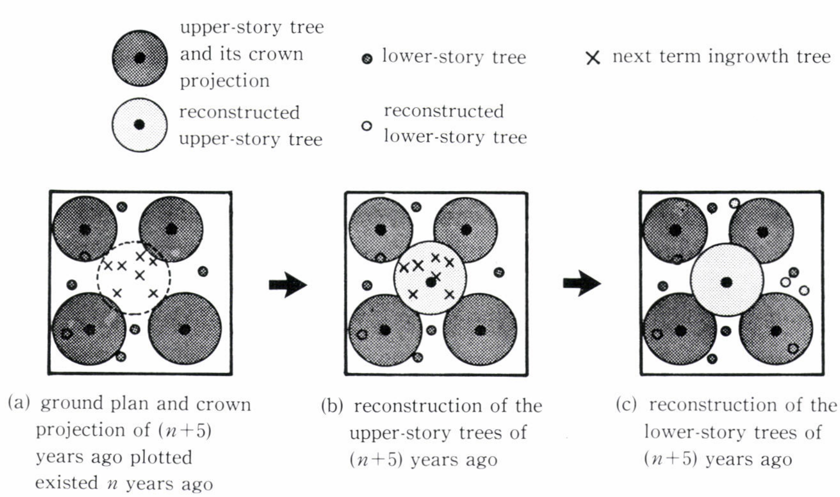

Fig. 5 The method to reconstruct past stand structure

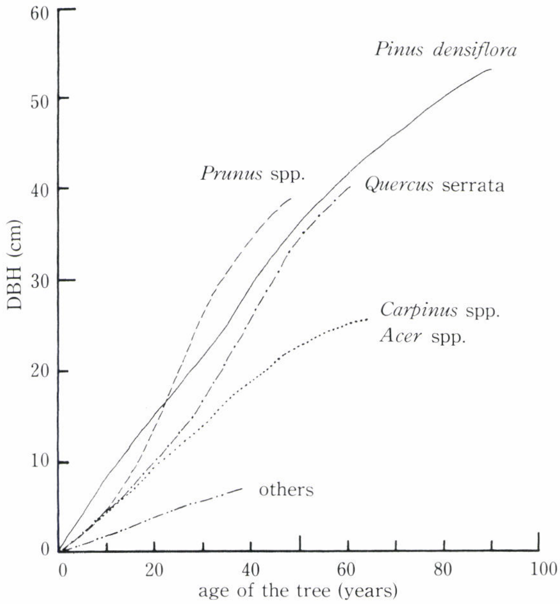

Fig. 6 Average growth curve for each species

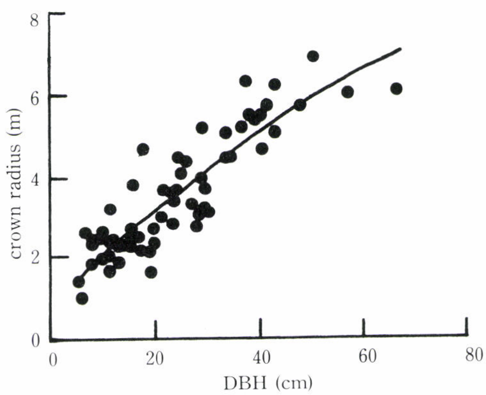

Fig. 7 The relationship between DBH and crown radius (broadleaved trees)

smaller than the smallest crown size, no gap circle was fitted. The upper-story trees which had disappeared in the previous 5 years, were reconstructed for each gap circle.

The species of the reconstructed upper-story trees were determined by the Monte Carlo method using a species component ratio of upper-story trees of 5 years ago (Table 1). If more information about species composition becomes available, the species component ratio of upper-story trees should be corrected. Since there was information that the pines had been cut and removed about 10 years ago, we reconstructed pine trees for upper-story trees of 10 years ago or more. After the species were determined, the DBH of the reconstructed trees as determined from the relationship between DBH and radius of the crowns (Fig. 7).

Table 1. The component ratio of species of the upper-story tree

species	number of trees	percentage (%)
Acer spp.	1	7.7
Quercus serrata	3	23.1
Prunus spp.	3	23.1
Carpinus spp.	5	38.5
others	1	7.7
total	13	100.0

Table 2. The number and the distributions of the lower-story trees

shaded ratio of sub plot	<50%		>=50%	
species	number	ratio	number	ratio
Acer spp.	1	3	0	0
Prunus spp.	1	3	0	0
Carpinus spp.	9	29	3	4
others	5	16	6	9
total	16	51	9	13
number of sub plot	31		69	

Reconstruction of Lower-story Trees

After reconstruction of upper-story trees, we reconstructed the lower-story trees using the shaded ratio and species component ratio of existing lower-story trees.

First, we divided the plot into 2m×2m subplots and obtained the shaded ratio and species component ratio of existing lower-story trees for each subplot. Then we compiled a table on the relationship between shaded ratio and species component ratio of lower-story trees. The shaded ratio for each subplot was calculated as the ratio of the area shaded by upper-story trees to the subplot area. In this study, we devided shaded ratios into two groups, "50% or more" and "less than 50%".

Next, we calculated the shaded ratio for each subplot of reconstructed ground plan and crown projection of 5 years ago. The number of reconstructed lower-story trees was determined to fit the distribution of lower-story trees shown in Table 2. The total number of lower-story trees which were expected to exist in the i-th shaded ratio class 5 years previous was determined by equation (1).

$$e_i = p_i \ r_i \quad (1)$$

where

p_i: number of subplots of i-th shaded ratio class

r_i: existing ratio of lower-story trees in subplots of i-th shaded ratio class

e_i: total number of lower-story trees in subplots of i-th shaded ratio class

The total number of trees which were expected to be reconstructed in a subplot of the i-th shaded ratio class was determined as the difference between e_i and n_i (equation (2)).

$$t_i = e_i - n_i \qquad (2)$$

where

n_i: number of lower-story trees which existed in subplots of the i-th shaded ratio class

t_i: number of lower-story trees which were expected to be reconstructed in subplots of the i-th shaded ratio class

The spatial distribution of reconstructed lower-story trees was determined at random. A subplot of the i-th shaded class was selected at random and the ordinate of each tree to be reconstructed was decided at random in the subplot. The species of the reconstructed lower-story trees were also determined with the Monte Carlo method using the species component ratio of existing lower-story trees. The DBH of reconstructed trees was determined to be 8cm, somewhat smaller than the mediam of the small-sized tree range. We could derive past stand structures in 5-year increment by applying this method the appropriate number of times.

