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Articles

Article

Historical Changes of Forest Area in Thailand —A Case Study of Mae Klong Watershed Research Station-Lintin, Kanchanaburi—

Suchat Kalyawongsa*[1], Masahiro Amano*[2], Komon Pragtong*[1], Teunchai Lakhaviwattanakul*[1], Adisorn Noochdumron*[1], Hirofumi Kuboyama*[2] and Hiroyasu Oka*[2]

ABSTRACT

During the past few decades, Thailand has sharply lost her forest area. The forest area has been declined from 53 % to 26 % of the total land area in 1960-1995. The forest covers have been changed to the other types of land use, such as, farmland, urban area, orchard and etc. This study tried to show the process of deforestation in the Mae Klong Watershed Research Station (Lintin), Thongphaphum District, Kanchanburi Province, Thailand. This case study is valuable to understand drastic land use and land cover changes in rural area in Thailand. Five different time series of aerial photographs have been interpreted and land use maps have been made over the period of 1954, 1969, 1974, 1986 and 1994 to consider anthropogenic forces of land use changes in rural Thailand. From aerial interpretation, we can classify land use types into two main land use types; forest land use and farming land use. From the land use maps of 1954 and 1994, the forest covers in mountainous area have been less converted to other types of land use than those forest covers in the flat areas. But forests in mountainous area have continuously degraded over the study period. On the other hand, forest land use in the flat area have been decreased gradually from 1954 to 1974, then forest land use in the flat area have been declined rapidly during the year of 1974 and 1994 while the farming land use has been increased. From the changes of forest covers in the mountainous and flat areas, it shows that the topographic factors are related to the changes of land use and land covers in the area. In flat area, increasing of households, in the two village, is an important driving factor of converting forest area to agricultural land. Therefore anthropogenic factor directly affects land use and land cover changes in the study area.

Keyword: land use change, deforestation, degradation of forest, aerial photograph, Thailand

INTRODUCTION

Land use and land cover changes are occurring at a dramatic scale around the world. Changes, such as deforestation and degraded soil conditions are seen not only as important specific topics but also have an impact on other forms of global change such as long term climate changes, the changing composition of atmospheric chemistry and biological diversity. Land use and land cover changes are caused by a complex of processes. Both natural and anthropogenic processes alter land use and land cover which in turn directly affect the environment. During the past few decades, Thailand has experienced a severe decline in her forest area. From 1960-1995 the total forest area has decreased from 53% to 26% (ROYAL FOREST DEPARTMENT, 1960-1995). Land formerly covered by forest has been converted to other uses such as farmland and orchards or it has become urbanized (CHARUPPAT, 1992).

The aim of this study is to describe the historical

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changes of land use and land cover at the research site, Mae Klong Watershed Research Station (Lintin), Thongphaphum District, Kanchanaburi Province. Five different aerial photographs taken during five different years over a forty year period have been used to study the changing characteristics of forest covers in the study area which encompasses approximately 220km². Questionnaires and interviews were also used when gathering data. In addition, land use statistics and agricultural statistics from Kanchanaburi Province (OFFICE of AGRICULTURAL ECONOMICS, 1976-1993) were used in order to provide a broader understanding of the characteristics of changing land use and land cover at the provincial level.

HISTORICAL LAND USE CHANGES IN THE STUDY SITE

Using aerial photographs, land use maps have been made for 1954, 1969, 1974, 1986, and 1994. The scales of aerial photographs used are 1/50,000, 1/50,000, 1/50,000, 1/20,000 and 1/50,000, respectively. In order to accurately interpret the aerial photographs, thirty-four ground sample points were surveyed within the study site. Analysis of the photographs showed that the land use could be classified into two main types: forest land use and farming land use. The forest land use category could then be further broken down into five types of forest cover: 1) high density forest (crown closure>80%), 2) medium density forest (crown closure between 50% to 80%), 3) low density forest (crown closure between 20% to 50%), 4) secondary forest and 5) bamboo forest. Secondary forest is defined as a forest which is generated after the slash and burn technique is used when shifting cultivation. The farming land use category is further divided into the following five types: 1) grass bush land, 2) agricultural land, 3) orchards, 4) plantations and 5) communities. It is apparent from the land use maps of 1954 to 1994 that the high density forest has declined from 17.73% to 4.83% of the total area while the agricultural lands have increased from 0.56% to 13.58% of the total area. All forest land use types, except secondary forests, have declined from 1954 to 1994. (Details in percentage of land use types are shown in Table 1.)

