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Review

Spatial Pattern Analysis of Individual Trees in Natural Forests

Kyoei Nishikawa*

ABSTRACT

This paper presents a review of the spatial pattern analysis of individual trees in natural forest stands by the quadrat and distance methods. These methods have been used for three purposes (1) to identify spatial pattern, (i.e. uniform, random, or aggregated), (2) to estimate density and (3) to analyze spatial pattern structure. The separate use for each of the above purposes causes bias in density estimation. The concept of "intensity and grain" developed by PIELOU (1977) was applied to overview spatial pattern analysis. The intensity expressed by an index of aggregation has three roles; (1) for identifying spatial pattern, (2) for correcting bias in density estimation and (3) for analyzing grain of spatial pattern, i.e. mosaics, or sizes of clumps etc. Spatial pattern analysis methods from the point of the three roles are reviewed and spatial patterns of individual trees in natural forests and the problems in natural forest inventories discussed.

Keyword: spatial pattern, quadrat and distance method, index of aggregation

DEVELOPMENT OF SPATIAL PATTERN ANALYSIS METHODS

Quadrat and distance methods have been used for different purposes, (i) to identify the spatial pattern of trees in a stand, i.e. uniform, random or aggregated, (ii) to estimate stand density, i.e. numbers of stem per ha and (iii) to assess the grain of spatial patterns of tree distribution, i.e. mosaics.

Spatial pattern analyses in both quadrat and distance methods have been separately developed for different purposes (i) and (ii). This separate development can cause bias in density estimation. The main techniques used for each of the above purposes are listed below.

Methods of Identification of Spatial Patterns

1) Quadrat method
   a. Relative variance method (CLAPHAM 1936)
   b. I_δ index (MORISITA 1959)
   c. LLOYD's index of patchiness (LLOYD 1967)
   d. KUNO's C_A index (KUNO 1975)
   e. LEFKOVITCH index (LEFKOVITCH 1966)
2) Distance method
   (1) Point to plant method
   a. HOLGATE index (HOLGATE 1965)
   b. EBERHARDT index (EBERHARDT 1967)
   c. T-square sampling method (BESAGE and GLEVES 1973)
   (2) Plant to plant method
   a. CLARK and EVANS index (CLARK and EVANS 1954)
   b. CATANA's index (CATANA 1963)
   (3) Point to plant and plant to plant method
   a. HOPKINS index (HOPKINS 1954)
   b. BATCHELER index (BATCHELER 1971)
3) Distance and quadrat method
   a. PIELOU index (PIELOU 1958)

Methods of Density Estimation and Grain Analysis of Spatial Pattern

1) Quadrat method
   (1) Graphical analysis of the relationship of an index of aggregation versus successive quadrat size
   a. I_δ index versus successive quadrat size analysis

* Forest Management Division, Forestry and Forest Products Research Institute, P.O.Box 16, Tsukuba Norin Kenkyu Danchinai, Ibaraki 305 Japan

(MORISITA 1959)

b. $\overset{*}{m}/m$ index versus successive quadrat size analysis (IWAO 1972)

c. IWAO's $\overset{*}{m}-m$ method (IWAO 1972)

d. SMITH-GILL index versus successive quadrat size analysis (SMITH-GILL 1975)

(2) Spatial pattern analysis based on non-random mathematical models

a. mathematical models such as gamma type compound Poisson distribution, Polya Eggenberger's contagious distribution etc. (TORII 1971)

(3) Stocking percent estimation corresponding to a degree of aggregation

a. Stocked quadrat method (GHENT 1969)

(4) Estimation of number of stems by tree height class

a. Variable quadrat method (BICKERSTAFF 1961)

2) Distance method

(1) Integrated spatial pattern analysis

a. Wandering quarter method (CATANA 1963)

(2) Graphical analysis of grain using a stem-mapped data

a. RIPLEY's K(d) analysis (RIPLEY 1981)

(3) Density estimation based on some aggregated models

a. MORISITA's density estimation by spacing method (MORISITA 1957)

(4) Density estimation through bias modification

a. BATCHELER method (BATCHELER 1971)

b. COX method (COX 1971)

(5) Density estimation only for random population

a. Nearest neighbour method (COTTAM *et al.* 1953)

THE BASIC CONCEPT OF SPATIAL PATTERN ANALYSIS

PIELOU (1977) stated that "a spatial pattern in a continuum has two quite distinct aspects; they may be called intensity and grain. By the intensity of a pattern we mean the extent to which density varies from place to place. In a pattern of high intensity the differences are pronounced and dense clumps alternate with very sparsely populated zones; when intensity is low, the density contrasts are comparatively slight. The grain of a pattern is independent of its intensity. If the clumps or patches in which the density is relatively high are large in area and widely spaced, we may say that the pattern is coarse-grained. Conversely, If the whole range of different densities is encompassed in a small space,the pattern is fine-grained."

Thus, intensity is the degree of aggregation and grain is pattern or features of the distribution of the trees. Intensity has the three important roles in spatial pattern analysis.

1) an index of aggregation used for identifying pattern, e.g. a LLOYD index of patchiness, HOPKINS's or PIELOU's index of aggregation.

2) a correction factor reducing for bias in density estimation. Intensity measures the degree of departure from randomness. Bias occurs when a model assuming randomness is applied to a non-randomly distributed population. The resultant bias can be corrected using intensity.

3) analyzing grain, i.e. mosaics, or features of tree distribution such as sizes of clumps, numbers of tree within clumps etc. MORISITA (1959) showed random and aggregation with small or large clumps through graphical analysis of I_δ indexes versus successive changes of quadrat sizes.

METHODS FOR BIAS REDUCTION IN DENSITY ESTIMATION

To reduce the bias in density estimation two approaches can be taken : the first is to combine a density estimation method with a corresponding index of aggregation, and the other is to use an index of aggregation as a correction factor.

Combined Density Estimation and Index of Aggregation Methods

NISHIKAWA and NISHIZAWA (1977) combined four density estimation methods with an index of aggregation so that the two combined methods were common in a sampling unit. The combined methods were CATANA's index of aggregation with CATANA's wandering quarter method, HOPKINS method with MORISITA's distance method, BATCHELER's index of aggregation with the BATCHLER method, and the relative variance method with the stocked quadrat method. These combined methods were applied to five kinds of tree maps (from random to extremely aggregated distribution) of naturally regenerating forests.

It was found that if trees were identified as randomly or aggregately distributed by the index of aggregation, it was desirable to use a corresponding density estimation method with random or aggregate assumptions. Applying this rule resulted in negligible bias except in extremely aggregated populations.

Methods Using an Index of Aggregation as a Bias Correction Factor

Bias occurs when a density estimation method assuming randomness is applied to non-randomly-distributed populations (MAWSON 1968, PERSSON 1971). Distance-density estimators have been tested and evaluated on several simulated and natural tree populations (PAYANDEH et al 1986) and efforts have been made to find a robust distance

-based density estimation(BATCHELER 1971, BYTH 1982, DELINCE 1986) .

Bias can also be corrected using an index of aggregation under the assumption that the bias is proportional to the deviation from randomness. NISHIKAWA(1985) used HOPKINS index as a correction factor in density estimation by MORISITA's method. He also corrected bias in existing stocking percent estimates calculated using the stocked quadrat method by using I_δ and $\overset{*}{m}/m$ indices for aggregated populations, and a H_δ index for uniform populations. The stocking percent used in the stocked quadrat method is the ratio of the numbers of quadrat that have at least one tree to all the numbers of allocated quadrats. This new system proved more robust than the generalized corrected ratio(r_α) developed by GHENT(1969) .

CLAYTON and COX (1986) proposed a method to modify existing estimators of density using a factor that counterbalanced bias, which qualitatively varied with the type of spatial pattern. The method did not work on all estimators, but did improve BYTH's(1982) estimators.

METHODS FOR GRAIN ANALYSIS OF SPATIAL PATTERN IN NATURAL FOREST STANDS

Information about grain can be gained by analyzing indices of aggregation versus changes of successive quadrats in a contiguous method. (see I_δ index versus quadrat size by MORISITA (1959) and $\overset{*}{m}/m$ versus quadrat size by IWAO (1972)) . The contiguous quadrat method has the disadvantage that quadrat size is doubled and their shape becomes rectangular with each subsequent pooling, resulting in poor resolution(BIGWOOD and INOUYE 1988) . NISHIKAWA(1983) investigated MORISITA and IWAO's method using systematic nested quadrat sampling in natural regeneration tree-maps. Both methods were sensitive to the average size of clumps and intensity of spatial pattern.

NISHIKAWA(1981) also examined the relationship of HOLGATE's distance-based aggregation index versus rank or average of the n th nearest distance. This method was sensitive to small clumps and the degrees of aggregation of spatial pattern but not effective in distinguishing different kinds of aggregated populations.

Intensity is expressed as an index of aggregation in single species populations. It is expanded to a diversity index for populations with two or more species. It is interesting that MORISITA's I_δ index is related to SIMPSON diversity index(SIMPSON 1949; PIELOU 1977) .

DISCUSSION

There are two problems associated with the application of spatial pattern analysis to natural forests. The first is spatial patterns of individual trees in natural forests and the other is application of spatial pattern analysis to natural forest inventory.

Spatial Patterns of Individual Trees in Natural Forests

The distribution of individual trees in natural stands is of concern to ecologists and forest planners. Spatial pattern of trees are related to characteristics of the tree species, the growth development stage, species competition, disturbances etc.

The distribution of trees in natural forests varies from random to aggregated. The distribution depends upon the tree species and canopy layer(TAKATA 1967; OHTA *et al.* 1975), regenerating trees(NISHIKAWA 1983), forest stand type and their developmental stage(PAYANDEH 1974) . There have been some recent studies showing that individual trees in natural forests are uniformly-distributed in certain conditions, e.g. dominant canopy trees. ISHIBASHI *et al.*(1989) pointed out that mid- and large-sized trees in natural forests in Hokkaido are uniformly distributed although tree spatial patterns are random or aggregated according to stand density calculated using I_δ and ρ index.

The nearest neighbor method uses tree to nearest tree distances, but RIPLEY's K(d) function (RIPLEY 1981) considers distances between all pairs of trees using stem-mapped data. Computer development has made it possible to calculate this complicated function. Using this new technology, MOEUR (1993) investigated spatial patterns of old growth trees in Idaho, especially canopy trees in different mortality, size, competition classes. He found that between-tree competitive interactions drove forest patterns from clustering to regularity.

It has been shown in many studies that regenerating trees have an aggregated distribution (GHENT 1969; OHTA *et al.* 1975; NISHIKAWA 1983) . Further study of how the aggregated patterns of regenerating trees change to random or uniform distributions when they grow in different environments and disturbances is required.

Application of Spatial Pattern Analysis to Natural Forests Inventory

Spatial pattern analysis methods have been used mainly in studies of gap development,tree species distribution and forest growth modelling.
Quadrat methods, especially I_δ or $\overset{*}{m}/m$ indices using contiguous quadrats improved the analysis. Distance-based simulation methods using stem-mapped data are also useful. However, these sophisticated methods are not always adequate for large scale forest inventory.

In forest inventory the assessment of regeneration is important, and density of regenerating trees is measured in part of the sampling survey, e.g. the smallest circular plot within a concentric circular plot in a continuous forest inventory. Density, stocking and distribution are also important components of regeneration survey in plantation forests (Brand *et al*. 1991). This concept can be applied to natural forest inventory. Density is a measure of the number of trees per unit area and stocking is the number of trees relative to some reference density, for example optimum number of desirable species trees for the site. However, stocking does not reflect distribution because desirable species may be unevenly distributed over the area being surveyed. To predict long term forest dynamics, spatial pattern of trees within each layer of main stands including the regeneration layer should be assessed.

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Article

Economic Evaluation of Area-based Forest Plans
—A case study for the Tokyo University Forest in Chiba Prefecture—

Tomoko Takahashi[*1,*2], Satoshi Tatsuhara[*1], Yuejun Zheng[*1,*3] and Hidejiro Nagumo[*1,*4]

ABSTRACT

This paper reports on the economic evaluation of simulated harvests resulting from various forest management plans. First, a series of procedures for the economic evaluation of forest management on the basis of sustainable forest plans were developed. The plans evaluated consist of a long-term plan, in which approximately equal areas would be cut during each working period, and medium-term plan, in which approximately equal amounts of labour would be involved each year. Costs, gross income, and net income of forest management are evaluated according to these plans. Next, Compartments 25 to 28 in the Tokyo University Forest in Chiba Prefecture were used as study areas, and they were assumed to be a working unit. The forest plans were made by using a geographic information system for sugi (*Cryptomeria japonica*) and hinoki (*Chamaecyparis obtusa*) plantations with 60-, 70- and 80-year rotations. Costs, gross income and net income for the plans were evaluated under nine sets of conditions of cost and timber price. Under the present conditions, net incomes per hectare were 1,176 thousand yen for the 60- and 70-year rotations and 852 thousand yen for the 80-year rotation. The investment in the study site was profitable even under the worst set of conditions, even though the internal rate of return for a coniferous plantation is low. Therefore, if Japanese foresters have sufficient growing stock and forest roads, they can derive high profits from forest management.

Keyword: geographic information system, investment evaluation, simulation, sustainable forest plan

INTRODUCTION

Both sustainability and economics have to be taken into consideration to manage forests. In general, forest plans are made to maintain sustainability of forest resources. NAGUMO *et al.* (1993b) propounded three types of forest management plans: long-term plans, medium-term plans and short-term plans. Long-term plans deal with assigning subcompartments to each working period over a rotation. Medium-term plans are annual plans, and they are made so that labour available will be assigned equally to each year. Short-term plans are operational schedules extending over a year. These types of plan have been developed as computer systems by NAGUMO *et al.* (1993a, 1993b) and ZHENG *et al.* (1995). However, they do not take economics into consideration.

The forest planning computer systems derived above have been developed on the basis of a geographic information system (GIS) for the Tokyo University Forest in Chiba Prefecture (hereafter called the "Chiba Forest") as a study site. Economic evaluation of forest management in Japan had already been studied for a stand by KUMAZAKI

[*1] Faculty of Agriculture, the University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113 Japan
[*2] Present address: Mitsui-Shin Information System Co., Ltd., 6-1-21 Shimomeguro, Meguro-ku, Tokyo 153 Japan
[*3] Present address: The Institute of Statistical Mathematics, 4-6-7 Minamiazabu, Minato-ku, Tokyo 106 Japan
[*4] Present address: College of Agriculture and Veterinary Medicine, Nihon University, 1866 Kameino, Fujisawa, Kanagawa 252 Japan

(1989) and IEHARA (1993a, 1993b). It is also useful, however, to analyze forest plans economically by their simulation under various conditions for forest management. Therefore, this paper reports on the development of a computer system to evaluate forest plans made with GIS data. A relational database management system, dBASEIV, was utilized to develop the computer system. Sugi (*Cryptomeria japonica* D.DON) and hinoki (*Chamaecyparis obtusa* (SIEB. et ZUCC.) ENDLICHER) plantations in the Chiba Forest were studied in this research.

METHOD

A flow chart of the procedures is shown in Fig. 1. The evaluation procedures are divided into three main parts: evaluation of cost, of gross income evaluation and of net income evaluation. Before the procedures are implemented, two kinds of forest plans should be made: long-term and medium-term. The medium-term plan is evaluated from an economic standpoint.

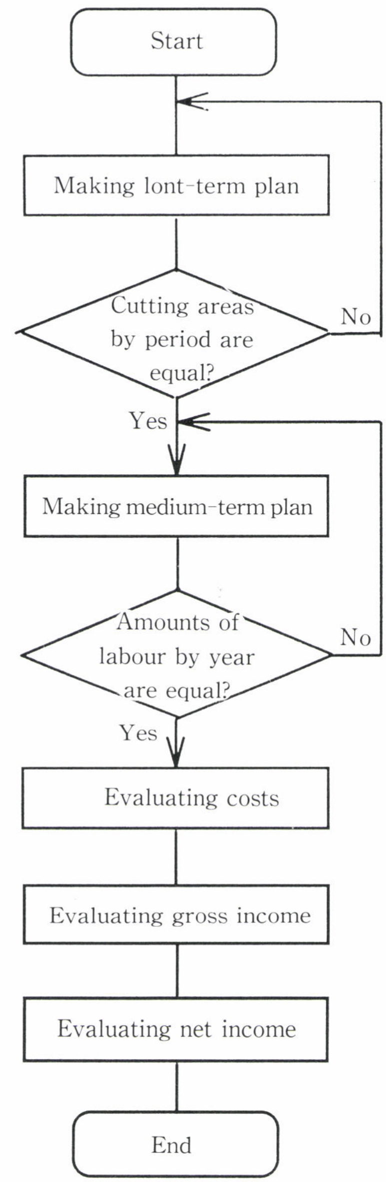

Fig. 1 The evaluation procedures

Long-term plan

The long-term plan is made by the area-period method ("Flähenfachwerksmethode") with the computer system developed by NAGUMO *et al.* (1993a). If a user specifies the beginning fiscal year, length of rotation, length of working period and tolerance limit of variation in the area, the system retrieves stand data from the database, reads yield tables, and makes a plan so that approximately equal areas and volumes will be contained in each working period under the specified conditions.

At the outset, the average cutting area per working period is calculated by means of total area and number of working periods. Then, each subcompartment is assigned to a certain period so that each cutting area will satisfy the following restriction:

$$\left|\frac{A_i - A}{A}\right| \leqq t_A$$

where A_i is cutting area in the i-th period, A is the average cutting area per period and t_A is the tolerance limit. The volume of each stand to be cut is estimated from yield tables. Finally, the yield in each working period is estimated.

Medium-term plan

The medium-term plan is made with the computer system developed by NAGUMO *et al.* (1993b) so that each fiscal year will involve approximately equal amounts of labour. First, the fiscal year of each stand to be cut in the first period is specified, as are length of working period and tolerance limit of labour amount. Then, the system calculates the amount of labour needed for each operation according to the tending system established for the Chiba Forest, as shown in Table 1. Each amount of labour is estimated from a standard labour table, modified by slope and distance from the road. That is to say, the actual amount is estimated from the standard amount multiplied by two coefficients developed by ZHENG *et al.* (1995):

Amount of labour = Standard amount of labour × (distance coefficient + slope coefficient − 1).

Distance coefficient DI is determined as follows:

$$DI = 0.95858 + 0.01523S + 0.00008D,$$

where D is distance from the road (m), S is slope class (1 to 4) and slope coefficient is determined as in Table 2. The

Table 1 Tending system in the Chiba Forest

year	operation
1	Area measurement Land perpatation Transporting seedlings Dividing stand Planting Measuring growth Releasing
2	Supplementary planting Releasing Measuring growth
3	Releasing Measuring growth
4	Releasing Measuring growth
5	Releasing Measuring growth
6	Releasing
7	Cutting vines
8 - 10	Waste thinning
9 - 11	Pruning
14 - 15	Waste thinning
14 - 15	Pruning
20 - 25	Thinning
30 - 35	Thinning
60 and over	Final cutting

Table 2 Slope coefficient by slope class

Slope class	Slope (degrees)	Slope coefficient
1	0 - 15	1.0
2	16 - 25	1.1
3	26 - 35	1.2
4	36 and over	1.3

total amount of labour for the first period is calculated, and the average amount of labour is determined from the total amount and the length of the working period. Finally, the plan is checked to verify that amount of labour for each year satisfies the following restriction:

$$\left| \frac{L_i - L}{L} \right| \leq t_L$$

where L_i is amount of labour for the i-th fiscal year, L is the average amount of labour per year and t_L is the tolerance limit. If the amount of labour does not satisfy the restriction, the system modifies the years of thinning and pruning. If the amount of labour still does not satisfy the restriction after the modification, the user must change the harvesting schedule or the tolerance limit.

Evaluating costs

Foresters must pay such costs as planting, vegetation control and harvesting when they manage forests. The various costs of forest management can be sorted into four parts: personnel costs, working costs and construction costs for final felling and seedling costs. Personnel costs are expressed as follows:

Personnel costs (yen) = Amount of labour (persons・days) ×daily wages (yen/person/day).

Working costs are those for logging and is calculated as follows:

Working costs (yen) = Unit working cost (yen/m^3) × volume to be cut (m^3).

Construction costs are those for constructing facilities for log transportation, such as ropeways etc. Because the distance from the road to the working stand has little effect on the construction costs, such costs are assumed to be independent of the distance. Thus these cost are calculated as follows:

Construction costs (yen) = Unit construction cost (yen/ha) ×area to be cut (ha).

Seedling costs are fixed at the following:

210,000 yen/ha for sugi (A seedling costs 70 yen, and 3,000 seedlings are planted per ha),

280,000 yen/ha for hinoki (A seedling costs 80 yen, and 3,500 seedlings are planted per ha),

because these costs are much less than the others.

Personnel costs occur every year, and they are calculated for each fiscal year: specified daily wages are multiplied by the amount of labour calculated by the medium-term plan. Working costs apply only in fiscal years when final felling is carried out; they are calculated for each final felling year: unit working costs are multiplied by volume to be cut. Construction costs apply only in the fiscal years when working costs also apply; they are calculated for each final felling year: unit construction costs are multiplied by area to be cut. Seedling costs apply only in fiscal years when planting is carried out. In the medium-term plan, cut stands should be planted the next year after cutting. Seedling costs are calculated for each planting year: seedling costs are multiplied by areas to be planted. Total costs for each fiscal year are determined by adding the four costs of forest management.

Evaluating gross income

In this procedure, it is assumed that income from forest management derives from final felling only. First, tree prices per unit volume in 50-year-old sugi and hinoki plantations are specified. Next, ratios of unit tree prices to the unit tree price in 50-year-old plantations are determined and stored for 60- to 120-year-old plantations of each species at 10-year intervals and then each unit tree price is calculated: each ratio is multiplied by specified unit tree price in 50-year-old plantations because these ratios generally do not vary (FUKUSHIMA, 1976, 1977). Finally, gross income for each fiscal year is calculated as follows:

Final felling income (yen) = cutting volume (m^3) × unit tree price (yen/m^3).

If a stand age does not exist among the ages used for the stored ratios, unit tree price for the stand age is obtained from the two nearest existing unit tree prices. For example, unit tree price for 84-year-old plantations is calculated as follows:

Price for 84-year-old stands = Price for 80-year-old stands + {Price for 90-year-old stands - Price for 80-year-old stands}/10×4.

Evaluating net income

Net income for the first working period is obtained from the costs and the gross income. First, net income for each fiscal year is calculated: then total costs are subtracted from final felling income. Thus, net income will be negative in every fiscal year during which final felling does not occur. Next, net income for the n-th fiscal year is discounted into net present value as follows:

$$N = V / (1 + p / 100)^n = V / 1.0p^n,$$

where N is net present value at the beginning of the period, V is net income for the n-th fiscal year of the period and p is discount rate. Finally, net present value of the net income is obtained for the first period by totaling net present value for each fiscal year.