RESULTS AND DISCUSSION

In this study, stand structures were reconstructed back to 30 years ago. Figs. 8 and 9 show the diameter distributions and ground plans of the present stand and those of 10, 20 and 30 years ago which were reconstructed.

Comparisons with another broad-leaved forest stand in the Karasawa-yama University experimental forest show that the reconstructed stand structure of past upper-story trees seems to be reasonable. This indicates that this method has potential to be used to determine parameters of a stand growth model using only data obtained by investigations in the present.

However, the use of this method for reconstruction is constrained by the age of upper-story trees. For example, since many upper-story trees were less than 40 years old (Fig. 2), in this study we didn't reconstruct past stand structures older than 30 years ago. If we try to reconstruct past stand structures older than 30 years, most of the data which we can use will come only from "reconstructed" trees.

KAMITANI and MARUYAMA (1978) and KOOP (1989) developed methods to reconstruct past stand structures. With these methods, it is posible to estimate changes in past stand structures using size distribution, spatial distribution and tree ring data. However, the method of KAMITANI and MARUYAMA is developed for balanced diameter distribution of closed stand and cannot reconstruct past stand structures which have changed. KOOP's method needs

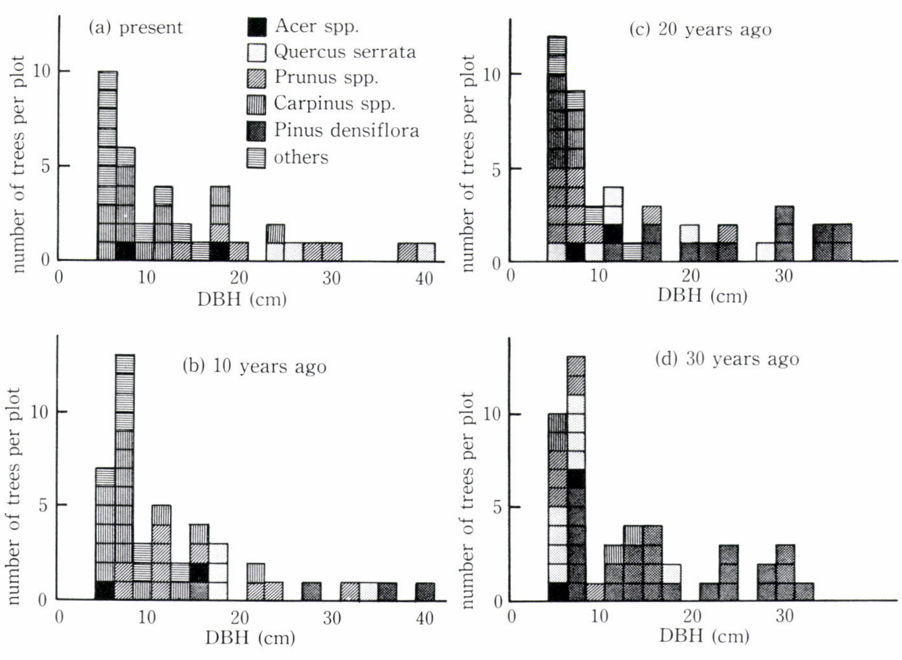

Fig. 8 Present and reconstruted diameter distribution

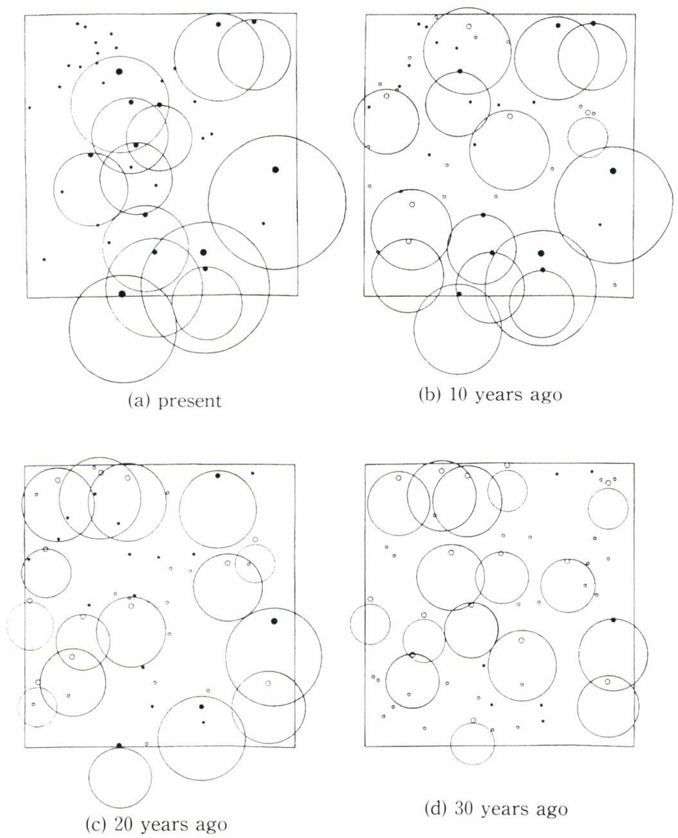

Fig. 9 Present and reconstructed ground plans and crown projections

	upper-story tree	lower-story tree
reconstructed tree	○, ◦	◦
present tree	●, •	•

detailed analysis about uprooting and fallen trees and is difficult to apply to Japanese forest stands which are steep and contain large amounts of decomposed materials. On the other hand, KOHYAMA and FUJITA (1981) and NAKASHIZUKA (1984) analyzed many forest stands which had different growth stages and discussed population dynamics. However, that method requires detailed investigations of many stands.

The method which has been discussed in this paper can reconstruct past stand structures using investigations of one or a few small stands. This method only needs information obtained from investigations of present stand structure and some tree ring data analysis. Then it can be applied to determine parameters of stand growth models used in developing a management plan, if there is no continuous forest inventory data for a natural forest.

