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Article

Site Classification for Sugi Plantations using GIS

Jinhua Chen*[1] and Nobuyuki Abe*[2]

ABSTRACT

This study aims to evaluate the effects of topographical factors on tree height growth and to classify stands of sugi (*Cryptomeria japonica* D.Don) into different site classes with Geographic Information System (GIS) analysis. To evaluate these effects, seventy-four plots (10 by 10m) were established in the study area. Calculations for all plots showed that the mean site index for northerly aspects is greater than for westerly and easterly aspects, and the lowest is for southerly aspects. Also, mean site indices are lower the closer the stand locations are to ridges. The lowest mean site indices are those of stands located within 10m of ridges. Next we classified sugi stands into three classes according to slope aspect and location on slope respectively. Integrating the two topographical factors with the growth data, sugi plantations were classified into four site classes: Class I, Class II, Class III and Class IV. GIS technology was used as an efficient means of performing geographical analysis, classifying sugi stands on the basis of topographical factors, and displaying the results.

Keyword: site classification, GIS, slope aspect, location on slope

INTRODUCTION

Classification of forest stands is very important to forest owners and managers. The work should be implemented in the early stage of forest management. Without understanding the potential productivity, forest managers are unable to make efficient silvicultural and management plans, e.g. where to plant trees, which species to plant, when to thin or fell, and how much income they might gain after felling trees.

Timber productivity in a forest stand is determined by environmental factors including soil, terrain and micro-meteorology around the tree, and the physiological mechanism of the tree. Tree growth is also affected by natural occurrences such as fire, disease and insect pests, and human disturbances like stocking density and thinning (Nishizawa *et al*. 1965). A site index (SI) can be used to some extent to evaluate timber productivity. Timber volumes, tree diameter, tree height and mean growth increments are generally accepted site indices (Japan Forestry Improvement & Extension Association 1983).

Estimation of SI from soil conditions and environment factors in Larix forests was reported by Nishizawa *et al*. (1965). But there are two problems in estimating and using SI. One is that site indices on different stands are defined as the same as ones on a small-scale area, although they are not appropriate for evaluating forest stands on large-scale areas. The other problem is that measurement of SI is costly because soil investigation is the main component in the work (Nishizawa *et al*. 1965; Niigata Prefecture 1979). Soil factors have been considered as the most important factors affecting sugi growth (Japan Forestry Improvement & Extension Association 1983). Soil investigation needs specialized knowledge and is to some extent subjective; that is, results depend on the individuals who carry out the investigation even though they use the same methods on the same location. Also, limited availability of soil maps and manpower makes it more difficult to do the work.

It is therefore desirable to find other more objective and easily implemented methods for investigation and evaluation. This study is based on the research results of silviculture geology that analyses the effects of location, topography and geology on tree growth as suggested by Yamada (Yamada 1971). Surface water and underground water, their transportation, distribution and evaporation

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around trees are controlled by topographical factors. Moisture, depth, structure, temperature, microorganisms and nutrients in different soil conditions are also determined by different topographical factors (Nishizawa *et al.* 1965; Yamada 1971). Topographical factors are natural factors that are seldom subject to human manipulation. We have therefore tried to use topographical factors for detailed classification of sugi stands on a large-scale level, on the assumption that water and soil conditions which are critical for sugi growth are controlled by topographical factors. Measuring topographical factors is easier for forest managers who lack pedologic knowledge. Also it is easy and efficient to analyze topographical factors with GIS technology which is more and more commonly accepted by forest managers. Investigation of topographical factors instead of complex soil factors is therefore more efficient.

The objectives of this study are (1) to evaluate the effects of topographical factors such as slope aspect and location on slope on tree growth of sugi at the stand level, (2) to define the criteria for classifying sugi stands into different site classes according to site indices, and (3) to employ GIS as a means of classifying sugi stands into different site classes on the basis of topographical factors.

METHODS AND PROCEDURES

Study Area

The study area is located in Kamo City, Niigata Prefecture, Japan. This area belongs to the northern land climate zone. Generally the seasonal wind is strong in winter. The precipitation is concentrated in the rainy season (mainly summer) and in winter. The study area is in the Niitsu Hills where the elevation is between 60m and 300 m. Most of the mountains have a slope of 20°to 30° (Niigata Prefecture 1979). The study area encompasses about 1,028 ha of forest compartments numbered from No. 1 to No. 23. The main vegetation is sugi plantations, covering about 687.1ha. Fig. 1 shows the areas of sugi stands at different ages. 47.3% of sugi stands are immature (325.3ha) and 52.7% are mature (361.8ha) when 40 years is defined as the mature age when they are ready for cutting. There are some broad-leaved forests mixed with pines and bamboo in the study area.

Field Investigation

1) Selection of research locations: Research locations were selected and plotted on forest maps and forest base maps (1: 5,000 scale) by referring to forest inventory books. The locations were selected to meet three requirements: (1) the location is in a forest stand that is broad enough to cover streams and ridges, (2) stand age at any one location is uniform, and 3) the species is sugi. Forest stands that cover complex terrain were excluded. Stand ages were directly read from forest inventory books. For this study eight places were selected as research locations. Stand ages at eight places are: Place1--46 yr., Place2--46 yr., Place3--60 yr., Place4--45 yr., Place5--86 yr., Place6--86 yr., Place7--50 yr., and Place8--50 yr.

2) Plot investigation: Assuming that water and nutrient conditions in soils have significant effects on sugi growth, locations of trees from ridges and streams and slope aspects were the main topographical factors measured. On a single research location, plots (10 by 10m each) were established consecutively from ridge to stream on a slope in accordance with the same azimuth (Fig. 2). The first plot was located beside the ridge and last plot on the stream. All slanting sides of plots were designed to be nearly perpendicular to contours. The distances of each plot from the ridge and slope aspects were recorded. Also two to three dominant trees were selected on every plot and their diameters at breast height (DBH) and heights were measured and recorded. In total, 74 plots were investigated.

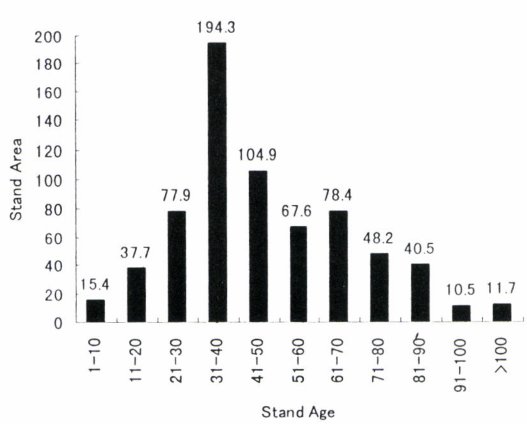

Fig. 1 Sugi stand areas at different stand ages

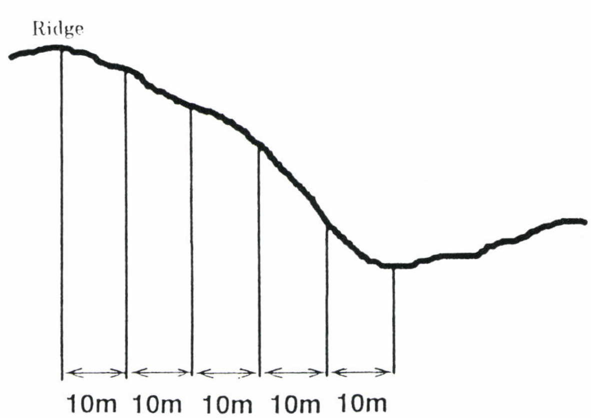

Fig. 2 Plot locations on a slope

RESULTS

Because the age of the sugi stands varied between plots (from 45 up to 86 years), it was necessary to estimate dominant tree height at a standard age for each plot in order to compare growth rates between plots. Heights at a standard age of 60 years were calculated by referring to formulae based on the SI of sugi plantations. The site class of each plot at forest stand age was obtained by referring to SI curves (NIIGATA PREFECTURE 1980). From this the mean height of dominant trees at 60 years old on each of the 74 plots was estimated. These were used as site indices to distinguish well-grown sugi stands from poorly grown ones in the study area.

Next the relationships between topographical factors and site indices were analyzed.

1) Slope aspect

Aspect is the compass direction of the line of descent down the slope. Aspect is expressed in positive degrees from 0° to 360°, measured clockwise from the north (ESRI 1995). Fig. 3 shows the site indices of plots in 8 places according to aspect. Aspects were divided into four groups according to degrees: north: 0°-45°and 315°-360°, east: 45°-135°, south: 135°-225°, west: 225°-315°. Mean site indices of forest stands in these four aspect groups were calculated. It was clear that the mean SI for the northerly aspect (25.18 m) was greater than that for the westerly aspect (22.93m) and easterly aspect (22.36m). The lowest was for the southerly aspect (17.69m). As the differences between the site indices for sugi stands with easterly and westerly aspects were insignificant, they were put into the same class. Hence the following three aspect classes were used (Fig. 4):

Class 1: northerly aspect (x1)
Class 2: easterly and/or westerly aspect (x2)
Class 3: southerly aspect (x3)

The student's t-distribution method was used to test the difference between the mean site indices of the three populations, and the testing results showed that there were significant differences between them at the 5% level (Table 1; ALDER and ROESSLER 1968).

2) Location on slope

Ridges and streams were directly identified from forest base maps, entered into the database and displayed with GIS software. By creating buffer zones around ridges, areas within the zones at different distances from a ridge were extracted. By combining the GIS data with field investigations, forest stands were classified into several classes in GIS-derived maps, i.e. coverages (ABE 1993).

Plot location was calculated as the distance of the

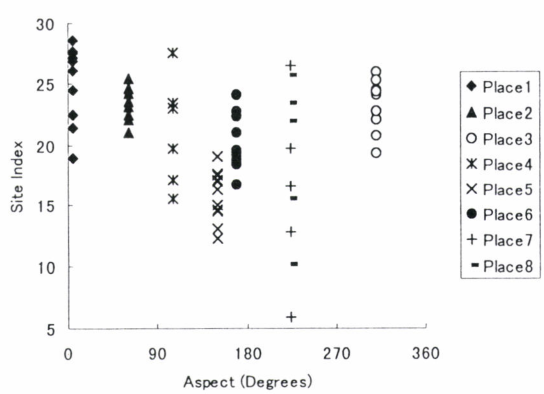

Fig. 3 Site indices of plots according to slope aspect (degrees) and place (research location)

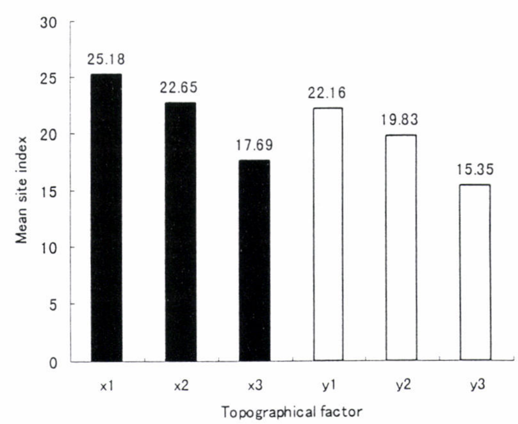

Fig. 4 Mean site indices of sugi stands in topographical factors

Table 1 Significant differences between mean site indices of stands by aspect

	North	East and/or West	South
North	–	*	*
East and/or West		–	*
South			–

Note: *Significant difference at 5% level

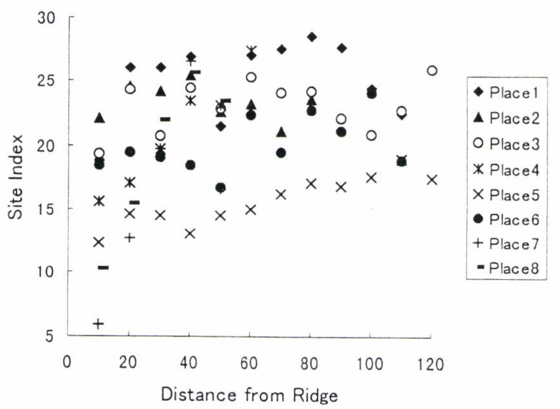

Fig. 5 Site indices of plots according to distance from ridges

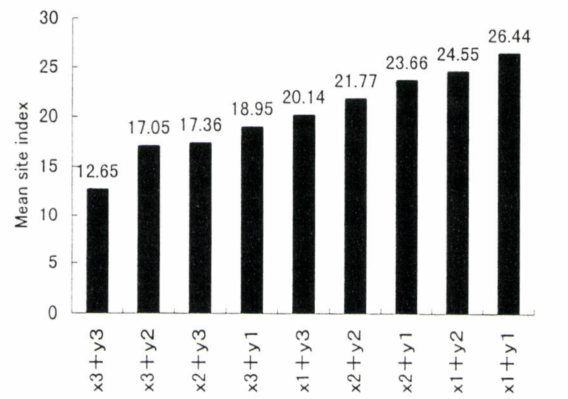

Fig. 6 Combination of topographical factors and the mean site indices

Table 2 Significant differences between mean site indices of stands by location

	Beyond 50m from ridge	Between 10-50m from ridge	Within 10m from ridge
Beyond 50m from ridge	—	*	*
Between 10-50m from ridge		—	*
Within 10m from ridge			—

Note: *Significant difference at 5% level

central point of a plot from the ridge. Forest stands on a slope were divided into several zones at intervals of 10m. The mean SI was estimated for each zone. Fig. 5 shows the site indices of plots in 8 places according to location on slope. The field data showed that mean site indices are lower the closer as the locations are to ridges. The lowest mean site indices are those of stands within 10m of the ridge.

Because the differences between the mean site indices of neighboring 10m zones are insignificant, they need to be divided into three broader groups which have greater differences between their mean site indices. Grouping neighboring zones makes it more time-efficient to manipulate GIS buffering later. The following table shows how the mean SI of the groups decreases the closer they are to the ridge (Fig. 4):

Class	Mean SI
Class 1: stands located beyond 50m from ridge (y1)	22.16
Class 2: stands located between 10-50m from ridge (y2)	19.83
Class 3: stands located within 10m from ridge (y3)	15.35

Student's t-distribution testing showed that there were significant differences between the mean site indices of Class 1 and Class 2, between Class 1 and Class 3, and between Class 2 and Class 3 (Table 2).

Table 3 Site classification criteria according to topographical factors

	SLOPE ASPECT	LOCATION ON SLOPE
Class I	North North	Beyond 50m from ridge Between 10-50m from ridge
Class II	East · West East · West North	Beyond 50m from ridge Between 10-50m from ridge Within 50m from ridge
Class III	South East · West South	Beyond 50m from ridge Within 10m from ridge Between 10-50m from ridge
Class IV	South	Within 10m from ridge

3) Integrated analysis

The analysis above describes the site classification with two topographical factors separately. In fact sugi

Table 4 Four site classes and the mean site indices of field data

Site class	No. of plots	Mean site index	Max.	Min.
Class I	10	25.81	28.5	21.48
Class II	26	22.92	27.45	17.13
Class III	34	18.51	26.51	12.71
Class IV	4	11.7	18.43	5.9
Total	74			

Table 5 Significant differences between mean site indices of stands in four classes

	Class I	Class II	Class III	Class IV
Class I	–	*	*	*
Class II		–	*	*
Class III			–	*
Class IV				–

Note:*Significant difference at 5% level

growth is affected by complex and interactive topographical factors (Abe 1993). In the next step we calculated the mean SI of a sugi stand on a particular location on slope in a particular aspect. Fig. 6 shows the mean site indices of the nine different combinations of aspect and location on slope. Taking an equal range of mean SI of 4 meters as the class interval, the nine combinations were divided into four new classes: Class I (SI = 24−28m), Class II (SI = 20−24m), Class III (SI = 16−20m), Class IV (SI = 10−16m). Those combinations were used as the site classification criteria for this study (Table 3). The student's t-distribution method was used to test the difference between the mean site indices of the four classes (Table 4), and the testing results showed that there were significant differences between them (Table 5). Based on the analysis results, it was concluded that slope aspect and location on slope are two major topographical factors that have a significant effect on the growth of sugi plantations.

SITE CLASSIFICATION USING GIS

A Geographic Information System (GIS) is an information technology that is used to integrate topographical information and attribute data, to retrieve information from large databases, to calculate distance and area quickly, and to describe topographical factors in 3-D graphs (Burrough 1986; Abe 1991; Abe 1993; Sano *et al*. 1994; Aronoff 1995; Blaszczynski 1997). In this study, the spatial data resources are forest base maps and forest planning maps (1: 5,000 scale). Feature coverages such as forest compartments, sub-compartments, stands, contours, ridges, streams, and forest roads are created in ARC/INFO. Attribute tables are imported and created from CSV-format data of Niigata Prefecture (Updated in 1995), and are related to spatial data in GIS.

On the basis of the site classification criteria defined above, by creating triangle irregular networks (TIN) from the contour coverage in GIS, stands were classified into three classes according to slope aspect. And by creating buffer zones around ridges in GIS, stands were classified into three classes according to location on the slope. Then by overlaying one polygon coverage on another to create a new polygon coverage, all sugi stands were classified into four classes.

First of all, querying the feature attribute table PLAN. PAT created a coverage, sugi, which contained only sugi stands in the study area (Fig. 7). In the feature attribute table, code '1' in item 'SPECIES' indicates sugi. The total area of sugi plantations was also calculated to be 687.0578 ha. This value can be used to check for classification errors later.

Site classification was then carried out in two steps as follows:

1. Classifying the whole area into three classes according to slope aspect, i.e. north, east and west, and south.

In GIS a TIN surface model was created from the contour coverage. The TIN was converted into an ARC/INFO polygon coverage that contained thousands of polygons representing different slope degrees and aspects. Those polygons were divided into three subsets according to aspect degrees: north, east and west, south. By performing an overlay, sugi stands inside the three aspects were identified and extracted in GIS.