APPLICATION

The study site is Compartments 25 to 28, in the Tokyo University's Chiba Forest. These compartments were assumed to be a working unit for simulation of the procedures outlined above. Fig. 2 depicts the study area with sugi and hinoki plantations. The area of coniferous plantations in the study site is 79.83 ha. Age-class distributions are shown in Table 3. Of the total coniferous plantations on the site, 40% are 60-year-old or older; the site already contains a large amount of growing stock. A stand table and forest map of the study area have been stored and linked together on the GIS by TATSUHARA et al. (1993, 1994).

Establishing plans

Rotations were set at 60, 70 and 80 years and length of the working period was set at 10 years. The minimum of the area tolerance limit was obtained for each long-term plan by carrying out the procedure outlined above. These values were 0.07, 0.05 and 0.07 for 60-, 70- and 80-year-rotation plans, respectively. Table 4 shows the resulting cutting volumes for these simulations.

After the long-term planning, the amount of labour needed according to the medium-term plans were calculated (Table 5). Because the same stands will be cut in the first working period in the long-term plans for 60- and 70-year rotations, these two long-term plans had the same medium-term plan. Therefore the table shows only two

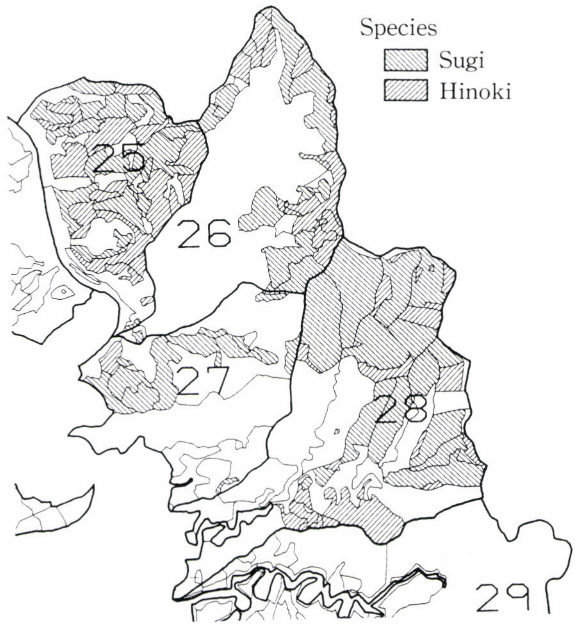

Fig. 2 Study area.
Note: Thick lines and thin lines show compartment and subcompartment boundaries, respectively. Numbers are compartment codes

Table 3 Age-class distribution of the study site

Age class	Age (yrs.)	Area (ha)
1	1- 10	2.60
2	11- 20	8.01
3	21- 30	10.85
4	31- 40	13.29
5	41- 50	3.96
6	51- 60	6.24
7	61- 70	0.42
8	71- 80	17.08
9	81- 90	11.22
10	91-100	0.00
11	101-110	6.16
12	111-120	0.00

Table 4 Simulated cutting volumes for the long-term planning

(a) 60-year-rotation plan

Working period	Cutting area (ha)	Cutting volume (m^3)
1	9.00	9,076.7
2	13.91	9,985.8
3	14.23	8,386.5
4	14.23	9,910.8
5	14.23	8,270.6
6	14.23	6,415.4
Total	79.83	52,345.8

(b) 70-year-rotation plan

Working period	Cutting area (ha)	Cutting volume (m^3)
1	9.00	9,076.7
2	11.05	8,409.8
3	11.92	6,560.9
4	11.97	8,880.2
5	11.97	7,940.4
6	11.96	8,200.7
7	11.96	5,203.7
Total	79.83	54,272.4

(c) 80-year-rotation plan

Working period	Cutting area (ha)	Cutting volume (m^3)
1	0.00	6,420.0
2	6.03	8,028.3
3	10.02	6,902.1
4	10.56	6,991.4
5	10.62	8,403.0
6	10.64	7,188.9
7	10.65	7,337.1
8	10.66	5,224.8
Total	79.83	56,495.6

plans: the first is for 60- and 70-year rotations and the second is for an 80-year rotation. The minimums of tolerance limits of labour were 34% and 16% for 60- and 80-year rotations, respectively.

Economic evaluation

Management of the study site was evaluated on the basis of the medium-term plan discussed above. Conditions were specified as follows:

Daily wages = 8,000 yen,
Unit working cost = 10,000 yen / ha,
Unit construction cost = 20,000,000 yen / ha,
Price of sugi trees in a 50-year-old stand = 17,400 yen / m^3,
Price of hinoki trees in a 50-year-old stand = 37,000 yen / m^3,
Discount rate = 3 %.

Furthermore, the conditions were changed: it was assumed that all costs would increase or decrease by 10 % and that prices would also increase or decrease by 10 %. Table 6 shows the results of the simulation under the nine sets of conditions outlined above. Each value is the net present value of net income for each plan; net present value of net income per hectare is also shown in parentheses. Net incomes per hectare were 1,176 thousand yen and 852 thousand yen for the 60- and 80-year-rotation plans, respectively.

DISCUSSION

The results of the simulation show that investment in management of the site for the first working period (that is, one decade from now) is very profitable and it continues to be so even under the worst set of conditions in the simulation. Net income for the 60-year-rotation plan was larger than that for the 80-year-rotation plan. It does not follow, however, that a rotation of 60 years is more profitable than a rotation of 80 years, because this simulation evaluates management not of a stand but of the total working unit and not for the whole rotation but for a period. Thus, the results of this simulation depend not only on management costs and timber price but also on age-class distribution of the site and rotation. Because the study site contains large area of stands older than 80 years as Table 1 and more stands will be harvested for each period in the 60-year-rotation plan than in the 80-year-rotation plan, more gain from old stands will be derived for the first period in the 60-year-rotation plan than in the 80-year-rotation plan. Indeed, KUMAZAKI (1989) and IEHARA (1993 b) pointed out that long-rotations (that is 80 to 100 years) are more profitable than the present standard rotations (that is 45 to 50 years) for sugi and hinoki.

The present evaluation was made to cover specified periods on the basis of area-based forest plans. Generally, however, it is said that investments in forest management yield a bad return in Japan. For example, the JAPANESE FORESTRY AGENCY (1994) stated that an average rate of return for investment in sugi plantations was 0.9 % in 1993. In our case, the internal rate of return for sugi plantation was 0.6 % for a 60-year rotation and 0.9 % for an 80-year rotation. Nevertheless, the investment in the study site yielded a good return even under the worst set of conditions. Therefore, if foresters have sufficient growing stock and forest roads, they can derive good gains from forest management under the specified plans and rotations, even though the internal rate of return is low.

Table 5 Amount of labour needed for each kind of work according to the medium-term plans

(a) 60-and-70 year-rotation plans

Kind of work	Labour needed (persons·days)										
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
Final felling	17.4	0.0	13.1	0.0	41.5	0.0	22.4	0.0	22.4	0.0	116.8
Area measurement	0.0	3.0	0.0	2.0	0.0	7.0	0.0	4.0	0.0	4.0	20.0
Land preparation	0.0	62.0	0.0	46.5	0.0	147.6	0.0	79.5	0.0	79.5	415.1
Transporting seedlings	0.0	4.4	0.0	3.3	0.0	10.5	0.0	5.6	0.0	5.6	29.4
Dividing stand	0.0	7.3	0.0	5.5	0.0	17.4	0.0	9.4	0.0	9.4	49.0
Planting	0.0	60.1	0.0	45.1	0.0	143.1	0.0	77.1	0.0	77.1	402.5
Measuring growth	0.0	6.4	3.2	8.0	5.6	21.0	10.1	18.4	11.8	20.1	104.6
Releasing	0.0	15.7	31.4	43.2	54.9	76.5	113.9	106.6	126.7	97.6	666.5
Supplementary planting	0.0	0.0	8.2	0.0	6.2	0.0	19.5	0.0	10.5	0.0	44.4
Cutting vine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	4.2	9.8
Waste thinning	156.6	76.5	0.0	93.0	0.0	0.0	0.0	0.0	40.3	0.0	366.4
Pruning	101.3	0.0	227.8	0.0	246.4	0.0	0.0	0.0	0.0	0.0	575.5
Thinning	38.5	72.4	25.7	58.6	0.0	0.0	108.9	0.0	62.5	0.0	366.6
Total	318.8	307.7	309.4	305.4	354.6	423.1	274.8	306.0	274.2	297.3	3166.3

(b) 80-year-rotation plan

Kind of work	Labour needed (persons·days)										
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
Final felling	0.0	17.4	0.0	13.1	0.0	22.4	0.0	22.4	0.0	0.0	75.3
Area measurement	0.0	0.0	3.0	0.0	2.0	0.0	4.0	0.0	4.0	0.0	13.0
Land preparation	0.0	0.0	62.0	0.0	46.5	0.0	79.5	0.0	79.5	0.0	267.5
Transporting seedlings	0.0	0.0	4.4	0.0	3.3	0.0	5.6	0.0	5.6	0.0	18.9
Dividing stand	0.0	0.0	7.3	0.0	5.5	0.0	9.4	0.0	9.4	0.0	31.6
Planting	0.0	0.0	60.1	0.0	45.1	0.0	77.1	0.0	77.1	0.0	259.4
Measuring growth	0.0	0.0	6.4	3.2	8.0	5.6	13.9	6.5	14.8	8.2	66.6
Releasing	0.0	0.0	15.7	31.4	43.2	54.9	59.3	79.4	72.1	92.2	448.2
Supplementary planting	0.0	0.0	0.0	8.2	0.0	6.2	0.0	10.5	0.0	10.5	35.4
Cutting vine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	5.6
Waste thinning	99.3	57.3	76.5	93.0	0.0	0.0	0.0	0.0	0.0	40.3	366.4
Pruning	101.3	144.5	0.0	83.3	111.2	135.2	0.0	0.0	0.0	0.0	575.5
Thinning	38.5	16.5	55.9	25.7	0.0	58.6	0.0	108.9	0.0	62.5	366.6
Total	239.1	235.7	291.2	257.9	265.0	282.9	248.6	227.7	267.9	213.7	2529.7

CONCLUSION

Procedures were developed for the economic evaluation of forest management on the basis of sustainable forest plans made with GIS. Long- and medium-term plans were integrated with the evaluation of costs and income. The procedures are useful for evaluating a forest plan under specified conditions of timber price and management costs and comparing various forest plans before one is implemented.

The procedures still need to be improved. If a site without sufficient forest roads is to be evaluated, the cost of constructing such roads must be considered and the amount of labour needed for their construction must be included in the medium-term plan. Moreover, income from thinning was not taken into consideration in the procedures. For old stands, however, thinning is generally profitable even in Japan. Thus, income from thinning should be considered for plans established for very long rotation.

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Table 6 Results of economic evaluation of the study site (Unit, yen)

(a) 60-and 70-year-rotation plans

Timber price	Cost −10%	Cost Present	Cost +10%
−10%	84,378,685	72,636,143	60,893,604
	(1,056,980)	(909,885)	(762,791)
Present	105,587,223	93,844,691	82,012,152
	(1,322,651)	(1,175,557)	(1,027,335)
+10%	127,085,524	115,342,983	103,600,443
	(1,591,952)	(1,444,858)	(1,297,763)

Note: Values in parentheses are net present values per hectare.

(b) 80-year-rotation plan

Timber price	Cost −10%	Cost Present	Cost +10%
−10%	61,119,354	52,663,948	44,208,540
	(765,618)	(659,701)	(553,783)
Present	76,434,652	67,979,244	59,523,838
	(957,467)	(851,550)	(745,632)
+10%	91,954,156	83,498,749	75,043,342
	(1,151,875)	(1,045,957)	(940,039)

Note: Values in parentheses are net present values per hectare.

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Article

Tactical Harvest Scheduling using Zero-one Integer Programming

Atsushi Yoshimoto*

ABSTRACT

Searching for an optimal harvest scheduling regime has been a major concern of forest managers. The balance of costs and benefits of a management practice vary depending upon its efficiency. This study addresses the harvest scheduling problem with a log transportation network within the integer programming framework. A harvest scheduling system was constructed with using commercial software, CPLEX, as an optimizer to search for an optimal tactical solution. A case study was conducted using a forest management problem in Chile over a short time horizon to investigate the effect of integer restrictions on road construction and harvest decision variables on the regime. Computational comparison of a linear programming formulation and integer programming formulation showed that without considering road construction constraints in the problem formulation, serious costs may result in the management regime. Timing of the harvest of a unit may also change when integer restrictions are imposed on the harvest decision variables.

Keyword: Forest economics, harvest scheduling, mathematical programming, 0-1 integer programming, transportation network

INTRODUCTION

Harvest scheduling is a major concern of forest managers. Depending on their scheme, the balance of costs and benefits for the management varies. For long-term harvest scheduling, problems would be when and how much of forest stands should be harvested under certain constraints. Harvest timing and volume over the time horizon have been the main interests. Constraints can be the harvest flow requirements, cash flow requirements and non-monetary resource requirements, such as wildlife protection, watershed protection and other societal concerns. This kind of long-term harvest scheduling is called a strategic harvest scheduling problem (NELSON *et al.* 1991). To solve a strategic problem, a forest is divided into several strata of harvest units with the same attribute. A linear programming solution technique plays a central role in solving strategic planning problems. Timber RAM (NAVON 1971), MUSYC (JOHNSON and JONES 1979), and FORPLAN (JOHNSON and STUART 1987) are examples of an LP based model.

A major shortcoming of the strategic planning technique is the lack of site specific information about harvest decisions. Since solutions from an LP based model are nonnegative real values, rounding techniques have to be implemented for such solutions to provide a site specific variable, even though the derived solutions may not be optimal or even feasible.

Site specific information is necessary to achieve the management regime on the working ground, especially over a short time horizon. When a harvest takes place, how much volume is harvested, which forest stand is harvested, and which logging roads have to be build, are practical and necessary problems for managers on the working ground. The problems involve such decisions as "harvest a unit"-or-"not harvest a unit", and "build a logging road"-or-"not build a logging road. This kind of problem is called a tactical harvest scheduling problem. Because of the requirements for site specific information, which is represented by dichotomous decision variables, a mix or 0-1 integer programming (IP) solution technique is used to

* Faculty of Agriculture, Miyazaki University, 1-1, Gakuen-kibanadai-Nishi, Miyazaki 889-21 Japan

solve the problem. KONOHIRA (1982) developed the forestry oriented algorithm to solve harvest scheduling problems within the IP framework. His algorithm is basically the same as the branch-and-bound algorithm, which was introduced by LAND and DOIG (1960) and DAKIN (1965), but utilized the weighting procedure to accelerate solution speed. IRPM (KIRBY *et al.* 1980) was constructed to solve IP harvesting scheduling problems with a road network. Recent applications of such IP problems focus on the harvest scheduling with adjacency constraints (SESSIONS and SESSIONS 1988; TORRES 1989; NELSON and BRODIE 1990; CLEMENTS *et al.* 1990; ROISE 1990; NELSON *et al.* 1991; YOSHIMOTO *et al.* 1994; YOSHIMOTO and BRODIE 1994), where a problem was solved by heuristics within the IP framework. This is because the computational burden is a serious problem for an exact solution algorithm for IP, e.g., the branch-and-bound algorithm.

The objective of this paper is to address a log transportation problem as a tactical harvest scheduling problem within the IP framework, then analyze the effect of the 0-1 integer restrictions for the decision variables on the scheduling regime. To conduct the analysis, the tactical harvest scheduling system is built in conjunction with the commercial software, CPLEX, where the branch-and-bound algorithm is embedded. A case study is conducted for a timber company in Chile. The remainder of the paper is organized as follows. In the next section, the proposed tactical harvest scheduling problem is presented, then formulated in the IP framework. The tactical harvest scheduling system is constructed in the third section. In the fourth section, an effect of the 0-1 integer restriction is presented, followed by conclusions in the fifth section.

TACTICAL HARVEST SCHEDULING PROBLEM FORMULATION

The following is the tactical harvest scheduling problem we are concerned with. The X forest company in Valdivia, Chile has a harvest scheduling problem over next 5 years. Harvest is conducted twice a year, in summer and winter. The company has two kinds of forests. One has been managed before, and the other has not. The tree species is Radiata pine (*Pinus radiata*). In the managed forests, logging roads are already built, while they have to be built for the unmanaged forests. There are several options for harvesting, i.e., to use a skidder, a logging cable, or a mechanical harvester. If a mechanical harvester is used, all harvested trees are delivered to the mill directly. This is because the harvester can harvest a tree and scribe it ready for the mill operation. Otherwise, harvested trees have to be shipped to the yard first to be scribed, then to the mill. A road construction decision in the unmanaged forests is dependent on which harvest option is used. If a skidder or a mechanical harvester is used, roads have to be constructed up to a harvest area, while a cable logging does not require such road construction. Some of the roads among harvest units, yards and mills are already built, and others are not.

As for the company's current management practice, they predicted that if they continue harvesting their mature forests at the current harvest rate, they will have a large shortage of logs in the near future. Therefore, the company decided to buy logs from third parties now to narrow the gap in the harvest flow level over time. Due to the contracts with other companies, the company has several output constraints for scheduling, i.e., pulp volume flow, sawlog volume flow and veneer volume flow constraints. Also, since the company cannot buy or sell their harvest equipment more than a certain amount, there are harvest equipment constraints. In addition, there are nonnegative cash flow constraints, and yard capacity constraints.

Under these circumstances, the company tries to allocate unmanaged and managed forests into their scheduling framework, considering road construction costs and log transportation costs to yards and mills. In what follows, the problem is formulated within the IP framework. Note that in this problem only one yard and one mill are considered. For problems with more than one yard and mill, the formulation can be easily extended.

Let us define decision variables and coefficients, then formulate the problem. In this problem, there are seventeen decision variables. The first fifteen variables are continuous, while the other two variables are 0-1 integer variables. The continuous variables are;

$VP3_{n,t}$: pulp volume to be bought from the n-th party at time t

$VS3_{n,t}$: sawlog volume to be bought from the n-th party at time t

$VV3_{n,t}$: veneer volume to be bought from the n-th party at time t

$XP_{i,t}$: pulp volume harvested by a skidder or cable then shipped through the i-th road at time t

$XS_{i,t}$: sawlog volume harvested by a skidder or cable then shipped through the i-th road at time t

$XV_{i,t}$: veneer volume harvested by a skidder or cable then shipped through the i-th road at time t

$XPM_{i,t}$: pulp volume harvested by a harvester then shipped through the i-th road at time t

$XSM_{i,t}$: sawlog volume harvested by a harvester then shipped through the i-th road at time t

$XVM_{i,t}$: veneer volume harvested by a harvester then shipped through the i-th road at time t

$PVYD_t$: pulp volume shipped to the yard at time t

$SVYD_t$: sawlog volume shipped to the yard at time t

$VVYD_t$: veneer volume shipped to the yard at time t

$PVML_t$: pulp volume shipped to the mill at time t

$SVML_t$: sawlog volume shipped to the mill at time t

$VVML_t$: veneer volume shipped to the mill at time t

The 0-1 integer variables are;

$$ZF_{i,t}=\begin{cases}1 & \text{if the } i\text{-th road is built at time } t\\ 0 & \text{otherwise}\end{cases}$$

$$ZO_{j,o,t}=\begin{cases}1 & \text{if the } o\text{-th harvest option is implemented at the } j\text{-th harvest at time } t\\ 0 & \text{otherwise}\end{cases}$$

Coefficients are defined as follows;

PP_t : price of pulp per unit volume at time t

PS_t : price of sawlog per unit volume at time t

PV_t : price of veneer per unit volume at time t

$CV_{i,t}$: variable cost per unit volume for transportation at the i-th road at time t

$CF_{i,t}$: fixed cost for the i-th road construction at time t

$CO_{j,o,t}$: setup costs in the j-th harvest unit at time t to carry out the harvest option o

$CE_{e,t}$: the e-th equipment usage cost at time t

$BP_{n,t}$: cost per unit volume to buy the n-th party's pulp at time t

$BS_{n,t}$: cost per unit volume to buy the n-th party's sawlog at time t

$BV_{n,t}$: cost per unit volume to buy the n-th party's veneer at time t

PVL_t : lower bound of pulp flow at time t

PVU_t : upper bound of pulp flow at time t

SVL_t : lower bound of sawlog flow at time t

SVU_t : upper bound of sawlog flow at time t

VVL_t : lower bound of veneer flow at time t

VVU_t : upper bound of veneer flow at time t

$SPV_{k,j,o,t}$: pulp volume obtained by the o-th harvest option using a skidder or cable at the j-th harvest unit, then shipped to the k-th node at time t

$SSV_{k,j,o,t}$: sawlog volume obtained by the o-th harvest option using a skidder or cable at the j-th harvest unit, then shipped to the k-th node at time t

$SVV_{k,j,o,t}$: veneer volume obtained by the o-th harvest option using a skidder or cable at the j-th harvest unit, then shipped to the k-th node at time t

$SPVM_{k,j,o,t}$: pulp volume obtained by the o-th harvest option using a harvester at the j-th harvest unit to the k-th node at time t

$SSVM_{k,j,o,t}$: sawlog volume obtained by the o-th harvest option using a harvester at the j-th harvest unit to the k-th node at time t

$SVVM_{k,j,o,t}$: veneer volume obtained by the o-th harvest option using a harvester at the j-th harvest unit to the k-th node at time t

$AREA_j$: area (ha) of the j-th harvest unit

$WV_{j,t}$: weighting value to reflect a future value of the j-th harvest unit after harvesting the unit at time t (this could be soil expectation value of that unit)

$EQ_{j,e,o}$: The e-th equipment usage (hours) required by the o-th harvest option at the j-th harvest unit

$HEL_{e,t}$: lower bound of the e-th harvest equipment utility at time t

$HEU_{e,t}$: upper bound of the e-th harvest equipment utility at time t

$P3U_t$: upper bound of pulp volume available from the third parties at time t

$S3U_t$: upper bound of sawlog volume available from the third parties at time t

$V3U_t$: upper bound of veneer volume available from the third parties at time t

YC : yard capacity

r : discount rate

M : a given large number

A : a node-arc incidence matrix for skidder or cable log delivery defined by

$$A_{i,j}=\begin{cases}1 & \text{if arc } j \text{ is directed away from node } i\\ -1 & \text{if arc } j \text{ is directed toward node } i\\ 0 & \text{otherwise}\end{cases}$$

(Note: no connection to a mill from any node, but from a yard)

AM : a node-arc incidence matrix for harvester log delivery defined by

$$AM_{i,j}=\begin{cases}1 & \text{if arc } j \text{ is directed away from node } i\\ -1 & \text{if arc } j \text{ is directed toward node } i\\ 0 & \text{otherwise}\end{cases}$$

(Note: no connection from any node to a yard)

E : the number of harvest equipments

I : the number of roads (arcs)

J : the number of harvest units

K : the number of nodes

N : the number of third parties

O_j : the number of harvest options for the j-th harvest unit

T : the number of periods for planning

The objective of the proposed harvest scheduling problem is to maximize the total present net value from selling pulp, sawlog and veneer, minus transportation costs consisting of variable costs (or delivery costs) and fixed costs (road construction costs), minus setup costs, minus harvest equipment use costs, minus costs of buying the third parties' pulp, sawlog and veneer, and plus the weighting value of remaining stands. This weighting value is a user defined value and could be soil expectation value of a stand after harvesting. This is considered in the objective function to reflect a future return of the stand because harvesting in the proposed problem is implemented only once over 5 years.

$$\max J=\sum_{t=1}^{T}\frac{1}{(1+r)^{t-1}}\{PP_t(PVML_t+\sum_{n=1}^{N}VP3_{n,t})+PS_t(SVML_t+\sum_{n=1}^{N}VS3_{n,t})$$

$$+PV_t(VVML_t+\sum_{n=1}^{N}VV3_{n,t})\}$$

$$-\sum_{i=1}^{I}\sum_{t=1}^{T}\frac{CV_{i,t}}{(1+r)^{t-1}}(XP_{i,t}+XS_{i,t}+XV_{i,t}+XPM_{i,t}+XSM_{i,t}+XVM_{i,t})$$

$$-\sum_{i=1}^{I}\sum_{t=1}^{T}\frac{CF_{i,t}}{(1+r)^{t-1}}ZF_{i,t}$$

$$-\sum_{j=1}^{J}\sum_{t=1}^{T}\sum_{o=1}^{0j}\frac{CO_{j,o,t}}{(1+r)^{t-1}}ZO_{j,o,t}$$

$$-\sum_{j=1}^{J}\sum_{t=1}^{T}\sum_{e=1}^{E}\sum_{o=1}^{0j}\frac{CE_{e,t}}{(1+r)^{t-1}}EQ_{j,e,o}\cdot ZO_{j,o,t}$$

$$+\sum_{j=1}^{J}\sum_{t=1}^{T}\sum_{o=1}^{0j}\frac{WV_{j,t}}{(1+r)^{t-1}}ZO_{j,t,o}$$

$$-\sum_{n=1}^{N}\sum_{t=1}^{T}\{\frac{BP_{n,t}}{(1+r)^{t-1}}VP3_{n,t}+\frac{BS_{n,t}}{(1+r)^{t-1}}+\frac{BV_{n,t}}{(1+r)^{t-1}}VV3_{n,t}\} \quad (1)$$

The following constraints are embedded.