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Definition of the System Yield Table

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ABSTRACT

A project study on the development of new type of yield table has been carried out since 1989. The result of this study was reported as "System Yield Table" in 1992 and "Programs of System Yield Table" in 1995. This report discusses the question "What is the system yield table ?" by overviewing programs developed. The yield table of the type used widely for Japanese forest management and forest planning to date since the 19th century is called a "conventional yield table". The conventional normal yield table or empirical yield table shows the estimated values of forest stand growth, in case of specific tree species in a specific area and under specific management as variables of site, stand age and density. This is called the yield table of the first generation.
A growth diagram of the stand prepared with the density effect of the stand as a basis is called a "forest stand density-control diagram". This diagram shows relationship corresponding to stand density, volume, tree height and diameter in the growth process of the stand on the plane. This can estimate the yield in the case of various density-controls. The conventional yield table of the first generation was line information on growth, while this density-control diagram would be plane information on growth, and is called the "yield table of the second generation".
The basic characteristic of the system yield table is that it is a computer-program with an algorithm to estimate the growth process in the future in cases of various types of management for the forest stand under various conditions. The system yield table can express countless growth processes in countless stands in a multi-dimensional space formed by variables including tree diameter, height, volume, density, tree age, thus it is called the third generation yield table to indicate the whole space. Evaluation shall be made for the function level of the system yield table by explaining the condition of the forest stand, management method and growth process. Functions are explained by the following four items.
(1) Quantity and quality of information on estimating forest stand condition, management and growth (information quantity).
(2) Range of applicable forest stand (applicable range).
(3) Usability of system yield table program (easiness of use).
(4) Rationality of growth model used for estimation (logic).

Keyword: yield prediction, yield table, growth model.

INTRODUCTION

Since April, 1989, a joint study on the "Preparation of a System Yield Table" has been carried out by 23 participants from 16 organizations. The result of this study was reported as "System Yield Table" in March, 1992. Following this, a project study aiming at the development of a practical program commenced in April, 1992. Through studies carried out over the past 6 years, the technical term "system yield table" has been used, and as a result of explaining its concept, "citizenship" is now being obtained to some extent among forest planning specialists. This report discusses the question "What is the system yield table ?" by overviewing programs developed thus far.

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CONVENTIONAL YIELD TABLE

Yield Table of the First Generation

The yield table of the type used widely for Japanese forest management and forest planning to date since the 19 th century is called a "conventional yield table". In comparison with this, a table with different types, functions and meaning is called a "system yield table". The main points of the conventional yield table will be summarized briefly below:

The conventional normal yield table or empirical yield table shows the estimated values of forest stand growth, in case of specific tree species in a specific area under a specific management as variables of site, stand age and density (NAGUMO and MINOWA 1990). As standards, stand volume and tree-number classified by major and sub tree, growing stock, average diameter, average height of stand are displayed for 5 year periods. This format commenced in the 1890s, and the format or development methods have been unified for national forests (MIZUTA 1977). In the 1950s, in particular, it was systematically developed on Japanese representative plantation tree species in each area (MIURA 1967).

The applications are estimation of yield in the future, judgment of management result, forestation policy and judgment of the site. This table has played a vital role as a basis for the calculation of standard cutting volume (allowable cutting volume) of national forests. As a representative example of the conventional yield table, a larch stand in Shinshu District (developed by Kazumi MINE, 1956) is shown in Table 1. The purpose of this yield table is to estimate the growth curve of the "normal" forest stand managed by the "normal method ". In other words, it is the function of the yield table to explain the growth process of a stand in a specific state and under specific management.

This can be explained by one curve for one growth process of one forest stand in the space with variables such as stand age, volume, tree height and density. In addition, even in the case of the multi-dimensional space of the growth process with variables of diameter, it may show one line displaying one pattern of one forest stand. This is called the yield table of the first generation (Fig.1).

This yield table does not explain anything about the stand in a state deviating from the line or about growth in cases deviating from this management. However, in actual planning practice, useful information has been obtained practically for this line-adjacent stand or similar management by using this line (SUGAHARA 1973). In calculating the standard cutting volume of national forest, a conventional yield table has been adjusted and used to show the average growth process of numerous and varied forest stands actually in existence.

Table 1 Format of conventional yield table

site	age (year)	major tree				sub tree	
		average height (m)	average diameter (cm)	1 ha		1 ha	
				tree number	volume (m^3)	tree number	volume (m^3)
I	10	8.4	9.6	1,390	45.8	810	11.1
	15	12.5	15.3	1,040	120.0	350	18.2
	20	16.3	19.0	796	187.0	244	31.5
	25	19.0	21.9	632	225.8	164	35.1
	30	21.5	24.7	514	256.7	118	37.1
	35	23.6	27.5	429	286.0	85	37.4
	40	25.4	30.2	362	311.1	67	39.1
	50	28.2	35.2	374	353.3	38	35.1
	60	29.5	39.6	226	383.6	20	25.8

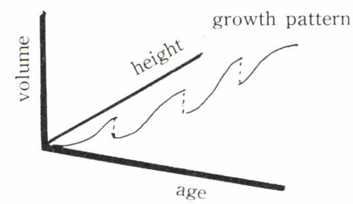

Fig. 1 Line information of stand growth process by the conventional yield table

FOREST STAND DENSITY-CONTROL DIAGRAM

Yield Table of the Second Generation

A growth diagram of the stand prepared with the density effect of the stand as a basis is called a "forest stand density-control diagram". This diagram shows relationships corresponding to stand density, volume, tree height and diameter in the growth process of the stand on the plane (ANDO 1968).

The following characteristics may be noted regarding application of this diagram: (i) it is possible to calculate the values of other variables from two variables as diameter and volume can be estimated when stand height and density are given, and (ii) it can estimate the yield in the case of various density-controls. It is possible to estimate the relation of each correspondence by drawing 4 variables together on the two dimensional plane. The greatest feature of this density-control diagram is the function explaining the growth process corresponding to various density controls under a certain condition, that is, an explanation is given for the growth process as one phase in the space with axes of density, volume and tree height.