2. Classifying the whole area into three classes according to location on slope.

In GIS a 10-m buffer zone around ridges was created. Sugi stands were selected and extracted inside the buffer zone, and saved as a coverage representing Class 3 stands. In the same way, a 50-m buffer zone around ridges was created, and the 10-m buffer deducted, producing areas within 10-50m from ridges. Sugi stands inside that 40-m zone were selected as Class 2 stands. Finally sugi stands beyond 50-m from ridges, representing Class 1 stands, were extracted.

After completing site classification work according to the two main topographical factors, aspect and location on slope, the whole area was classified into four classes (I , II, III and IV), by overlaying coverages based on the classification criteria defined earlier (Fig. 7). The areas of the four classes were calculated as: Class I , 138.2515ha; Class II, 307.9587ha; Class III, 217.0352ha; Class IV, 24.3275 ha. Sugi stands of Class II comprise 44.8% of the total area and sugi stands of Class IV comprise only 3.5% of the whole study area. The total area of sugi plantation on the study area was calculated to be 687.0578ha before classification and 687.5729ha after classification, giving a classification error of 0.5151ha.

DISCUSSIONS

According to statistics in 1995, most of the 10.40 million ha of man-made forest stands in Japan are sugi plantations. It is expected that sugi will be the main source of timber in the future. How to use the great areas of sugi plantation efficiently is the primary issue that Japanese foresters are facing now. Developing site classes for sugi stands is the most important foundation for sugi management, for example, for planning thinning and felling, and evaluating effects of clearcutting on future forest landscapes.

Until now, many factors have been used to estimate site classes on a small-scale area. NISHIZAWA *et al.* (1965) used a method of estimating SI from soil conditions (soil type, depth to the bedrock, content of humus, texture and gravel, structure) and environment factors (altitude, aspect, inclination, parent material) by quantitative techniques. He concluded that SI is mainly affected by five factors: altitude, soil texture and gravel, soil structure, content of humus, and soil type, in order of decreasing importance. Quantitative methods also showed that the partial correlation coefficient between SI and aspect is 0. 445. ABE (1991) analyzed differences in tree growth in relation to slope aspect, and concluded that todomatsu stands with a northerly aspect grow better than those with a southerly aspect.

The analysis in this study supports the viewpoint that aspect has a significant effect on sugi growth. In addition to aspect, this study used another factor, location on slope, to analyze the effect on sugi growth, and concluded that stand location on slope also affects sugi growth. The analysis shows that these two factors have significant effects on height growth of sugi stands. This result is consistent with Yamada's research, which explains that moister environments are created at lower positions on the slope as they benefit from runoff from all the up-slope area. If the slopes are facing south, stronger sunshine causes moisture deficiency in the soil. Moisture greatly affects the growth and differentiation of tree roots and leaves. This study also supports the viewpoint that complex factors, instead of a single factor, interactively affect tree growth and it is inadequate to estimate the effect of only one particular factor.

The analysis found that site classes with a difference in mean site index of about four meters are appropriate. From stand volume tables of Niigata Prefecture, the sugi stand volumes of Class I , II, III, IV, at age of 60 years, are 820m^3 /ha, 726m^3 /ha, 631m^3 /ha and 347m^3 /ha, respectively (NIIGATA PREFECTURE 1990). The differences in stand volumes of Class I , II, III and IV are clearly significant.

Using GIS, a site classification map was created as the end product in this study. The site classification map details the distribution of sugi stands with different slope aspects and on different locations on slope. Because it is a computer-created map, any part of the map can easily be printed out at any scale according to the forest manager's requirements. When integrated with attribute data for sugi stands, the GIS-derived map can also be used for deciding priorities in making thinning and felling plans according to site classes, for selecting the yarding and hauling road networks, and for evaluating landscape changes after thinning and felling.

CONCLUSIONS

This study describes the procedures used to estimate growth of sugi plantations at the stand level on the basis of topographical factors. GIS was used as an efficient means of analyzing those factors and presenting the results. By analyzing the site indices of sugi on individual plots, we evaluated the effects of topographical factors on tree growth and classified sugi stands into three classes according to slope aspect and three classes according to location on slope. Integrating these two topographical factors with height growth data, sugi plantations were classified into four site classes: Class I, Class II, Class III and Class IV.

Topographical factors are critical factors used for forest growth analysis, stand thinning decisions, biodiversity investigation, and the like. The GIS procedures used to

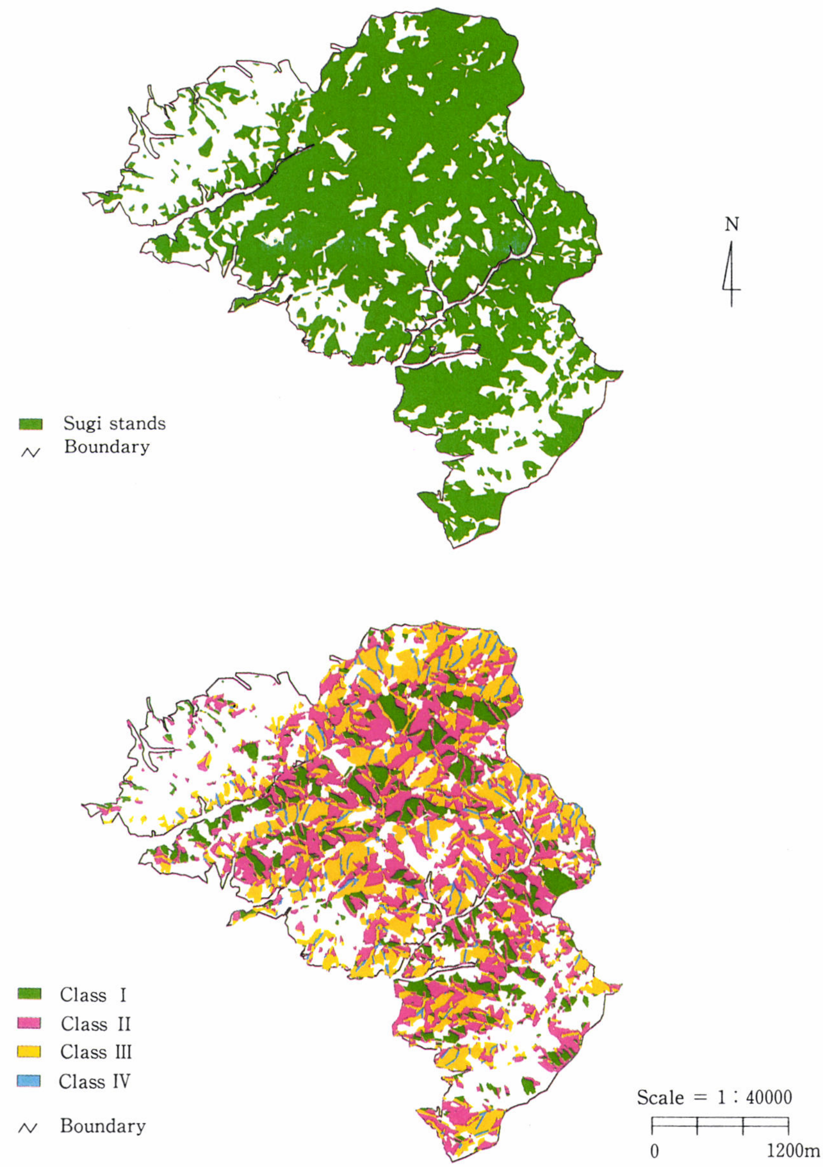

Fig. 7 Distribution of sugi stands in the study area (upper) and distribution of sugi stands classified into four site classes (lower)

manipulate topographical factors in this study should be generally useful for performing geographical analysis for similar research activities.

(We thank Mr. Hiroyasu Kanamori of Niigata University for his great assistance in our field work.)

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Article

Monitoring of Forest Area Change using Satellite Data with Special Emphasis on Sungai Buloh Forest Reserve, Malaysia

Kamaruzaman Jusoff*

ABSTRACT

This paper features the utilization of satellite remote sensing in monitoring of forest area changes for timber resource management planning. Landsat TM data was applied to the monitoring and estimation of future forest area in Sungai Buloh Forest Reserve. Quantification of forest changes due to urbanization was performed using the dot technique with multi-temporal data taken in 1989, 1991 and 1994. On the present trends, the forest area is projected to be reduced to 1,450ha by the year 2000 and 615ha by 2005. The forest in Sungai Buloh will be completely exhausted by the year 2011 if forest conservation practices are not implemented.

keyword: forest, monitoring, satellite data

INTRODUCTION

Only a few reports have so far dealt with the primary productivity of tropical or equatorial forests but there is already enough evidence to show that the methods for assessing area changes are essentially the same in both temperate and tropical forests. KIRA *et. al*. (1967) and HAZUMI *et. al.* (1969) successfully applied the techniques which had been developed in temperate forest studies to estimate productivity in tropical forests of Africa and South-East Asia.

Visual and digital interpretation of satellite remote sensing has been the principal technique for estimation of the areas of stands in almost all tropical forest inventories (UNESCO, 1978; KAMARUZAMAN and Abdul HAYE, 1993; KAMARUZAMAN and RASOL, 1995). This applies equally to inventories at national and sub-national level; as well as to pre-investment surveys for the granting of large concessions. The interpretation of satellite imagery is also used for the classification of forest stands according to criteria linked to their development, such as different types of forest, accessibility classes, density height of dominant canopy trees, etc. Some of these criteria are equally useful in stratification which permit a more precise estimation of the average unit area characteristics for both total and partial forest inventories. This interpretation can be supplemented by additional information on boundaries separating administrative units and on types of tenure.

The objective of the study is therefore to monitor, estimate and predict the forest area in Sungai Buloh Forest Reserve using satellite remote sensing .

METHODS AND MATERIALS

Description of Study Area

The study site was chosen in Sungai Buloh Forest Reserve (FR). This reserve is situated in the Mukim of Sungai Buloh which forms part of the overall administrative District of- Petaling in the State of Selangor Darul Ehsan (Fig. 1). Although the current state of the site is largely forested and sparsely populated, the,forest reserve is located close to major urban centers such as Kuala Lumpur (12km to the east), Shah Alam (12km to the west) and Port Klang (18km to the west), Petaling Jaya (19km to the south east) and Sultan Abdul Aziz Shah International Airport (11km to the south east).

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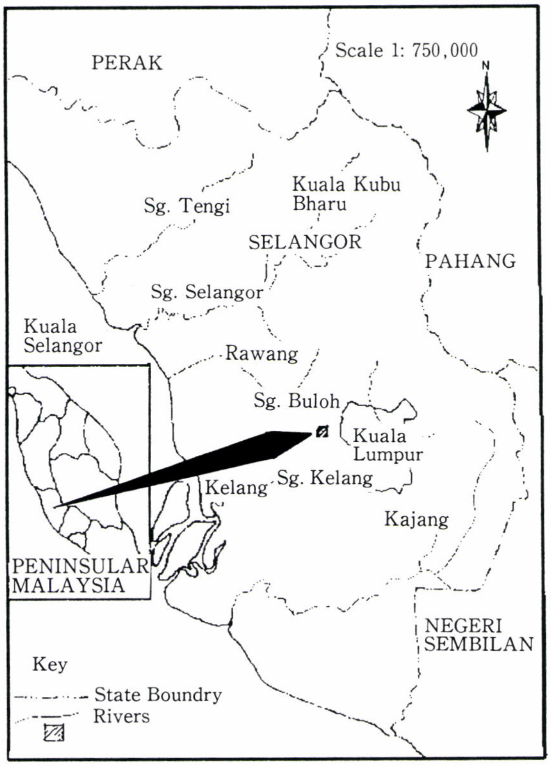
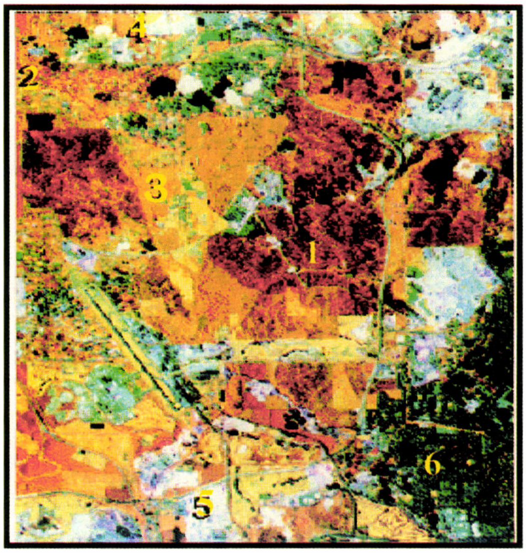


Fig. 1 Location of study area



1-Forest 2-Oil Palm 3-Rubber
4-Grassland 5-Bareland 6-Urban

Fig. 2 Landsat TM image of study area

The forest cover in the study area can be classified as the 'Red Meranti Keruing Forest' (WYATT-SMITH, 1963). The forest is reasonably rich with a high percentage of commercially important species of Shorea. The mean basal area of the forest inclusive of all species groups was estimated to be 26.9 m^2 /ha (ANON, 1987).

For the purpose of predicting forest productivity of the study site, a wider study area covering 25km × 25km was selected to detect the forest cover change reduction occurring from 1989 to 1994 (Fig. 2).

Topography

The Forest Reserve is undulating, ranging from about 30 to 333 m.a.s.l. The highest peak is Bukit Lanjan which is responsible for the hilly nature of the area, and several streams originate from this ridge, forming small valleys and swampy land in the lower reaches. The area is drained westerly by the Sungai, northerly by the Hampar and southerly by Sungai Rumput and its tributaries in the central and southern part. Fig. 2 showed the land use in the Mukim of Sungai Buloh which is generally agricultural, covering about 51.5% of the total land use.

Geology and Soils

The study area is almost entirely underlain by granitic bedrock, though the surficial soils are of variable textures, dependent upon topographic location. In the undulating and hilly areas, granitic residual soils are present, while along the flood-plains and terraces of the rivers, unconsolidated fluvial sediments are found.

Several varieties of granitic bedrock are present in the area and include both porphyritic and non-porphyritic ones. All of these granitic rocks are moderately to highly fractured and are cut by several faults. Several quartz veins and dikes are found within the study area with the veins being some 1 to 5cm thick, while the dikes are some 20 to 30m thick. A hot spring has also been reported to be present at the point where the Sg. Rumput intersects the longest quartz dike, though this has now been covered by tin-tailings.

The general soil strata forming the eastern fringe of the study area comprises a top stratum of residual soil of sandy clay / silt to clayey silty sand with subangular to angular quartz gravels derived from the weathering of granite rock.

Climate

The mean annual rainfall between 1966 and 1985 was 2,282mm falling over 193days of the year. Most of the precipitation occurs between the months of October and December and March to April. The period from June to August is the driest.

Annual temperatures are relatively uniform averaging about 26.4℃. The daily mean maximum and minimum temperatures are 32.1℃ and 22.7℃ respectively. The highest temperatures occur between April and June, and the lowest between November and January. The mean daily relative humidity is high with an annual mean of 83.9% and fluctuates between 50% and 99%. The relative humidity is highest in November and December, and somewhat lower between March and August.

Materials

Data Acquisition

Three Landsat digital spectral images taken on 15th February, 1988, 21st February, 1991, and April 1994 (path/row 271/58) were used. The satellite imageries were bought from Malaysia Center for Remote Sensing (MACRES). These scene had covered with less than 5% cloud cover and have been corrected for atmospheric haze. The multi-temporal images are shown in Fig. 3, 4 and 5.

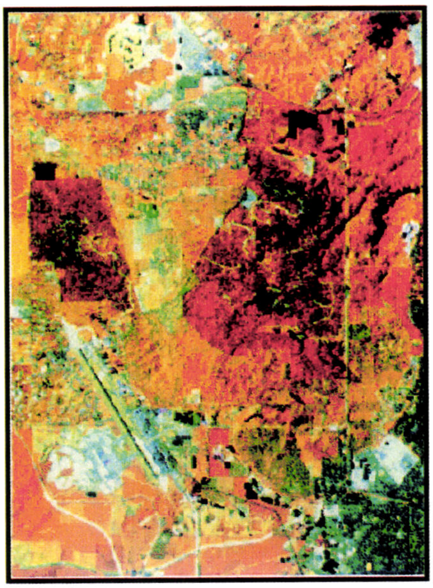


Fig. 3 1989 image of the study

Fig. 4 1991 image of the study area

Methodology

The area of Sungai Buloh Forest Reserve was determined by the use of satellite imagery and the Dot Technique. With this technique, satellite image were overlaid with a dot grid sheet to obtain forest area. The dot grid sheet contains squares where each square contains 100 dots. Each dot representing the area of forest was based on the satellite imagery scale. The scale of satellite imagery used was 1:200,000 and due to the scaling conversion, a multiplier factor of 6.44 was used to estimate the forest area with each dot overlaid on the forest area derived from satellite imagery.

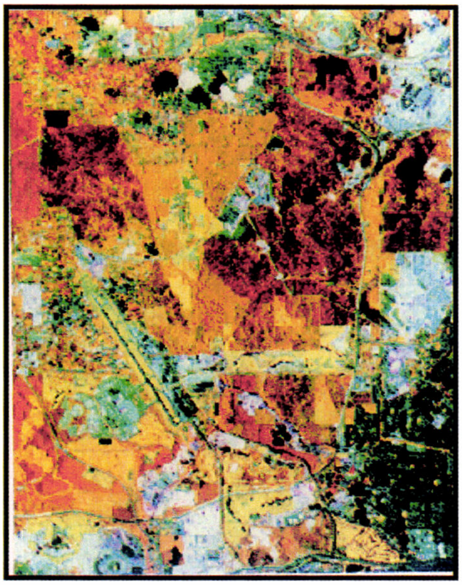


Fig. 5 1994 image of the study area

Table 1 Forest area estimate of study area

Year	Forest Area (ha)
1989	2,763
1991	2,222
1994	1,971

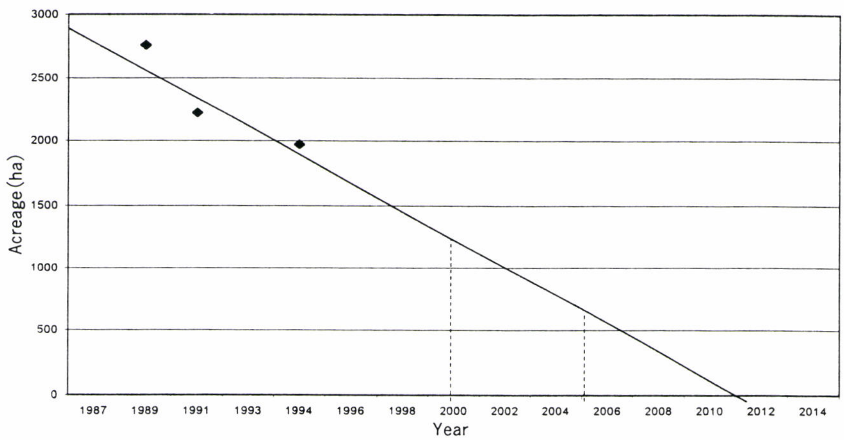


Fig. 6 Projection of forest area in Sungai Buloh Forest Reserve

RESULTS AND DISCUSSION

By using the dot technique, it is possible to calculate the area of forest in the study area. The forest areas for 1989, 1991 and 1994 were 2,763ha, 2,222ha and 1,971ha, respectively as shown in Table 1.