1: Constraints for one time road construction:

This constraint requires for all roads to be constructed at most once over the time horizon.

$$\sum_{t=1}^{T}ZF_{i,t}\leq 1 \;\; for \;\; i=1,,I \quad (2)$$

2: Road linkage constraints for one-directional transshipment:

If there is only one road directed toward the mill or the yard from any road connection, (node), the incoming roads to the node have to be built before the outgoing road.

$$\sum_{t=1}^{t_1}ZF_{i,t}-ZF_{j,t_1}\geq 0 \;\; for \;\; t_1=1,,T \quad (3)$$

where the j-th road (arc) is the incoming road and the i-th road (arc) is the outgoing road. If there is more than one road directed toward the mill or yard, it is not necessary to have this constraint for that incoming road. A road construction constraint for such a road is dealt with in the fifth constraint.

3: Simultaneous log transportation constraints:

There can be multiple entrances to one harvest unit. In such cases, implementation of a harvest option results in log transportation to several entrances connected to roads at the same time. Thus, construction of such roads has to be achieved simultaneously.

$$ZF_{i,t}-ZF_{j,t}=0 \;\; for \;\; t=1,,T \quad (4)$$

where the i- and j-th roads (arcs) are an end road directly connected to the same harvest unit, and share the concurrent log transportation.

4: Harvest unit and road linkage constraints:

Construction of roads, which is necessary for each harvest option, has to be achieved before transporting logs from a harvest unit.

$$\sum_{t=1}^{t_1}ZF_{i,t}-ZO_{j,o,t_1}\geq 0 \;\; for \;\; \forall o\in O_j, t_1=1,,T, j=1,,J \quad (5)$$

where the i-th road (arc) is connected to the j-th harvest unit, and the o-th option requires shipment through the i-th road first.

5: Constraints for road construction before shipping logs:

A road has to be constructed before any shipment of logs. Note that such a road is not taken into consideration in the second constraints described above. This is a common constraint formulation on the relationship between variable costs and fixed costs for transportation problems.

$$XP_{i,t}+XS_{i,t}+XV_{i,t}+XPM_{i,t}+XSM_{i,t}+XVM_{i,t}-M\sum_{t=1}^{t}ZF_{i,t}\leq 0 \;\; for \;\; i=1,,I, t=1,,T \quad (6)$$

where M is the maximum harvest flow for the i-th road or a given large number. The first three terms on the left hand side are for logs harvested by skidders or cables, and the next three terms are for harvesters.

6: Node-arc linkage constraints:

This is a constraint for shipment of logs through nodes and arcs. Note that nodes are such points that connect roads and an arc is equivalent to a road.

$$\sum_{i=1}^{I}A_{k,i}\cdot XP_{i,t}-\sum_{j=1}^{J}\sum_{o=1}^{0j}SPV_{k,j,o,t}\cdot ZO_{j,o,t}=0 \;\; for \;\; k=1,,K-2, t=1,,T \quad (7)$$

$$\sum_{i=1}^{I}A_{k,i}\cdot XS_{i,t}-\sum_{j=1}^{J}\sum_{o=1}^{0j}SSV_{k,j,o,t}\cdot ZO_{j,o,t}=0 \;\; for \;\; k=1,,K-2, t=1,,T \quad (8)$$

$$\sum_{i=1}^{I}A_{k,i}\cdot XV_{i,t}-\sum_{j=1}^{J}\sum_{o=1}^{0j}SVV_{k,j,o,t}\cdot ZO_{j,o,t}=0 \;\; for \;\; k=1,,K-2, t=1,,T \quad (9)$$

$$\sum_{i=1}^{I}AM_{k,i}\cdot XPM_{i,t}-\sum_{j=1}^{J}\sum_{o=1}^{0j}SPVM_{k,j,o,t}\cdot ZO_{j,o,t}=0 \;\; for \;\; k=1,,K-2, t=1,,T \quad (10)$$

$$\sum_{i=1}^{I}AM_{k,i}\cdot XSM_{i,t}-\sum_{j=1}^{J}\sum_{o=1}^{0j}SSVM_{k,j,o,t}\cdot ZO_{j,o,t}=0 \;\; for \;\; k=1,,K-2, t=1,,T \quad (11)$$

$$\sum_{i=1}^{I}AM_{k,i}\cdot XVM_{i,t}-\sum_{j=1}^{J}\sum_{o=1}^{0j}SVVM_{k,j,o,t}\cdot ZO_{j,o,t}=0 \;\; for \;\; k=1,,K-2, t=1,,T \quad (12)$$

Note that the $(K-1)$-st node is the yard, and the K-th node is the mill. The node-arc linkage constraints for those are considered in the ninth and tenth constraints later.

7: Area constraints for harvest units:

The harvested area cannot exceed its own total area. The sum of harvested areas for each unit must be less than or equal to its total area.

$$AREA_j \cdot \sum_{t=1}^{T}\sum_{o=1}^{O_j} ZO_{j,o,t} \leq AREA_j \;\; for\;\; j=1,,J \quad (13)$$

8: Nonnegative cash flow constraints:

This requires a nonnegative cash flow at each period. Cash flow consists of benefits from selling pulp, sawlog, and veneer, and such costs as fixed and variable transportation costs, setup costs, equipment usage costs, and costs to buy products from the third parties.

$$\begin{aligned} & PP_t(PVML_t+\sum_{n=1}^{N} VP3_{n,t})+PS_t(SVML_t+\sum_{n=1}^{N} VS3_{n,t})+PV_t(VVML_t+\sum_{n=1}^{N} VV3_{n,t}) \\ & -\sum_{i=1}^{I} CV_{i,t}(XP_{i,t}+XS_{i,t}+XV_{i,t}+XPM_{i,t}+XSM_{i,t}+XVM_{i,t}) \\ & -\sum_{i=1}^{I} CF_{i,t}\cdot ZF_{i,t} \\ & -\sum_{j=1}^{J}\sum_{o=1}^{O_j} CO_{j,o,t}\cdot ZO_{j,o,t} \quad (14) \\ & -\sum_{j=1}^{J}\sum_{e=1}^{E}\sum_{o=1}^{O_j} CE_{e,t}\cdot EQ_{j,e,o}\cdot ZO_{j,o,t} \\ & -\sum_{n=1}^{N}\{BP_{n,t}\cdot VP3_{n,t}+BS_{n,t}\cdot VS3_{n,t}+BV_{n,t}\cdot VV3_{n,t}\} \\ & \geq 0 \;\; for\;\; t=1,,T \end{aligned}$$

9: Constraints for logs shipped to the yard at each period:

Logs can be left over at the yard, or shipped to the mill.

$$\sum_{i=1}^{I} A_{k-1,i}\cdot XP_{i,t}+PVYD_t-PVYD_{t-1}=0 \;\; for\;\; t=1,,T \quad (15)$$

$$\sum_{i=1}^{I} A_{k-1,i}\cdot XS_{i,t}+SVYD_t-SVYD_{t-1}=0 \;\; for\;\; t=1,,T \quad (16)$$

$$\sum_{i=1}^{I} A_{k-1,i}\cdot XS_{i,t}+VVYD_t-VVYD_{t-1}=0 \;\; for\;\; t=1,,T \quad (17)$$

$$PVYD_0=SVYD_0=VVYD_0=0 \quad (18)$$

Note that no log harvested by a mechanical harvester goes to the yard, the $(K-1)$-st node.

10: Constraints for logs shipped to the mill at each period:

Logs are shipped to the mill either from the yard, or by other roads only if a mechanical harvester is used for harvesting.

$$\sum_{i=1}^{I} A_{Ki}\cdot XP_{i,t}+\sum_{i=1}^{I} AM_{K,i}\cdot XPM_{i,t}+PVML_t=0 \;\; for\;\; t=1,,T \quad (19)$$

$$\sum_{i=1}^{I} A_{Ki}\cdot XS_{i,t}+\sum_{i=1}^{I} AM_{K,i}\cdot XSM_{i,t}+SVML_t=0 \;\; for\;\; t=1,,T \quad (20)$$

$$\sum_{i=1}^{I} A_{Ki}\cdot XV_{i,t}+\sum_{i=1}^{I} AM_{K,i}\cdot XVM_{i,t}+VVML_t=0 \;\; for\;\; t=1,,T \quad (21)$$

Note that the K-th node is the mill.

11: Constraints for yard capacity at each period:

This requires that the volume of logs left over at the yard is less than its storing capacity, YC.

$$PVYD_t+SVYD_t+VVYD_t \leq YC \;\; for\;\; t=1,,T \quad (22)$$

12: Constraints for an annual harvest flow for pulp, sawlog and veneer:

This requires that the annual harvest flow of each product is within a certain range.

$$PVL_t \leq PVML_t+\sum_{n=1}^{N} VP3_{n,t} \leq PVU_t \;\; for\;\; t=1,,T \quad (23)$$

$$SVL_t \leq SVML_t+\sum_{n=1}^{N} VS3_{n,t} \leq SVU_t \;\; for\;\; t=1,,T \quad (24)$$

$$VVL_t \leq VVML_t+\sum_{n=1}^{N} VV3_{n,t} \leq VVU_t \;\; for\;\; t=1,,T \quad (25)$$

13: Constraints for harvest equipment utilities:

This requires that harvest equipment usage is within a certain range. It is neither economical nor convenient to buy or sell equipment frequently.

$$HEL_{e,t} \leq \sum_{j=1}^{J}\sum_{o=1}^{O_j} EQ_{j,e,o}\cdot ZO_{j,o,t} \leq HEU_{e,t} \;\; for\;\; e=1,,E, t=1,,T \quad (26)$$

14: Constraints for availability of pulp, sawlog, and veneer from the third parties:

$$\sum_{n=1}^{N} VP3_{n,t} \leq P3U_t \;\; for\;\; t=1,,T \quad (27)$$

$$\sum_{n=1}^{N} VS3_{n,t} \leq S3U_t \;\; for\;\; t=1,,T \quad (28)$$

$$\sum_{n=1}^{N} VV3_{n,t} \leq V3U_t \;\; for\;\; t=1,,T \quad (29)$$

Using the above constraints, an optimal harvest scheduling over the short time horizon was determined. Notice that since the time horizon is only 5 years, shorter than the minimum rotation age for Radiata pine, there is no reharvesting assumed in the above formulation. For a problem with a reharvesting option, decision variables for harvesting have to be modified as in Model I (JOHNSON and STUART 1987) within the IP framework.

MODEL DEVELOPMENT AND EXPERIMENTS

In this section, the harvest scheduling system was constructed along with a transportation network problem over the short time horizon, then an example problem was presented to show how the 0-1 integer restrictions affect the tactical harvest scheduling regime.

Model Development

To solve the proposed problem, a tactical harvest scheduling system with a transportation network was constructed. The system consists of two parts, i.e., the Input File Generator and the IP optimizer. Like FORPLAN, which uses LINDO (SHRAGE 1987) as an optimizer, this system uses commercial software called CPLEX developed by CPLEX Optimization, Inc. (1994) to search for a final IP optimal solution. The Input File Generator formulates the problem in the MPS format retrievable by CPLEX. MPS format has been established on mainframe LP systems, and widely accepted as a standard to define not only LP problems but also IP problems. It is a column-oriented format, meaning that problems are specified by column.

The Input File Generator was made by the FORTRAN programming language. Fig. 1 shows the basic structure of the Input File Generator. The Input File Generator requires the following input information;

1. MPS output file name
2. the time horizon (T) for planning
3. the number of harvest units (J)
4. the number of nodes (K)
5. the node number for the yard (K-1)
6. the node number for the mill (K)
7. the number of arcs (roads) (I)
8. the number of harvest equipment (E)
9. the limitation of equipment usage ($HEL_{e,t}$, $HEU_{e,t}$)
10. the number of the third parties to supply products (N)
11. a node-arc incidence matrix for a skidder or cable (A)
12. a node-arc incidence matrix for a mechanical harvester (AM)
13. forest growth data for harvest units
14. price data for forest products
15. discount rate (r)
16. yard capacity (YC)

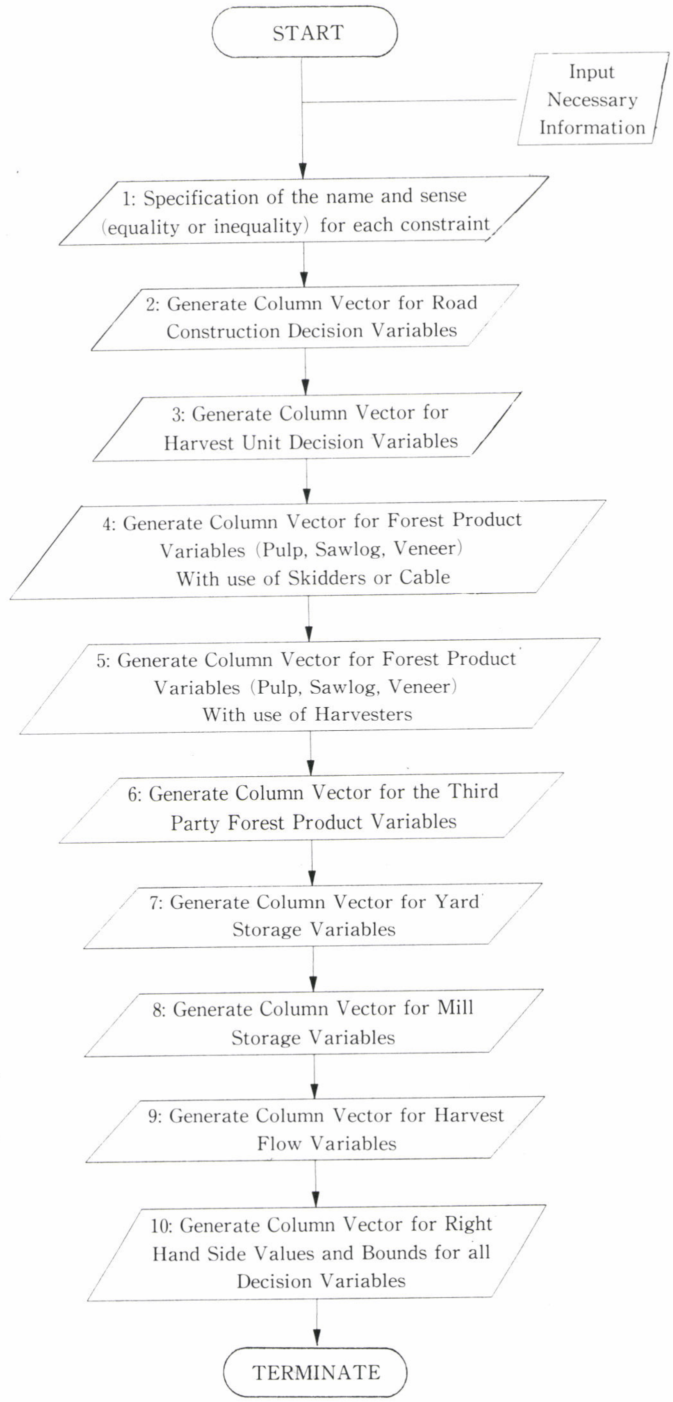

Fig. 1 Flowchart of the Input File Generator

Given the above information, the Input File Generator creates the MPS formatted input file for CPLEX in the order described in Fig. 1. The main components of the MPS file are the row names and sense (equality or inequality sign) for each constraint (the first part), the name assigned to each variable (column) and the nonzero constraint coefficients corresponding to that variable (from the second part to the ninth part), the names of right-hand side vectors and values for each constraint (row), and the limits for each variable (the tenth part). The resultant input file was retrieved into CPLEX to solve the problem.

Data Description

An example problem had six harvest units with sixteen nodes, one yard and one mill. The number of roads (arcs) was eighteen. Except the 18-th road, which connected the yard to the mill, all roads had to be built before any shipment of logs. Fig. 2 depicts the network of this problem. Harvest units were labeled by S1, S2, S3, S4, S5 and S6. Table 1 shows the initial condition of each harvest unit. Except for harvest unit S5, all harvest units were on a slope less than 35 degrees. For S5, 20.1ha out of 59.5ha had a slope greater than 35 degrees. The slope is one of the important factors determining which harvest option should be implemented. If the slope is too steep, a harvester cannot be used. The proportion of veneer, sawlog, and pulp produced from a unit volume was assumed to be constant over time. No veneer was produced from the harvest units, S1, S2, S3, S4, and S6. Only S5 could produce veneer. The price of each product was also assumed to be constant over time, and no real price premium was assumed The price of veneer was US\$80.00/m³, the price of sawlog was US\$50.00/m³, and the price of pulp was US\$30.00/m³. As for the growth of a forest stand, the future mean annual increment was assumed to be 10m³/ha/yr if the stand stock was less than 300m³/ha, 5m³/ha/yr if the stand stock was greater than 300m³/ha and less than 500m³/ha, and 0m³/ha/yr if the stand stock was greater than 500m³/ha. The weighting value for each stand was set to zero.

Logs from each harvest unit can be shipped in the following manner. All logs from S1 will be shipped to the 4 th node. In the case of S2, 20% of logs goes to the 2nd node, and the other 80% goes to the 5th node. All logs from S3 will be shipped to the 5th node. Thirty percent of logs from S4 goes to the 6th node, and the rest goes to the 12th node. For S5, 20% of logs are shipped to the 7th node, 30% to the 11th node, 35% to the 14th node, and 15% to the 15th node unless cable logging is applied. If the cable is used for this unit, all logs go to the 16th node. In the case of S6, 80% of logs go to the 8th node, and the other 20% go to the 9th

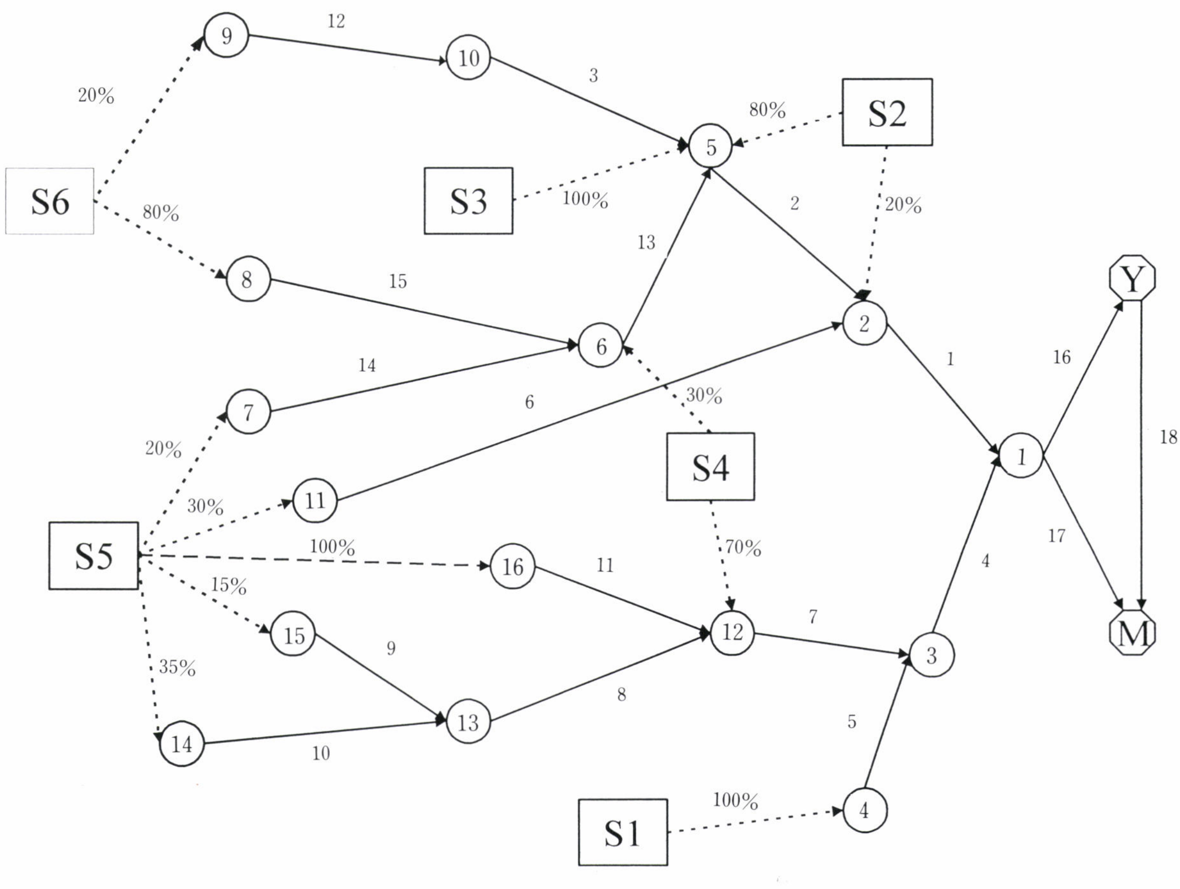

Fig. 2 Forest map and road network
○: node, → : directional existing road, □ : harvest unit, Y : yard, M : mill

Table 1 Initial conditions of harvest units

Harvest Unit	Total Area (ha)	Area with Slope >35° (ha)	Area with Slope <35° (ha)	Volume per hectore (m^3/ha)	Veneer Production (%/ha) Price: US$80.00/$m^3$	Sawlog Production (%/ha) Price: US$50.00/$m^3$	Pulp Production (%/ha) Price: US$30.00/$m^3$
S1	33.3	0	33.3	261.5	0	18.5	81.5
S2	16.8	0	16.8	343.2	0	1.7	98.3
S3	14.4	0	14.4	68.7	0	17.8	82.2
S4	12.6	0	12.6	149.9	0	27.2	72.8
S5	59.5	20.1	39.4	352.5	4.3	11.91	83.8
S6	20.1	0	20.1	417.6	0	13.5	86.5

Note: Mean annual increment per ha is assumed to be:
0m^3/ha/yr if volume per ha is greater than 500m^3
5m^3/ha/yr if volume per ha is greater than 300m^3 and less than 500m^3
10m^3/ha/yr if volume per ha is less than 300m^3

Table 2 Connection among harvest units and nodes

Harvest Unit	Option Number	Node	% of Log Shipment
S1	1,2	4	100
S2	1	2	20
		5	80
S3	1	5	100
S4	1,2	6	30
		12	70
S5	2	7	20(Skidder)
		11	30(Skidder)
		14	35(Skidder)
		15	15(Skidder)
	1	16	100(Cable)
S6	1,2	8	80
		9	20

node (see Table 2 and Fig. 2).