The conventional yield table of the first generation was line information on growth, while this density-control

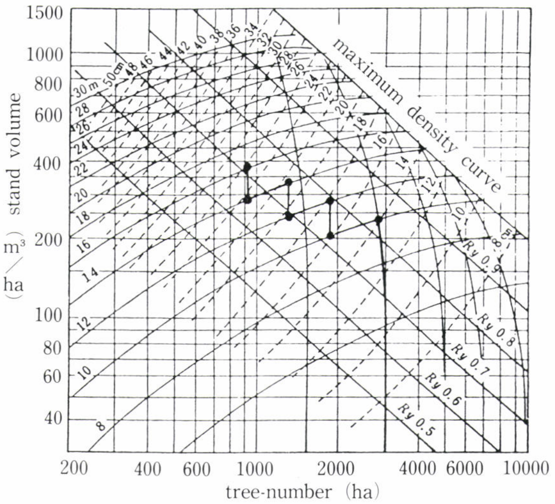

Fig. 2 Format of the stand density-control diagram

Table 2 Evaluating items of the system yield table

(1) Quantity and quality of information on estimating forest stand condition, management and growth (information quantity).
(2) Range of applicable forest stand (applicable range).
(3) Usability of the system yield table program (easiness of use).
(4) Rationality of growth model used for estimation (logic).

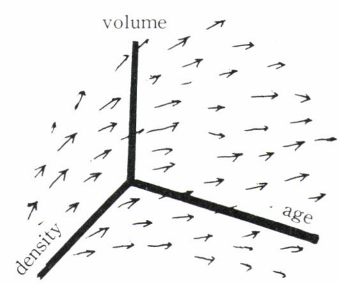

Fig. 3 Concept of multi-dimentional space information on stand growth process by the system yield table.

diagram would be plane information on growth, and is called the "yield table of the second generation". There are restrictions such as the difficulty in logic to draw 4 variables on one plane as a diagram, and the fact that stand age should be obtained secondarily. However, this density-control diagram has played a vital role in formulating policies on thinning in national and private forests.

SYSTEM YIELD TABLE

Yield Table of the Third Generation

The basic characteristic of the system yield table is that it is a computer-program with an algorithm to estimate the growth process in the future in cases of various types of management for the forest stand under various conditions (KONOHIRA 1992, 1995). Evaluation shall be made for the function level of the system yield table by explaining the condition of the forest stand, management method and growth process. Functions are explained by the following 4 items (Table 2), and levels are divided into 2 parts from the evaluating viewpoint (Table 3).

Using the above 4 evaluating items, definitions were made for each level according to the function necessary for the system yield table. Whereas, the system yield table means the explanation of the concept discriminating the conventional yield table, its basic function is, as mentioned above, said to be a "computer-program with an algorithm for estimating growth process in the future in cases of various types of management for the forest stand under various conditions". A stricter definition may not be necessary at present. With the development of further higher level programs, its definition will be enlarged, and there is high possibility of the development of a yield table of the 4 th generation.

For the time being, such mixed items as: "having a function just like the system yield table", "lacking parts even though it is the system yield table", or "having the complete function of the system yield table" may exist. These programs will survive if they are useful, and disappear if not in the field of forest management.

The conventional yield table has been called the "first generation yield table" with the display of one line in the forest stand growth. The forest stand density-control diagram is called the "second generation" meaning it displays one phase in the space with variables such as density, volume and tree height. The system yield table can express countless growth processes in countless forest stands in a multi-dimensional space formed by variables including tree diameter, height, volume, density, tree age, thus, it is called the third generation yield table to indicate the whole space.

Table 3 Levels and functions of the system yield table

Evaluating item	First level	Second level
Information quantity	Growth of stand is estimated by representative value or mean value of growing stock, volume, tree height, diameter, density (stand information). With stand age as variables, estimation is made for the condition of stand at an age in the future (optional stand age). There is no restriction on stand age or initial condition of stand starting the estimate (freedom of initial value). As a management method, density-control is conducted by thinning and planting tree numbers, and thinning is carried out at the optional time (thinning).	Single tree information composing the stand is estimated (single tree information). As contents of thinning, not only the thinning rate but selecting method are freely handled (complicated thinning). Estimation is made for the effect and influence of management other than thinning, e.g. selective cutting, prunning, vine cutting, fertilizing, damage by storms, damage by insects (complicated management method).
Applicable range	Applied for single tree species, same aged plantations (simple plantation). Applied for specific district (specific area). Applied for specific tree species (specific species). Applied for various site (site).	Applied for two-layer or multi-storied stand (non clear cutting management stand). Applied for natural forest or selective cutting forest (natural forest). Easy adjustment of parameter to apply for wider area or more tree species. (flexibility of application). Applied for density-control or long rotation management not existing at present (long rotation).
Easiness of use	Simple and easy operation and environment for full use with limited knowledge of the computer (easy use). Easy understanding with constant indication for use by program of conversation type (dialogue function) Free format with less input data. Effective use of existing data file (free format, data base, easy input). Easy re-trial or repeating calculation (simulation function). Display of estimating value with easily understandable type (freedom of output).	Estimable from other data in case of shortage of input data (default function). Earlier reach to the target in repeating the trial calculation (learning function). Improvement of estimating accuracy by adding the field survey data (self-growth function). Easy connection to other systems such as forest register, allowable cut calculation, harvest and sale (systematization function). Easy reforming of program for specific necessity by specific user (customizing function). Guide and instruction available for trouble during operation (helping function). Diagramming of output result (graphic function). High compatibility of hardware with software (compatibility).
Logic	Prospect of no serious error in the range of approval in practice with no complete rationality by many assumptions (rationality). Some reliable numerical calculation by experience or existing data without conformable model (credible). Distinction with explanation of calculating algorithm (algorithm).	Assembled with widely recognized growth formula (growth model). Consistent rationality to the applications among variables (logic consistence). Automatic checking test with clear explanation of calculating algorithm (autocheck function). Detection of abnormal value with prevention of runaway (self control function)

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Applicability of JERS-1 SAR Data for Monitoring of Forest Function and Environment

—Preliminary analysis of forest stand structure using JERS-1 SAR data for forest management—

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Sotaro Tanaka** and Toshiro Sugimura**

ABSTRACT

A verification study has been done using JERS-1/SAR data for forest stand structure analysis. The initial survey conducted at a relatively flat forest at in the Mt.Fuji area showed that there was a relationship between the radar backscatter intensity and the forest tree parameter in the azimuthal slope direction. In the secondary survey,investigation of the relationships between forest tree parameters (tree height, diameter at breast height (DBH), stand volume, stand density, standcoverage etc.) and the SAR data showed that JERS-1/SAR data were highly applicable for analyzing forest stand structure.