For the purpose of predicting future forest area, a graph of forest area versus years was plotted and a straight line was fitted to the points (Fig. 6). On the basis of the declining trend of this graph, it was estimated that the forest area will declined to 1,450ha by the year 2000 and to 615ha by year 2005. The projection indicates that if the area is continuously reduced and opened up for urban and other land uses, there will be no forest left in Sungai Buloh Forest Reserve by the year 2011.

CONCLUSION

Satellite remote sensing is becoming more widely used in predicting forest area. The case study in Sungai Buloh Forest Reserve demonstrates the role of satellite data as an effective tool to predict future forest area with aid of other data.

Continuous forest monitoring should also indicate trends in regional and world wood production and could give an overview of the roles of these forests as raw material producers and as protectors of the environment.

National forest inventories, on the other hand, must not be limited to the inventory of available growing stock and growth rate, but must link these to ecology and floristic composition of the forest stands. To be effective, inventories must not neglect ground operations, which are often complex. Problems which require further study, include sampling methodology, extraction systems, terrain classification, and production and costs.

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Article

Modelling Crown Form of Hinoki (*Chamaecyparis obtusa*) Based on Branch Measurement

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ABSTRACT

Modelling for this study was based on branch data from a sample of hinoki (*Chamaecyparis obtusa*) stands of different ages, silvicultural histories and varieties. Calculations of the relative crown curve of the exposed part of the crown were then made, based on branch tip position. We then investigated differences in relative exposed crown form due to tree age, silvicultural treatment and variety. It was concluded that the changes in crown length, diameter and slenderness ratio in the growing stages for Hinoki show similar tendencies to sugi (*Cryptomeria japonica*). It was confirmed that the difference of due to stand age, silviculture and variety. There are significant differences in the relative exposed crown form. The relative crown curve was calculated from a regression equation based on branch data for all the sample trees.

Keyword: hinoki (*Chamaecyparis obtusa*), crown form, branch measurement, growing stage

INTRODUCTION

We have been developing spatial tree shape models based on hinoki (*Chamaecyparis obtusa*) stands (Matsue *et al*. 1998). Such models, when displayed three-dimensional view on computer graphics can be used in landscape simulation. The location and form of individual trees, and the spatial position of the crown (with living branches and leaves) can be represented in a realistic three-dimensional view. Consequently, it is quite an effective way to study tree morphology and to predict the growth of both stand structure and individual trees. To simulate management practices such as thinning, it is desirable to build a growth model that models individual trees and their relationship with neighboring trees in a three-dimensional form. To build such a tree shape model, there is a need to measure crown shape and position of branches and leaves, then analyze them, and understand changes in crown form over time.

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In this case, it is important not to deal in simple geometrical forms, but to study real crown shapes. There have been many previous reports of tree crown models. These include models for sugi (*Cryptomeria japonica*) by Kajihara (1975, 1976a) and Hashimoto (1986), todo-fir (*Abies sachalinensis*) by Inose (1981a, 1981b), and douglas-fir by Mitchell (1975). However, these reports involve the modeling of crown form, rather then researching crown shape differences in detail.

Koide (1942) and Kajihara (1975) expressed Hinoki crown form as a combination of cone and cylinder. The upper cone-shaped part of the crown is the part exposed to sunlight, while the lower cylindrical-shaped part is the shaded part. Compared with the leaves of the shaded crown, the leaves of the exposed crown have higher photosynthetic capacity make a bigger contribution to tree growth. In this paper, we survey and study the variation in the shape of the part of the crown exposed to sunlight, and changes in crown form due to thinning.

Kajihara (1975) says that an effective expression for exposed crown form is in terms of relative crown curve, defining the diameter and the length of the exposed part of the crown both as 1. Deleuze *et al*. (1975) and Cluzeau *et al*. (1994) estimated crown form from branch position such as branch length, branch chord angle, and so on.

In this study, we calculated the relative crown curve of the exposed crown form branch tip position. We then examined differences in relative exposed crown form due to tree age, silviculture and variety.

STUDY SITES AND METHOD

The study sites were hinoki plantations ranging from 10 to 60 years old. They are located in Sikoku in Japan, Kochi University forest (in Kochi prefecture), Tosa in Kochi Prefecture, and a community stand of Uwa and Kuma in Ehime Prefecture. The study stands comprised a low-management stand, an intensively managed stand, a stand managed primarily for density control, and a stand of cultivated cuttings.

The low-management forest has had little thinning and no pruning. the intensively managed forest has been thinned by 13 to 25%, and pruned 17 times in 11 years. The stand managed primarily for density control, has been thinned by 27 to 30%, and has been pruned twice. On this stand, Iwagami *et al.* (1996) reported in detail.

The hinoki cuttings (KamikoII variety) demonstrated good height growth.

On these stands we measured a total of 42 individual trees as follows. First, we measured tree height, diameter at breast height, height of crown base and crown width. Then we felied the trees and measured for each branch the base height, chord angle and length Matsue *et al.* (1998) reported in detail on these branch measured characteristics. Branch is classified by their life-stage, morphology as shown in Fig. 1. From the branch data plotted branch tip position for dominant branches and dominated branches, then calculated the relative branch curve.

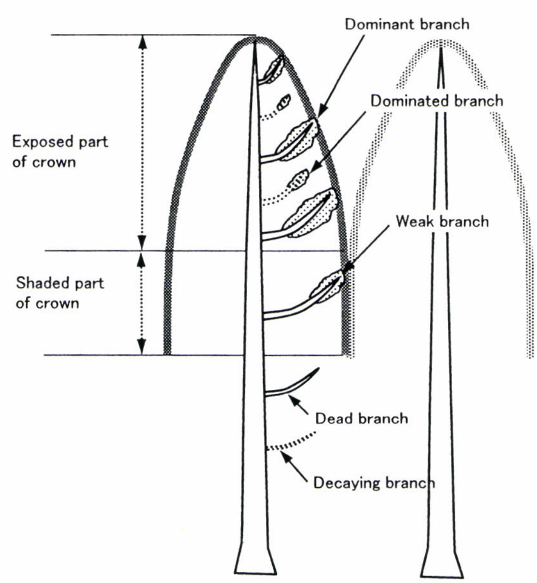

Fig. 1 Crown parts and branch types

RESULTS

Crown length is defined here as the difference in height between the tree and the exposed crown base. Kajihara (1976b) developed a growing stage index for tree height for sugi, then examined the change of crown shape (the length, diameter and slenderness ratio) through the following 3 stages:

I. At first the whole crown is exposed and the length, diameter and slenderness ratio all increase rapidly.

II. The shaded crown then develops rapidly; the length and slenderness ratio of the whole crown continue to increase, but the exposed crown length, diameter and slenderness ratio decrease for a while.

III. For both parts of the crown, the length and diameter increase but the slenderness ratio shows little change.

This paper did like it, was a similar approach, dividing the crown between exposed and shaded parts, and analyses the changes in crown length, diameter and slender-

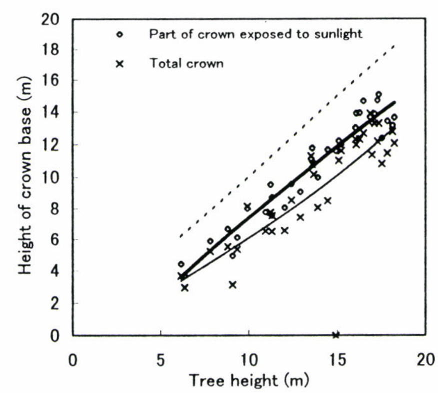

Fig. 2 Development of height of crown base
Note: Eq.: $y=ax^2+bx+c$. $R^2=0.9305$ (thick line), $R^2=0.6467$ (thin line)

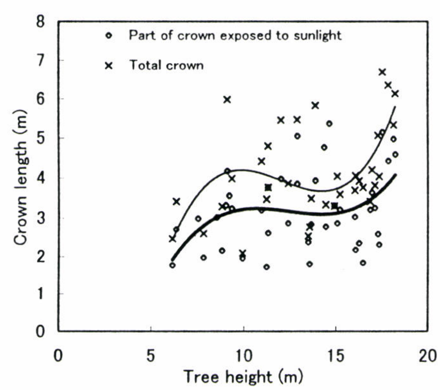

Fig. 3 Development of crown length
Note: Eq.: $y=ax^3+bx^2+cx+d$.
$R^2=0.1537$ (thick line), $R^2=0.3377$ (thin line)

ness ratio.

Fig. 2 shows a plot of crown base height base against tree height. The broken line shows the change of tree height. The difference between tree height and the height of the base of the crown exposed to sunlight is the exposed crown length, while the difference between tree height and the base of the total crown is the whole crown length. The difference between shaded crown base height and exposed crown base height will be shaded crown length. Fig. 3 shows the change in crown length against tree height. Fig. 4 shows the change in crown percentage (crown length/tree height). Fig. 3 and 4 also shoe trinomial curves fitted to the data for the exposed crown (thick line) and whole crown (thin line). Fig. 2 suggests that the exposed crown base height tends to level out after a stage of increasing with tree height. The shaded crown increases rapidly at first, then tends to maintain a fixed length. From Fig. 3, exposed crown length is constant in the stage of tree height from 10 to 15meters. From Fig. 4, in stage of tree height from 10 to 15 meters, crown percentage decreases, then increases.

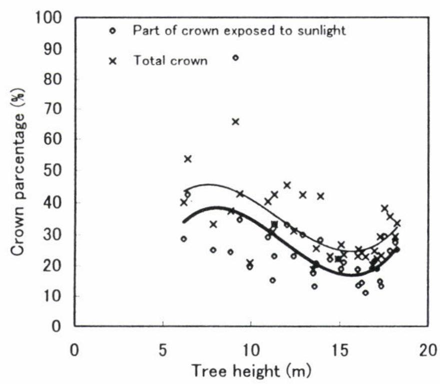

Fig. 4 Development of the percentage of crown length to tree height
Note: Eq.: $y=ax^3+bx^2+cx+d$.
$R^2=0.302$ (thick line), $R^2=0.4268$ (thin line)

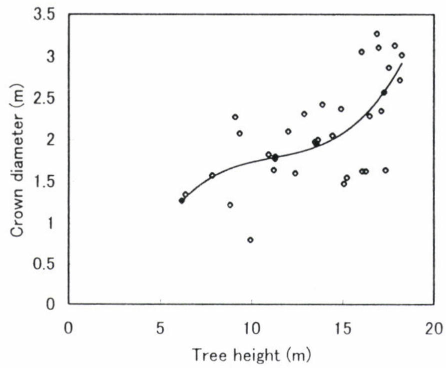

Fig. 5 Development of crown diameter
Note: Eq.: $y=ax^3+bx^2+cx+d$. $R^2=0.4818$

Fig. 5 shows the change of crown diameter (or width) which is the exposed crown base diameter, and also shaded crown diameter. From Fig. 5, we can see that the rate of increase in crown diameter changes in different growing stages. It appears that crown diameter is affected by the stage of its stand density. In the stage of tree height 5 to 15 meters, the increace in crown diameter is slower then in the over 15meters stage. This is because, when the stand reaches crown closure, it competes with the nearest neighboring trees, and branch growth is restrained. After it escapes that stage, crown diameter increases is more rapidly.

Fig. 6 shows the change of crown slenderness ratio (crown length/crown diameter). From Fig. 6, the slenderness ratio decreases over the stage of 10 to 15meters height, then increases. The decrease in the slenderness ratio occurs as the length increases more slowly than the diameter.

The change of crown length, diameter and slenderness ratio shows corresponding tendencies. The common influence appears to be stand density. Stage "I" data is lacking, but the results for Hinoki show similar tendencies to those for sugi reported by KAJIHARA (1976b).

We calculated the relative branch tip height (x) and relative branch spread (y) of dominant branches, given that the length and diameter of the exposed part of the crown were both defined to be one. To test for, differences in exposed crown form, the relative crown curve of the exposed crown was defined by the formula ⟨$y=ax^3+bx^2+cx$⟩ .

Differences in Crown Form Due to Stand Age

Based on the measurements for unthinned stands of 24, 34, 39 and 60years, we estimated the relative crown curve of the exposed crown for each stand age. Table1 shows parameters a, b, and c for each curve and the coeffi-

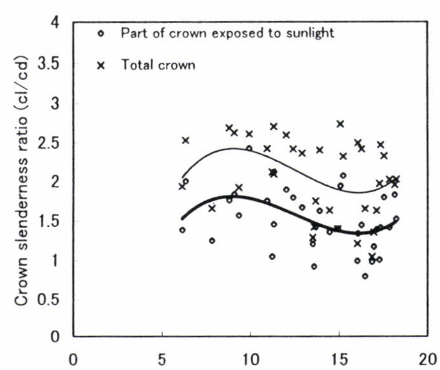

Fig. 6 Development of crown slenderness ratio
Note: Eq.: $y=ax^3+bx^2+cx+d$.
$R^2=0.1803$ (thick line), $R^2=0.1616$ (thin line)

Table 1 Regression equations and coefficients of relative crown curve of exposed crown

Formula : $y = ax^3 + bx^2 + cx$				$R^{2'}$
Stand age	a	b	c	
24	2.407	−4.943	3.536	0.421
34	1.941	−3.356	2.415	0.599
39	1.039	−2.181	2.142	0.600
60	0.432	−1.154	1.722	0.801

Note: $R^{2'}$ −Coefficient of determination adjusted for degrees of freedom

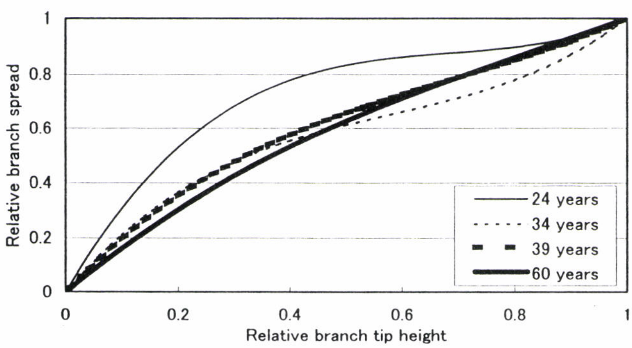

Fig. 7 Relative crown curve of exposed crown at various ages

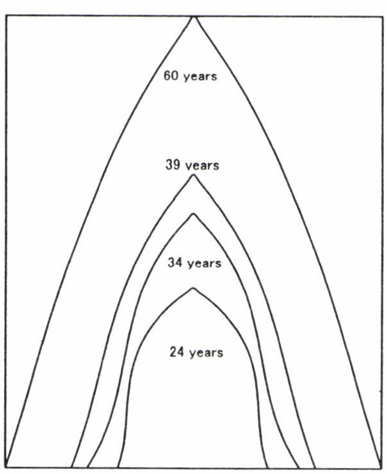

Fig. 8 Difference in crown form with tree age

cient of determination adjusted for degrees of freedom ($R^{2'}$). The $R^{2'}$ of the regression equation is higher for older stands. It shows that as tree age increases, the crown form reaches equilibrium because suppressed trees are removed, and then the surviving individuals have a larger fixed space.

Fig. 7 is the relative crown curve of the exposed crown. Fig. 8 shows a model sketch of the relative exposed crown form. In Fig. 8, for younger trees the uppercrown's relative width is bigger. In contrast, for older trees the

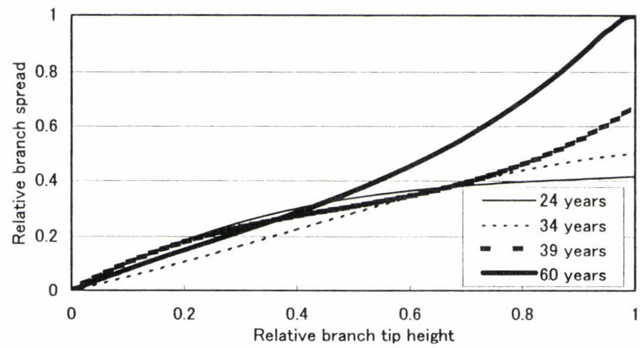

Fig. 9 Relative crown curve of inside crown at various ages

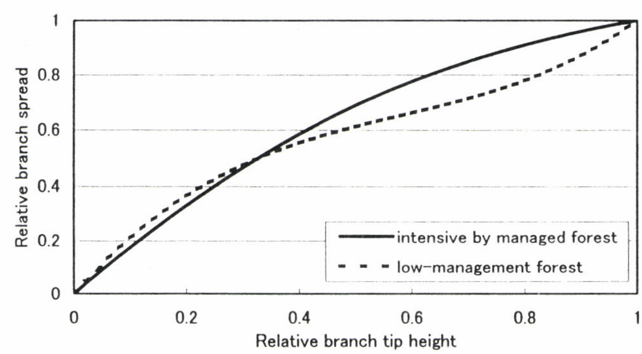

Fig. 10 Differences in crown form due to silviculture

lowercrown's relative width is bigger. It be seen that the shape at 60years is the best for receiving solar radiation. These patterns are due to spatial competition among neighboring trees. At the young tree stage, the competition among neighboring trees is intense to the extent that their crowns overlap. As a result, the growth of lowercrown branches is restrained. However, after a certain period, the stage of competition and dominance stabilizes, and exposed crown form also stabilizes. Thus it can be said that the exposed crown form evolves to a better form for solar ray reception. This is does not contradict the change of crown length, diameter and slenderness ratio through the different growing stages.