Table 3 shows the relationship between nodes and roads with road construction costs (fixed costs) and log transportation costs (variable costs). Transportation costs were calculated by;

$$\text{Cost}(\text{US\$}/m^3) = 1.0186 + 0.0788 \times \text{Road Length}(\text{km}) \quad (30)$$

There was no road construction cost for the 18-th road. This road had been built already.

Table 4 shows the harvest options for each harvest unit, the harvest equipment used under each harvest option, and the setup costs. Harvest units S1, S4, S5, and S6 have two options, while S2 and S3 have only one option. A mechanical harvester can be used at S1, S4 and S6. A skidder can be used at S1, S3, S4, S5 and S6, while cable logging is required at S2, and can be used at S5.

The harvest equipment utility limitation is shown in Table 5. There is no limitation for use of a skidder. There are five cables and three mechanical harvesters. It is assumed that there is no yard capacity limitation to hold logs over time.

Model Experiments

In this study, five problems were solved. The first two problems, Problems 1 and 2, did not contain the 0-1 integer requirements. That is, the road construction costs were not taken into consideration, and area to be harvested was allowed to be any nonnegative real value less than 1. Problem 1 did not have the harvest flow constraints, either. Problem 2 was the same as the first, but with the harvest flow constraints. Next two problems, Problems 3 and 4, had the 0-1 integer requirements for the road construction decision variables, but no 0-1 integer requirements for the harvest decision variables. Problem 3 did not have the harvest flow constraints, while Problem 4 did. The last problem, Problem 5, was the same as the third problem with the 0-1 integer requirements for the harvest decision variables. Since the number of harvest units in this example was few, there was no feasible solution satisfying the harvest flow constraints with all 0-1 integer restrictions. Thus, the harvest flow constraints were not embedded into Problem 5.

The harvest flow constraints used in Problems 2 and 4 were set to allow (10% fluctuation of the flow over the time horizon. The time horizon was set to 5 periods, where 1 period was 1 year. A discount rate of 5% was used. A Pentium 100MHz IBM compatible PC was used for the calculation. Table 6 shows a summary of the results.

The first problem, Problem 1, had 575 continuous

Table 3 Node-Arc connection

Arc #	From Node	To Node	Fixed Cost (US$)	Variable Cost* (US$m³)	Length (km)
1	2	1	10815	1.05	0.35
2	5	2	22445	1.07	0.67
3	10	5	44220	1.12	1.32
4	3	1	21630	1.07	0.7
5	4	3	24720	1.03	0.2
6	11	2	60255	1.17	1.95
7	12	3	24480	1.08	0.8
8	13	12	7650	1.04	0.25
9	15	13	15300	1.06	0.5
10	14	13	1530	1.02	0.05
11	16	12	3060	1.03	0.1
12	9	10	6732	1.04	0.22
13	6	5	12240	1.05	0.4
14	7	6	13770	1.05	0.45
15	8	6	19890	1.07	0.65
16	1	17(YARD)	77050	4.19	40.3
17	1	18(MILL)	77050	8.37	93.3
18	17(YARD)	18(MILL)	0	9.00	101.3

* : Variable costs were calculated by
Cost(US$/m³) = 1.0186 + 0.0788D(km)
where D is a length of road

Table 4 Harvest options at each harvest unit

Harvest Unit	Option Number	Skidder	Cable	Harvester	Total Setup Costs(US$)
S1	1	x			650
	2			x	500
S2	1		x		800
S3	1	x			650
S4	1	x			650
	2			x	500
S5	1		x		800
	2	x			650
S6	1	x			650
	2			x	500

Table 5 Harvest equipment utility

	Number of Machines	Harvest Capacity m³/machine/month	Cost (US$/m³)
Cable	5	1800	9.7
Skidder	no limitation	2200	8.5
Harvester	3	5000	6.0

Table 6 Summary of results from 5 problems

	Calculation Time (second)	Objective Value (US$)	Number of Iterations	Number of Branches	Number of Constraints	Number of Nonzero Variables	Number of Binary Variables
Problem 1	0.22	900,487.40	18	not available	536	575	not available
Problem 2	0.22	877,259.15	64	not available	566	578	not available
Problem 3	116.49	556,125.02	39,452	5,238	728	575	85
Problem 4	27.68	531,071.20	9,813	559	758	578	85
Problem 5	555.35	460,787.72	153,342	24,164	728	525	135

Note : Problem 1: No integer restriction without harvest flow constraints
Problem 2: No integer restriction with harvest flow constraints
Problem 3: Integer restriction on road construction variables without harvest flow constraints
Problem 4: Integer restriction on road construction variables with harvest flow constraints
Problem 5: Integer restriction on road construction and harvest unit variables without harvest flow constraints

variables with 536 constraints. The computational time to search for an optimal solution was 0.22 seconds with 18 iterations. The optimal objective value was US$900,487.40. Since no harvest flow constraint was considered, harvest took place at periods, 1, 2, and 5. Veneer was available only at period 1. The harvest decision variables were 1 for S2, S3, S4 and S6. A harvester was used at S1 at period 1 and 2, and at S4 at period 5.

The second problem, Problem 2, had 578 continuous variables with 566 constraints. Because of the additional harvest flow constraints, three variables were added as an even-flow variable for pulp, sawlog, and veneer. The computational time was also 0.22 seconds with 64 iterations. The optimal objective value became US$877,259.15, less than that of the first problem. This difference of US$23,228.25, can be regarded as a cost of restricting the harvest flow. Only the harvest decision variables for S2 and S3 were 1. A harvester was used over the entire time horizon.

The third problem, Problem 3, had 575 variables, the same as Problem 1, 85 out of which were 0-1 integer. The total number of constraints was 728. It took 116.49 seconds to solve the problem with 39,452 iterations under 5,238 branches. The optimal objective value was US$556,125.02. Although the harvest flow constraints were not taken into account, there was the flow over the entire time horizon. However, veneer was not available at period 5. Only the harvest decision variable for S4 was not 1, and the others became 1. A harvester was used at period 4 and 5 only. The number of roads constructed was 12. Four roads were built at period 1, two at period 3, two at period 4 and four at period 5.

Introducing the harvest flow constraints to the third problem, Problem 4, had 578 variables with the same number of 0-1 integer variables as in the third problem. The number of constraints was 758. The computational time was 27.68 seconds with 9,813 iterations under 559 branches. The optimal objective value was US$531,071.20. Reduction in the computational time was probably due to the harvest flow constraints. Intermediate solutions during the branching operation would become infeasible at an early stage of branching because of the flow constraints, resulting in less iterations and branches than the third problem. Only the harvest decision variable for S3 became 1. A harvester was used at period 2, 3, 4 and 5. The number of roads constructed was 12, the same as the third problem. However, seven roads were built at period 1, two at period 2 and three at period 4. This is because of the dispersion effect of the harvest flow constraints on the harvesting regime. That is, in order to spread harvest flow over time, more roads were constructed at earlier periods than in Problem 3.

The last problem, Problem 5, was the same as the third problem except the number of integer variables. The number of integer variables was 135. The computational time was 555.35 seconds with 153,342 iterations under 24,164 branches. The optimal objective value was further reduced to US$460,787.72. Compared to the third problem, the objective value was US$95,337.30 less, due to the 0-1 integer restrictions on the harvest decision variables. Under no harvest flow constraints, harvest took place at period 4 and 5. At period 4, S1, S2 and S5 were harvested, while others were harvested at period 5. Veneer was available at period 4. Sixteen roads were built, thirteen of which were at period 4 and the rest was at period 5. A harvester was used for S1 at period 4, and S4 and S6 at period 5.

DISCUSSION AND CONCLUSIONS

As can be seen in the above results, including the harvest flow constraints reduced the objective value by 30 to 40%. Since it was impossible to convert road construction costs (fixed costs) into variable costs for transportation by an amount of volume to be shipped, direct comparison could not be achieved precisely among the continuous problems and the IP problems. However, we can say that road construction costs could make a difference to the solutions. For instance, S6 in the LP problem (Problem 1) was harvested at period 1, compared to period 5 in the IP problem (Problem 3). This may be due to adding the road construction constraints. The same things can be said about harvest unit S1. It was harvested at the early period in the LP problem, and at period 4 in the IP problem. There are, of course, the same solutions for some harvest decision variables, such as S3 and S4, which were harvested at period 5 for both problems. The same tendency can be observed for the other problems with harvest flow constraints. The harvest unit S6 tended to be harvested at the early period for the continuous problem, while it was harvested at the late period for the IP problem. A delay in harvest is most likely due to the effect of discounting road construction costs on the objective function. The later the construction, the lower the costs on the basis of present net value.

Table 7 shows the effect of the integer restrictions on the objective value. Problem numbers with ' represent the solutions from the corresponding problem after subtracting imposed road construction costs. When road construction costs were calculated for the solution of Problem 1, the total road construction costs were US$442,837.00, which was 42% higher than that of Problem 3, US$312,652.30 (see Problem 1' column in Table 7). Thus, the resultant objective value became US$457,650.40, which was 18% lower than the corresponding optimal solution of Problem 3. As can be seen in the cash flow at period 1 of Problem 1', the cash flow decreased from US$781,292.80 to US$338,455.80, a difference equivalent to the total road construction costs. This implies that all road construction took place at period 1. On the other hand, when the integer restriction was imposed on road construction in Problem 3, roads were constructed at periods 1, 3, 4 and 5. This result implies that if no integer restrictions were applied, road construction would tend to take place in early periods since the objective function does not include any effect from road construction costs, but if road construction was treated as an integer variable, costs could be spread over different periods.

The 0-1 integer restrictions on the harvest decision variables further reduced the objective value by 17%, and increased the road construction costs by 20%. This led to no cash flow or no harvest at periods 1, 2 and 3. Under the harvest flow constraints, the road construction costs for Problem 2 would become US$344,332.00 (Problem 2') and be charged at period 1. Although this value was 4% higher than that of Problem 4, the objective value after subtracting the costs was slightly higher than the objective value of Problem 5. This inconsistency resulted from the infeasibility of the derived solution of Problem 2' because of the nonnegative cash flow constraints, as seen at period 1. Since all necessary roads were built at period 1, the costs were charged at period 1, resulting in negative final cash flow.

It is important to note from the above discussion that solutions from the LP formulation could be unexpectedly infeasible or inferior solutions to those from the IP formulation. Since the tactical harvest scheduling is usually a short-term problem, any error in the final regime could result in serious costs on the schedule. Therefore, formula-

Table 7 Effect of integer restriction on decision variables

		Without Harvest Flow Constraints				With Harvest Flow Constraints		
		Problem 1	Problem 1'	Problem 3	Problem 5	Problem 2	Problem 2'	Problem 4
Objective Value (US$)		900,487.40	457,650.40	556,125.02	460,787.72	877,259.15	532,927.15	531,071.20
Road Construction Costs (US$)		not available	442,837.00	312,652.30	376,981.80	not available	344,332.00	329,839.80
Cash Flow (US$)	Period 1	781,292.80	338,455.80	37,136.50	0	214,161.60	-130,170.40	9,718.36
	Period 2	50,596.82	50,596.82	163,341.30	0	201,056.60	201,056.60	98,756.22
	Period 3	0	0	112,085.20	0	177,570.80	177,570.80	185,982.40
	Period 4	0	0	126,419.80	345,161.00	188,061.10	188,061.10	129,474.30
	Period 5	86,309.16	86,309.16	185,417.90	197,657.90	180,007.00	180,007.00	178,379.10

Note : Problem 1: No integer restriction without harvest flow constraints
Problem 1': Road construction costs charged to a solution from Problem 1
Problem 2: No integer restriction with harvest flow constraints
Problem 2': Road construction costs charged to a solution from Problem 2
Problem 3: Integer restriction on road construction variables without harvest flow constraints
Problem 4: Integer restriction on road construction variables with harvest flow constraints
Problem 5: Integer restriction on road construction and harvest unit variables without harvest flow constraints

tion of the problem should not be misspecified.

From the viewpoint of the computational time, a major issue for the IP problem has been the computational burden. While the proposed continuous problems were solved in less than a second, it took 100 to 600 times longer to solve the corresponding IP problems with integer variables for the harvest decision variables. For the last problem, where both the road construction and harvest decision variables were treated as 0-1 integer, it took about 2500 times longer. The computational time of the IP problems is highly affected by the "tightness" of the constraints. The tighter the problem, the faster the solution is found (WILLIAMS 1974). Since the branch-and-bound algorithm starts branching from the LP relaxed solution, a final solution could be found at the early stage of branching if the number of integer solutions in the LP relaxed problem is large. For the first two IP problems, we can say that the constraints for the 0-1 integer variables were very tight, because of the combination of the second constraint (road linkage constraints for one-directional transshipment), the third constraint (simultaneous log transportation constraints), and the fourth constraint (harvest unit and road linkage constraints). Our other experiments showed that without these three constraints, applying the fifth constraint (constraints for road construction before shipping logs) to all roads took much more computational time to find the final solution compared to the times shown in Table 6.

If the computational burden cannot be resolved by reformulating the 0-1 integer problem, a prior knowledge about the largest lower bound of the objective value would be helpful. The lower bound is the objective value of one of the feasible solutions. Thus, the optimal objective value has to be equal to or greater than the lower bound. Such a feasible solution can be found by using heuristics. For a larger problem with the 0-1 integer requirements for both road construction and harvest decision variables, heuristics may play an important role in finding "good" feasible solutions.

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Article

Development of a Public Participation Handbook

Yukichi Konohira*

ABSTRACT

In this paper, a prototype of a public participation handbook is presented. This proposal can become a reference for producing official handbooks of the national forests in Japan. Procedures for public participation in the planning process are divided into following seven stages. (1) Pre-planning (2) publicity of the planning system and public participation process, (3) explanation of the present states and problems of forests, (4) collection of opinions, discussion and analysis, (5) preparation of assessments and alternative plans, (6) determination, explanation and recording of the final plan, (7) promotion of acceptance of the final plan.
Under the present planning system in the national forests, an acceptable handbook is required, because public participation in the forest planning process is an essential factor.

Keyword: public participation, forest planning

INTRODUCTION

A prototype of a handbook has been produced to explain a procedure appropriate for public participation under the present planning system of Japanese national forests. Public participation has two outcomes; the process promotes a better understanding through dialogue with people of different opinions, and this leads to the building of consensus. The author believes that it is possible to reach satisfactory results after proper process is used. Accordingly, the public participation handbook would be a guidebook for promoting a better understanding of forest management by the public.

Participation can be divided into two types, namely, participation in the forest planning process and daily participation. The former is a planning process by which land uses of the forest estate can be rationally determined. On the other hand, the daily participation of people in the forest includes recreational activities such as mountain climbing, camping and so on. In this paper, a method will be proposed for encouraging public participation in the planning process.

* Faculty of Agriculture, Tokyo University of Agriculture and Technology, 3-5-8 Saiwaicho, Fuchu, Tokyo 183 Japan

The handbook is a manual based on the technical standards of the national forests. The proposals in this paper are offered as references for producing official forest handbooks. (Kakizawa 1989)

PROCEDURE FOR PUBLIC PARTICIPATION IN THE PLANNING PROCESS

The suggested basic procedure for public participation during the formulation of regional national forest plans is roughly divided into PR-activities, disclosure of information, assessment, collection of opinions and discussion, preparation of alternative plans, selection and records. The basic schedule of the planning for one year is shown in Fig. 1. The procedures will be explained by the sequence. (Konohira 1995a)

STAGE ONE : PRE-PLANNING

Production of a list of customers

The first material to be prepared is a list of customers who have the interests in the national forests. For this list, the traditional organizations and customers associated with the national forests are sawmills, construction com-

Stage One	Pre-planning
Stage Two	Publicity of the planning system and public participation procedures
Stage Three	Explanation of the present state and problems of forest
Stage Four	Collection of opinions, discussion and analysis
Stage Five	Assessment and preparation of assessments and alternative plans
Stage Six	Determination, explanation and recording of the final plan
Stage Seven	Promotiog acceptance of the final plan

Fig. 1 Basic schedule of public participation procedures in the planning process of the national forests

loggers, local municipalities, government offices such as the Environment Agency, Ministry of Construction and forest and labor unions.

In addition, the list shall include recreational customers of the forests; fishermen, campers, bird-watchers, nature conservation groups, etc. The list can be arranged through daily communications and by increasing the opportunities for people to visit forestry offices. Important customers are those who express their opinions by telephone or letter, those who attend the meetings, etc. All people interested in forests can be potential customers. The list may be updated at any time.

This list is used for communication of events, meetings, collection of opinions, and publicity of management policy in the planning process. Publicity by mass-communication is important, however, it is essential that direct communication be made with each person. (Konohira 1995 b)

Network and database for outside information

Database and retrieval systems can provide external information to national forests. Information of mass-media is important to understand the views of local residents. The development of a computer-based information database is essential. For public participation, it is necessary to build a network system to advance the collection of outside information and transmission of inside information. The national forests require personnel having information skills and those in majoring mass communication. The network can become the information highway connecting society with forest management planners.

Publicity and information disclosure

Public relation activities can be made not only at the time when plans are prepared, but also daily in the area. It is necessary to support environmental education and conservation activities by the display of educational materials of forestry and by holding educational meetings and introducing people to the national forest system. It is intended to deepen the understanding of forests by offering information to those interested in such matters (Cortner 1995).

For conveying the plans of the national forests, "user friendly" information is required. This should be produced with brief, clear sentences and illustrations. Overly technical documents published by forest offices cannot attract the average citizen, who prefer brief, easily readable sentences.

The basic public relation activity is to provide the opportunity to enjoy the forest for those who have no relationship with forests in daily life. Because they have the potential to enjoy the experience at the forests, outdoor recreations in forest is desirable. Proper interpretation is a good opportunity for better understanding forests, and it is an opportune time to understand the roles of the national forests.

STAGE TWO : PUBLICITY OF THE PLANNING SYSTEM AND PUBLIC PARTICIPATION PROCEDURES

The planning starts in April and is completed in March of the next year. In order to build a social consensus for the forest plan within the short period of one year, it is first necessary to promote people's understanding of the planning system and public involvement processes.

Publicity of the planning system

The planning system of the national forests is not well understood by the average citizen. Forest planning identifies a goal and enables a design of the forest to be prepared. For achieving this goal, schedules for necessary projects are established. Otherwise, this goal will be lost, and rich natural resources will disappear. The forest area is divided into areas for protection and development. Operating plans are discussed for how to harvest, plant and foster the forest. Also the economic and technical feasibility of the plan must be checked. These systematic procedures are called forest planning. The explanation of the systems enables people to understand the process and their involvement leads to better plans.

Publicity of public participation procedures

This is an announcement of the opportunity for local people to participate. At present, there are few opportunities for them to express their opinions on the planning of the national forests, thereby, it will be difficult for society to understand the new system even when public participation opportunities are provided. Explanation is necessary on how and when and where the participation is appropriate.

A difficulty with these procedures may be very little interest may arise and very few expression of opinions by people may be made. No publication of the governmental planning process is customary in this country and people are not familiar with professional technology and knowledge. It is necessary to interpret problems of forest plan in simple language. Participation activities will increase if people know that the opinions of the people regarding the forests will be incorporated into the plan.

STAGE THREE : EXPLANATION OF THE PRESENT STATE AND PROBLEMS OF FOREST

Present state of the forest

The present state of the forest in question must be explained first. Features of the natural environments and management conditions are summarized by showing tables and maps of the area. Problems in planning are explained. By describing the policy and direction of the national forests up to date, legal regulations, financial policy and the technical limits will be clarified. By providing their basic information on forests, people will be encouraged to show an interest in them and to give their opinions. Provision of data must be objective. It is unfair if the data is biased to per-judge the policy of the national forests.

Disclosure of detailed information

The above mentioned information is merely an outline whose purpose is to promote a better understanding of the basic conditions, however detailed information is also necessary for building consensus. For instance, for the forest plan itself, statistics, the forest register, and the forest map of the areas may be relevant. The information disclosure system will be improved by clarifying the range of publication and costs. Unless the information disclosure system is progressively improved, people will become dissatisfied. (KONOHIRA 1992)

STAGE FOUR: COLLECTION OF OPINIONS, DISCUSSION AND ANALYSIS

Collection of outside opinions

Opinions can be collected from various outsiders, in addition to the information from the central government and local municipal governments. This can be in the form of letter or interview. Opinions given at forums such as public hearings should be recorded. Field trips and surveys by interested people will be encouraged.

These days, society is keenly interested in forests but the management and workers of the forest are scarcely understood. The first problem to advance the public participation process is to offer ordinary people the opportunity to show opinions on forests. Since the feudal age, governmental officials have not been regarded as receptive to the opinions of the common people.

Exchange of opinions

Opinions can be exchanged through mass communications, meetings, and interviews with individuals and groups. Participants can easily show their opinion frankly in relaxed meetings. It is effective to explain many different opinions and to make problems understandable by using data and visual aids.

Opinions are exchanged between the public and the national forest personnel, or between members of the general public. In the former case, there may be a tendency for confrontation between the ordinary people and the specialist, and between the people giving information and people receiving it. In the latter case, it is possible to make free exchanges of opinions if the national forest personnels work as "moderators" or "facilitators".

STAGE FIVE : ASSESSMENT AND PREPARATION OF ALTERNATIVE PLANS

Assessment

Assessment means estimating the results of a certain management practice in the forest. Sustainablility is a basic principle of forestry, and the harvest volume and growing stock can be changed by changing management policy, production and protection areas, rotation periods, and cutting methods.