The study site includes both mountainous and flat areas which are divided by a change in the terrain as seen in the photographs. Mountainous and flat areas are 70% and 30% respectively of the total area which was roughly divided in Fig. 1-e. In 1954, there were already agricultural areas in the study site in both the mountainous and the flat areas. Nevertheless, the total area of farmland was small compared to the total study area, this indicates that some resettlement had already occurred in both the mountainous and flat areas. As agricultural areas have increased over time, forest areas have decreased. The interviews pointed out that the construction of a railway in the area during world war II might have had an effect on changes in the land use and in land covers. (The details of land use types throughout the study are shown on Fig. 1-a to 1-e.)

From the aerial photographs of 1977, we detected a road built as part of a logging operation in the study area. The photographs from 1986 and 1994 show an additional number of roads in the area. The existence of roads built for logging has had an effect on the forest covers because the trees have been harvested . It was also noted that there were several logging operations at a time in the area which in turn, accelerated the degradation of forest covers. The logging roads were subsequently used by the rural people as a means of accessing to the forest areas. This information has been confirmed by the interviewees that live in the mountainous region.

The land use maps from 1954 and 1994, further indi-

Table 1 Percentage of land use types in 1954, 1968, 1974, 1986 and 1994

	1954	1968	1974	1986	1994
High density forest	17.73%	9.47%	5.94%	4.29%	4.83%
Medium density forest	22.75%	18.64%	23.10%	11.00%	11.28%
Low density forest	21.04%	31.94%	33.39%	20.86%	19.48%
Secondary forest	31.32%	28.20%	29.82%	41.34%	43.92%
Bamboo forest	0.54%	2.02%	2.00%	1.98%	0.97%
Grass-Bush land	6.08%	7.87%	3.61%	10.84%	3.61%
Agricultural land	0.56%	1.84%	1.92%	9.09%	13.58%
Orchard	0.00%	0.01%	0.21%	0.45%	1.85%
Plantation	0.00%	0.00%	0.00%	0.15%	0.27%
Community	0.00%	0.00%	0.00%	0.00%	0.22%
Total	100%	100%	100%	100%	100%