For dominated branches, as for dominant branches, we researched the change of branch tip position with stand age. Fig. 9 shows curves for dominated branches at different stand age. Relative branch tip height (x) and relative branch spread (y), like dominant branches, are related to exposed crown length and diameter.

For younger trees, the branch growth in the lower crown is restrained. The dominated branches remain inside the crown, and compare not with neighboring trees but within their crowns. It can be said that the curve of the dominated branches is the border of inside crown competition. For older trees, the crown form changes to a better solar ray ratio, so that the growth of the dominated

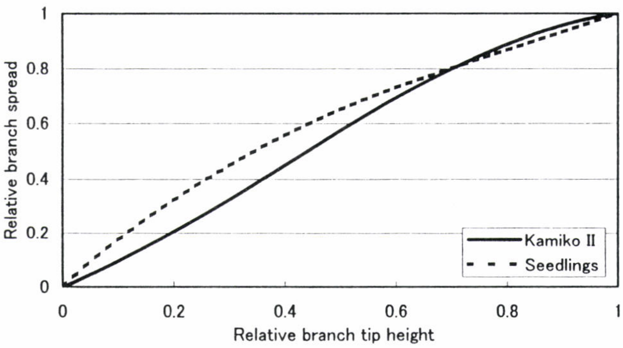

Fig. 11 Differences in crown form due to variety

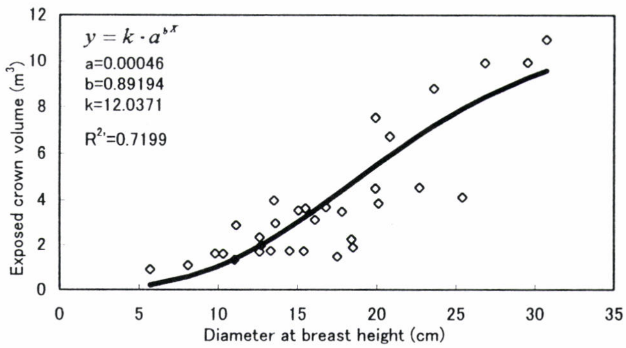

Fig. 12 Relationship between crown volume and diameter at breast height

branches in the lower part of the exposed crown eventually improves.

Differences in Crown Form Due to Silviculture

We compared the relative crown curve of the exposed crown between two stands of the same age (34years): (i) a low-management stand, and (ii) an intensively-managed stand which has had good density control. Fig. 10 show the relative crown curve of exposed crown for each stand. For the low-management forest, the branch growth in the lower part of the exposed crown is restrained. The stand which has had intensive density control has a better solar ray ratio form. The exposed crown form of the stand with intensive density control is similar to that for the 60year old stand (Fig. 7).

Differences in Crown Form Due to Variety

We compared KamikoII (a variety of hinoki cuttings) with common Hinoki seedlings, both 11 years old. KamikoII is becoming popular because it has good height growth and straight stems, and is sturdy against wind damage. Fig. 11 shows the relative crown curve of the exposed crown for each variety. This hinoki seedlings stand has been maintained with intensive silviculture. It has exposed crown form similar to the 60year old one shown in Fig. 8, but the exposed crown form of KamikoII has a better form with a higher solar ray ratio. This crown form may help explain the good growth of KamikoII.

CONCLUSION & DISCUSSION

It has found that the changes in crown length, diameter and slenderness ratio in the growing stages of hinoki show similar tendencies to sugi. We studied the crown form of hinoki on the basis of the relative crown curve of the exposed part of the crown.

The relative crown curve of the exposed crown was calculated in this paper from branch measurements from the sample trees. It was confirmed that these are significant differences, in the relative exposed crown form due to stand age, silviculture and variety. The change of exposed crown form with stand age for low-management stands, depends on the change of competitive status with stand density. In particular, the exposed crown form of intensive by managed stands is similar to the crown form of old trees (60years) in low-management stands. Low management stands evolve to a better exposed crown form with a higher solar ray ratio as competition progresses over a long period. In contrast, an intensive by managed stand has an exposed crown form with a better solar ray ratio at an early stage.

Fig. 12 shows the relationship between diameter at breast height and crown volume which is calculated from the relative crown curve of the exposed crown. The regression equation had an $R^{2\prime}$ of 0.7199. Combining a competition and growth model with this crown form model would enable crown form growth simulation. Moreover, by predict of future crown size more accurately, we would be able to estimate diameter at breast height and volume using the regression equation we have developed recently.

In this paper, we have reported on factors affecting relative exposed crown form but next we need to investigate how crown form affects growth. We also need further investigation of changes in relative exposed crown form due to silviculture. This would allow the development of a model which would help in formulating recommendations for better systems of intensive individual tree silviculture, based on spatial tree morphology and tree position.

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Article

Relationship between Current Forest Operations and Provision of Roads in Private Forests*[1]

Takeshi Matsumoto*[2] and Katsuhiro Kitagawa*[2]

ABSTRACT

We analyzed the relationship between current forest operations and the provision of roads in private forests in a mountain village area, as a basis for improved planning of forest road networks. The study area was Toei district in Aichi prefecture, and the forest operations studied involved the planting and tending (weeding, pruning, cleaning cutting, and thinning) of forests performed by the Forest Owners' Association from 1994 to 1996. Most of the work, both with respect to the number of operations and the area of each operation, involved the thinning and weeding of forest stands. Only a small amount of pruning and planting took place. Over the 3 years, there was little change in the nature of the operations. An analysis of the operations with respect to the access distance from the nearest road for each type of operation each year showed that the proportion of operations decreased as the access distance increased. There were a few discrepancies when the area of operations was considered, but the basic trend was essentially the same. All the different kinds of operations were concentrated within 300m of a road, and the average access distance each year was approximately 210m. This is shorter than the average distance of access across the whole of the forests in Toei, which was about 275m. This means that there are too few forest roads from the perspective of current forest operations. In order to resolve this problem, it is suggested that an additional 6m/ha of forest roads are needed immediately. This would nearly double the current forest road density of 7.0m/ha.

Keyword: forest operation, road network, accessibility, road equipment

INTRODUCTION

Seventy percent of forests in Japan today are less than 35 years old, and the total standing volume of wood is increasing by about 70 million m^3 per year. However, the situation for mountain villages and for the forestry is becoming increasingly severe, because of decreasing forest management activity, the decreasing numbers and increasing age of forest laborers, and the depopulation of mountain villages. This is the result of low prices for domestic timber under competition from imported timber which now has an overwhelming share of the market. Consequently, the quality of forest is deteriorating, because of the lack of a uniform forest operations for fostering good forests. Improving the efficiency of forest management and forestry productivity are immediate necessities for the Japanese forestry.

Forest operations tend to occur near forest roads (SHIRAISHI 1994), and therefore the number of forest roads plays an important role in the Japanese forestry. In private forests, however, construction of new forest roads occurs at a slow pace (SHIBA and PARK 1995), and public roads are often used for forest operations because of the lack of forest roads in a region. In this study, we analyzed the relationship between current forest operations and roads in private forests in a mountainous village area from the view points of space and time series, as a basis for improving forest road network planning.

*[1] A part of this paper was presented at the 109th Annual Meeting of Japanese Forestry Society (1998)

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MATERIALS AND METHODS

We chose Toei (Fig. 1) in Aichi prefecture as the study area, because there is a high proportion of forestland in the area and a high proportion of the forests are privately owned, and Toei is a typical hilly mountain village. The total forest area is 11,000ha, which is 90% of the land in the study area. 83% of the forests are plantations and almost 100% are privately owned. The total stand volume is 2.9 million m^3, and the unit stand volume of 255m^3 per hectare is the highest in the Okumikawa Forestry Area. In the study area, 55% of the forests are less than 40 years old (age class 8 or under), and more than half of the forests need tending. The regional population has decreased by half in the past 30 years, and employment in the forestry has declined.

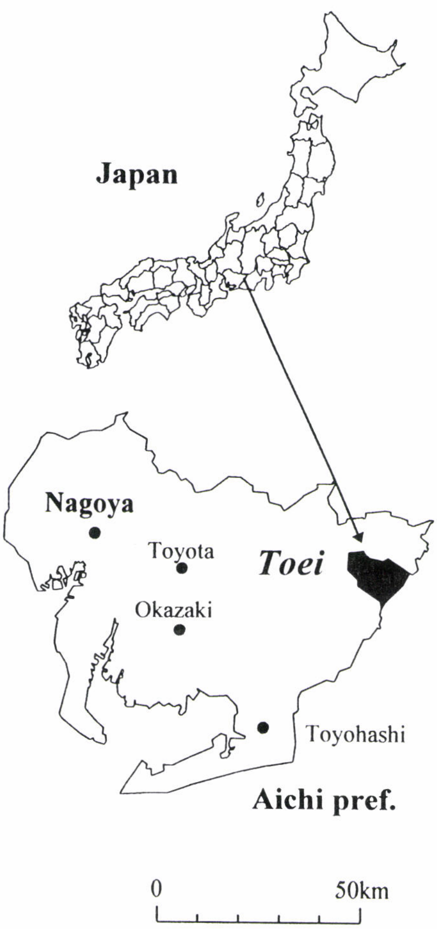

Fig. 1 Location of study area

Five basic types of forest operation were conducted by the Forest Owners' Association in the 3 years from 1994 to 1996. These were planting, weeding, pruning, cleaning cutting, and thinning. We first made a list of the areas in which each type of operation was carried out, in cooperation with the town office and the Forest Owners' Association. This list included the owner's name, lot number (called *Chiban*), treated area, and additional comments. The areas were then plotted on the "Toei Basic Forest Plan Map" (scale 1: 5,000, total 12 maps) according to lot number. Then, we input these vector data into a computer with a digitizer. Information on the road network (both public and forest roads) and forest area locations was entered into the computer with a digitizer, from two forest road maps (1: 50,000, published in 1993 and 1997) and a map showing forest function (1: 50,000). Since new forest roads are built every year, for the time series study the road network available for forest operations in a given year was defined as the road network present in the previous year (e.g. the road network in 1994 was used for the analysis of forest operations in 1995). Information on forest roads built from 1993 to 1995 for the time series analysis of the relationship between forest operations and the road network was taken from the "Operating Statement of Toei District". Finally, we converted all the data to rectangular plane coordinates and calculated the shortest distance between the center of gravity of each area of forest operations and the nearest road.

RESULTS AND DISCUSSION

Current Forest Operations

Table 1 lists the operations carried out by the Forest Owners' Association in the 3 years studied. Cleaning cutting was combined with thinning, because little took place. Most of the work undertaken was weeding and thinning, and less than 10% was planting and pruning.

Table 1 Statistics of forest operations by Forest Owners' Association, 1994-1996

	number			areas(ha)			average areas(ha)		
	1994	1995	1996	1994	1995	1996	1994	1995	1996
planting	39	37	24	23.0	13.9	8.0	0.59	0.38	0.33
weeding	145	100	120	112.6	64.8	90.9	0.78	0.65	0.76
pruning	28	23	25	24.1	24.7	15.0	0.86	1.07	0.60
thinning & cleaning cutting	116 (3)	121 (2)	127 (2)	136.5 (2.8)	193.5 (6.8)	167.4 (1.9)	1.18	1.60	1.32
total	328	281	296	296.1	296.9	281.2	0.90	1.06	0.95

* : ( )only cleaning cutting

Forest owners tend to have the Forest Owners' Association do the thinning and weeding, as special techniques or machines are required, but they do the pruning themselves. The operation that took place at the greatest number of sites was thinning, followed by weeding, planting, and pruning. Although weeding occurred in as many cases as thinning, the total area involved was much smaller. The ranking of operations in order of average area treated was thinning, pruning, weeding, and planting. According to the Toei local forest improvement plan, the total planned area for each forest operation other than planting during the 5 years from 1993 to 1997 was: weeding 720ha, pruning 90ha, cleaning cutting and thinning 1,570ha (cleaning cutting 140 ha, thinning 1,430ha). On annual basis this corresponds to: weeding 144ha, pruning 18ha, cleaning cutting and thinning 314ha. The actual average annual areas for each operation during the three years studied were weeding 89.4ha, pruning 21.2ha, and cleaning cutting and thinning 165.8ha. The amount of pruning therefore exceeded the planned value, while the amounts of weeding and thinning were much smaller. The amount of thinning achieved was only a little more than half the amount planned, and it is clear that the amount completed by the Forest Owners' Association was very inadequate. Furthermore, the thinning specified by the plan was only for areas within 260m of a road, but it should be noted that forests requiring thinning (from age classes 3 to 8) cover about 6,000ha, which is more than half of the total forest area of 11,000ha.

There were minor fluctuations in the number, area, and average area of each kind of operations, but the total number of sites (around 300) and treated area (around 290 ha) were approximately constant over 3 years.

Table 2 shows the number of owners, and the number and area of operation for each class of owner. There were 287 owners who carried out one or more operations in the

Table 2 Forest operations by Forest Owners' Association by class of owner

	number of forest owners	number of operations	treated aera (ha)
Individual	259	843	790.2
Common forest	23	40	38.5
Company forest	2	12	5.7
Shrine and temple forest	3	10	39.8
Total	287	905	874.2

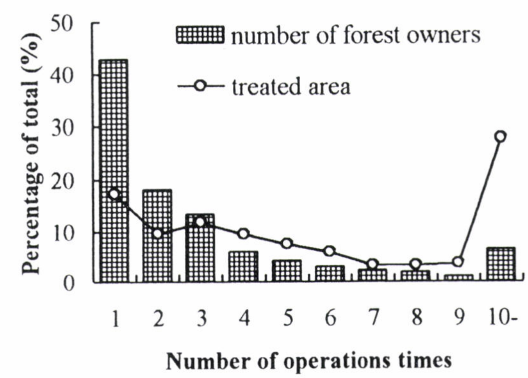

Fig. 2 Distribution of percentage of owners and treated area for different number of operations

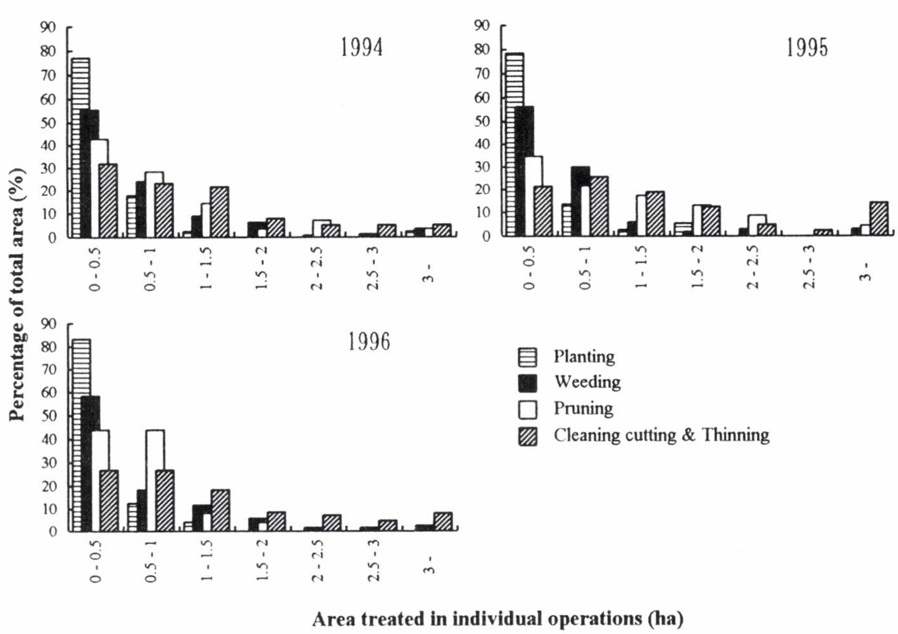

Fig. 3 Distribution of number of sites by area size class

3-year period. This is about 10% of the total number of forest owners in Toei (2,940 owners in 1992). Individuals owned over 90% of the sites treated, and a very low proportion was owned by shrines and temples or held as common forests. The average number of sites where operations were conducted was 3.2, and the area of sites treated per owner over the 3 years was 3.0ha.

Fig. 2 shows the distribution of the percentage of owners and the percentage of treated area for each number of operations carried out by individual owners over the 3-year period. Over 40% of the forest owners conducted only one operation, and the percentage of owners treated to decline for larger numbers of operations. For owners conducting fewer than 10 operations, there was also an inverse relationship between the number of operations and the area involved. However, this did not hold for owners that conducted more than 10 operations. Fewer than 10% of the forest owners performed nearly 30% of the total area in which operations were conducted. The number of individual owners who carried out any operations each year was 151 (1994), 135 (1995), and 139 (1996).

Fig. 3 shows the distribution of the size of the forest operations. Generally, operations were performed on a small scale, and there were few large sites for each type of operation. The frequency distribution for the size of the areas in which forest operations were conducted each year was fairly constant.