Estimation of changes will be quantitative in many cases. However, the results of the timber harvest, conservation and erosion control can relate to the safety of the area.

Visual imaginary made by computers will be effective in evaluating scenic beauty, wild animals, and recreational value. This requires detailed data and knowledge based on surveys and studies.

One basic item of assessment concerns timber harvesting. It is necessary to estimate ecological changes to the environment including the soil, scenery, wildlife habitats, erosion and disaster prevention, watershed management, all of which can be influenced by timber harvesting. Assessment is a technical evaluation. Society is composed of people with different views, therefore, evaluation of the results of technical assessments will be made based on their views.

Preparation of alternative plans

When the opinions are collected, discussion is advanced, and assessment is made, the critical points on planning will be clarified, and then, forest personnel will produce several alternative plans. Management methods differ by the purposes for which the forests are planned, such as water resource protection, recreation, timber-production, and wildlife habitat. Plans must be checked so that they are feasible in terms of labor, technology and funding. The purpose and problems of each plan should be explained step by step.

These alternative plans will reflect the discussion. Three or four alternative plans would be sufficient. Summaries should be published, and opportunities for discussion provided. It is recommended that the plan based on the viewpoint of the specialists is separately identified.

STAGE SIX : DETERMINATION, EXPLANATION AND RECORDING OF THE FINAL PLAN

Deciding the final plan

With the progress of review on several alternative plans, and better understanding on the forest, a consensus may emerge, though some differences in opinions will remain. At the present stage, forestry specialists may select a final plan among these alternative plans or revised plans. However, for the final selection, it is necessary to give full consideration to the discussion and the collected opinions, and the reasons of the selection must be clarified. These reasons are most important for the participants in the planning processes. The final decision is left to the forestry specialists because of the expectation that they can make better judgments based on the long-term view and integration of the multiple viewpoints.

Explanation of the final plan

Upon deciding the final plan, a summary of the plan is produced and published. At the same time, the detailed statement is published. Emphasis is to be placed on the results and opinions of people who actively participated in the discussion.

The recording of the process

The planning process and opinions expressed should be recorded completely. Should problems occur at the stage of the execution of the plan, these records will be useful in finding a solution. Opinions are changed easily and the memories are often clouded . The discussion at the planning stage will be good references in many cases, and therefore, records should be complete. These records are useful for the improvement of participation process. The experience will lead to the subsequent improvement of the handbook.

STAGE SEVEN : PROMOTING ACCEPTANCE OF THE FINAL PLAN

Explanation of the plan

Even if the plan is produced with the consensus of the local residents, the contents of the plan should be explained and published. The contents will not be understood by those who do not participate in the planning process. It is necessary to publicize the plan for those who have not shown any interest.

Exchange of opinions

During the planning stage, the main policies and important items will have been discussed, however, minor problems must be expected to occur in the field, but even in such cases, opinions should always be exchanged. This leads to daily participation in planning.

CONCLUSION

For public participation in the planning process of the national forests, a proposal has been made for the procedures that forest planners should follow. Under the present planning system, it is necessary to produce an acceptable handbook for the national forests. Public participation is an essential for advancing the planning process. Also, it is necessary to continuously revise the handbook through experiences and based on results in order to improve the contents systematically.

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Article

Information Oriented Problems in Newly Established Forest Management Systems

—A case study in the river basin of the Yoshino River (Miyoshi)—

Shigeki Yamada* and Naoto Matsumura*

ABSTRACT

The profitability of forest management has been declining due to stagnating domestic timber prices and increasing management cost. With a waning in enthusiasm on the part of the forest owners, forest management is now in a state which is less than desirable. With this, there is no supply system which corresponds to the maturing of forest resources. In the river basin forest management system, it is necessary to constitute a system encompassing production, processing and distribution, from upstream to downstream. For this, it is vital that comprehensive information related to forests and forestry be systemized and a networked information system in a management unit be established. Such a network should provide the following functions
1) information exchange
2) collection of information for marketing
3) inter-connection with various industries
4) efficient management.
In this paper, a sample system is proposed for the study site and related problems are discussed.

Keyword: information oriented, forest information system, river basin forest management system

INTRODUCTION

In March 1991, referring to a report issued by the Forest Administration Council in 1990, the Forest Agency established a new forest policy, the River Basin Forest Management System. The purposes of this new policy were 1) improvement of diverse forest as sources of green and water, 2) improvement of the lumber production, processing and distribution system toward achieving an enhanced awareness and increased sales of domestic lumber.

In 1991, the Forest Law was revised toward improving forest planning systems and it has now become necessary to establish a new forest management system connecting these forest planning systems.

The economical and social backgrounds of this policy are as follows :

1) Domestic forest resources, especially those planted during the post-war period, are maturing rapidly.
2) A lumber processing and distribution system suited to imported timber has been established.
3) The shortage in and the rapid aging of the forestry work force is becoming more pronounced.
4) The demands on forests by the general public is diversifying.
5) Due to these changes, forest management has also changed.
6) Improvement in national forest management efficiency has progressed.

To achieve the two purposes described above, the Forest Agency started a new project to promote activation of forestry and upstream areas from 1992. Through this policy, some progress has been made.

As noted above, the new policy was introduced in order to properly control forest resources and to maintain and develop upstream villages. In this paper, we discuss the necessities of the Forest Information System (F.I.S.) for the establishment of a river basin forest management sys-

* Forest Management Laboratory, Shikoku Research Center, Forestry and Forest Products Research Institute, 915 Asakura-Tei, Kochi 780 Japan

tem together with key points for that system by investigating movements in the Miyoshi region, Tokushima Prefecture, as a case study site.

NECESSITY OF A FOREST INFORMATION SYSTEM

In the river basin forest management system, the river basin area as a whole becomes the direct object of the forest policy. Taking the river basin as a unit, and with the consensus of people concerned, timber production, processing and distribution are streamlined. This makes it possible to formulate a plan wherein the structure of the downstream area becomes the lumber production, processing, distribution and consumption site linked with the situation of the forest resources in the upstream areas (MOCHIDA 1994). Specifically, it is systemization from production to consumption linking the forest resources in the upstream areas to the consumer market in the downstream areas (KAWAMURA 1995).

Except for several famous timber producing area such as Yoshino in Nara Prefecture, many timber producing areas are now facing serious problems in producing and selling their growing forest resources. A high percentage of the forest resources in these areas is sugi, which faces strong competition from imported timber such as western hemlock, for example. To overcome this competition, it is necessary to make every effort to cut production costs throughout the entire series of processes. From the standpoint of marketing strategies especially, it is vital that manufactured goods be supplied in the most appropriate manner. For example, the sawmills must constantly maintain the quality of their product and supply them in a timely manner while also fully complying with the prevailing demands. In order to decide the types and quantities of their products it is, therefore, necessary for the sawmills to obtain accurate information related to supply and demand as soon as possible. With this, strictly stockpile control is also vital. Several papers have reported such information oriented movements in the forest products industry (ANDO 1986, 1991; KATO 1991).

From the forest management and log production aspect, however, it is necessary to constitute a networked information system (AMANO 1986). To fully demonstrate a forest's multiple functions and to ensure forest conservation, it is vital that the present situation of the forests be determined in order to provide effective management, weeding and thinning, etc. However, many forest owners gave up due to a shortage of forest workers. Certain forestry enterprises such as forest owners' cooperatives have made some attempts wherein intentional cutting, cooperation in management practice, efficient operation of high performance forest machinery, distribution of the labor force were practiced by employing a forest information system (KATO 1994).

As stated, to establish a river basin forest management system, it is necessary to constitute a system of forest management and domestic timber supply system encompasses production, processing and distribution from upstream to downstream. For this, it is also vital a wide range of information related to forests and forestry be utilized synthetically. For this, a networked information system would be required.

OUTLINE OF FORESTS AND FORESTRY IN THE MIYOSHI REGION

The basin area lies within the north-western part of Tokushima Prefecture (see Fig. 1) and contains five towns - Mino, Miyoshi, Ikawa, Ikeda, Yamashiro, and two villages - Higashi-iyayama and Nishi-iyayama. The population of this area is about 58,000, although depopulation has continued here. In 1990, there were 18,646 households of which 7,445 (40%) owned forest land. As there are many scenic areas in the region, tertiary industry was comparatively high at about 40% in the population ratio, or over 60% in the output. However, the importance of primary industry was not high, its percentage of the yield being only 6%.

The following section provides an outline of forest and forestry using the data of the 1990 Census of Forestry and the Report of Fundamental Plans published in 1992.

The forest area occupies 72,313ha (86%). of this, 9,565ha (11%) is national forest and 62,743ha (89%) is private forest. The total stand volume is about 8,000,000m^3 with 90% of that volume being in private forest. In private forest, the ratio of artificial forest was 63%, being relatively high to that of national forest(42%). The plantation forests mainly consist of sugi (71%) and hinoki (20%). In distribution of age class, about 90% were under the VII age

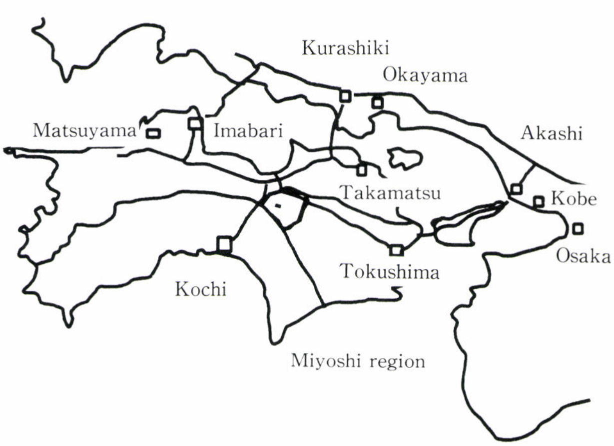

Fig. 1 Miyoshi region

class.

The scale of household-owned and operated forest is generally small with an average area of 7.4ha. However, 82% of these people own and operate areas of less than 5ha. There are 26 large scale owners of over 100 hectares, although their activities provide no great influence upon the forestry in this region. The area owned by absentee land owners was 9,472ha (15%). The farm household ratio was 71% and the remainder non-farm households. The main source of income for these people was regular work such as office work etc, with 44% so engaged. Only 0.9% of the total households are engaged in self-employed forestry.

Table 1 illustrates the activities of forest owner households according to the type of work in which they were engaged for their own forest in 1980 and 1990. It is seen that the percentages of households carrying out afforestation declined in every town and village. Overall, the percentage had fallen 5 points, almost 50% of that of 1980. The same is true of tending activities where in almost every town and village, the percentage had largely declined. Regarding thinning, circumstances are somewhat different and the ratios of households carrying out thinning showed a slight rise. In the Miyoshi region, therefore, it is seen that the forest owners were motivated only little in afforestation. However, in the face of the maturing of the forest resources and an increasing necessity to tend and thin, they made certain efforts in such activities but, perhaps due to the shortage of forest workers, were unable to adequately carry out those activities.

In 1990, the total log production for the area had increased to 107,000m^3 from the 80,000m^3 of 1972. This increase was mainly observed in the private forest which at 98,000m^3, provided 91% of the production volume.

In 1990, the plantation area was 169 hectares, being only 25% of that of 1975. The recent trend is, therefore, a decrease in reforestation. In 1972, the reforestation area was 81 hectares which fell to a mere 19 hectares in 1990.

In 1988, there were 77 logging contractors including eight forest owners' cooperatives. In their production scale, many logging enterprises were marginal producers with an annual production less than 700 − 800m^3. However, the cooperative in Yamashiro is relatively active. Its production volume was about 3,400m^3 which represented 58% of all the timber produced by the forest owners' cooperatives. Yamashiro also has a small timber processing plant so this cooperative should be one of the core subjects in the region.

There is no market dealing with sawn timber, but there is one log market able to handle 42,000m^3 per year. However, due to narrow space, although the production volume in the region is rising, the total growth of its handling volume remains stagnant. In 1990, there were 29 sawmills in the region with a total log handling volume of 68,000m^3. In terms of log processed by these plants, 25 handled domestic logs.

As previously described, the Miyoshi region is not a famous forestry region nor a forest region with a long

Table 1 Number and percentage of households which carried out afforestation, weeding and thimming in 1980 and 1990

		Mino		Miyoshi		Ikeda		Yamashiro		Ikawa	
		Number	percent.	Number	percent.	Number	percent.	Number	percent.	Number	percent.
Number of Households	1980	952	100	838	100	1,815	100	1,247	100	751	100
	90	521	100	736	100	1,517	100	1,025	100	684	100
Afforestation	1980	27	5	106	13	205	11	162	13	117	16
	90	20	4	63	9	92	6	39	4	62	9
Weeding	1980	171	29	329	39	818	45	711	57	478	64
	90	155	30	249	34	462	30	210	20	277	40
Thinning	1980	32	5	49	6	226	12	248	20	80	11
	90	50	10	53	7	176	12	173	17	99	14

		Mikamo		Higashi-iyayama		Nishi-iyayama		Miyoshi region		Tokushima pref.	
		Number	percent.	Number	percent.	Number	percent.	Number	percent.	Number	percent.
Number of Households	1980	1,012	100	670	100	528	100	7,453	100	32,116	100
	90	872	100	509	100	432	100	6,296	100	27,364	100
Afforestation	1980	102	10	74	11	59	11	852	11	448	2
	90	72	8	4	1	7	2	359	6	1,438	5
Weeding	1980	426	42	431	64	306	58	3,670	49	1,959	7
	90	334	38	75	15	76	18	1,838	29	6,529	24
Thinning	1980	68	7	115	17	40	8	858	12	684	3
	90	116	13	82	16	75	17	824	13	2,843	10

Source: 1980 and 1990 Census of Forestry history. In general, it is a private forest dominated region with maturing forest resources and, therefore, the grade of its logs fall within the ordinary level. With this, no effective domestic timber supply system encompassing production, processing and distribution from upstream to downstream has been established here. Presently, therefore, the upstream-downstream cooperation activities in the forestry and lumber industries do not fulfill their functions. To overcome the keen competition exerted by foreign timber and other domestic timber producing areas, it is necessary to construct the system with the aid of the Forest Information System.

FUTURE VISION OF THE INFORMATION STREAM DESCRIBED IN THE FUNDAMENTAL PLAN

Table 2 provides a brief history of the activities promoting regional forestry. The Fundamental Plan was agreed and published in March, 1992. The following eight factors indicate the future course described in this plan.

(1) Construction of a general forestry center
(2) Education and reservation of forest workers
(3) Reorganization and intensification of forestry enterprises
(4) Investment in high performance forestry machinery
(5) Consolidation of the forest product processing and distribution system.
(6) Improvement of forests
(7) Achievement of locality-brand forest by-products
(8) Synthetic utilization of forest space

The principle of this plan aims at the establishment of lumber processing estates in Mino Town and in the western part of the region, together with the construction of a general forestry center, the reorganization and intensification of logging contractors as forest owners' cooperatives in this region as the hardware-based policy, and the establishment of an F.I.S. as the software-based policy.

The General Forestry Center should provide five functions:

1) Promotion of forestry
2) Exhibition and sale of forest products
3) Instruction and education in the form of seminars
4) Forestry information center
5) Tourist information

With the office of the River Basin Forestry Vitalization Center located in this building, the Center should generally regulate subjects related to forests and forestry as well as serve as a timber information dissemination center. Toward establishing the domestic timber supply system, a domestic timber distribution/processing base with a log market, sawmills and other related facilities is now under construction in Mino town, with another in the planning stages.

This base should collect a wide range of information related to timber distribution, processing and sales. However, intensification will be attained in more upstream areas in the region through the introduction of high performance forestry machinery to the forestry enterprises. Due to an adequate distribution of their machinery and work force, these forestry enterprises should collect and utilize as much information related to their area as possible. The most important factor is, therefore, to effectively integrate and adjust this information.

SUBJECT TO THE ESTABLISHMENT OF A NETWORKED INFORMATION SYSTEM

As stated, in the Miyoshi region, preparations of the hardware required for domestic timber supply and forest management is now in progress. However, while preparations for the software, in this case a networked information system, is underway, certain problems are being encountered. Therefore, the information system is aimed at the following four points;

(1) Information exchange and sending: As much as possible, information should be exchanged between the inner members of the system. With this, the promotion of electrification should also be considered to enable such information exchange.
(2) Marketing: Not only the normal form of forestry information should be collected, but information related to marketing should also be obtained, such as the diameters of the timber which will be produced in the region. Forest enterprises such as the forest owners' cooperatives would obtain information related to the present

Table 2 Progress of activities for promoting river basin forest management system

Sep. 1991	Establishment of the River Basin Forestry Vitalization Center and the River Basin Forestry Vitalization Council
Dec. 1991	Establishment of Sectional Meeting for improvement of log distribution
Apr. 1992	Establishment of Sectional Meeting for introducing high performance forestry machinery
July 1994	Establishment of Sectional Meeting for improvement of forest labor force
July 1995	The General Forestry Center was completed

Source: Materials offered by the office of the River Basin Forestry Vitalization Center true state of their forest resources and intentions of the forest owners. With this, information regarding demands is also collected at the timber processing estate. By considering this information synthetically, the system is enabled to function in the most suitable manner and provide effective results.

(3) Connection between various industries: as business opportunities are to be found almost everywhere, connection to various industries and people becomes highly valuable factor.

(4) Efficient management − cost down: the networked information system enables effective cost-down. As a first step, an information center is planned to be located in the General Forestry Center in Yamashiro in the southern part of this region. To conduct efficient forest management such as producing thinning schedules, road planning and logging operations, the development of GIS-based system is now in progress.

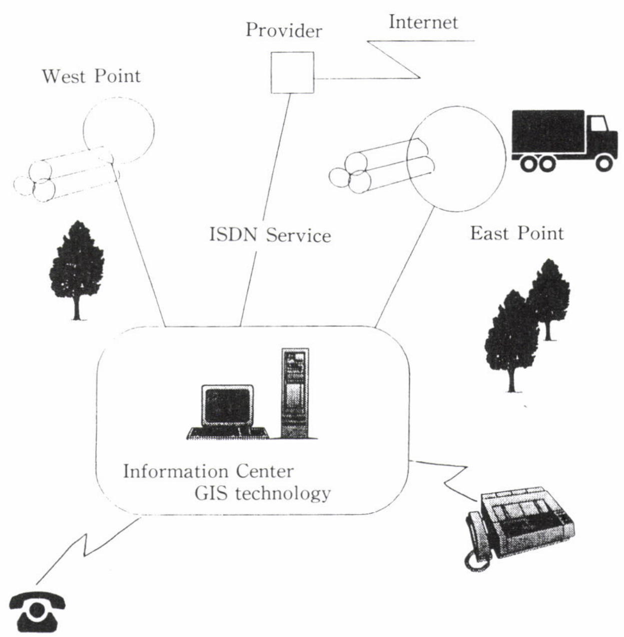

Fig. 2 Network system

From the standpoint of these four factors, the network system shown in Fig. 2 would be very suitable for the Miyoshi region. As the hub, the Center is located in Yamashiro Town because forestry activities are fairly intense there. As the second hub of this region, a Forestry Machinery Center is planned in the timber processing estate in Mino Town in the eastern part, with another estate in the western part. A distributed processing network between these hubs via an ISDN service is, therefore, made available. The forest sectors are also connected to the information center via public network. As a connection to a wide area network, the Internet service may be a viable solution.

Certain investment in hardware and payment to persons to operate the system are inevitable. Also, as the information system is improved, the cost required for its operation will increase accordingly. In this region, the forestry section does not have the financial foundation required for such an enterprise although it would be very advantageous for such a region to establish and maintain a relatively compact information system such as that described herein.

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Article

New Index for Analyzing the Stem Taper Variations within a Stand

Kazukiyo Yamamoto*

ABSTRACT

Based on the system volume equation presented previously, a new index was proposed for analyzing the change of stem taper within a stand in competitive situations. Using this index, the stem taper variations was analyzed over time within a stand for *Cryptomeria japonica* and *Chamaecyparis obtsusa*. In both species, the stem taper was highly correlated with the diameter at breast height. The change in stem taper variations over time was examined in this paper and was found to be different between species.

keyword: stem taper variation, *Cryptomeria japonica, Chamaecyparis obtsusa*

INTRODUCTION

The form and taper of forest tree stems have been studied mainly as a mensurational exercise for more than 100 years. The main objective had been to provide the quantitative models for estimating the stem volume accurately. However, a new demand has appeared for stem form models to explain the variation of stem form and taper, both within and among trees, over time in the competitive situations (OSAWA 1992; MUHAIRWE 1994).

Previously, I derived a system of stem volume and profile equations based on the relationship between the stem volume and the stem cross-sectional area in *Cryptomeria japonica* trees (YAMAMOTO 1994a). The derived system implied that for the portion below the sunny crown the form of a tree stem was nearly constant, although the taper of tree stem varied amongst trees. Based on this compatible stem volume and profile equations, I further proposed the simple volume estimation system. In comparison with the prediction accuracy of existing volume equations from the literature, using the data from *C. japonica, Chamaecyparis obtsusa* and *Pseudotsuga menziesii*, this system had the advantage in reducing the prediction errors (YAMAMOTO 1994b).

In many other system volume equations (e.g., BRUCE *et al*. 1968; CAO *et al*. 1980; REED and GREEN 1984), the relationships between the stem form, the stem taper and the stem volume is unclear. On the other hand, a parameter of the system derived previously, related directly to both the stem taper and stem volume (YAMAMOTO 1994b), and therefore can be used as an index for analyzing the stem taper variations over time in the competitive situations. In this study, I investigate and compare the feature of the stem taper variations over time in *C. japonica* and *C. obtsusa* using this index.

* Faculty of Agriculture, Niigata University, 8050 Ikarashi Ninocho, Niigata 950-21 Japan

MATERIALS

The stem analysis data from 18 *Cryptomeria japonica* D. DON trees and 18 *Chamaecyparis obtsusa* ENDL. trees, the stems of which had respectively been obtained in a 38-years-old monoculture stand, were taken from the University Forest in Chichibu and Laboratory of Forest Measurement (1987). Some simple statistics for these trees are summarized in Table 1.

In every tree, the stem had been sectioned at 1.0m intervals from 0.3 until 2.3m above ground, and at 2.0m intervals from 2.3m above ground to tree top. Diameter outside bark, diameter inside bark, and diameters of inner rings at one year intervals had been presented at any section. The actual stem volume above breast height in any age was calculated with the stem analysis data mentioned above and Smalian's formula.

Table 1 Summary of stem analysis data

Plot code	Species	Number of stems	Ages	Diameters (cm)	Heights (m)
001S	*Cryptomeria japonica*	18	33-38	8.75-30.05	10.40-21.60
002H	*Chamaecyparis obtsusa*	18	30-38	8.00-27.75	8.50-16.26

Note: The stand age at the time of felling was 38 years old in both stands.