To obtain normalized backscattering coefficients with exclude topographical effects for any specified direction, we must develop an estimation formula for key parameters of stand analysis.

Keyword:L-band Synthetic Aperture Rader (SAR), Forest stand structure, backscattering coefficient

INTRODUCTION

The first Japanese Earth Resources Satellite (JERS-1) was launched successfully on February 11,1992. It was equipped with an L-band Synthetic Aperture Radar (SAR) and Optical Sensor (OPS) which consists of a Visible and Near Infrared Radiometer and a Short Wavelength Infrared Radiometer (VNIR & SWIR). JERS-1 is a joint project of the National Space Development Agency of Japan (NASDA) and the Ministry of International Trade and Industry (MITI). The verification program by MITI and NASDA is pioneering global monitoring through the use of this satellite system.

The forestry industry in Japan has deteriorated due to a decrease in the number and advancing age of foresters resulting from a long term slump in domestic wood production demand. It is difficult to obtain accurate forest information because of insufficient inventory data. Periodical and simultaneous wide area observation provided by satellite remote sensing are useful for forest observation.

Although, data on forest stand structure parameters are difficult to acquire from satellite optical sensor systems, we obtained SAR data from both JERS-1 and the first European Remote Sensing Satellite (EERS-1). The SAR, situated on satellite platforms, transmits microwaves through the atmosphere to the ground and receives the scattered waves (backscattering). Compared with an optical sensor, it better enables high-resolution, high-contrast observation, and accurate determinations of topographical features such as undulations of slopes, independently of weather conditions including fog or cloud cover (KIMURA 1993 ; SUGIMURA et al. 1993 ; TAKEUCHI 1995 ; WAKABAYASHI and ARAI 1995). SAR can detect microwaves scattered at the tree crown or stem of the forest.

Our objective is to find the correlation between the backscattering coefficient and the stand tree parameters. As the first step, we conducted a survey on forest management using SAR data on a uniform slope in the Mt.Fuji

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area to avoid the effects of terrain on SAR images.

STUDY AREA AND METHODOLOGY

The Initial Survey

The study area was the lower slope of Mt. Fuji around the Subaru Highway in Yamanashi prefecture. (See

Fig. 1 Location of study area

Fig.1). The area encompasses about 430 km^2 of forest between 900～2,300 meters in elevation on the northern slope of Mt.Fuji. Forty-four ground truth plots were selected for the verification in this area (NISHI et al 1993). The forest area extends from the warm temperate forest zone to the subalpine zone. The soil consist of basalt lava. Four forest types occur within the study area; Japanese red pine (*Pinus densiflora* S. et Z., 900～1,300m), coniferous wood (Hemlock: *Tsuga diversifolia* M. , Veitch fir: *Abies veitchii* L., and Spruce: *Picea jezoensis* CARR.H., 1,600～2,300 m), deciduous broad leaved forest (Birch: *Betula ermani* CHAM., 2,200～2,400m) and larch (*Larix leptolepis* GORD., 800～1,600m). Larch and spruce are planted on good sites on plane slope.

The Secondary Survey

From the results of the initial survey, we focused on the northern slope of Mt.Fuji,which lies along the azimuth direction of the radar. The ground truth plot areas were selected from artificial forest stands of over 10,000m^2 to obtain a good position for image analysis. The topographic conditions of the selected plots were 2.2～37.6 hectare, 1,125～1,490 m in elevation, S190W～S230W in slope direction , 3°～9° in slope angle. Tree species in the artificial stands were red pine, larch, fir,a mixed stand of red pine and larch, fir and larch. The total number of ground truth plots was 51 from 11 forest stands, with plot size ranging from 10m×10m to 20m×20m.

ANALYSIS METHOD

JERS-1/ SAR data and EERS-1/SAR data acquired on 23 April 1992 and 4 December 1991 were chosen for this study because of their high quality. Since SAR data are influenced by slope direction and angle on the Earth's surface, it is difficult to determine the relationship between stand structure parameters and SAR data in complex terrain areas. In the initial survey, the uniform terrain in all directions on Mt.Fuji was examined to identify complex topography. The ground truth area of 44 plots (20m × 20 m) seemed to provide standard growth conditions for each tree species throughout the study area. In each plot, vegetation was classified by the Brown-Blanquet method, and diameter at breast height (DBH), relative illuminance, stand density, slope direction, slope angle and mean tree height were measured. The SAR data characteristics are shown in Table 1 and the process flow chart is shown in Fig.2. The SAR images were converted to orthographic projections using a 1:5,000 topographic map. Using the above data, correlation analysis was done between each tree parameter for every tree species and the SAR data intensity (digital numbers), which were picked up from the pixels corresponding to the ground truth plots. The image processing method (geometric correction and map projection) used in this study is shown in Fig.3. Statistical approaches such as principal component analysis, regression analysis and correlation analysis were also employed.