Relationship between Forest Operations and Accessibility

Fig. 4 shows the location of treated forest sites (based on lot number) in the 3 years. It is clear that these sites are concentrated near to roads and that few are in remote areas. Table 3 shows the percentage of the number of sites

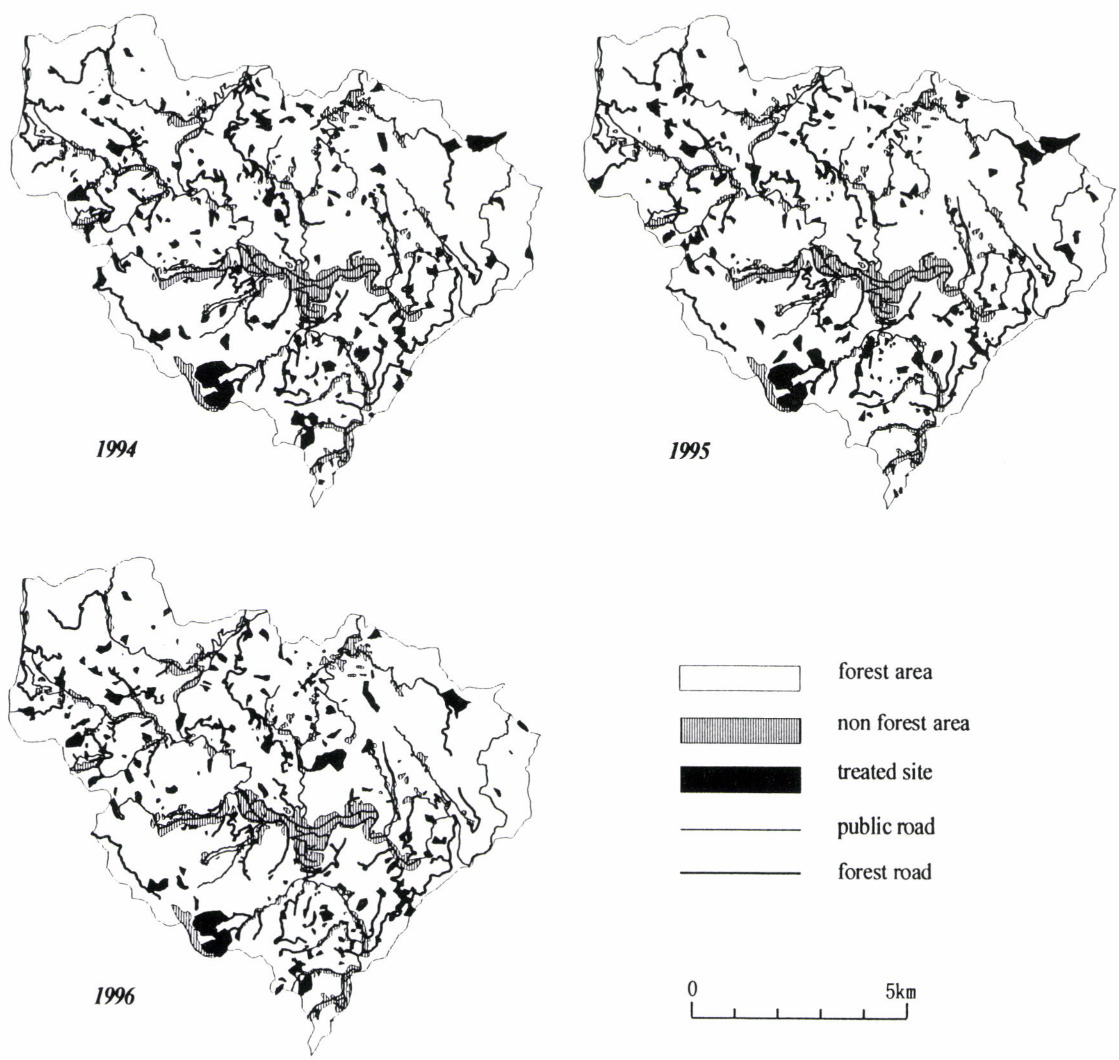

Fig. 4 Location of treated forests and road network in Toei district

Table 3 Percentage of sites in each distance class

Year	Distance from road (m)	Number of sites in each distance class as % of total (%)			
		Planting	Weeding	Pruning	Cleaning cutting & Thinning
1994	0-100	35.9	28.5	30.8	33.9
	100-200	23.1	27.7	26.9	23.2
	200-300	20.5	16.8	23.1	22.3
	300-400	10.3	10.2	0.0	7.1
	400-500	5.1	8.8	11.5	4.5
	500-	5.1	8.0	7.7	8.9
1995	0-100	34.3	34.4	40.0	25.9
	100-200	31.4	26.9	35.0	23.3
	200-300	11.4	15.1	15.0	19.0
	300-400	8.6	12.9	0.0	14.7
	400-500	5.7	4.3	10.0	5.2
	500-	8.6	6.5	0.0	12.1
1996	0-100	25.0	32.5	25.0	31.5
	100-200	33.3	28.2	29.2	26.2
	200-300	12.5	15.4	20.8	21.5
	300-400	16.7	11.1	8.3	7.7
	400-500	4.2	6.8	4.2	3.8
	500-	8.3	6.0	12.5	9.2

Table 4 Percentage of treated area in each distance class

Year	Distance from road (m)	Percentage of area (%)			
		Planting	Weeding	Pruning	Cleaning cutting & Thinning
1994	0-100	17.9	18.8	16.1	24.7
	100-200	12.3	38.2	35.9	22.1
	200-300	18.7	12.0	16.5	26.4
	300-400	3.6	8.6	0.0	7.8
	400-500	3.1	14.4	25.0	5.8
	500-	44.5	8.0	6.4	13.1
1995	0-100	46.3	28.9	34.7	18.2
	100-200	20.5	22.8	41.2	18.6
	200-300	10.6	15.0	21.5	22.7
	300-400	8.3	10.9	0.0	18.5
	400-500	6.4	12.8	2.5	5.3
	500-	7.9	9.6	0.0	16.7
1996	0-100	25.5	24.2	26.9	28.3
	100-200	19.6	35.3	34.4	24.2
	200-300	17.5	13.3	16.0	18.3
	300-400	15.6	7.6	11.0	11.3
	400-500	1.5	11.7	4.0	3.7
	500-	20.4	7.9	7.6	14.3

in each distance class (the distance from a road to the worked forest). The proportion was obtained by dividing the number of operations in each distance class by the total number of each operations. The majority of treated sites for each operation were within 200m of a road. The amount of planting and weeding fell sharply in areas greater than 200m from a road, while the amount of pruning and thinning fell sharply in areas greater than 300m away. Over 70% of the sites treated in each kind of operation were within 300m of a road. This remained essentially constant for the 3 years.

Table 4 shows the percentage of the area involved in each operation in each distance class. The proportion was obtained by dividing the sum of the area for each operation in each distance class by the total area of each operation. Although the relationship between area and distance was not as clear as the relationship between number of sites and distance, the percentage of area treated decreased with increase in the access distance in most cases, and most operations were concentrated within 300m of a road.

Fig. 5 compares the number of operations and the treated areas, with the area of whole forest in each distance class, as percentages of the total. This was calculated by the point-grid method (Hori and Kitagawa 1987), using a grid scale of 500m. The percentage of the area treated that was within 300m of a road was higher than for the whole forest, and conversely the percentage over 300m from a road was lower than for the whole forest.

These results show that forest operations tend to be concentrated near roads, and forests in more remote areas tend not to be worked.

Current Road Utilization

We analyzed the utilization of public and forest roads, with the assumption that the road nearest each site was the

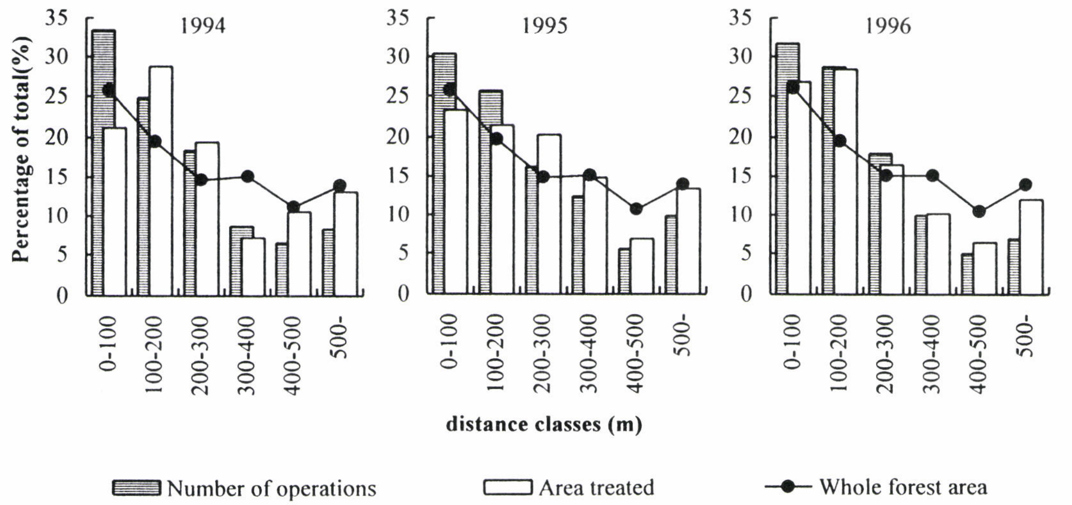

Fig. 5 Distribution of sites, area treated, and whole forest by access distance class

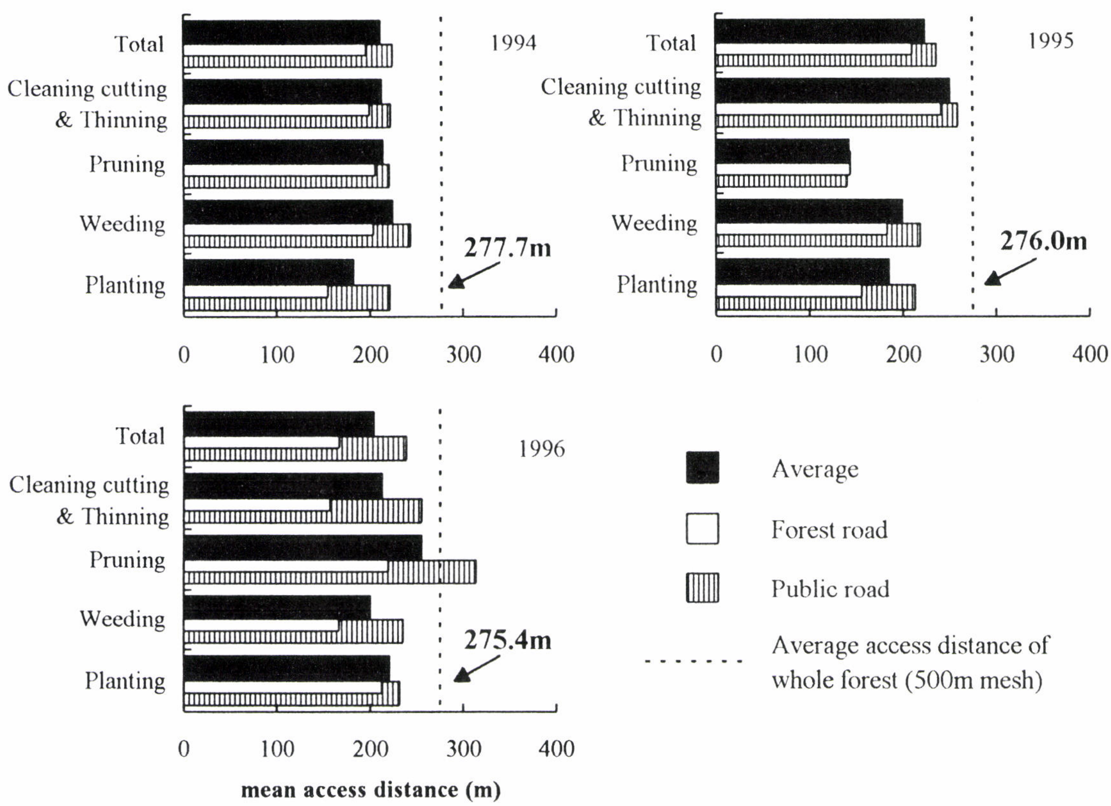

Fig. 6 Average access distance for each operation and whole forest

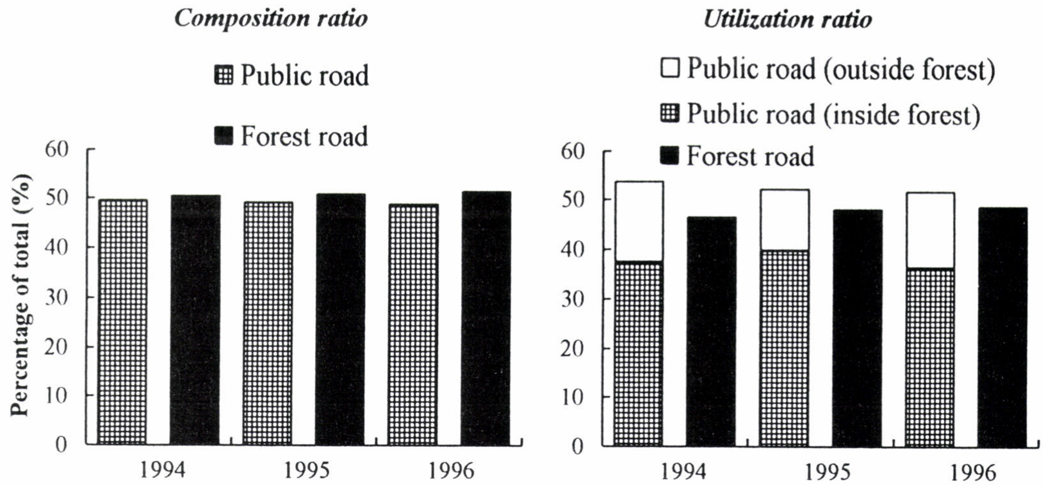

Fig. 7 Composition ratio and utilization ratio for public and forest roads

one used for forest operations. Fig. 6 shows the average access distance from sites to the nearest road in each category. The dotted lines in the figure are the yearly average access distances for all the forests in Toei district, calculated by the point-grid method. The average distance for each operation was shorter than the average distance for forests as a whole, except for pruning in 1996. The yearly averages for all operations were from 205 to 225m; these were smaller than the 275m average for forests as a whole. This indicates that forest operations are concentrated near roads, and that roads are inadequate for current forest operations. In addition, the access distances of most operations that were nearer to a public road were longer than those where the nearest road was a forest road. We defined the composition ratio as the proportion of total length of roads in the Toei district that were in each category (public and forest), and defined the utilization ratio as the proportion of areas worked using each type of road. In Aichi prefecture, public roads within forests and those less than 200m from the forest edge, except those in built up areas, are normally treated as forest roads. For the public roads, however, we picked up only public roads within forests because of these are similar condition of location as forest roads. Fig. 7 compares the composition ratio with the utilization ratio.

Each year the composition ratio for forest roads increased slightly, and that of public roads fell, with the construction of new forest roads. For the utilization ratio, the percentage of public roads was higher than that of forest roads. With public roads, roads both inside and outside forests are utilized. Fig. 7 shows the proportion of public roads inside and outside forests utilized. Although the composition ratios for public roads within forests and forest road were much the same, the utilization ratios of public roads within forests were lower than forest roads.

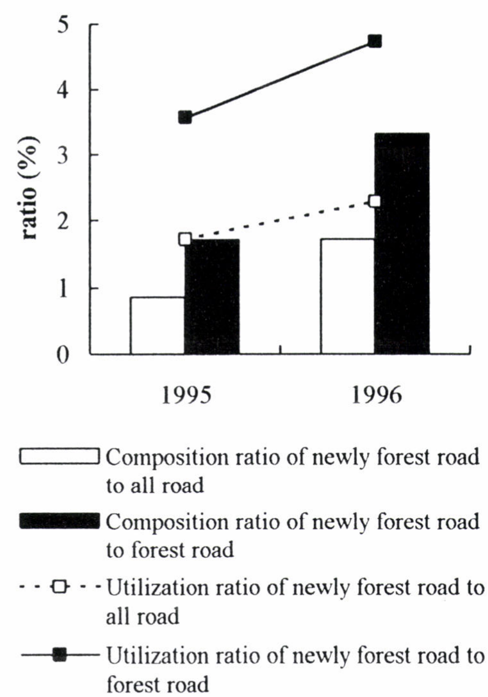

Fig. 8 Cumulative composition and utilization ratios for newly constructed forest road

However, the overall utilization of public roads exceeded that of forest roads because of the utilization of public roads outside the forests. The access distance of half of the forest operations that used public roads outside forests was less than 200m. It is clear that there is a high dependence on public roads for forest operations.

In Fig. 7, the utilization ratio of forest road increased from about 46% to 49% between 1994 to 1996. However, it is impossible to determine whether this increase resulted from road construction or chance. We attempted to clarify the effect of road construction by analyzing the relationship between forest operations and construction each year. We assumed that forest roads constructed the previous year were available for operations in the current year and then compared the annual composition and utilization ratios. Fig. 8 shows the cumulative composition ratio and utilization ratio of forest roads built since 1994. In the figure, the composition ratio in 1996 is the ratio of cumulative construction length since 1994 to whole or forest road length in 1995 (as a percentage), and the utilization ratios are annual figures for the newly constructed roads.

The cumulative composition ratio increased due to annual construction, and the utilization ratio increased. When we analyzed the construction year of forest roads used for forest operations in 1996, however, we found that the forest roads built in 1995 were not used; consequently the utilization ratio in 1996 only includes the forest roads constructed by 1994. The composition ratio was low compared to the total and forest road lengths, because only a short total length of new forest roads was built. The utilization ratio was higher than the composition ratio. This shows that newly constructed forest roads are used to a greater extent, and that most of the increase in the utilization ratio in Fig. 7 is from the utilization of new roads.

The Amount of Road Necessary from the Viewpoint of Current Forest Operations

In the preceding sections, it is clear that in Toei district: (1) Forest operations are concentrated near roads. The average access distance of forest operation ranged from 205 to 225m over the study period, while the current average access distance to the whole forests was longer, at about 275m. (2) The majority of forest operations depended on public roads. (3) According to current forest operations, there are too few forest roads.