METHODS

In the previous paper (YAMAMOTO 1994a), the stem profile below the base of sunny crown to breast height (BH: 1.3m above ground) was described as

$$SA(h)=\frac{1}{2k}(h_0-h) \quad (1)$$

where $SA(h)$ was the stem cross-sectional area (m^2) at a given height h(m) above ground, and k and h_0 were constants. The stem volume (m^3) above h, $V(h)$, was also described as

$$V(h)=kSA(h)^2 \quad (2)$$

Based on this compatible stem volume and profile equations, the stem volume above BH, $V(\mathrm{BH})$, was predicted from two measurements of stem cross-sectional areas at BH and at an another point along the upper stem, h_u, by use of the following equations:

$$V(\mathrm{BH})=kSA(\mathrm{BH})^2 \quad (3)$$

$$k=\frac{h_u-\mathrm{BH}}{2(SA(\mathrm{BH})-SA(h_u))} \quad (4)$$

In the previous paper (YAMAMOTO 1994b), I showed that eqs. 3 and 4 most accurately predicted the stem volume above BH, $V(\mathrm{BH})$, when the upper stem cross-sectional area in the relative height 0.5 ($h_{0.5}$) was used for *C. japonica*, and when the upper stem cross-sectional area in the relative height 0.6 ($h_{0.6}$) was used for *C. obtsusa*. Here, I defined the relative height as $\frac{h_u-1.3}{\mathrm{H}-1.3}$, where H was the total height of a tree (YAMAMOTO 1994b).

In *C. japonica*, KAJIHARA (1995) showed that the average crown ratio within a stand was larger than 0.5 before 20 years old. In *C. obtsusa*, the crown ratio of a tree was also mostly larger than 0.6 before 20 years old (MIYAMOTO *et al*. 1980; HAGIHARA *et al*. 1993). The sunny crown was nearly two-thirds of the live crown (FUJIMORI 1970; KAJIHARA 1980, 1995). Therefore, the positions of $h_{0.5}$ for *C. japonica* and $h_{0.6}$ for *C. obtsusa* would exist at the lower portion of the sunny crown before 20 years old. Because the system of eq. 1 and 3 was applicable for the stem below the base of the sunny crown (YAMAMOTO 1994 a), I excluded to apply this system at the stand ages before 20 years old.

Using the stem analysis data of both species and eq. 4, the values of k in eq. 3 after 20 years old were calculated from the stem cross-sectional areas at BH and $h_{0.5}$ for *C. japonica* and $h_{0.6}$ for *C. obtsusa*. Here, the cross-sectional areas at $h_{0.5}$ for *C. japonica* and $h_{0.6}$ for *C. obtsusa* were respectively estimated by the same procedure as that of YAMAMOTO (1994b).

For investigating the prediction accuracy of eq. 3 in each year, I compared the prediction accuracy of eq. 3 with that of the mathematical model of Pressler as

$$V(\mathrm{BH})=\frac{2}{3}SA(\mathrm{BH})(\mathrm{H}_{0.5\mathrm{DBH}}-1.3 \quad (5)$$

where $\mathrm{H}_{0.5\mathrm{DBH}}$ was the height above ground at 0.5 DBH, and was estimated by the same procedure as that of YAMAMOTO (1994b) (LOETSCH *et al*. 1973). For the criterion of the prediction accuracy in eqs. 3 and 5, I used the mean percent difference (MPD) and the standard error of estimates (SEE) as

$$MPD=\frac{\sum_{1}^{N}\frac{V(\mathrm{BH})-Ve(\mathrm{BH})}{V(\mathrm{BH})}}{\mathrm{N}}\times 100 \quad (6)$$

$$SEE=\sqrt{\frac{\sum_{1}^{N}(V(\mathrm{BH})-Ve(\mathrm{BH}))^2}{\mathrm{N}-p}} \quad (7)$$

where $Ve(\mathrm{BH})$ was the estimated $V(\mathrm{BH})$, N was the number of trees (N = 18 in this study), and p was the number of estimated parameters ($p=1$ in both models) (RUSTAGI and LOVELESS 1991, YAMAMOTO 1994b).

LONG *et al*. (1981) suggested that the dominance resulted in proportionately greater growth in diameter than in height. In addition, WEST and BOROUGH (1983) showed that in a monoculture *Pinus radiata* stand the diameter growth rate of a tree tended to relate positively to its diameter in trees with diameter above a given size, but in the trees below that size the growth rate appeared to be unrelated to diameter, to be small and sometimes even negative. Thus the diameter of a tree would show its position within the stand. Therefore, the stem taper variations over time were analyzed in relation to the diameter inner bark at BH (dbh: cm) in every year.

RESULTS

The standard error of estimates (*SEE*) and the absolute value of mean percent difference (*MPD*) in eq. 3 were mostly less than those in the mathematical model of Pressler (eq. 5) (Fig. 1). In addition, the absolute value of *MPD* in eq. 3 was less than two, independent of stand age and species. Thus eq. 3 could accurately predict the stem volume above BH independent of stand age and species.

The relationship between *dbh* and the value of *k* was represented by the straight line on the log-log plot in every year (Fig. 2) ($P < 0.001$). At any stand age, the stem taper in *C. japonica* was lower than that with same *dbh* in *C. obtsusa*, because the stem taper was represented by 1/2 *k* (see eq. 1). The slope of log(*dbh*)-log(*k*) relationship obtained by the least squares method apparently decreased with stand age in *C. obtsusa* ($P < 0.001$), and was slightly decreased in *C. japonica* ($P < 0.05$) (Fig. 3). On the other hand, the intercept of log(*dbh*)-log(*k*) relationship apparently increased with stand age in both species ($P < 0.01$) (Fig 3).

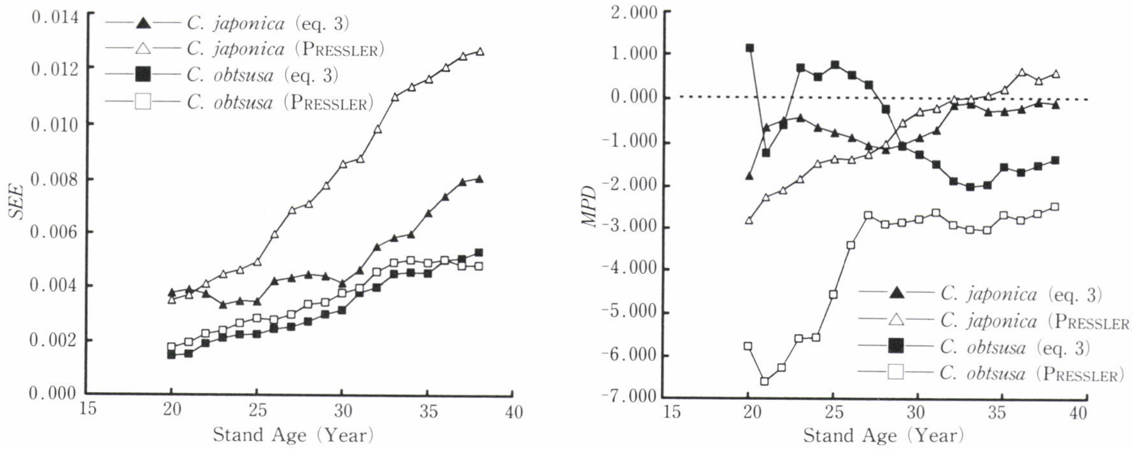

Fig. 1 Comparisons of mean percent difference (*MPD*) and standard error of estimate (*SEE*) in volume prediction between eq. 3 and mathematical model of Pressler (eq. 5) for *Cryptomeria japonica* and *Chamaecyparis obtsusa* at stand ages after 20 years old. The values of *MPD* and *SEE* were respectively calculated by eqs. 6 and 7

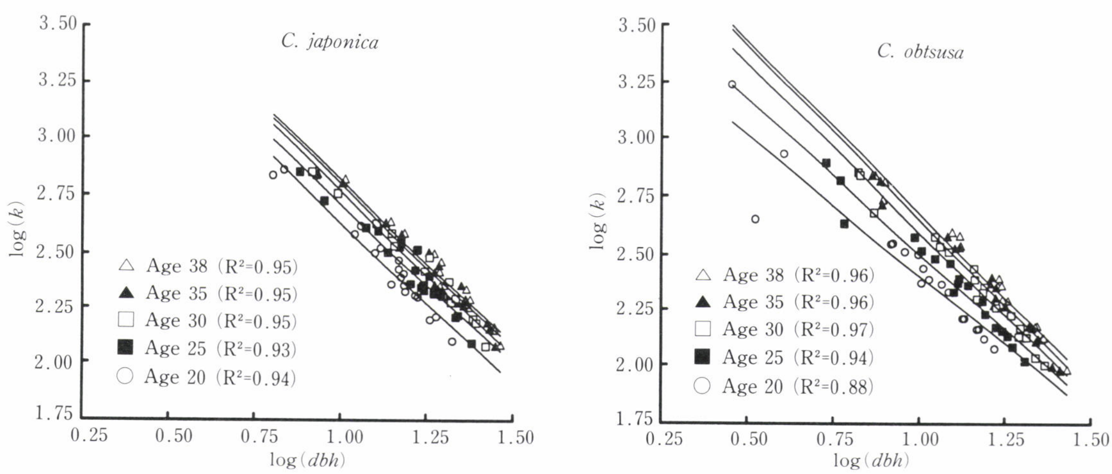

Fig. 2 Relationships between log(*dbh*) and log(*k*) at stand ages of 20, 25, 30, 35, 38 years old for 18 *C. japonica* trees and 18 *C. obtsusa* trees. Note: *dbh* is a diameter immer bark (cm) at breast height (1.3m above ground) and *k* is a constant of eq. 3 calculated by eq. 4

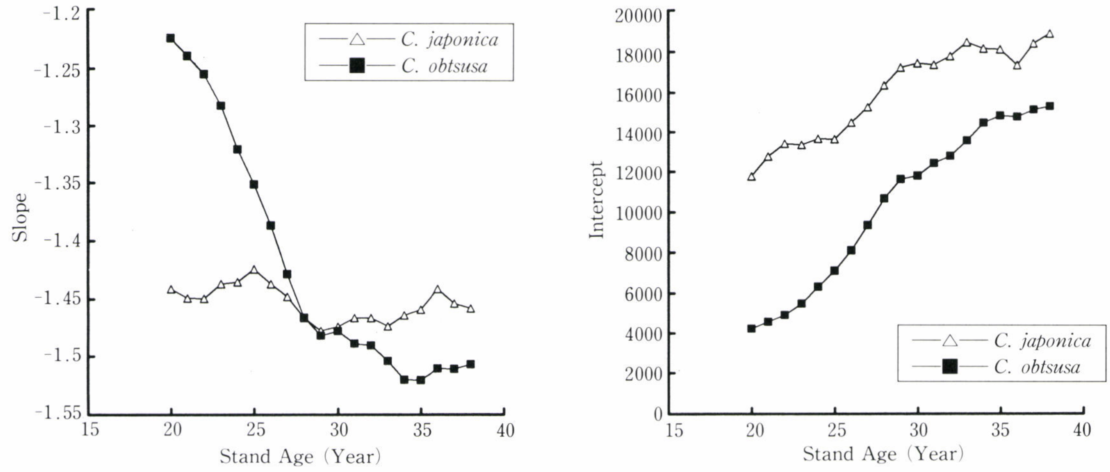

Fig. 3 Slopes and intercepts of regression lines for log(*dbh*)-log(*k*) relationships at stand ages after 20 years old

DISCUSSION

The volume estimation system in this study can accurately predict the stem volume independent of the stand age and species without updating and calibrating the model (Fig. 1, YAMAMOTO 1994a, b). Although the measurement of upper stem diameter required for the estimation of $SA(h_u)$ is somewhat difficult to measure in the field, the further exploitation of this technique would warrant more accurate and easy measurement (e.g., INADA and KOYAMA 1993; SHIRAISHI *et al.* 1995).

As mentioned in the previous paper (YAMAMOTO 1994 b), eq. 1 in this study agrees with the Gray's taper line, that $SA(h)=a - bh$ where a and b are constants. Although NEWNHAM (1965) suggested that the value of b, which is equal to the slope $1/2k$ in eq.1 of this study, was not affected by stand age and varied very little between species, the results obtained in this study suggested that the stem taper, expressed as the value of b in Gray's taper line and $1/2k$ in eq. 1 of this study, of a tree and its variation within a stand were different between species and slightly among stand ages. In *C. japonica*, the log(*dbh*)-log(*k*) relationship nearly moved parallel with stand age, and in *C. obtsusa*, apparently turned clockwise (Fig. 2, Fig. 3). This result indicated that the stem taper of a tree with a given *dbh* would linearly decrease with stand age in *C. japonica*, but would nonlinearly decrease, i.e., greatly decreased in small trees and slightly decreased in large trees, with stand age in *C. obtsusa*.

These results may increase the difficulties for modeling the stem taper variation over time. However, the ability of accurate volume predictions of eq. 3 and the high correlation of log (*dbh*)- log(*k*) relationship at any stand age in both species may give a clue to the solution of this problem. Further investigations were needed for modeling the stem taper variation over time in the competitive situations. However, the value of k in eq. 3 would be a useful index for this purpose as shown in this study.

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Article

Management System for Japanese Oak on the Kyushu University Forest in Hokkaido: 20-year Report

Morio Imada*

ABSTRACT

Since 1972, an experimental management system for Japanese oak (*Quercus mongolica* var. *grosseserrata*) has been studied in a natural Japanese oak forest approximately 200 ha in area in the Kyushu University Forest in Hokkaido. The management system was imposed by clearcutting in tongue-shaped blocks surrounded by shelterbelts; rotations were 150 years. The silvicultural process to which the natural oak forest has been subjected was designed to produce high-quality timber. For the 20 years between 1973 and 1992, the number of first-year oak seedlings established by the silvicultural process averaged 61,000 per ha per year. For the 20 years between 1972 and 1991, the area managed averaged 8.64 ha per year. For the 20-year period, the timber volume derived from thinning and final cutting averaged 240 m^3 per year. The average revenue obtained by selling this timber was 1,169,000 yen per year. The average cost of silvicultural management was 600,000 yen per year, excluding the management costs for staff members and related factors on the Kyushu University Forest. Thus, the average net revenue per year was 569,000 yen for the 20-year period.

Keyword: forest management system, Japanese oak forest, working system, silvicultural system

INTRODUCTION

In April 1972, an experimental management system for Japanese oak (*Quercus mongolica* var. *grosseserrata*) was established in a natural Japanese oak forest, approximately 200ha in area, in the Kyushu University Forest in Hokkaido. The management system was imposed by clearcutting in tongue-shaped blocks surrounded by shelterbelts (IMADA 1973). Rotations were 150 years. Hence, 150 cutting blocks for staggered annual cutting were set up. The natural stands containing these blocks have been managed by a silvicultural process designed to produce high-quality timber from Japanese oak (IMADA 1972, 1976).

This experiment is expected to continue for the 150 years between 1972 and 2121. The 150 years are divided into 15 periods of 10 years each. The results obtained for the 20 years between 1972 and 1991 (the first and second periods) are reported here. Abstract reports some results for 1992.

* Faculty of Agriculture, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka 812 Japan

THE REGENERATION PROCESS

The experimental stand in this natural forest was set up in accordance with various data related to technology, ecology and economics. It was established by clearcutting in blocks, which were naturally seeded with seeds fallen from the just-harvested trees. In the case of poor seed years, planting was substituted for this natural seeding system. An outline of the regeneration process follows:

(1) Site preparation before regeneration cutting— Before seed dispersal in the area to be cut (early September), non-seed trees and weeds are removed and line scarification of the forest floor under the stand is carried out either by cultivator on gentle slopes or manually by hoe on steep slopes. The pattern of this scarification is shown as regeneration strips in Fig. 1.

(2) Seed supply for the regeneration strips— After all of the seeds have been dispersed (in mid-October), the dispersed seeds on the non-regenerated strips (1m wide) are transferred to the regeneration strips (0.5m wide) (see Fig.

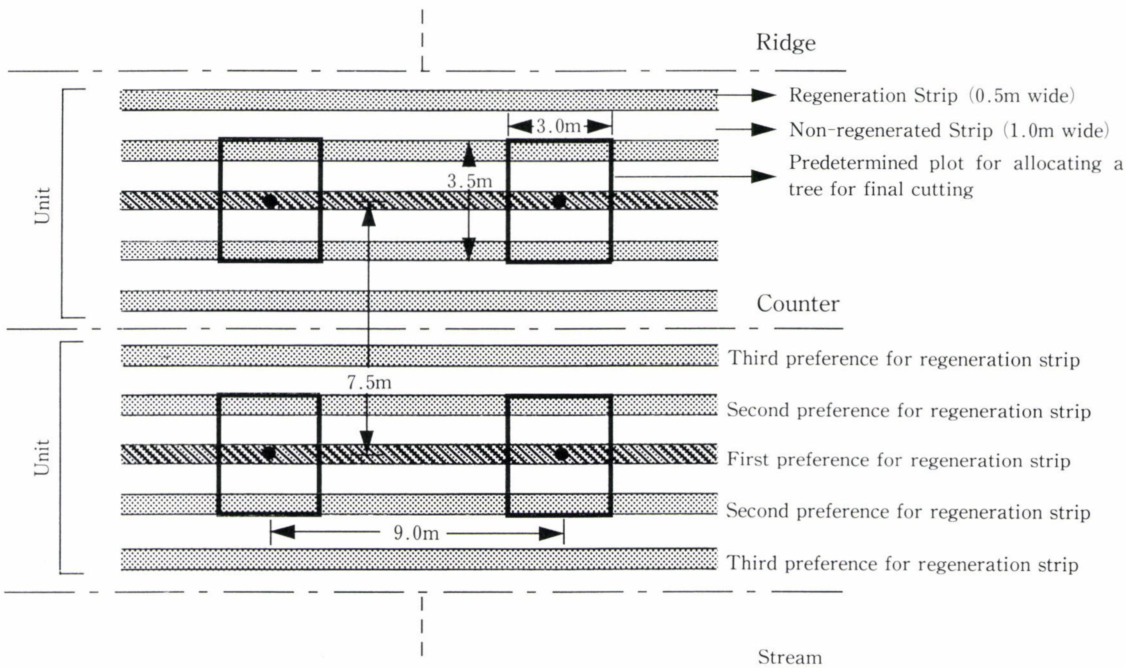

Fig. 1 Pattern of regeneration strips under the management system for Japanese oak

1). If the number of dispersed seeds on the regeneration strips after transfer is insufficient for the desired goal—a first-year stocking of 15 seedlings per m (100,000 per ha) —, the seeds collected near the harvested stand are simultaneously disseminated on the regeneration strips.
(3) Soil covering for dispersed seeds— Immediately after seed supply, the dispersed seeds on the regeneration strips are covered with soil by the same methods used for site preparation.
(4) Regeneration cutting— When the forest floor under the stand is frozen and covered with snow (in March of the following year), the uppermost trees (seed trees) in the stand are clearcut and removed from the forest floor.
(5) Removal of logging debris— After the snow on the forest floor has melted but the forest floor is still frozen (late April), logging debris is removed.
(6) Organizing the regeneration-cut area— After all of the seedlings have germinated (mid-July), the regeneration-cut areas are organized as shown in Fig. 1. This operation means that allocations of the 150 seed trees per ha have been roughly predetermined and thereby the preferential order for regeneration —i.e., which strips the seed trees are located on—is given simultaneously for each of 5 regeneration strips combined into one unit. In addition, the density of the seedlings is investigated.
(7) Seedling supply for regeneration strips— In accordance with the preferential order and the data on density obtained in step 6, nursery-grown seedlings and natural seedlings collected near the harvested stand are planted in those regeneration strips with poor seedling establishment. This planting is in late September when the seedlings are dormant.
(8) First weeding— In the year after seedling establishment, the non-regenerated strips are weeded, and both tall weeds and undesirable tree sprouts are removed from the regeneration strips.
(9) Second weeding— In the year after the first weeding, the non-regenerated strips are again weeded, and both the natural and planted seedlings (3 years old) in the regeneration strips are cut close to the groundline with a brush cutter in order to convert the seedlings to vigorous stump sprouts.

THE SILVICULTURAL PROCESS AFTER FIRST CLEANING

After the year when the experimental stand which has been subjected to the preceding regeneration process develops into 15 years old, this stand is established by the silvicultural process shown in Fig. 2 along with the target stand. An outline of the silvicultural process follows:
(1) Cleaning—In the year when the stand develops into 15 years old, the first cleaning is carried out, and wolf trees in the stand and undesirable trees both in the predetermined plots for allocating a tree for final cutting illustrated in Fig. 1 and near those plots are cleaned subject to the number of trees to be cut represented in Fig. 2. In the year when the

stand develops into 20 years old, the second cleaning is carried out by the same methods used the first one.
(2) Pruning—In the year when the stand develops into 25 years old, a desirable oak tree for final cutting is selected from each of the 150 predetermined plots per ha in Fig. 1, and is pruned up to 6m above the ground. The second pruning for the preceding pruned trees is extended to 7m (the target height shown in Fig. 2) above the ground in the year when the pruned trees develop into 30 years old.
(3) Thinning—As shown in Fig. 2, thinning is started when the stand develops into 35 years old, 13.0cm in dbh, 13.3m in height, 7m in clear length, 1,320 trees per ha in number and 103m³ per ha in volume. Fig. 2 indicates that eleven times thinnings are carried out for 35- to 130-year-old stand subject to the number of trees to be thinned. The trees to be thinned are selected from the neighboring trees with the pruned ones for final cutting at any thinning.

In Fig. 2, the 150-year-old target stand established by the above experimental silvicultural process including the regeneration process is shown as follows: 55cm in dbh, 27m in height, 7m in clear length, 150 trees per ha in number and 365m³ per ha in volume.