Table 1 Characteristics of EERS-1 and JERS-1 SAR sensor

	EERS-1/SAR	JERS-1/SAR
Frequency	5300MHz	1275MHz
Wavelength	5.66cm	23.5cm
Polarization	HH	VV
Incidence age	23	35
Resolution	30m	18m
Swath with	100km	75km
Date	1991.12.4	1992.4.23

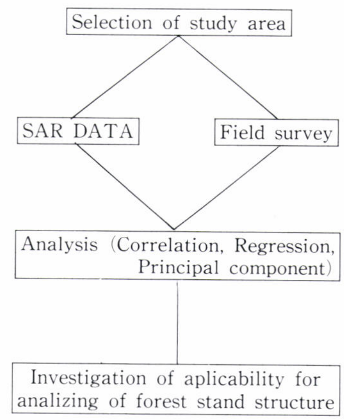

Fig. 2 Flowchart of study

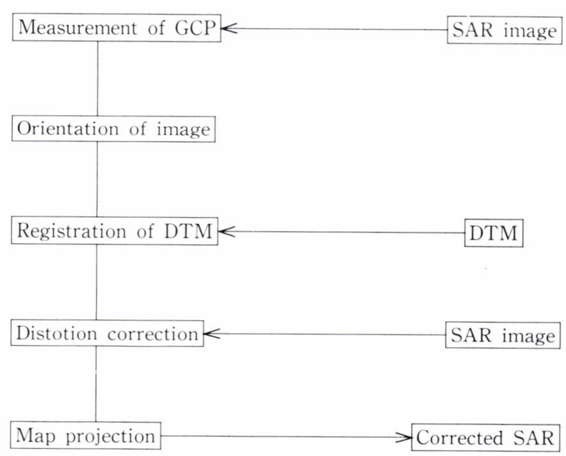

Fig. 3 Flowchart of geometric correction

Table 2 Forest stand factors

Area	Stand density (n/ha)	Stand density* (n/ha)	Mean DBH (cm)	Mean DBH* (cm)	Basal area (m^2/ha)	Basal area* (m^2/ha)	Mean tree height (m)	Mean tree* height (m)	Stand volume (m^3/ha)	Stand volume* (m^3/ha)	Stand coverage (%)	Stand coverage* (%)
A	1945	765	18.5	23.8	55.5	35.2	14.2	17.3	452.6	317.7	141.0	100.0
B	1490	365	16.5	21.6	33.9	13.5	11.0	16.9	260.4	117.1	154.2	98.4
C	1900	705	17.6	24.7	53.5	36.1	13.4	17.1	437.3	316.9	179.5	100.0
D	2100	1900	25.6	26.5	112.1	48.8	15.3	15.7	838.2	815.9	175.4	100.0
E	1500	867	20.1	23.9	50.9	39.4	12.3	14.1	324.6	265.6	189.0	100.0
F	2550	0	12.9	0.0	35.0	0	9.0	0.0	167.2	0.0	200.0	100.0
G	525	495	31.6	32.5	42.9	42.4	17.9	18.2	358.9	355.7	169.8	100.0
H	788	700	22.7	23.2	32.0	29.8	15.9	16.2	255.8	240.4	118.4	50.0
I	800	508	22.0	29.2	39.2	37.1	14.1	17.6	334.5	324.7	208.1	100.0
J	1867	375	16.7	21.2	42.5	14.0	10.8	13.2	238.3	90.2	190.4	100.0
K	1275	621	22.5	28.7	55.1	44.6	15.8	19.1	520.1	433.9	162.9	100.0
L	5200	0	3.1	0.0	8.2	0	1.1	0.0	14.5	0.0	130.9	0.0
M	1350	920	23.6	29.5	69.6	64.9	16.1	19.2	675.0	674.1	128.6	100.0
N	2200	0	7.6	0.0	11.3	0	6.5	0.0	46.3	0.0	128.6	100.0
O	1065	840	26.9	30.4	66.5	62.8	17.8	19.5	649.5	623.4	173.6	100.0

* : Results for trees greater than or equal to 20 cm in DBH

Table 3 Topography information of forest stand and SAR data

Area	Tree species	Survey area (ha)	Stand area (ha)	Number of Plot	Slope Direction	Slope Angle (°)	Elevation (m)	JERS SAR (CCT count)	EERS SAR (CCT count)
A	A/L	0.04	37.6	5	N31E	6	1490	97.6	97.4
B	A/L	0.04	10.8	5	N34E	6	1355	95.8	107.0
C	A/L	0.04	19.4	5	N24E	5	1295	102.4	113.3
D	P	0.01	11.1	2	N35E	5	1220	109.3	108.6
E	P	0.0175	12.6	2	N30E	5	1210	97.1	119.7
F	P	0.02	5.8	1	N10E	5	1240	96.5	112.4
G	P/L	0.04	11.0	5	N32E	5	1125	107.3	110.1
H	L	0.04	9.0	2	N50E	5	1130	102.2	106.3
I	L	0.04	5.4	3	N18E	9	1140	105.7	105.7
J	P	0.04	5.6	3	N38E	6	1255	94.7	99.9
K	A	0.037	14.8	6	N48E	7	1317	112.5	95.0
L	A	0.01	2.4	1	N40E	7	1455	78.8	81.3
M	A	0.037	3.6	5	N19E	6	1475	106.7	91.8
N	L	0.02	2.2	1	N28E	8	1465	94.9	92.6
O	A	0.04	20.2	5	N30E	3	1430	103.4	95.9

* A: *Abies veitchii* L. L: *Larix leptolepis* GORD. P: *Pinus densiflora* S. et Z.

RESULTS AND DISCUSSION

The results of the initial survey are shown in Table 2, 3 and 4. It was recognized that JERS-1/SAR data correlated with the per hectare basal area and the stand coverage. The stand coverage was calculated as the projected floor space of every tree crown. The second survey showed the relationship between JERS-1/SAR data andmean stand height, mean DBH, stand forest volume, stand density and stand coverage as shown in Figs. 5, 6, 7, 8 and 9, respectively. Table 5 shows the result of principal component analysis. Finally, Fig.4 shows the relation between tree height and DBH estimated by the regression analysis.