We attempted to estimate from the current level of forest operations the appropriate amount of road. There are various models for determining the amount of forest road. In this study, we used a simple formula (Sakai 1990, Sawaguchi *et. al*. 1994) that gives the relationship between the average access distance in meters (S_m) and the road density in per hectare (D).

$$S_m = 2{,}500\, V_{-corr} / D$$

In the ideal rectangle model, average access distance is $2{,}500 / D$, and V_{-corr} is adjustment factor for the actual road network. First, we obtained the value of $V_{-corr} = 1.7$ from the road density of 15.6m/ha (public roads within forests and within 200m of the forest edge: 8.6m/ha, forest roads: 7.0m/ha) and the average access distance for all of the forests of 275.4m in 1996. Next, we assumed that the average access distance of actual forest operations was 200 m, and calculated the necessary road density to be 21.3m/ha. If the public road density remains fixed at 8.6m/ha, then the forest road density must increase to 12.7m/ha. Consequently, 5.7m/ha of future construction is necessary, which corresponds to about 63km of new roads. The road density in 1995 used for the estimate was smaller than the actual value, because it was based on two-dimensional lengths taken from digitized data and there were a few problems with the accuracy of the maps showing the location of forest roads. If we use the road density statistics for Aichi prefecture (public road: 8.7m/ha, forest road: 7.6m/ha, total: 16.3m/ha), the calculated density required becomes 22.4m/ha, andthe required forest road density increases to 13.7m/ha. This means that 6.1m/ha of forest road should be built, with a total length of about 67km.

CONCLUSION

An analysis of the relationship between forest operations conducted by the Forest Owners' Association and the existing forest road network found that:

(1) Current forest operations concentrate on weeding and thinning, and little planting or pruning is being conducted. The number and area of sites where forest operations are being conducted was approximately 300 and 300ha, respectively, in each year of the study. The average number of operations per owner was 3.2, although 40% of forest owners conducted only a single operation. On the other hand, fewer than 10% of the owners conducted more than 10 operations, although the area they treated was over 30% of the total area treated.

(2) Operations were concentrated near roads. Most operations were within 200m of a road, and over 70% of the forest operations were within 300m of a road. On the other hand, the average distance from a road to the whole forest exceeded the average distance of the forest operations. It is clear that few operations are conducted in remote forests.

(3) There was a slightly greater proportion of forest roads, but the utilization ratio of public roads was higher than that of forest roads, indicating a relative dependency on public roads. Although the composition ratio of newly constructed forest roads was very low in comparison with the total composition ratio, their utilization ratio was relatively high in comparison, indicating the effect of newly-constructed forest roads.

(4) The average access distance to forest operations was approximately 210m each year, which was nearly 60m shorter than the average distance to the forests as a whole. There are not enough roads for the current level of forest operations. From the viewpoint of actual forest operations, a total road density of over 21m/ha is required, and over 13

m/ha of this is forest road density. This is about 1.8 times the current density of forest roads, indicating that the length of forest roads that should be built is approximately the same as the length of existing forest roads.

The results show that forest roads are very important. However, approximately 66km of roads should be built, and this cannot be done immediately. In fact, the regional forest plan for Aichi prefecture calls for a road density of 25.8m/ha. Of this, the forest road density is supposed to be 15.9m/ha by the year 2026. This is a long-term plan, to be implemented over 30 years. In the meantime, it is feared that a lack of forestry operations will lead to the ruin of many forests. Therefore, it is important to accelerate road construction to improve both the quantity and quality of roads and efficiently reduce the access distance.

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Article

Difference in Diffuse Site Factors Due to Spatial Distribution of Sky Luminance

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ABSTRACT

The difference in estimation of the diffuse site factor due to different models of the spatial distribution of sky luminance was examined. The examined models were the uniform overcast sky (UOC) and standard overcast sky (SOC). The difference between the diffuse site factors for UOC (Ψ_{UOC}) and for SOC (Ψ_{SOC}) was 1.5% in average and ranged from −0.4% to 5.2%. A strongly positive correlation was observed between Ψ_{UOC} and Ψ_{SOC}: $\Psi_{SOC}=1.109\Psi_{UOC}$ ($n=270$, $r=0.999$, $p<0.001$). This shows that Ψ_{SOC} tends to be larger than Ψ_{UOC}, and the difference increases with the increase in Ψ_{UOC} or Ψ_{SOC}. The difference is determined by three factors: 1) the decrease in gap fraction (gap ratio) with zenith angle; 2) the incident angle of cosine law; 3) the difference in spatial distribution of sky luminance.

Keyword: diffuse site factor, hemispherical photograph, spatial distribution of sky luminance, standard overcast sky, uniform overcast sky

INTRODUCTION

Light is critical to the emergence, establishment, survival and growth of understory trees and herbs (FUJIMORI 1989; KIYONO 1990; TURNER 1990; YAHATA 1993), which are related to water and soil conservation (SHIMIZU *et al*. 1984) and site productivity (KIYONO 1990). Hence, it is important for forest scientists and managers to understand light conditions within a forest and to develop simple and reliable methods for measuring and/or estimating these conditions.

ANDERSON (1964a) has reviewed the various methods and has shown the usefulness of hemispherical photographs in estimating light conditions within a forest. Hemispherical photographs have been used to estimate both diffuse sky light and direct sun light penetrating the tree canopy (ANDERSON 1964b; MADGWICK and BRUMFIELD 1969; TAMAI and SHIDEI 1972b; CHAZDON and FIELD 1987; STEEGE 1993; YAHATA 1993). Diffuse sky light and direct sun light have been often termed the 'diffuse site factor' and 'direct site factor', respectively (ANDERSON 1964b; MADGWICK and BRUMFIELD 1969; TAMAI and SHIDEI 1972b), and the term site factor is used in that restricted sense in this paper.

Light conditions fluctuate both daily and seasonal shifts in solar angle and weather (REIFSNYDER *et al*. 1971; TAMAI and SHIDEI 1972a; KAWAHARA 1983) and are influenced by differences in the slope and aspect of a forest stand (ANDO 1983; NONODA 1985). There is a question as to what extent changes in light conditions are caused by fluctuation in direct sun light or by changes in stand structures such as tree growth, thinning and pruning operations. Fluctuations in light conditions are primarily caused by fluctuations in direct sun light, and the fluctuations in diffuse sky light are comparatively small. Hence, in order to discuss changes in light conditions with stand structures, the diffuse site factor may be more significant than the direct site factor.

The diffuse site factor is mainly determined by the spatial distribution of sky luminance and light-absorbing structures. The uniform overcast sky (UOC: MONSI and SAEKI 1953) and standard overcast sky (SOC: MOON and SPENCER 1942) are widely used as simple models for the spatial distribution of sky luminance (STEEGE 1993). The UOC makes the assumption that every part of the sky is of equal luminance (MONSI and SAEKI 1953; CHAZDON and FIELD 1987; STEEGE 1993). On the other hand, the SOC is expressed by the following empirical equation:

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$$L(\alpha) = L_Z(1+2\sin\alpha)/3 \quad (1)$$

where $L(\alpha)$ is the sky luminance at any α, L_Z is the luminance at the zenith, and α is the angle above the horizon (MOON and SPENCER 1942; ANDERSON 1964b; MADGWICK and BRUMFIELD 1969; GRACE 1971; STEEGE 1993). The SOC was officially adopted by the International Commission on Illumination in 1955 (ANDERSON 1964b; GRACE 1971).

In order to estimate the diffuse sky light using hemispherical photographs, it is necessary to understand the difference in the estimation of the diffuse site factor between the above two widely used models for the spatial distribution of sky luminance. These difference has not previously never been examined. The purpose of this paper therefore is to examine the difference in estimation of the diffuse site factor between the UOC and SOC.

MATERIALS AND METHODS

Study Area

This study was conducted in 13 Japanese cedar (*Cryptomeria japonica* D. DON) and 17 Japanese cypress (*Chamaecyparis obtusa* ENDL.) even-aged pure forest stands in the Kyushu University Forest in Fukuoka, Japan.

Square plots of area 0.02ha were set up for each stand, and the tree height, diameter at breast height (DBH), branch height and crown width of all living trees were measured. The general description of each plot is shown in Table 1.

Table 1 General description of each plot

Plot No.	Species*	Tree height** (m)	DBH** (cm)	Clear length** (m)	Crown width** (m)	Stand density (trees/ha)	Slope inclination (degree)
1303	C_j	19.0	26.9	10.7	2.2	750	36
1305	C_j	19.5	26.6	12.0	2.2	1,000	47
1306	C_j	19.0	24.6	12.2	1.9	1,450	39
1307	C_j	18.8	26.9	11.0	1.0	450	40
1308	C_j	13.9	20.3	8.1	1.6	1,000	42
1309	C_j	15.3	18.7	10.9	1.3	1,850	33
1404	C_j	25.5	35.6	15.0	2.1	650	31
1410	C_o	9.2	14.9	5.4	1.1	2,650	39
1501	C_o	20.5	37.0	10.7	1.8	650	30
1504	C_o	20.6	32.4	13.0	1.7	900	30
1505	C_o	19.3	29.7	13.1	1.6	950	18
1509	C_j	18.4	23.6	11.4	1.2	1,350	30
1510	C_j	20.6	31.1	8.4	1.5	800	19
1511	C_j	13.5	17.3	8.0	0.9	2,450	30
1513	C_j	16.6	19.2	11.6	0.9	1,900	21
1514	C_j	21.2	25.0	13.4	1.3	450	24
1515	C_o	19.8	31.7	12.1	1.7	1,050	28
1516	C_o	21.3	33.2	11.9	1.8	800	5
1519	C_o	20.9	37.1	13.1	2.0	600	15
1520	C_o	21.0	33.6	13.9	1.7	1,000	18
1526	C_j	19.1	34.2	4.8	1.8	550	19
1613	C_o	13.9	27.6	6.4	1.9	550	41
1804	C_o	20.0	34.0	11.0	2.1	500	38
1810	C_o	23.6	36.1	15.2	2.1	450	32
1811	C_o	25.0	37.5	14.2	2.0	1,500	30
1812	C_o	22.6	38.2	14.0	2.1	300	6
1902	C_o	6.7	9.8	3.1	0.9	1,750	35
1903	C_o	7.4	11.9	4.1	0.9	1,200	24
1904	C_o	8.4	13.1	4.1	1.1	1,600	32
1905	C_o	8.6	14.1	3.7	1.3	2,000	40

* : C_j and C_o mean Japanese cedar and Japanese cypress, respectively.
**: mean values

Hemispherical Photograph Data

Nine hemispherical photographs were taken in each plot under an overcast sky and still conditions, with a Nikkor 8mm f/2.8 fish-eye lens, mounted on a camera (high appoint body F3, Nikon). The lens had a 180° view angle and an equidistant or polar projection formula (HERBERT 1987; INOUE *et al*. 1996). The camera was mounted 1.2m above the ground on a tripod (TERAOKA 1995) and leveled looking upwards to the zenith. A negative film for color prints (Super G ACE100, Fuji Color) was used with an L1BC filter. The aperture was F=8 (TERAOKA 1995) and shutter speed was automatically determined. The size of all printed rectangular photographs was 8.9cm × 12.8cm, and the diameter of the circular hemispherical photograph image was 9.2cm.

Image processing

First, the printed photographs were digitized on a personal computer (Macintosh Quadra 800, Apple Computer) with a resolution of 200 dpi (dots per inch) and 256 color scale, using a flatbed image scanner (GT6000, Epson). Secondly, the digitized rectangular images were converted to the circular images in gray-scale using image processing software (Photoshop3.0J, Adobe), and the diameter of the circular image was reduced to 300 pixels on the display. Thirdly, the gray-scale images were visually thresholded by comparing the digitized gray-scale image with the binary one on the display (CHAZDON and FIELD 1987; YAHATA 1993; INOUE *et al*. 1996), and then sky and non-sky pixels were represented by white and black pixels on the display, respectively.

Image analysis

The hemispherical photograph can be regarded as consisting of 89 concentric rings, dividing the radius of the circular image into 89 parts. Each ring corresponds to a circular sphere segment in the sky hemisphere with an arc of 1 degree. The area of each segment is different and will be smaller on those segments nearer to the zenith. First, the gap fraction or gap ratio ($T(\theta)$), where θ is the zenith angle and is from 0.5 to 89.5, for each of the 89 parts given by each ring, was measured using a free software HEMIPHOT (STEEGE 1993).

Next, the diffuse site factors for uniform overcast sky (Ψ_{UOC}) and for standard overcast sky (Ψ_{SOC}) were calculated as follows: The total diffuse illuminance from the entire sky (ψ_T) can be calculated by the following equation (EDWARDS and THORNLEY 1973; HASHIMOTO 1985):

$$\psi_T = \int_0^{2\pi}\int_0^{\frac{\pi}{2}} L(\theta)\ \sin\theta\cos\theta d\theta d\phi \qquad (2)$$

where $L(\theta)$ is the sky luminance at any θ and ϕ is the azimuth angle. Since the zenith angle θ is equal to $(90-\alpha)$, eq. 1 can be changed to:

$$L(\theta) = L_z(1+2\cos\theta)/3 \qquad (3)$$

By solving a definite integral equation that substitutes eq. 3 into eq. 2, we obtain the total diffuse illuminance for SOC (ψ_{TSOC}):

$$\psi_{TSOC} = 7/9\pi L_z \qquad (4)$$

Denoting the uniform sky luminance for UOC by L_m, we also obtain the total diffuse illuminance for UOC (ψ_{TUOC}):

$$\psi_{TSOC} = \pi L_m \qquad (5)$$

On the assumption that no light is transmitted or reflected from foliage (CHAZDON and FIELD 1987; YAHATA 1993), the diffuse illuminance penetrating the tree canopy (ψ_D) was calculated using the measured gap fraction:

$$\psi_D = 2\pi \sum_{\theta=0.5}^{89.5} L(\theta)\, T(\theta) \sin\theta\cos\theta \qquad (6)$$

Using eqs. 4, 5 and 6, Ψ_{UOC} and Ψ_{SOC} were calculated, respectively, as:

$$\Psi_{UOC} = 100\ \psi_D/\psi_{TUOC} \qquad (7)$$

$$\Psi_{SOC} = 100\ \psi_D/\psi_{TSOC} \qquad (8)$$

RESULT

Fig. 1 shows the relationship between Ψ_{UOC} and Ψ_{SOC}. The observed Ψ_{UOC} and Ψ_{SOC} ranged from 1.4% to 37.9% and from 1.3% to 41.9%, respectively. The difference between Ψ_{UOC} and Ψ_{SOC} was 1.5% in average and ranged from −0.4% to 5.2%. A strongly positive correlation was

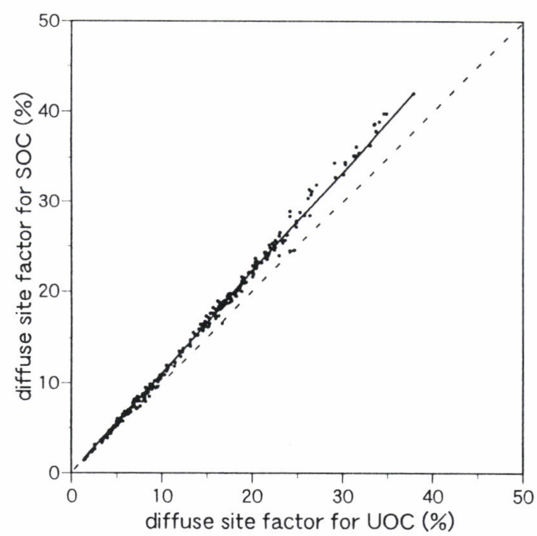

Fig. 1 Relationship between diffuse site factors for uniform overcast sky (UOC) and standard overcast sky (SOC)

Note: The solid and broken lines are the regression and 1:1 ones, respectively.

observed between Ψ_{UOC} and Ψ_{SOC} ($n=270$, $r=0.999$, $p<0.001$) :

$$\Psi_{SOC}=1.109\ \Psi_{UOC} \quad (9)$$

This showed that Ψ_{SOC} tends to be larger than Ψ_{UOC}, and the difference increases with the increase in Ψ_{UOC} or Ψ_{SOC}.

DISCUSSION AND CONCLUSION

The difference between Ψ_{UOC} and Ψ_{SOC} is determined by three factors: 1) the decrease in gap fraction with zenith angle; 2) the incident angle of cosine law; 3) the difference in spatial distribution of sky luminance.

Fig. 2 shows an example of the change in gap fraction with zenith angle. It is obvious that the gap fraction tends to decrease with the zenith angle, and the gap fraction is greater around the zenith than around the horizon. This is considered to be caused by two factors: 1) the gap fraction tends to occur more frequently directly above the photographic points (ANDERSON 1964b); 2) the cover ratio of light-absorbing structures such as tree crowns, stems and the stand floor increases with zenith angle (OKAMURA *et al.* 1995; INOUE *et al.* 1996).

By the incident angle of cosine law, the diffuse illuminance reaching a point is proportional to the cosine of the incidence angle (ANDERSON 1964b; MADGWICK and BRUMFIELD 1969; GRACE 1971). By this law, the diffuse illuminance from a unit sky area decreases with the increase in the zenith angle. Thus, the gap fraction around the zenith will tend to give a larger diffuse site factor than the fraction around the horizon.

By the assumptions of the spatial distribution of sky luminance, the total diffuse illuminance from the entire sky for UOC and SOC were represented by eqs. 4 and 5, respectively. Assuming that the total diffuse illuminance from the entire sky for UOC and SOC are equivalent, we obtain:

$$L_m=7/9\ L_z \quad (10)$$

This shows that the sky luminance at the zenith for SOC is 9/7 times larger than the uniform sky luminance for UOC. Fig. 3 shows the changes in sky luminance with zenith angle for UOC and SOC. It is obvious that the sky luminance around the zenith is greater for SOC than for UOC. Since the diffuse site factor is also proportional to the sky luminance (ANDERSON 1964b), the gap fraction around the zenith will give a relatively larger diffuse site factor for SOC than for UOC.

It is considered that Ψ_{SOC} tends to be larger than Ψ_{UOC} because of these three factors, and the gap fraction around the zenith plays an important role in the difference between Ψ_{SOC} and Ψ_{UOC}. From this viewpoint, it is suggested that the difference in the diffuse site factor would become larger in a gap site, for which a greater gap fraction is concentrated around the zenith.