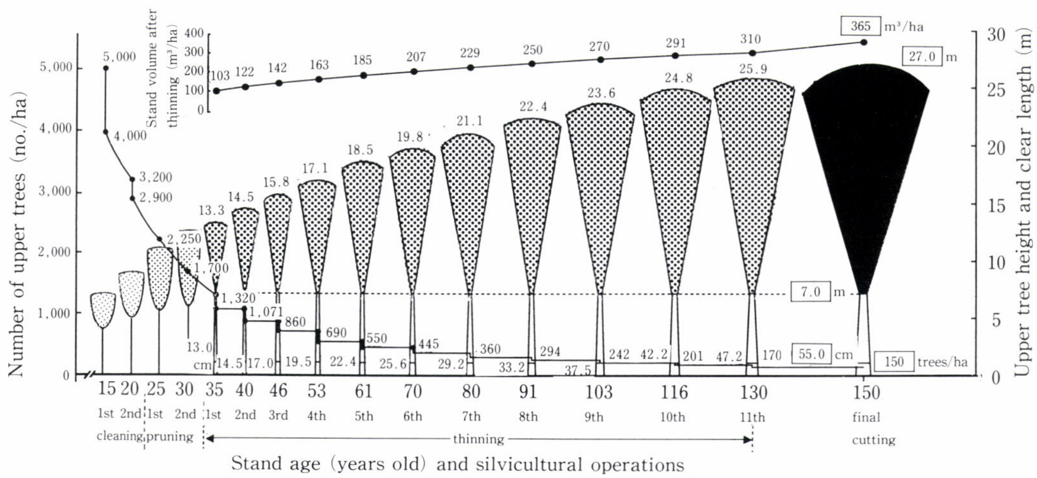

Fig. 2 Experimental silvicultural process after first cleaning for Japanese oak stands

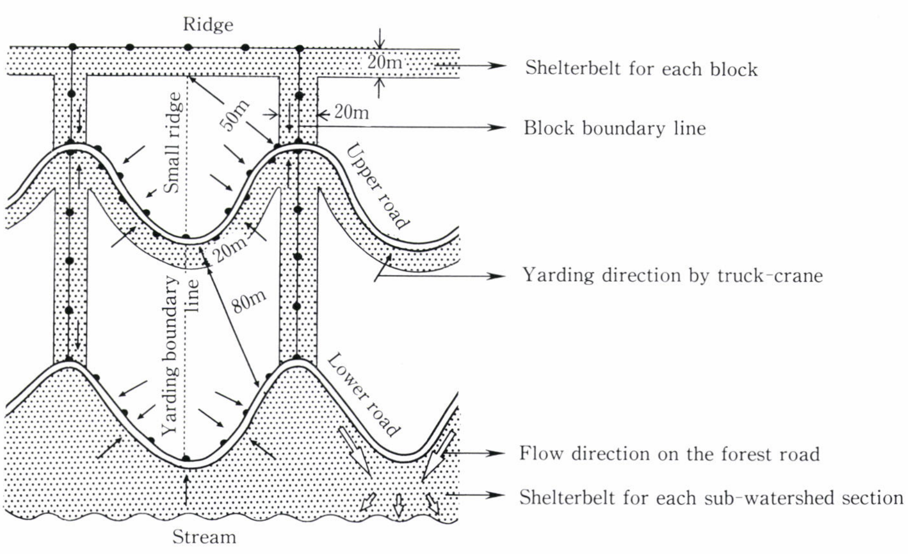

Fig. 3 Establishment tongue-shaped blocks and forest roads for management of Japanese oak

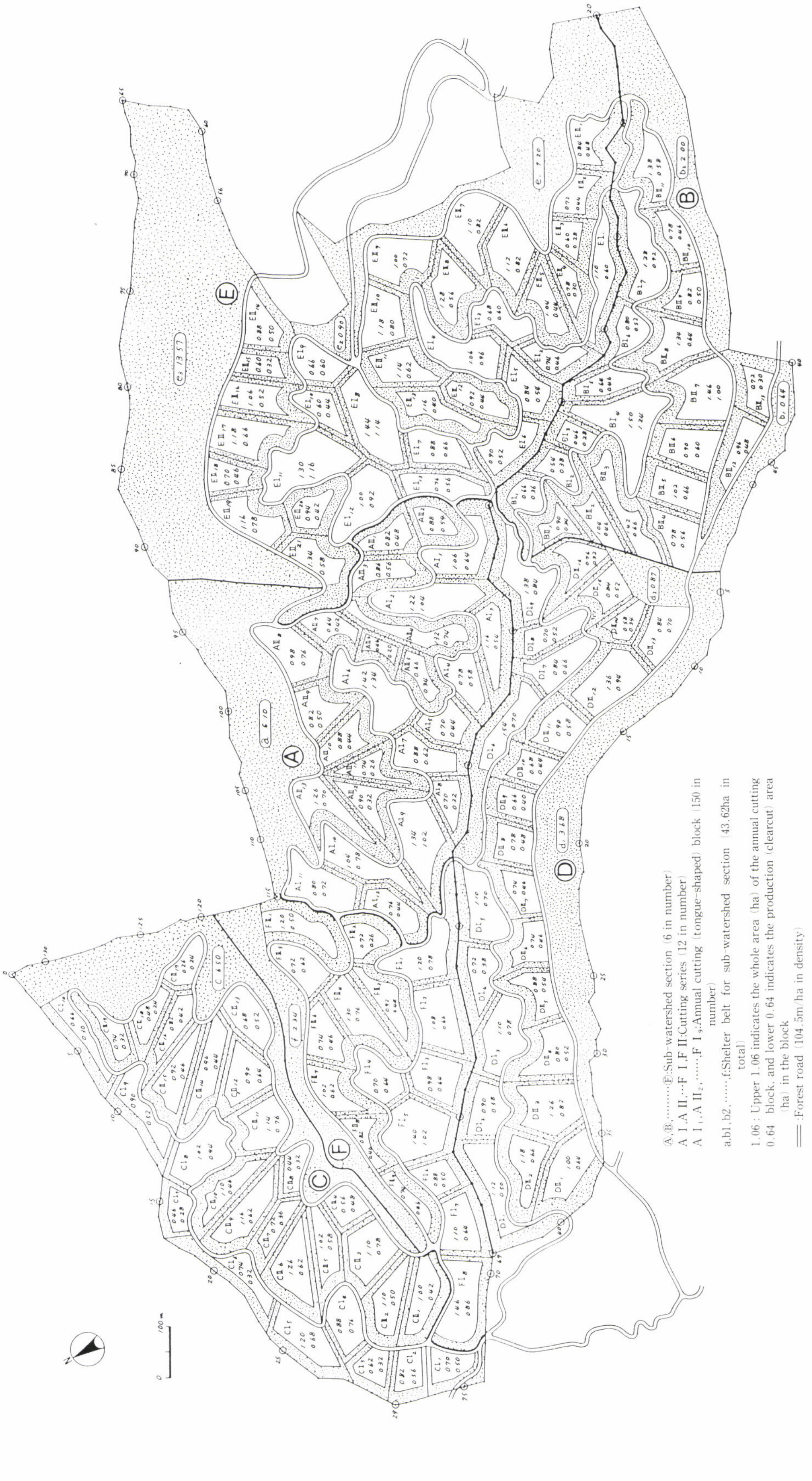

Fig. 4 The complete experimental forest of Japanese oak (203.08ha)

ESTABLISHING CUTTING BLOCKS AND ROADS

A diagram of the establishing of the tongue-shaped blocks and forest roads in the management system appears in Fig. 3. The center part of the tongue-shaped block is a small ridge, which is equivalent to a yarding boundary line. The production (clearcut) area within the block is surrounded by shelterbelts, which are natural (unclearcut) oak forests.

The forest roads are constructed so that the surface water on them flows toward the small ridge top under a standard gradient of - 5 %. Because of the resulting road curves, the cutting block looks as if it were a tongue. The complete 200-ha experimental forest with its various tongue-shaped cutting blocks and shelterbelts is shown in Fig. 4.

EXPERIMENTAL RESULTS : THE FIRST 20 YEARS

The experimental plan for this 150-year study was established at the outset, in 1972. Table 1 shows the plan for the first 20 years. As can be seen, at the beginning of this experiment the 7th through 11th thinnings, which are incorporated into the experimental silvicultural process shown in Fig. 2, were not carried out because of a lack of 80- through 130-year-old stands in the forest.

Fig. 5 shows the number of first-year oak seedlings per ha established by natural seeding or planting for the 20 years between 1973 and 1992. This number varied widely—from 6,000 (in 1987) to 133,000 (in 1974);it averaged 61,000. Such variation was due to noted variations in size of seed crop for natural forests of Japanese oak (IMADA et al. 1990).

Because of poor seed yields, planting was substituted for natural seeding in 1975, 1976, 1982, and 1987. The numbers of planted seedlings in these 4 years ranged from 6,000 (in 1987) to 23,800 (in 1982). In the present planting system, a spacing of 1.5m (the interval between regeneration strips) by 0.35 to 0.50m, that is, 13,000 to 20,000 seedlings per ha, is the desired goal. In comparison with this goal, the number for 1987 (6,000 per ha) was insufficient.

When the planted seedlings are excluded, the average for seedlings established by natural seeding increased by 12,000 per ha over the 20-year period—to 73,000 per ha. This average number is insufficient for a natural seeding system, the goal being 100,000 seedlings per ha, as shown in Figure 5. Years in which the numbers were nearly sufficient for or exceeded this goal were 1974 (133,000), 1978 (90,000), 1985 (87,200), 1988 (99,900), 1990 (87,000), and 1992 (117,000).

The areas managed by the experimental silvicultural process for the first 20 years are illustrated in Fig. 6. The areas managed varied from 7.02 (in 1973) to 11.10ha (in

Table 1 Experimental plan for the natural oak forest for the first 20 of the 150-year period

	Year \ Operation	Regeneration I	Regeneration II	1st weed.	2nd weed.	1st clean.	2nd clean.	1st prun.	2nd prun.	1st thin.	2nd thin.	3nd thin.	4th thin.	5th thin.	6th thin.	7th thin.	8th thin.	9th thin.	10th thin.	11th thin.
1st planning period	1972	A I$_{1}$	–	–	–	E II$_{6}$	A II$_{8}$	B II$_{12}$	D II$_{13}$	D II$_{1}$	D I$_{1}$	D I$_{6}$	A I$_{11}$	A II$_{13}$	E I$_{7}$	–				
	1973	B I$_{3}$	A I$_{1}$	–	–	E I$_{3}$	B I$_{7}$	B II$_{13}$	B II$_{6}$	E I$_{11}$	D II$_{2}$	D II$_{9}$	F II$_{6}$	F II$_{1}$	E II$_{14}$	–				
	1974	C I$_{1}$	B I$_{3}$	A I$_{1}$	–	E II$_{7}$	E II$_{16}$	B II$_{8}$	D I$_{3}$	D II$_{3}$	D I$_{2}$	F II$_{5}$	F II$_{7}$	C I$_{7}$	C II$_{10}$	–				
	1975	D I$_{4}$	C I$_{1}$	B I$_{3}$	A I$_{1}$	E II$_{9}$	E II$_{17}$	B II$_{5}$	A I$_{10}$	E I$_{13}$	B I$_{1}$	E II$_{15}$	E II$_{11}$	E I$_{10}$	E II$_{1}$	–				
	1976	E I$_{4}$	D I$_{4}$	C I$_{1}$	B I$_{3}$	E II$_{8}$	B II$_{11}$	D II$_{12}$	E I$_{12}$	A II$_{12}$	F II$_{3}$	C II$_{7}$	E II$_{2}$	F II$_{8}$	C II$_{15}$	–				
	1977	F I$_{1}$	E I$_{4}$	D I$_{4}$	C I$_{1}$	B II$_{10}$	E II$_{6}$	A II$_{8}$	B II$_{12}$	D II$_{13}$	D II$_{1}$	D II$_{4}$	D II$_{10}$	B I$_{6}$	E I$_{6}$	–				
	1978	A I$_{2}$	F I$_{1}$	E I$_{4}$	D I$_{4}$	E II$_{5}$	E I$_{3}$	B I$_{7}$	B II$_{13}$	B II$_{6}$	E I$_{11}$	D I$_{1}$	D II$_{8}$	E II$_{10}$	B I$_{2}$	–				
	1979	B I$_{4}$	A I$_{2}$	F I$_{1}$	E I$_{4}$	B II$_{1}$	E II$_{7}$	E II$_{16}$	B II$_{8}$	D I$_{3}$	D II$_{3}$	D II$_{2}$	D I$_{6}$	B II$_{3}$	E I$_{8}$	–				
	1980	C I$_{2}$	B I$_{4}$	A I$_{2}$	F I$_{1}$	F I$_{6}$	E II$_{9}$	E II$_{17}$	B II$_{5}$	A I$_{10}$	E I$_{13}$	D I$_{2}$	D II$_{9}$	A I$_{11}$	A II$_{2}$	–				
	1981	D I$_{5}$	C I$_{2}$	B I$_{4}$	A I$_{2}$	B II$_{9}$	E II$_{8}$	B II$_{11}$	D II$_{12}$	E I$_{12}$	A II$_{12}$	B I$_{1}$	F II$_{5}$	F II$_{6}$	A II$_{13}$	–				
2nd planning period	1982	E I$_{2}$	D I$_{5}$	C I$_{2}$	B I$_{4}$	E I$_{1}$	B II$_{10}$	E II$_{6}$	A II$_{8}$	B II$_{12}$	D II$_{13}$	F II$_{3}$	E II$_{15}$	F II$_{7}$	F II$_{1}$	E I$_{7}$	–			
	1983	F I$_{2}$	E I$_{2}$	D I$_{5}$	C I$_{2}$	B II$_{4}$	E II$_{5}$	E I$_{3}$	B I$_{7}$	B II$_{13}$	B II$_{6}$	D II$_{1}$	C II$_{7}$	E II$_{11}$	C I$_{7}$	E II$_{14}$	–			
	1984	A I$_{3}$	F I$_{2}$	E I$_{2}$	D I$_{5}$	D II$_{5}$	B II$_{1}$	E II$_{7}$	E II$_{16}$	B II$_{8}$	D I$_{3}$	E I$_{11}$	D II$_{4}$	E II$_{2}$	E I$_{10}$	C II$_{10}$	–			
	1985	B I$_{5}$	A I$_{3}$	F I$_{2}$	E I$_{2}$	D II$_{6}$	F I$_{6}$	E II$_{9}$	E II$_{17}$	B II$_{5}$	A I$_{10}$	D II$_{3}$	D I$_{1}$	D II$_{10}$	F II$_{8}$	E II$_{1}$	–			
	1986	C I$_{3}$	B I$_{5}$	A I$_{3}$	F I$_{2}$	D II$_{7}$	B II$_{9}$	E II$_{8}$	B II$_{11}$	D II$_{12}$	E I$_{12}$	E I$_{13}$	D II$_{2}$	D II$_{8}$	B I$_{6}$	C II$_{15}$	–			
	1987	D I$_{7}$	C I$_{3}$	B I$_{5}$	A I$_{3}$	A I$_{1}$	E I$_{1}$	B II$_{10}$	E II$_{6}$	A II$_{8}$	B II$_{12}$	A II$_{12}$	D I$_{2}$	D I$_{6}$	E II$_{10}$	E I$_{6}$	–			
	1988	E I$_{5}$	D I$_{7}$	C I$_{3}$	B I$_{5}$	B I$_{3}$	B II$_{4}$	E II$_{5}$	E I$_{3}$	B I$_{7}$	B II$_{13}$	D II$_{13}$	B I$_{1}$	D II$_{9}$	B II$_{3}$	B I$_{2}$	–			
	1989	F I$_{3}$	E I$_{5}$	D I$_{7}$	C I$_{3}$	C I$_{1}$	D II$_{5}$	B II$_{1}$	E II$_{7}$	E II$_{16}$	B II$_{8}$	B II$_{6}$	F II$_{3}$	F II$_{5}$	A I'$_{11}$	E I$_{8}$	–			
	1990	A I$_{4}$	F I$_{3}$	E I$_{5}$	D I$_{7}$	D I$_{4}$	D II$_{6}$	F I$_{6}$	E II$_{9}$	E II$_{17}$	B II$_{5}$	D I$_{3}$	D II$_{1}$	E II$_{15}$	F II$_{6}$	A II$_{2}$	–			
	1991	C I$_{4}$	A I$_{4}$	F I$_{3}$	E I$_{5}$	E I$_{4}$	D II$_{7}$	B II$_{9}$	E II$_{8}$	B II$_{11}$	D II$_{12}$	A I$_{10}$	E I$_{11}$	C II$_{7}$	F II$_{7}$	A II$_{13}$	–			

Note: Regeneration I indecates the regeneration process from site preparation to regeneration cutting.
Regeneration II indecates the regeneration process from removal of logging wood debris to seedling supply.
A I$_{1}$, B I$_{3}$,·····,A II$_{13}$ indicate annual cutting (tongue-shaped) blocks in Figure 4.

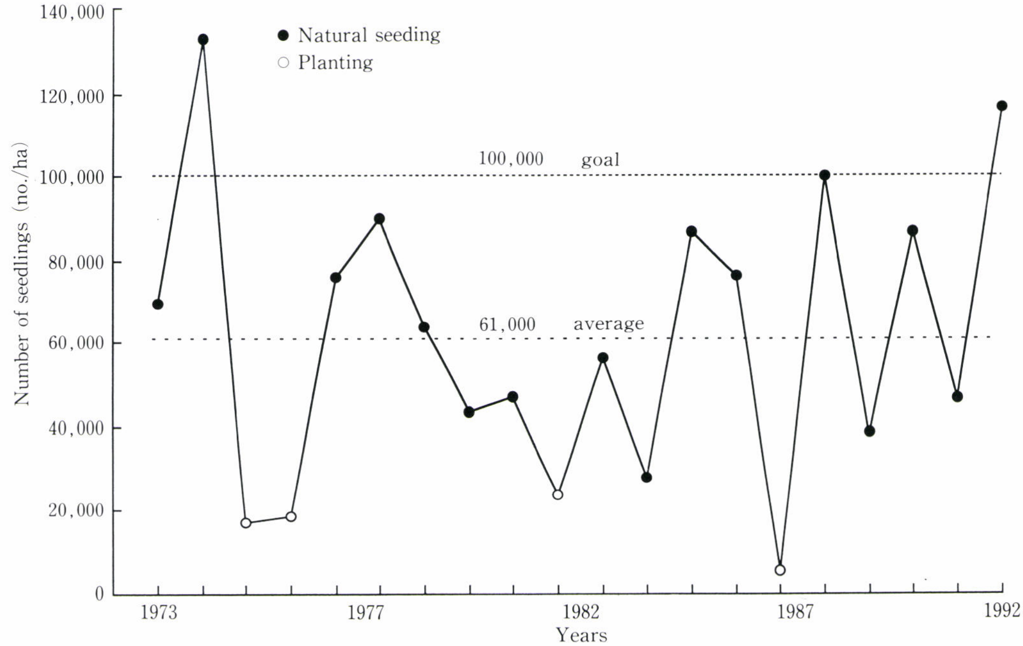

Fig. 5 First-year oak seedlings established by natural seeding or planting for the 20 years between 1973 and 1992

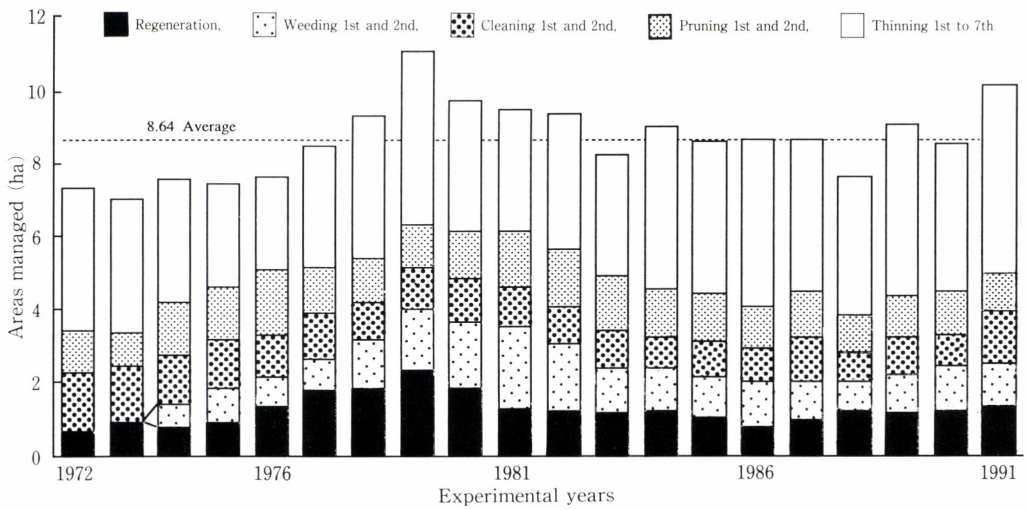

Fig. 6 Areas managed by the silvicultural process for the 20 years between 1972 and 1991

Note: ■ Regeneration includes regenerations I and II in Table 1

1979), with an average area of 8.64ha. Collating the areas in Fig. 6 with the experimental plan outlined in Table 1 indicates that the areas managed between 1972 and 1981 were reduced by the areas occupied by stands in which the 7th thinning was not carried out;furthermore, those managed between 1972 and 1974 were reduced by the areas on which regeneration II (see Table 1) was being carried out and by the areas where weeding was not carried out. However, the variation in the managed areas was caused mainly by the variation in the size of the tongue-shaped clearcutting blocks, as shown in Fig. 4.

The areas managed by each silvicultural operation,i. e.,regeneration, weeding, cleaning, pruning, and thinning, as shown in Fig. 6, can be described briefly as follows:

(1) The area devoted to regeneration averaged 1.24ha, ranging widely from 0.64 (in 1972, when regeneration II

Fig. 7 Cost, revenues, and volumes yielded for the 20 years between 1972 and 1991

was not carried out) to 2.28ha (in 1979), although only the clearcut areas were reduced to 0.64ha on the average (12.70ha in total).

(2) The area devoted to weeding averaged 1.10ha over the 20-year period. The area was reduced because areas for the first and second weedings were lacking in 1972 and 1973 and that for the second weeding was lacking in 1974 (Table 1).

(3) Over the 20-year period, the area devoted to cleaning averaged 1.15 ha and that devoted to pruning averaged 1.30ha. Thus, cleaning and pruning were carried out on nearly equal areas. There was considerable variation in both areas: that for cleaning ranged from 0.84 to 1.58ha and that for pruning ranged from 0.90 to 1.86ha.

(4) Thinning was carried out over a wide area—77.12ha in total. The number of tongue-shaped cutting blocks thinned in the first 10 years averaged 6 per year; average area per year was 3.52ha. The number of the blocks for the second 10 years averaged 7 per year; average area per year was 4.19ha. Despite the difference in the number of blocks thinned, the difference between the average areas for two periods was small because of fluctuations in the cutting areas within the blocks, as shown in Fig. 4.

Fig. 7 shows the costs, revenues, and volumes yielded for the 20 years between 1972 and 1991. The volumes yielded by the final harvests and thinnings decreased with time but averaged 240m³ per year. The revenue obtained by selling this timber volume varied widely—from 260,000 yen (in 1982) to 4,333,000 yen (in 1973)— and averaged 1,169,000 yen per year. The costs for the various silvicultural operations ranged from 312,000 yen (in 1983) to 1,286,000 yen (in 1978) and averaged 600,000 yen per year. Note that the annual management costs for staff members and the related factors on the Kyushu University Forest are excluded from the computed costs.

Cost exceeded revenue in the years 1982, 1986, 1989, and 1991, as shown in Fig. 7. However, the average net annual revenue for the 20-year period was 569,000 yen, an amount calculated by subtracting the average cost per year (600,000 yen) from the average revenue per year (1,169,000 yen).

FUTURE PROSPECTS

The management system reported for Japanese oak forest was profitable for the first 20 years since its installation in 1972. The profitability will vary in accordance both with the cost of silvicultural operations as determined by the market prices of labor, equipment, materials, etc., and with revenues as determined mainly by the market price of Japanese oak timber. Of course, improvements must be made both to the silvicultural operations themselves and also to the system of clearcutting in tongue-shaped blocks surrounded by shelterbelts. Investigating the profitability of this applied management system and improving its shortcomings will require that the experiment be continued over a long period.