Relation between Basal Area and JERS & EERS Data Intensity

To find the relationship between diameter classes and SAR signal intensity, the correlation coefficients were

Table 4 Correlation matrix

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
A: stand density (n/ha)	1													
B: stand density* (n/ha)	-0.342	1												
C: mean DBH (cm)	-0.820	0.652	1											
D: mean DBH* (cm)	-0.759	0.658	0.899	1										
E: basal area (m^2/ha)	-0.339	0.933	0.667	0.634	1									
F: basal area* (m^2/ha)	-0.594	0.751	0.838	0.869	0.757	1								
G: mean tree height (m)	-0.867	0.640	0.961	0.897	0.663	0.853	1							
H: mean tree height* (m)	-0.744	0.628	0.840	0.981	0.602	0.835	0.877	1						
I: stand volume (m^3/ha)	-0.433	0.888	0.739	0.739	0.954	0.887	0.762	0.722	1					
J: stand volume* (m^3/ha)	-0.426	0.884	0.756	0.740	0.902	0.920	0.750	0.700	0.972	1				
K: stand coverage (%)	-0.219	0.089	0.245	0.204	0.257	0.072	0.169	0.120	0.133	0.048	1			
L: stand coverage* (%)	-0.674	0.300	0.500	0.447	0.478	0.384	0.567	0.432	0.462	0.345	0.474	1		
M: JERS-1/sar (cct)	-0.796	0.610	0.845	0.757	0.671	0.752	0.886	0.720	0.750	0.741	0.233	0.643	1	
N: EERS-1/sar (cct)	-0.483	0.283	0.407	0.290	0.269	0.110	0.375	0.254	0.125	0.052	0.596	0.482	0.343	1

* : Results for trees greater than or equal to 20 cm in DBH

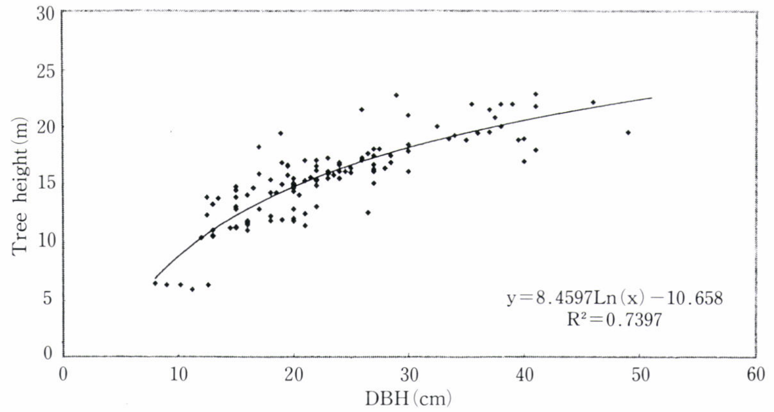

Fig. 4 Tree height and DBH (Lariox Leptolepis)

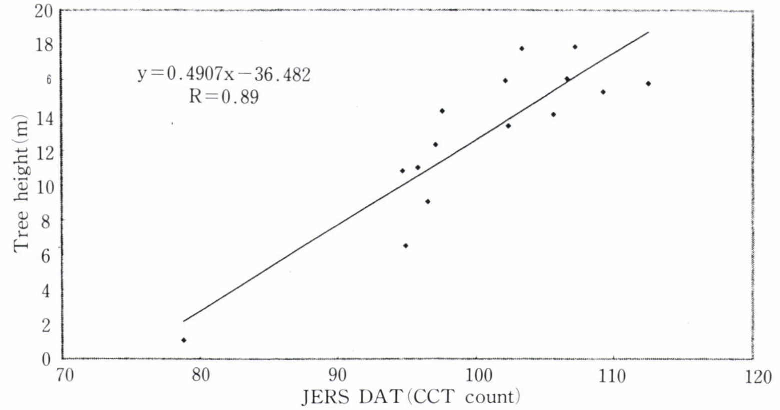

Fig. 5 JERS DATA and mean Tree height

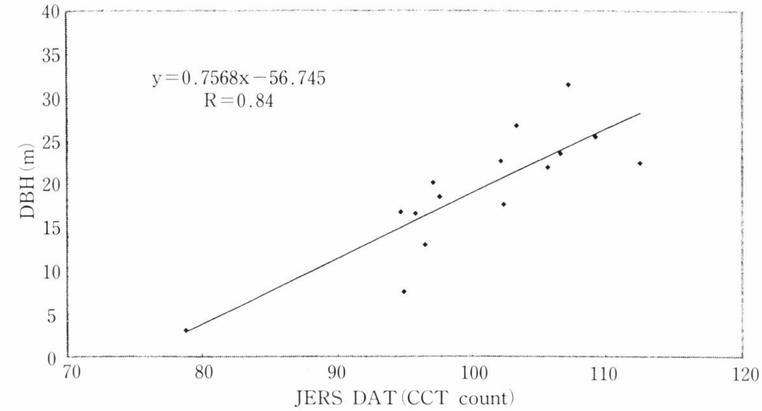

Fig. 6 JERS DATA and mean DBH

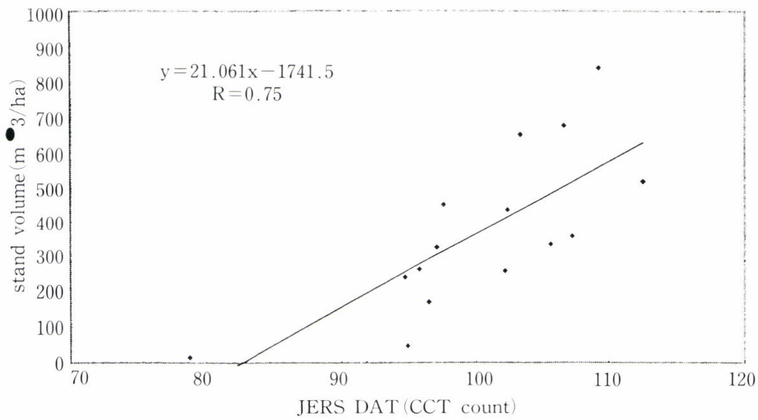

Fig. 7 JERS DATA and stand volume

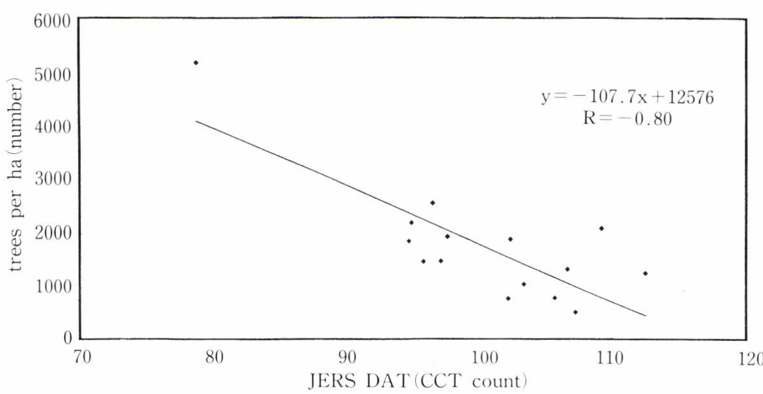

Fig. 8 JERS DATA and stand density

calculated for the following five tree diameter classes: below 5cm, 6～10cm, 11～20cm, 21～30cm, over 30cm. All correlation coefficients between the basal area and JERS-1/SAR data intensity were high.