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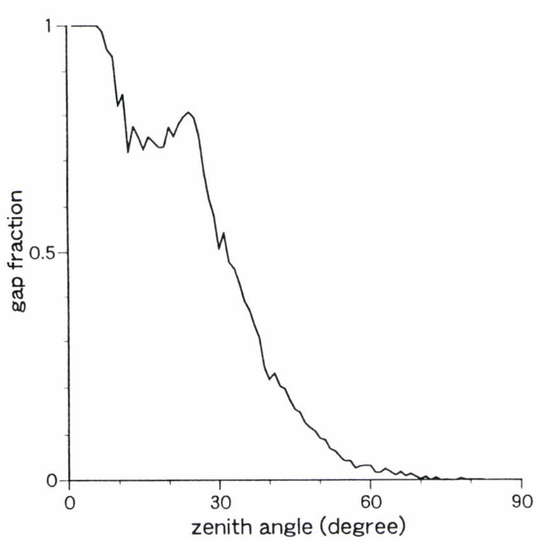

Fig. 2 An example of the change in gap fraction with zenith angle

note: The measured photograph was taken in plot 1307.

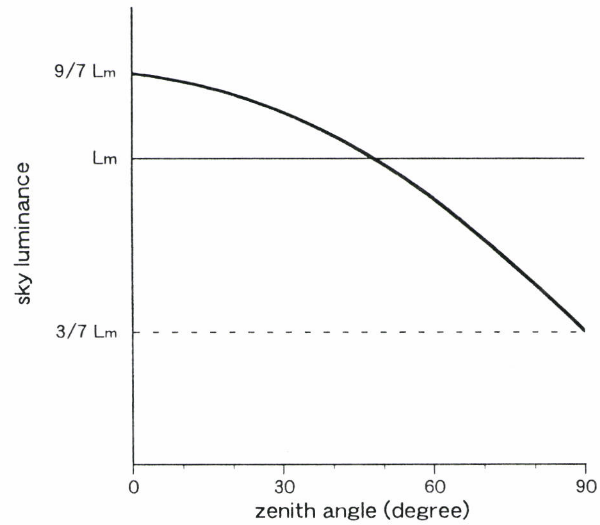

Fig. 3 Changes in sky luminance with zenith angle for UOC and SOC

note: The thin and thick lines show the changes for UOC and SOC, respectively. L_m is the uniform sky luminance for UOC.

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Short communication

Estimation of Crown Closure through Line Sampling

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ABSTRACT

I proposed two new theoretical methods for estimating the crown closure through line sampling. These are an application of Masuyama's method for estimating an area based on a line sampling unit, using integral geometry. The first method is as follows: First, we establish a sample line of fixed length L in the stand, on the assumption that the crown projection area of all trees is included in an area of the stand T. Next, we define a continuous variable l_j which takes the value of that part of the length of the sample line which is included within the crown projection area of the j-th trees s_j. Then, its expectation is: $E(l_j)=Ls_j/T$. This holds true for the N trees: $E(\sum_{j=1}^{N} l_j)=L\sum_{j=1}^{N} s_j/T$. Dividing L into the sum of expectations of l_j $(L\neq 0)$, we obtain: $E(\sum_{j=1}^{N} l_j)/L=\sum_{j=1}^{N} s_j/T$. $\sum_{j=1}^{N} l_j/L$ is an unbiased estimator of crown closure. The second method is as follows: A sample line is established as in the first method, and a uniform random number is selected within the length of the line L. Next, a discrete variable ϕ_j is defined which takes the value 1 if the value of the random number is smaller than l_j, otherwise zero. Then, its expectation is: $E(\phi_j)=s_j/T$. This holds true for the N trees: $E(\sum_{j=1}^{N}\phi_j)=\sum_{j=1}^{N} s_j/T$. $\sum_{j=1}^{N}\phi_j$ is also an unbiased estimator of crown closure.

Keyword: crown closure, line sampling, integral geometry

INTRODUCTION

The problem of obtaining basic information about forest resources easily is one of the most fundamental ones in the field of forest mensuration (Ueno 1993). Since angle count sampling was proposed by Bitterlich (1947), this method has been developed and applied by several scientists. Using this approach, total basal area (Bitterlich 1947; Grosenbaugh 1952), stand volume (Kitamura 1964; Minowa 1976; Ueno 1982), mean tree height (Hirata 1955), mean diameter (Grosenbaugh 1952), and stand density (Ueno 1992) can be estimated without setting up a plot and measuring trees directly. However, those studies all involved the estimation of the size of tree stems, and no studies have ever tried to estimate the size of tree crowns through angle count sampling.

Crown closure is related to the growth of trees and/or stands and light interception. Hence, it is very important for forest management to understand crown closure, and simple methods for estimating the extent of crown closure have been sought. Ueno and Hiramori (1996) proposed a method for estimating crown closure through point sampling. However, estimation through line sampling has not previously been proposed. The purpose of this paper is to propose two kinds of theoretical methods for estimating crown closure through line sampling.

ESTIMATION OF CROWN CLOSURE THROUGH POINT SAMPLING

The method of estimating crown closure through point sampling proposed by Ueno and Hiramori (1996) is as follows:

First, it is assumed that:

1) There are N trees in the stand,
2) The crown projection area of all trees is included in an area of the stand T.

δ_j is a discrete variable which can take the value 1 if a sample point is included in the crown projection area of the j-th trees s_j $(j=1, 2, \cdots, N)$, otherwise zero. Then, its expected value is:

$$E(\delta_j)=1\times s_j/T+0\times(T-s_j)/T=s_j/T. \quad (1)$$

This equation holds true for the N trees:

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$$E(\sum_{j=1}^{N}\delta_j)=\sum_{j=1}^{N}s_j/T. \qquad (2)$$

$\Sigma\delta_j$ gives an unbiased estimator of the extent of crown closure.

ESTIMATION OF CROWN CLOSURE THROUGH LINE SAMPLING

In this section, two theoretical methods for estimating crown closure through line sampling on the same assumptions as point sampling are proposed.

Method 1

Masuyama (1956; 1957) proved the estimation of an area on the basis of a line sampling unit by the use of integral geometry, applying the condition of unbiasedness to the theorem of Santalò. The proof is as follows: To begin with, let D and E denote two end points of a line of length L, and let the coordinates of D be x, y. Next, let θ be an angle between the line DE and a fixed direction ($0 \leq \theta \leq 2\pi$). Furthermore, let l denote the length of that part of the line DE included in the area of a closed curve S. By the theorem of Santalò, we obtain,

$$\iiint l dx dy d\theta = 2\pi LS. \qquad (3)$$

On the condition of unbiasedness, that is, the end point D is always in an area T which completely includes the area of a closed curve S, equation (3) can be written as:

$$E(l)=\iiint_T l dx dy d\theta/T=2\pi LS/T, \qquad (4)$$

where $E(l)$ is the expectation of l.

Finally, because it is unnecessary to randomize the angle θ by the condition of unbiasedness, we obtain,

$$E(l)=\iint_T l dx dy/T=LS/T. \qquad (5)$$

This can be changed to:

$$TE(l)/L=S. \qquad ((L/T)\neq 0) \qquad (5')$$

Then, it can be proved that Tl/L is an unbiased estimator of the area of the closed curve S.

Now we consider a continuous variable l_j which takes the value of the length of that part of the sample line which is included in the crown projection area of the j-th tree s_j, otherwise zero if no part is included (see Fig. 1). By Masuyama's proof (1956; 1957), the expected value of l_j is:

$$E(l_j)=Ls_j/T. \qquad (6)$$

Dividing L into the equation (6), we obtain,

$$E(l_j)/L=s_j/T. \qquad (L\neq 0) \qquad (7)$$

This equation holds true for the N trees:

$$E(\sum_{j=1}^{N}l_j)/L=\sum_{j=1}^{N}s_j/T. \qquad (8)$$

$\Sigma l_j/L$ gives an unbiased estimator of the extent of crown closure.

The sampling procedure for this method is as follows: We select a sample point at random in the stand, and establish a sample line of fixed length L in a given direction with the sample point at one end of the line. As shown in

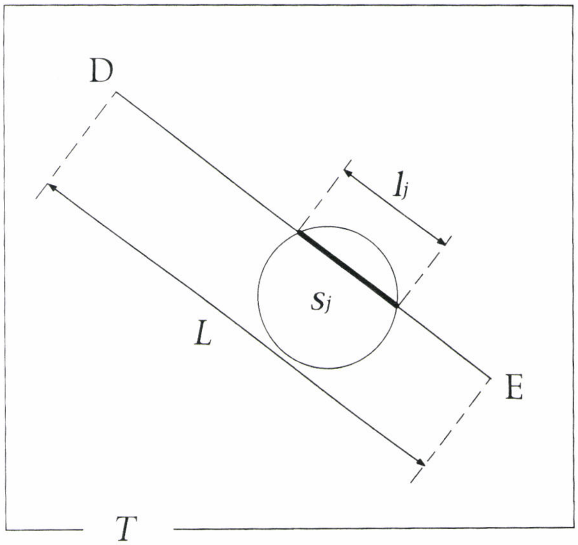

Fig. 1 Outline of the method for measuring the continuous variable l_j

Note: T is an area of the stand, and s_j is the crown projection area of the j-th tree. L is the length of the sample line DE, and l_j is that part of the line DE included in s_j.

Fig. 1, then, we measure the continuous variable l_j which takes the value of the included length if part of the sample line is included within the crown projection area of the j-th tree s_j, otherwise zero. Finally, we obtain an unbiased estimator of crown closure by dividing L into the sum of l_j.

Method 2

The second method, combining point sampling (Ueno and Hiramori 1996) and line sampling (first method), is explained as follows:

By equations (2) and (8), we obtain,

$$E(\sum_{j=1}^{N}l_j)=L\,E(\sum_{j=1}^{N}\delta_j). \qquad (9)$$

This shows that the expected value of the sum of the continuous variable l_j can be obtained by multiplying the expected value of the sum of discrete variable δ_j by the length of a sample line L. Hence, the expectation $E(\Sigma l_j)$ on the first method can be obtained as follows: Let l_j denote that part of the length of a sample line L included in the crown projection area of the j-th tree s_j. Let ϕ_j be a discrete variable which takes the value 1 if the value of a uniform random number which was selected within the length L is smaller than l_j, otherwise zero. Then, its expectation is:

$$E(\phi_j)=l_j/L. \qquad (10)$$

This can be written as:

$$L\,E(\phi_j)=l_j. \qquad (L\neq 0) \qquad (10')$$

By substituting equation (10') into the left side of (6), we obtain,

$$E(l_j) = E\ [L\ E(\phi_j)] = L\ E(\phi_j), \tag{11}$$

and this holds true for the N trees:

$$E(\sum_{j=1}^{N} l_j) = L\ E(\sum_{j=1}^{N} \phi_j). \tag{12}$$

This corresponds with equation (9), and the expectation of the sum of the continuous variable $E(\sum l_j)$ can be obtained by multiplying the expectation of the sum of the discrete variable $E(\sum \phi_j)$ by the length of the line L. By substituting equation (12) into (8), we obtain,

$$E(\sum_{j=1}^{N} \phi_j) = \sum_{j=1}^{N} s_j / T, \tag{13}$$

and $\sum \phi_j$ also gives an unbiased estimator of the extent of crown closure.

DISCUSSION AND CONCLUSION

In this paper, I showed theoretically that the crown closure can be estimated not only through point sampling but also by two methods involving line sampling. Since the sum of l_j is obtained by selecting a random number, the second method is equivalent to the point sampling method proposed by UENO and HIRAMORI (1996). The basic difference between the first and second methods is that we give the value of zero or 1 to the discrete variable ϕ_j in equation (13) without measuring the sum of the continuous variable l_j.

It is considered that the sampling procedure is simple, and these methods could be both useful and practical for providing ground truth for remote sensing. The population variance of the crown closure estimator and the precision of this method would be discussed in a later paper. Furthermore, I will try to develop a method for estimating crown volume through angle count sampling on the basis of these methods.

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Short communication

Mapping of "Green" Cover using LANDSAT TM: A Case Study in Putrajaya New Township, Malaysia

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ABSTRACT

The need to manage the resource in a more sustainable way and the changing demands of society on its forest are confronting the modern forester. Rapid population growth and development activities has caused high growth and development of urban land use and this result in the decrease of urban environmental quality and traffic disturbances. The objective of this study is to assess the usefulness of LANDSAT TM data in "green" cover mapping of a new township Putrajaya. A LANDSAT TM image of 126/58 (path/row) in Computer Compatible Tape (CCT) form, taken on June 14, 1996, with less than 5% cloud, was acquired for image processing and analysis using the PCI Software System (Version 6.2). Results indicated that band combination of 4-5-3 (FCC) was the best combination for the purpose of the study since it can clearly differentiate the "green" cover. A supervised classification of the image results in 12 classes of "green" cover classification. The overall accuracy obtained for this study was 70%. A total of four classes were allocated as potential sites for the development of a forest landscape map. Urban forestry landscaping using satellite remote sensing has the potential in Putrajaya because the area is still mostly surrounded by a "green" cover.

Keyword: "Green" cover, satellite remote sensing, mapping

INTRODUCTION

Forestry and natural resource management in general is facing a very challenging period. The state and extent of the Earth's natural resources are changing very rapidly and worldwide human influence is leading to large-scale deforestation. The need to manage the resources in a more sustainable way and the changing demands of society on its forest are confronting the modern forester (Linden 1997). Traditionally the management of trees has been considered a serious matter for a forester. Trees in cities are being managed by urban foresters, park managers, tree commissioners, professional arborists, and indeed, citizens themselves in an attempt to improve the physical environment of urban man (Pitt *et al.*, 1979). Whilst the social need for a "green" urban landscape is now widely accepted, certain techniques used for its establishment are beginning to be questioned. This stems from certain philosophical changes related to a 'back to nature' movement, and has led to a belief that many cities may need a new type of greenery landscape (Tregay 1979).

Throughout the world, many scientists are using remotely sensed data from various satellites, particularly high resolution images, to monitor urban environment for a variety of purposes (Forghani 1994). Utilization of high -resolution image data such as LANDSAT TM and SPOT is rapidly increasing in the field of land-use mapping and urban change monitoring. However, effective and successful analysis techniques, particularly for accurate mapping, have still not been well established (Forghani 1994).

The general objective of the study is to utilize satellite remote sensing for urban land-use development planning of a new township. The specific objective is to assess the usefulness of LANDSAT TM data in mapping of "green" cover for urban forestry planning particularly the newly developed Eco-media City Putrajaya.

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METHODOLOGY

Description of Study Area

The location of this study is centered in Putrajaya new township and it's surroundings, which is in the Sepang District of Selangor Darul Ehsan. It lies at the latitude of 101°38′ to 101°47′E and longitude 02°50′ to 02°59′N. Putrajaya is located about 23km south of Kuala Lumpur and about 50km from Kuala Lumpur International Airport (KLIA). It is being developed to be the center for Federal administration and also being a center of Multi-media Super Corridor (MSC).

Putrajaya covers an area of about 4,580ha with a development cost of about RM24 billion. From the previous planning, about 30% of the area will be reserved for leisured area, lake and accommodations for people. The location of the study area is as shown in Fig. 1.

Most of the study area is covered with rubber and occasional patches of jungle, grassland, paddy and minor cultivation in the valleys are commonly present. The average rainfall per year is 2,250 to 2,500mm and the mean temperature of 22° to 32℃ with a high relative humidity of 70 to 98%.

Almost every parts of the study area is hilly with dissected sediments at an altitude of 10 to 120m. It has a varied terrain of gentle and moderate conical hills with long, sinuous gullies and very long major valleys with small terraces. Most slopes are gentle, but patches of high ground, steep and dissected slopes are common. The soil structure is composed with shales and mixed sediments, with some sandstone and conglomerates. It has sandy silty clays on sandstone; stiff clays, often with laterite, on the phyllites and shales. Upper soil layers are frequently gravelled.

Most of the people are staying in rural areas especially in oil palm and rubber estates. The oil palm industry (formerly known as *ELAEIS*) started as early as 1917, but production grew slowly. The impetus to expand came in the late 1950s when the government encourages crop diversification from rubber to oil palm. Malaysia became the world's largest producer and exporter of oil palm (produced 589,000tonnes) replacing Nigeria as the chief producer since 1971 (produced 460,000tonnes) since 1971. The total area under oil palm in Malaysia had increased to 2.819 million hectares. The oil palm development in Malaysia has been colourful. Starting off as ornamental, the crop has developed to the multi billion ringgit industry as what is witnessed today. The planting of cover crops, construction of terraces and silt pits, correct placement of frond piles, and mulching with empty fruit bunches are additional practices aimed at minimizing environmental degradation. Unlike the coconut palm, in which the seed and its oily endosperm are harvested, the mesocarp of the red oil palm fruit is where the oils are concentrated. The Malays were the largest ethnic group (42%), followed by Chinese (37%) and Indians (14%).

MATERIALS AND METHODS

Data Sources

The LANDSAT TM data digital spectral data was acquired with spatial resolution of 30m for path/row 126/58 taken on June 14, 1996 in Computer Compatible Tape

Fig. 1 Location of study area (Putrajaya)

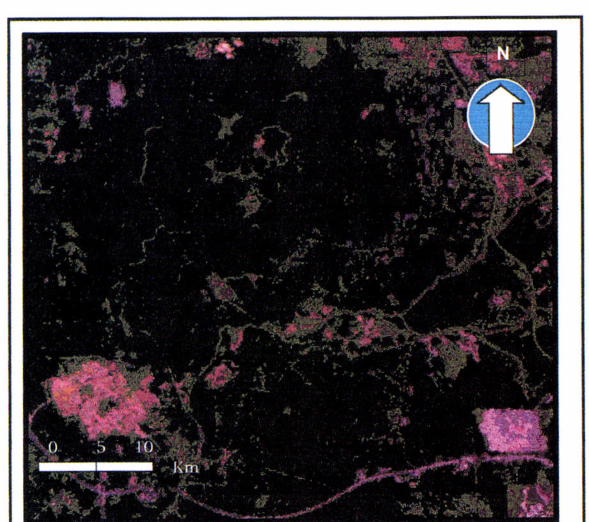


Fig. 2 Raw data LANDSAT TM image of Putrajaya

(CCT) form. The data was taken on June 14, 1996 because this is the only latest data archieve available from The Malaysian Center for Remote Sensing (MACRES) during the study. The scene was acquired from the Malaysian Center for Remote Sensing (MACRES) with less than 5% cloud cover. Fig. 2 shows the raw data image of Putrajaya.