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(Accepted 26 December 1995)

Short communication

Development of an Image Database for Forests

Mariko Tanaka*

ABSTRACT

The author has developed "The Reserved Forests Database", which contains maps, photographs and attributive information for the retrieval of forest data. From this database, one can retrieve various types of information about reserved forests, including maps and photographs.
The computer system of this database is based on the Macintosh personal computer. The hardware devices required by this system are a CPU, a monitor and an optical-disk driver, and the application software programs required are FilemakerPro and Grand-muse. Although graphic data requires large memory capacity, 300 data sets were successfully stored on one optical disk by using a data compression technique.
This database can be applied to various purposes and can be used for the visual interpretation of a forest.

Keyword: image database, reserved forest, data compression, digital data, interpretation

INTRODUCTION

Dr. Konohira and I of the Japan Society of Forest Planning have developed an image database named "The Reserved Forests Database", which contains maps, photographs and attributive information on the reserved forests in Japan. This image database is designed to be used by foresters and non-foresters alike. The unique characteristic of this database is that it has visual materials like photographs and maps which can help people to understand forests more easily. It therefore differs from conventional forest databases.

We started the development of this image database in 1992 with the support of the Ministry of Education. We finished the design of the database at the end of March 1993.

We then made a prototype system. We presented this database in September 1993 at the database meeting of the Japan School Forest Society (TANAKA 1993), and in October 1993 at the 45th meeting of the Kanto Branch of the Japanese Forestry Society (TANAKA and KONOHIRA 1994a). The prototype system had data about thirty-three forests in Nagano prefecture. In December 1993, we discussed the reserved forests database among specialists on gene reserve forests.

Next, we tried to compress the image data and wrote a handbook. We presented the results of the data compression technique in April 1994 at the 105th meeting of the Japanese Forestry Society (TANAKA and KONOHIRA 1994 b). The first volume of the handbook (FOREST PLANNING 1994) was printed in Japanese in March 1994, and was distributed at the meeting.

We then input image data using CD-ROM and Photo-CD technology. We announced the CD-ROM system in October 1993 at the 46th meeting of the Kanto Branch of the Japanese Forestry Society (TANAKA and KONOHIRA 1995a).

Research workers were invited to a joint study, but no one answered. Data about reserved forests was then offered to school forests, and we had responses from three interested schools.

We used the database for interpretation and discussed this application of the database at the 106th meeting of the Japanese Forestry Society (TANAKA and KONOHIRA, in press).

So far, the database contains data from more than 300 forests.The first phase of the development has been completed. We reported it in October 1995 at the 47th meeting of the Kanto Branch of the Japanese Forestry Society

* Faculty of Agriculture, Tokyo University of Agriculture, 1-1-1 Sakuragaoka, Setagaya-ku, Tokyo 156 Japan

(TANAKA and KONOHIRA 1995b) and at a symposium at Niigata University in October 1995 (TANAKA 1996).

This paper briefly describes the image database.

RESERVED FORESTS IN JAPAN

Forests in Japan are classified into three categories by owner; National Forest, public forest and private forest. Within each forest there are many reserved forest areas.

There were 779 reserved forests in National Forest in 1994 (Table 1). These reserved forests are classified into six categories; protected ecosystems, gene reserve forests, protected plant communities, habitats for particular plants and/or animals, unique geographical areas, and forests of birthplace.

Table 1 Six categories of reserved forest in Japanese National Forests

	Number	Area (ha)
Protected ecosystems	21	233,357
Gene reserve forests	335	9,448
Protected plant communities	346	95,459
Habitats for particular plants and/or animals	23	10,842
Unique geographical areas	30	31,439
Forests of birthplace	24	1,928
Total	779	382,478

Forestry White Paper (1994)

Fig. 1 Example of map and photographic display about a natural forest of red pine (*Pinus densiflora*) in Nagano Prefecture.

Additional reserves exist in prefectural forests, and in the fifty-seven school forests controlled by the twenty-six universities which offer forestry courses in Japan. Shrines and temples have forest groves, many of which have not been cut for many years. Often shrines and temples have a lot of big trees and especially big trees become sacred. There are also some special reserved forests in private forests.

First, we input data from thirty-three reserved forests in the National Forest of Nagano prefecture. These included gene reserve forests and other reserved forests. Our primary interest was in the gene reserve forests.

PURPOSE OF THE IMAGE DATABASE

There are many reserved forests in Japan but they are not known well. The image database enables researchers and instructors to retrieve information about one or two areas among many reserved forests. Retrieval attributes include tree species, location and so on. After retrieval, one can read many items of information; location, natural environmental conditions, forest characteristics, forest mensuration data, and other descriptions; as shown in Fig. 3. Maps and photographs are also displayed, as shown in Fig 1.

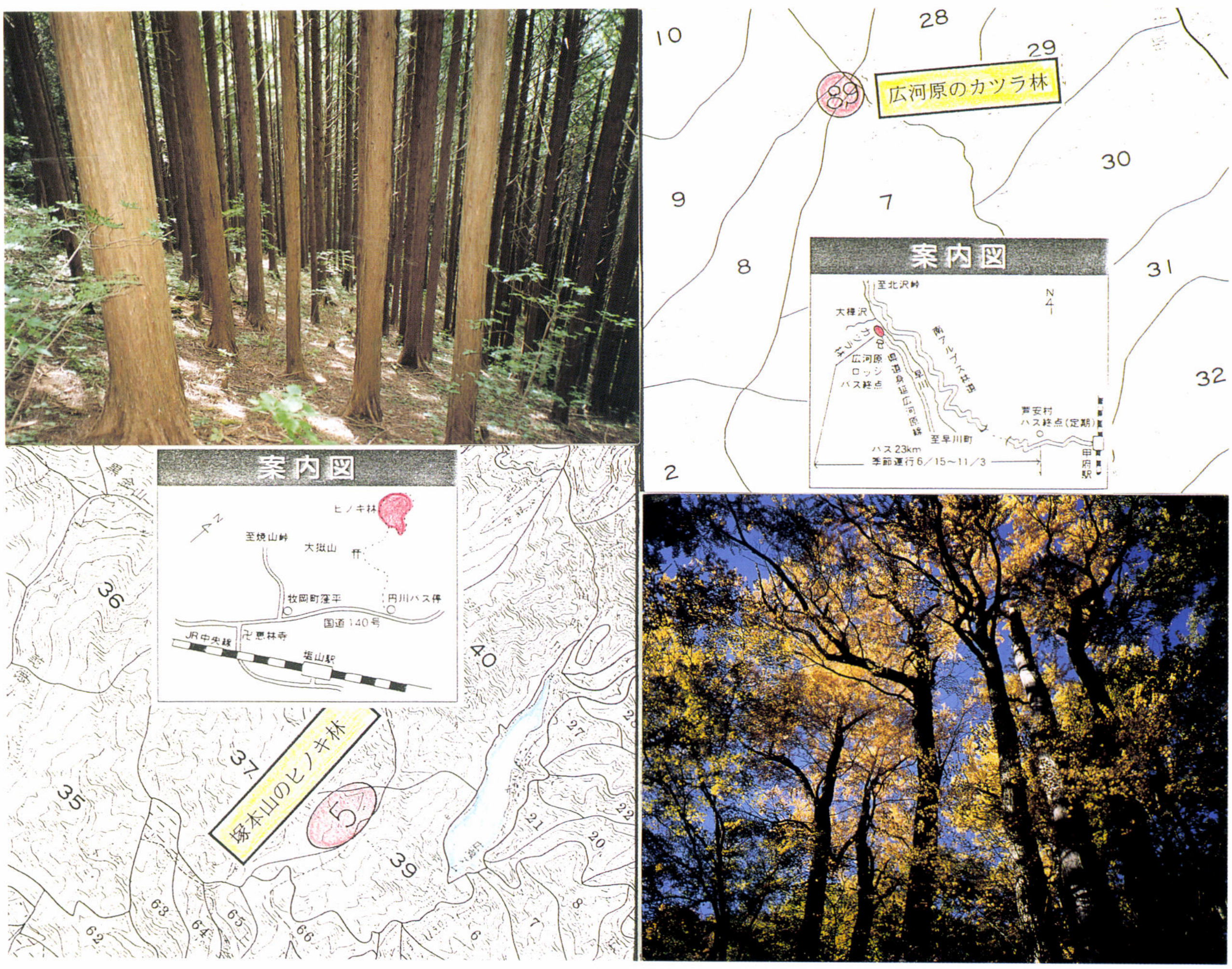


Fig. 2 Examples of maps and photographs of forests in Yamanashi Prefecture.
The left shows a man-made forest of Japanese cypress (*Crptomeria japonica*), and the right shows a natural forest of katsura trees (*Cercidiphyllum japonicum*).

CONTENTS OF THE IMAGE DATABASE

This image database is mainly designed so that descriptive and visual information about reserved forests can be retrieved. The information available in the data base is described below.

The following items are contained in the descriptive data,

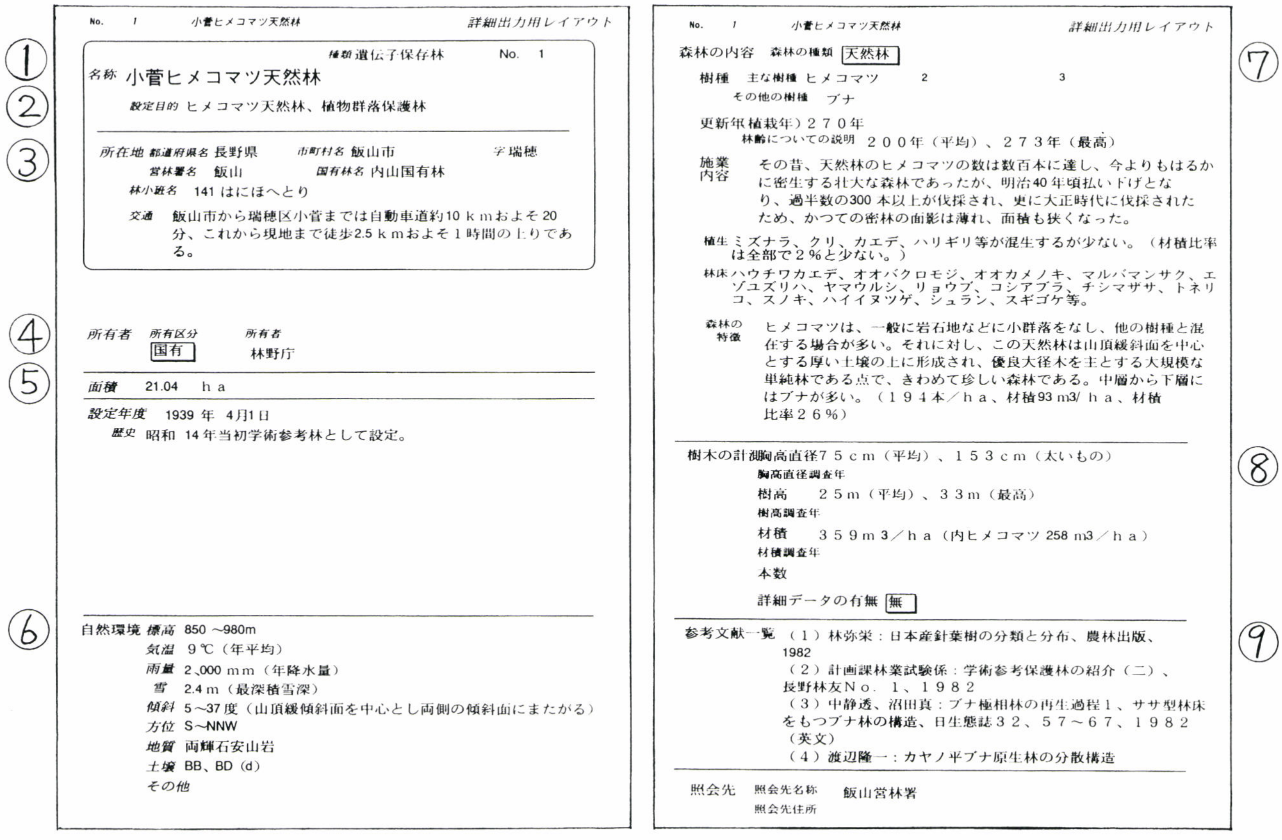
1. Name of reserved forest
2. Category of reserved forest
3. Location
4. Ownership
5. Area (unit:ha)
6. Natural environmental conditions
7. Forest characteristics (natural or man-made forest, tree species, forest age, vegetation)
8. Forest mensuration data (breast height diameter, tree height, volume)
9. Literature
10. Other descriptions in free format.

Since each forest has different characteristics which are difficult to describe in the fixed formats, "other descriptions in free format" can be useful in explaining unique conditions.

In this database, each forest data set contains five to six photographs. Photographs are whole views and snapshots which show typical scenes over the four seasons. Maps are also presented, at a scale of either 1/50,000 or 1/25,000, whichever is most suitable for understanding the locality of the forest. An example of the display of photographs and maps is shown in Fig. 2.

HARDWARE AND SOFTWARE

The Macintosh personal computer is used as the hardware platform for this database. The configuration of the hardware for retrieval is a Macintosh, a display and a magneto-optical device as shown in Fig. 4: a large display is desirable for viewing photographs and maps. Storage of image data requires other devices which can store photo-


No. 1 小菅ヒメコマツ天然林 詳細出力用レイアウト

①
種類 遺伝子保存林 No. 1
名称 小菅ヒメコマツ天然林
②
設定目的 ヒメコマツ天然林、植物群落保護林

③
所在地 都道府県名 長野県 市町村名 飯山市 字 瑞穂
営林署名 飯山 国有林名 内山国有林
林小班名 141 はにほへとり
交通 飯山市から瑞穂区小菅までは自動車道約10 k mおよそ20分、これから現地まで徒歩2.5 k mおよそ1時間の上りである。

④
所有者 所有区分 国有 所有者 林野庁

⑤
面積 21.04 h a

設定年度 1939 年 4月1日
歴史 昭和 14年当初学術参考林として設定。

⑥
自然環境 標高 850 ~980m
気温 9 ℃(年平均)
雨量 2,000 m m(年降水量)
雪 2.4 m(最深積雪深)
傾斜 5~37度(山頂緩傾斜面を中心とし両側の傾斜面にまたがる)
方位 S~NNW
地質 両輝石安山岩
土壌 BB、BD (d)
その他

No. 1 小菅ヒメコマツ天然林 詳細出力用レイアウト

⑦
森林の内容 森林の種類 天然林
樹種 主な樹種 ヒメコマツ 2 3
その他の樹種 ブナ
更新年(植栽年)2 7 0年
林齢についての説明 2 0 0年(平均)、2 7 3年(最高)
施業内容 その昔、天然林のヒメコマツの数は数百本に達し、今よりもはるかに密生する壮大な森林であったが、明治40年頃払い下げとなり、過半数の300本以上が伐採され、更に大正時代に伐採されたため、かつての密林の面影は薄れ、面積も狭くなった。
植生 ミズナラ、クリ、カエデ、ハリギリ等が混生するが少ない。(材積比率は全部で2%と少ない。)
林床 ハウチワカエデ、オオバクロモジ、オオカメノキ、マルバマンサク、エゾユズリハ、ヤマウルシ、リョウブ、コシアブラ、チシマザサ、トネリコ、スノキ、ハイイヌツゲ、シュラン、スギゴケ等。
森林の特徴 ヒメコマツは、一般に岩石地などに小群落をなし、他の樹種と混在する場合が多い。それに対し、この天然林は山頂緩斜面を中心とする厚い土壌の上に形成され、優良大径木を主とする大規模な単純林である点で、きわめて珍しい森林である。中層から下層にはブナが多い。(1 9 4本/h a、材積93 m3/ h a、材積比率2 6%)

⑧
樹木の計測 胸高直径7 5 c m(平均)、1 5 3 c m(太いもの)
胸高直径調査年
樹高 2 5 m(平均)、3 3 m(最高)
樹高調査年
材積 3 5 9 m 3/h a(内ヒメコマツ 258 m3/h a)
材積調査年
本数
詳細データの有無 無

⑨
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(3)中静透、沼田真:ブナ極相林の再生過程1、ササ型林床をもつブナ林の構造、日生態誌3 2、5 7~6 7、1 9 8 2(英文)
(4)渡辺隆一:カヤノ平ブナ原生林の分散構造

照会先 照会先名称 飯山営林署
照会先住所

Fig. 3 Exampl of information display. The following items are described in Japanese; ① Name of Reserved Forest, ② Category of Reserved Forest, ③ Location, ④ Ownership, ⑤ Area, ⑥ Natural environmental conditions, ⑦ Forest characteristics (natural or man-made forest, tree species, forest age, and vegetation), ⑧ Forest mensuration data (breast height diameter, tree height, and volume), ⑨ Literature.

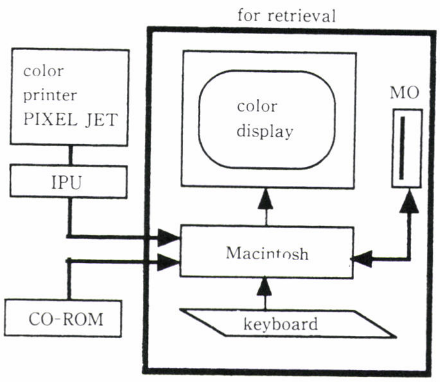

Fig. 4 Configuration of hardware for the image database on the Macintosh.

graphs and maps. The details will be explained later, but a scanner or CD-ROM is needed.

The usability of the database depends on the software. Many software programs have been on the market since 1990, so users can easily choose software suitable for their purposes. Two software programs were chosen for this database: one is FilemakerPro for attributive information, which is a world-famous database software for the Macintosh. In FilemakerPro it is easy for users to manipulate attributive information such as tree species or place names, especially since one retrieval of attributive information takes only about ten seconds.

The other program is Grand Muse which can manipulate image databases. In Grand Muse image data can be viewed like pictures in a museum. Grand Muse does not store image data directly, but manages them by an index system. The data are stored on a hard disk and an optical magnetic disk.

The software requirements are summarised in Fig. 5. The operating system is KanjiTalk7. A front end processer for Japanese is needed to input information data, and FilemakerPro for the information database. CJ-LINK-SCAN-UTILITY is required to read image data from a scanner, Color-it to modify the image data, and Grand Muse for the image database.

INPUT OF IMAGE DATA

Storing the Image Data

We used a Canon PIXEL-JET as a scanner. This required IPU hardware and the CJ LINK SCAN UTILITY software. The configuration of hardware used for storing image data is shown in Fig. 4. It took about 10 minutes to store one photograph by scanning, which is similar to the copy machine process.

When digital data for one picture is divided into many

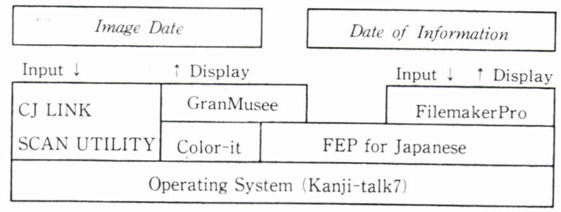

Fig. 5 Software requirements for the image database on the Macintosh.

Table 2 Requirements of scanning compared with using photo-CD

	PIXEL-JET	photo-CD
Hardware	PIXEL-JET and IPU	CD-ROM
Software	CJ Link Scan Utility	For driver
Input process	Scanning (10minutes)	1. Ask a photo-studio to make CD from films 2. Read from CD (30seconds)
Visibility	○	◎
Memoriy required	50～60KB	50～60KB
Cost	Nothin	About 250yen

pixels, the image data occupies a large volume. The image data for printing needs to be more precise than data for display only. If we need three times more precise data, the volume of data increases by a factor of nine. If both printing and display is required, the pixel scale must be ten times as precise. The image database has been designed mainly for display. The scale of the minimum pixel depends on the monitor. The monitor of Macintosh has 70 dpi (dots per inch). With this configuration, one snapshot requires 300 kilobytes of memory.

Input of Digital Data

There is a technique to input digital data from negatives or slide-film, which is called Photo-CD. Using this service, digital data can be stored directly on a CD. Use of this service requires a CD-ROM as shown in Fig. 4.

Two methods of image data input were compared, i.e., the one described in last section and the one using CDs. The results are shown in Table 2. Both of these methods use compressed data, so there are few differences. However, the CD method can display images more clearly than the other one. The CD method is also comparatively cheap, and a more simple procedure. The CD method is therefore preferable for negatives or slide-film.

Digital data from negatives or slide-film was recorded on CD at a camera shop, and we then read images from the CDs, modified them, and stored them on a magneto-

Table 3 Memory requirements and retrieval tune of compressed data compared with non-compressed data

(for twelve photographs)

	max.	min.	average
SIZE (KB)			
Non-compressed	248	232	237.7
Compressed	56	36	47.7
Compression ratio (%)	23.1	12.7	18.4
TIME (second)			
Non-compressed	10	8	8.5
Compressed	7	5	6.3

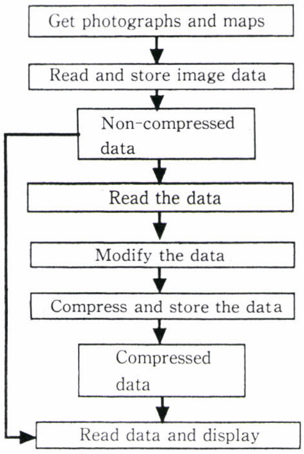

Fig. 6 Process of data compression.

optical device using data compression shown in Fig. 6 (described in the next section). If we received photographs without negatives, we used the PIXEL-JET as a scanner. After scanning images, we modified them, compressed the data and stored them on a magneto-optical device. After storing an image we added a record to the database using Grand Muse.

Effect of Data Compression

There are many data compression techniques for saving memory capacity. We chose JPEG. In order to check the effect of data compression, compressed and non-compressed data were compared by using three criteria: visibility of the photographs, required memory capacity and processing speed. We checked data from twelve photographs. The results are shown in Table 3. There was no clear difference in visibility between the methods, but data compression can save about 80% of memory capacity in the case of forest photographs, which each required 60 kilobytes of memory. Compressed data also needed less time to display than non-compressed data, because the reading time of compressed data was shorter.

CONCLUSION

We have successfully developed an image database for forests which contains maps and photographs. The maps help to locate the forests, and the photographs give more information than a conventional forest database. This image database can be used by foresters and non-foresters alike.

Besides images, the database contains standard information and other descriptions in free format. It can be applied readily to other forests. If additional information is required, further descriptions can be written in free format. As we gather further images and expand this database, we will develop a database as large as the Japanese forest database. Moreover, if old photographs of a forest are available, images of the past forest structure can be re-created and stored in the database.

We stored and distributed the data of this image database on a magneto-optical device. As networks are becoming more useful and popular, we will adopt a system using a network in the future. This will allow the number of users of this image database to increase.

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