As a result, the relation with EERS-1/SAR data intensity (digital numbers) did not depend on the basal area (Table 4). Thus, it appears that the EERS-1/SAR beam did not permeate through tree stems or branches because of its short wavelength (CHUAH and KANG 1994 ; HIROSAWA et al. 1987 ; HOEKMAN 1987 ; MATZLER 1994 ; MOUGIN et al. 1993 ; ULABY et al. 1984).

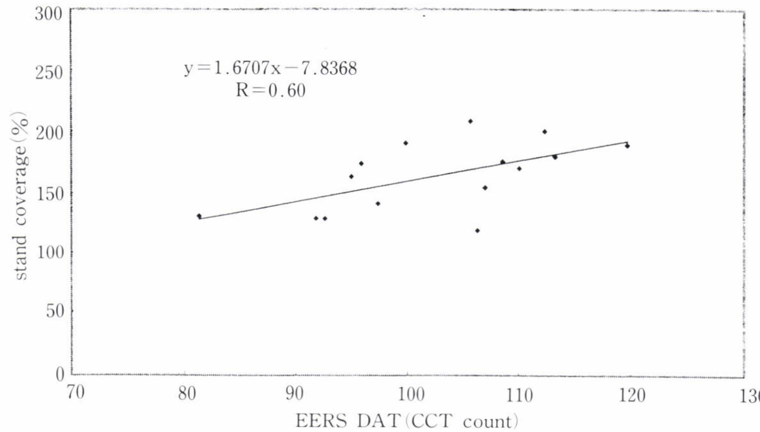

Fig. 9 JERS DATA and stand coverage

Table 5 Result of Principal component analysis

Accumulated proportion(%)	Parameter	Factor loading
First principal component	JERS SAR	0.890
	EERS SAR	0.377
	stand density	−0.761
	stand density (DBH≧20cm)	0.805
	mean DBH	0.933
	mean DBH (DBH≧20cm)	0.915
	basal area	0.836
65.09	basal area (DBH≧20cm)	0.912
	mean tree height	0.947
	mean tree height (DBH≧20cm)	0.882
	stand volume	0.897
	stand volume(DBH≧20cm)	0.879
	stand coverage	0.302
	stand coverage(high layer class)	0.606
Second principal component	JERS SAR	0.121
	EERS SAR	0.706
	stand density	−0.450
	stand density (DBH≧20cm)	−0.348
	mean DBH	0.105
	mean DBH (DBH≧20cm)	0.007
	basal area	−0.257
78.96	basal area (DBH≧20cm)	−0.264
	mean tree height	0.101
	mean tree height (DBH≧20cm)	−0.021
	stand volume	−0.337
	stand volume(DBH≧20cm)	−0.420
	stand coverage	0.614
	stand coverage(high layer class)	0.531

Relation between Stand Density and SAR Data

To find the relationship between the tree diameter class in the forest stand stratum and the stand density, the stand diameter class was divided into 2 groups: all stand diameter class, and the other diameter class with DBH bigger than 20 cm which occupied upper layer class in vertical distribution. Table 2 shows the area parameters. The results of correlation analysis (Table 4) show that JERS-1/SAR data was more highly correlated with the stand density of all trees. We should especially note that JERS-1/SAR beams permeate tree leaves and are scattered after hitting stems or branches (Matzler 1994 ; Mougin et al. 1993 ; Ulaby et al. 1984).

Correlation between Tree Stem Parameters and JERS-1/SAR Data

Fig.5 to 8 show that SAR data had a high correlation with every tree stem parameters. In all cases, correlation coefficients between tree stem parameters and SAR data were obtained at a level more than 0.75. Thus, there are obvious quantitative relationships between SAR and mean DBH, mean height and stand tree volume.

Correlation between Stand Density and JERS-1/SAR Data

Fig.8 shows that the stand density (as expressed by the number of trees per hectare) had a negative correlation with SAR data. The opposite tendency appeared for the stand density to the stem parameters agrees with the results of field surveys indicating that stand density increases with a decrease in mean stand height and DBH.

This is proof that the radar back scatter increases against large objects and decreases against small trees. In forest stands, the stand density, i.e.,number of trees per hectare, decreases when the mean DBH and height increase.

Correlation between Stand Coverage and SAR Data

It was found that EERS-1/SAR data has a high correlation with coverage as shown in Fig.9. However,JERS-1/SAR data was not correlated if tree crowns were closed, apparently due to differences in microwave wavelengths.

Results of Principal Component Analysis

From the results of principal component analysis (Table 5),it became clear that the first principal component is composed of stem parameters such as height, DBH, basal area, and tree volume. The first principal component with JERS-1/SAR data had a high correlation because the factor loading was 0.89. From the factor loading in principal component analysis, it was assumed that the second principal component may be related to tree leaves, due to the mixture of deciduous and evergreen trees. This may also be due to the differences in tree crown volume among plots with falling leaves.

CONCLUSION

Considering all the possible items relating to the stand structure, results obtained so far are as follows:

1. JERS-1/SAR data are potentially applicable to stand analysis since SAR data in tensity and tree stand parameters were apparently highly correlated.
2. EERS-1/SAR data intensity had little correlation with stand coverage. The correlation with this parameter was likely caused by the differences in microwave wavelengths.
3. The results of principal component analysis showed that JERS-1/SAR data had high correlation with tree stem parameters such as tree height, DBH, basal area and tree volume. EERS-1/SAR data, however, had little correlation with tree para meters. This may have been caused by differences in microwave wavelengths.
4. SAR data without radiometric corrections are difficult to be apply to stand structure analysis because of terrain effects. To obtain normalized backscattering coefficients for any direction free from topographical effects, we must develop an estimation formula for key parameters of stand structure analysis.

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