Secondary data is used for supporting the primary data. The secondary data that were used are as follows:

a) Topographic map obtained from Department of Survey and Mapping Malaysia (JUPEM), (Series L7030, sheet 3756, scale 1: 50,000)

b) Land Use Map obtained from Department of Agriculture, Malaysia

c) Land Cover Map obtained from Malaysian Center for Remote Sensing (MACRES)

The above data were used as a guide in ground truthing and visual interpretation.

Image Processing System

PC-based PCI Software System version 6.2 was used for digital image analysis. The capabilities of PCI system are for remote sensing, GIS, terrain analysis, digital photogrammetry, data visualization and image analysis. The data can be handled in raster and vector format. It is very useful and one of the sources for GIS database management. For this study, however, only remote sensing analysis was carried out.

Methodology

The flowchart in Fig. 3 illustrated the study workflow such as data correction, data analysis and interpretation, image enhancement and classification, ground truthing work and image interpretation. Both visual interpretation and computer assisted analysis were used for the "green"

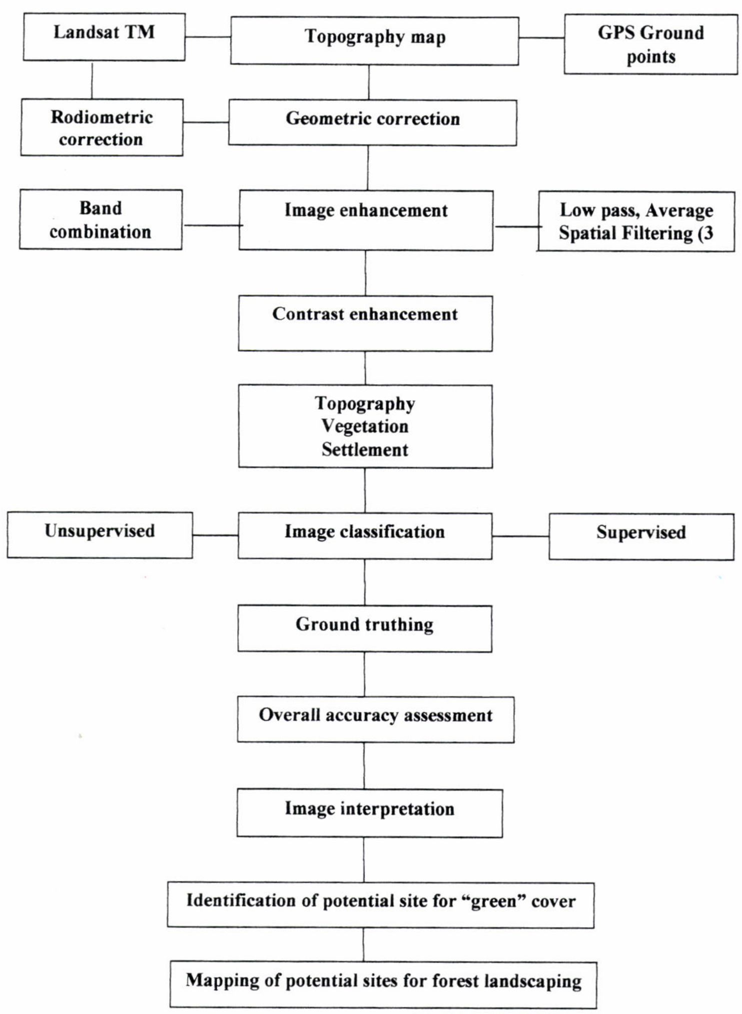


Fig. 3 Flowchart of the study

landcover classification.

Training areas or sampling points were chosen after an examination of the LANDSAT TM images. This represents each class and also for testing the accuracy of the mapping. Sampling points were located for ground truthing using sources from LANDSAT Imagery and land use/cover map. Field observations were conducted and every details were also recorded at the site (Putrajaya).

The accuracy was calculated using the following formula (KAMARUZAMAN and HASMADI, 1998):

$$\text{Accuracy} = \frac{\text{Total accurate number of training areas}}{\text{Total number of training areas}} \times 100$$

A total of 20 training areas were selected based on the supervised and unsupervised classification and the land cover and topo map.

RESULTS AND DISCUSSION

Image Enhancement

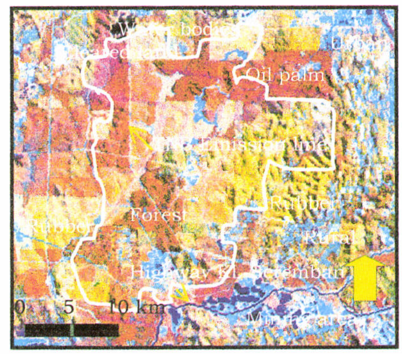
The most important steps in image enhancement are the band combinations. KAMARUZAMAN and HASZULIANA (1996) reported that band 4 and 5 are relatively effective for separation of vegetation categories/types. However both bands 2 and 5 in addition to band 4 gave more information on forest, water and urban areas classification.

All the seven bands (1, 2, 3, 4, 5, 6 and 7) are selected to obtain a suitable band combination for visual interpretation for separation of land cover classes of Putrajaya. All the seven bands are tested for visual comparisons. Band 6 was finally excluded for band combination visualization due to it's blur image.

It showed that band 4 and 5 gave the best result. From both bands, we can get more and quality information about the "green" cover features such as vegetation types namely forest, oil palm and rubber and also the water bodies and urban areas. The bright areas represented a high temperature zone like urban area, cleared land and grassland/shrubs. The dark spots such as forested areas and dense vegetation indicated the low temperature zones. Water bodies are represented by very dark or black area.

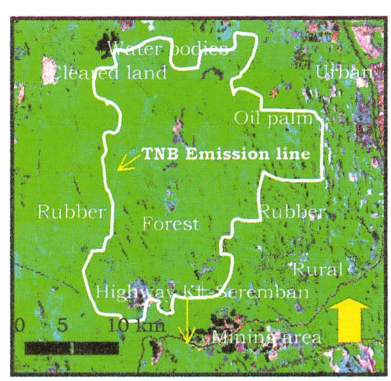
Several band combination was derived using the False Color Composite (FCC) using Red (band 5), Green (band 4) and Blue (band 2) namely 4-5-3 (R-G-B), 5-4-3 (R-G-B), and 3-4-5 (R-G-B) (Fig. 4). Amongst all, the 4-5-3 (R-G-B) using adaptive enhancement band combination gives the best visual displayed. The 4-5-3 combination is very successful in differentiating the vegetation types and urban area and very suitable to Putrajaya because of the green surroundings.

From the image, the oil palm and rubber plantations can easily be recognized as their colors are contrasted to each other (dark red and yellowish colors respectively). However, there are spectral reflectance differences in young and old rubber and oil palm trees. The young rubber trees showed up in green-yellow color but the old ones is yellow-light red color. For oil palm, the darker red is the



(a) Band combination 4-5-3
(Adaptive enhancement)

(b) Band Combination 5-4-3
(Equalization enhancement)



(c) Band Combination 3-4-5
(Linear enhancement)

Fig. 4 LANDSAT TM image with several band combination matured trees and the lighter color are the younger trees. However, the forest area and young oil palm trees were confused with each other. After a careful examination, and with reference to the ancillary data, the color of forested area is darker.

The urban and rural areas were represented by a blue and light blue color. The blue areas with dark and purple spots are normally mining areas. The cleared land and water bodies were detected by white and black colors, respectively. Smaller areas such as horticulture, shrubs, grassland and bushes were not clearly identified on the image due to their "confused" pixels on the image and the low resolution of LANDSAT TM.

Image Classification

Unsupervised classification categorized nine classes (Fig. 5) of land cover as follows :

1) Forest - green
2) Rubber - brown
3) Oil palm - blue
4) Grassland/shrubs - light magenta
5) Water bodies - light blue
6) Cleared land - Magenta
7) Urban/associated area - dark yellow
8) Rural - light yellow
9) Unclassified - light gray

Unsupervised classification is not recommended because of unsatisfactory result due to a broad classification of the "green" cover of study area. Small units of area cannot be well detected using this classification. Features that can be easily detected are forest, rubber and oil plantation, but some patches of the oil palm trees are classified together as forest area. It was quite difficult to separate the urban and rural area rather than the cleared land and it was the same to grassland and shrubs seem to be a bit confused due to its similar spectral reflectance.

The roads network can be easily detected if located in the plantation area but gave difficulties if located in urban areas. Water bodies do not have any problems to be identified because it shows up obviously in dark spots in most bands due to the complete absorption of the wavelengths. The color was changed into light blue for a visual display.

In the supervised classification, 12 classes were chosen and identified manually by using training areas. They are as follows :

1) Primary forest - dark green
2) Secondary forest - green
3) Rubber - yellow
4) Oil Palm - brown
5) Water bodies - blue
6) Grassland/shrubs - white
7) Urban and associated area - indigo
8) Mining area - magenta
9) Cleared land - bright yellow
10) Bush - light yellow
11) Mixed horticulture - purple
12) Rural area - dark brown

Maximum likelihood classifier (MLC) was used as an approach to obtain more information on the image features using band combination 4-5-3 (R-G-B) (Fig. 6).

From the previous study, it was proven that supervised classification gave more reliable result than the unsupervised. All the land cover features can easily be recognized and separated except for some classes of small farm or plantation patches that usually belongs to the farmers whom usually practices intercropping or mixed horticulture.

From the classification, differences in urban, cleared land, water bodies, oil palm and rubber areas can easily be differentiated. However, there were difficulties in identify-

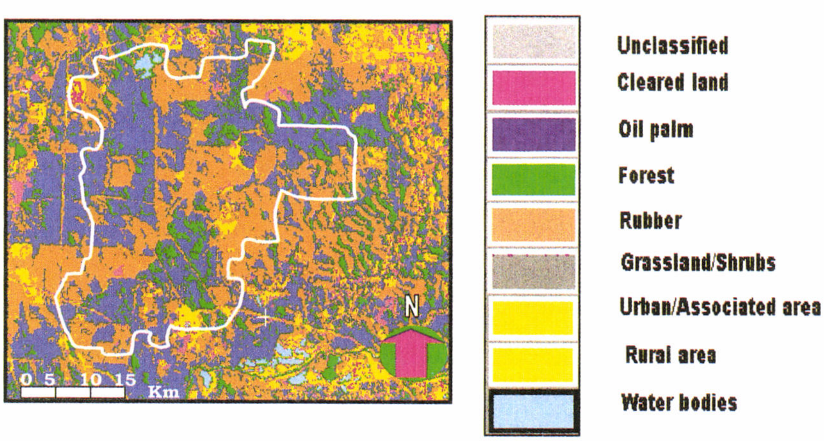


Fig. 5 Nine clusters of unsupervised classification

ing a matured oil palm and forest due to the shadowed slopes. In addition, mixed horticulture crops and grassland shrubs are difficult to be mapped if they are located close to each other.

Ground Truthing

A total of 20 sample points were selected for the ground truthing work which was conducted with reference to topography and land cover/use map on February 8, 1998. It has been realized that the forest areas were confused with oil palm and rubber plantations. This is probably due to the shadow effect of the topography. Mixed horticulture and rural areas also have close proximity if located together. Another confusion was the proximity of mining and urban areas. However, the mining areas were finally clustered into urban areas at the end of this study.

Results from this ground truthing showed that forest area, oil palm and rubber plantations, cleared land and water bodies can be identified and discriminated easily in the Landsat TM data. However, the other classes are quite difficult to be identified due to their small areal size and proximity between each other.

The overall accuracy assessment obtained from ground check was shown in Table 1. For every correct sample points, a tick mark was allocated and vice-versa.

The accuracy assessment was calculated using the formula:

$$\text{Overall Accuracy Assessment} = \frac{\text{Total Correct No. of Sample Points}}{\text{Total No. of Sample Points}} \times 100$$

$$= \frac{14}{20} \times 100$$

$$= 70\%$$

The overall accuracy of the ground truthing is 70%.

Identification and Allocation of Potential Site for Urban Forestry Land-use

The identification of forest landscape and natural environment is very important in determining the allocation of potential areas for urban forestry land-use planning. Supervised classification (FCC) result was chosen as a reference for this study.

Most of the "green" cover available in Putrajaya is very suitable for the allocation of forest edges as well as the oil palm and rubber plantation which have the potential to be conserved for urban forest landscape planning. Allocation of potential site for forest edges was mostly based on "green" cover resources such as forests, oil palm, rubber trees and natural environment such as water bodies, which can be easily quantified and mapped by satellite remote sensing.

The allocation for most potential urban forest planning at Putrajaya is located in undeveloped areas or with minimal development. From Fig. 7, it can be found out that most of the areas, which are still under forest cover, have the most and moderate potential sites for urban forest planning and management.

Effective management of natural landscape features such as a reservoir is needed for the purpose of planning. It

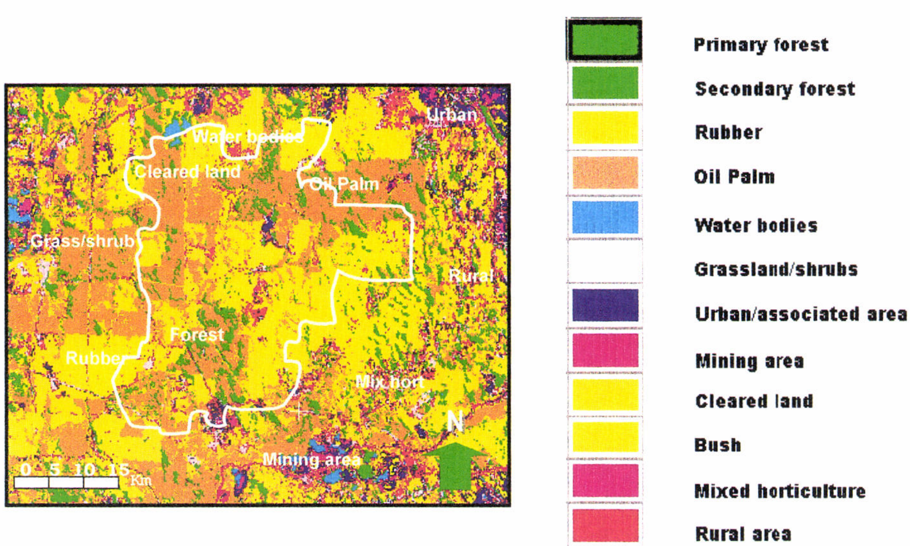


Fig. 6 Twelve clusters of supervised classification

Table 1 Overall accuracy assessment for ground truthing

Training No.	Expected Classes	Correct/Incorrect Sample Points
1	Urban	✓
2	Rural	✓
3	Rural	✓
4	Rubber	✓
5	Rubber	✓
6	Forest	×
7	Urban	×
8	Mining	✓
9	Bush	×
10	Urban	×
11	Water bodies	✓
12	Oil palm	✓
13	Urban	×
14	Forest	✓
15	Oil palm	✓
16	Rubber	✓
17	Rubber	×
18	Cleared land	✓
19	Urban	✓
20	Water bodies	✓
	Overall accuracy	14/20

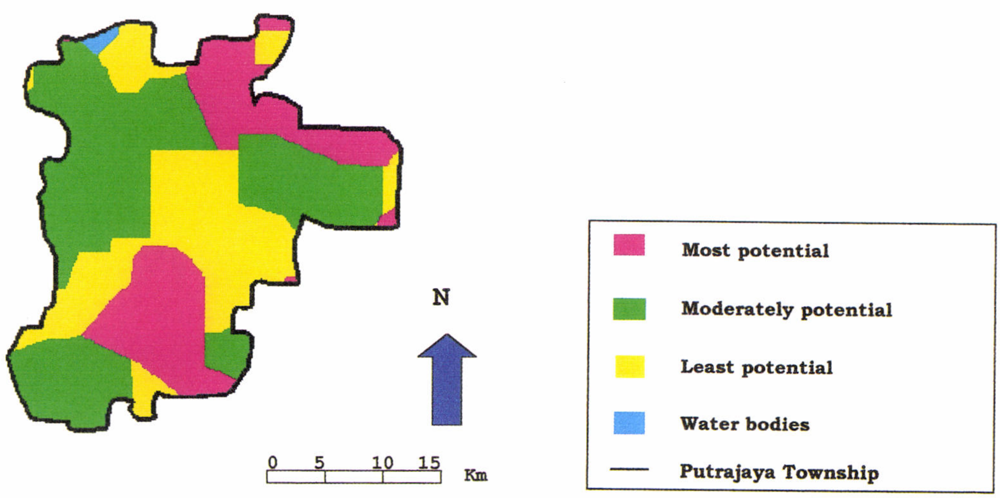


Fig. 7 Allocation of potential sites for urban forest planning in Putrajaya based on "green cover" classification.

is due to the fact that the presence of water bodies may be useful for water supply in Putrajaya. Water bodies are normally surrounded by forest areas and justify the needs of urban forestry conservation in Putrajaya.

CONCLUSIONS

Several conclusions can be obtained from this study as follows :

1. LANDSAT TM is an effective tool in "green" cover mapping for urban forestry planning with a mean overall

accuracy of 70 percent.

2. Combinations of LANDSAT TM bands 4,5,3 (FCC) gave successful results in land use/cover classification. Most of the "green" cover types especially vegetation, forest, oil palm and rubber can easily be differentiated and separated from cleared land, urban and water bodies.

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