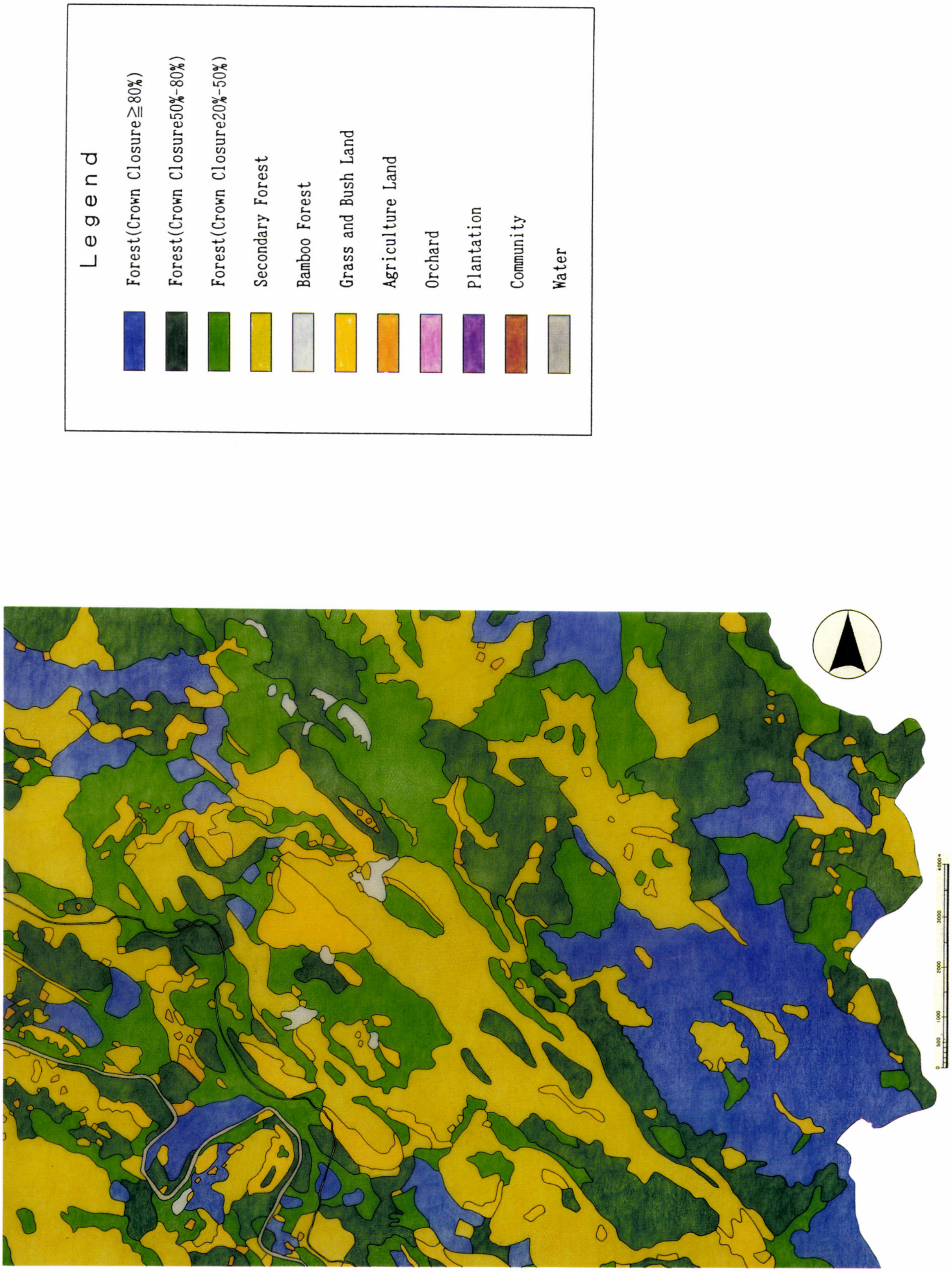

Fig. 1-a Land use maps of Mae Klong Watershed Area in Thailand (1953)

Fig. 1-c (1974)

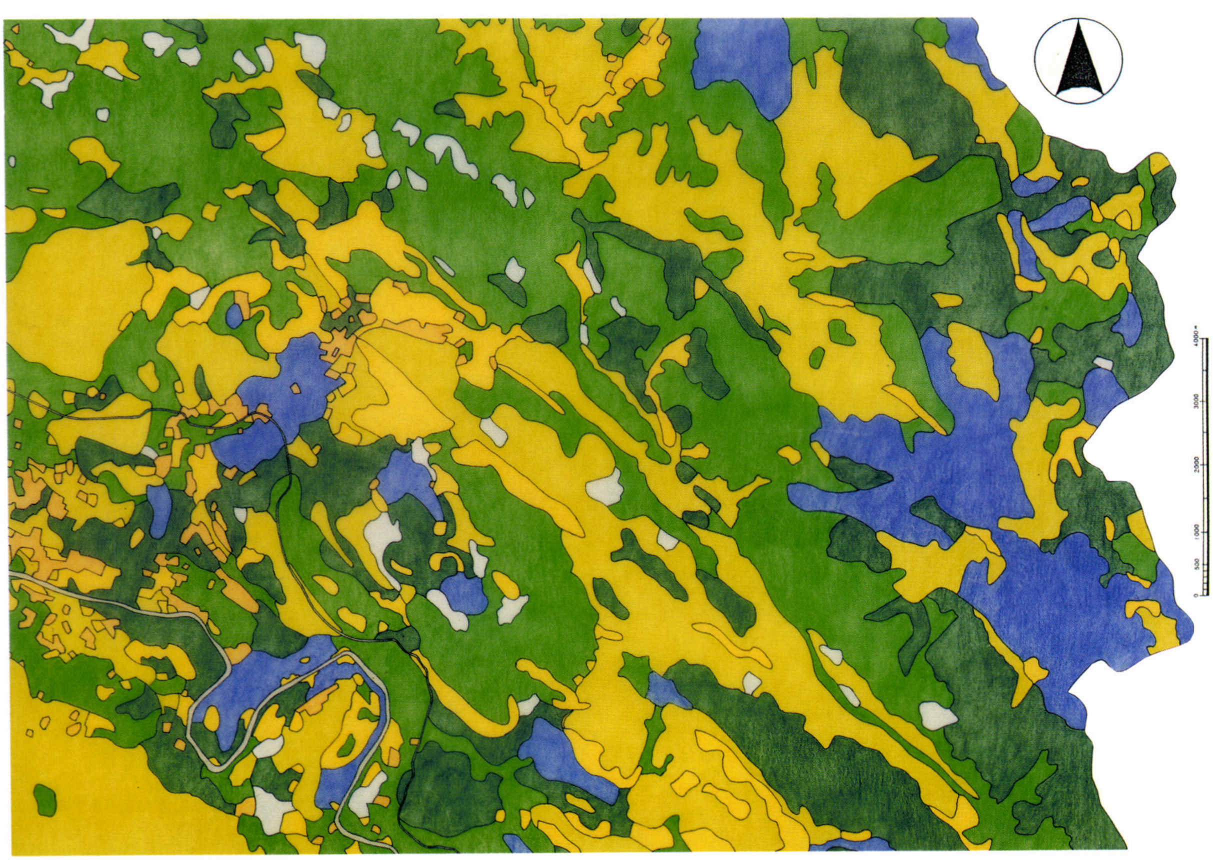

Fig. 1-b (1968)

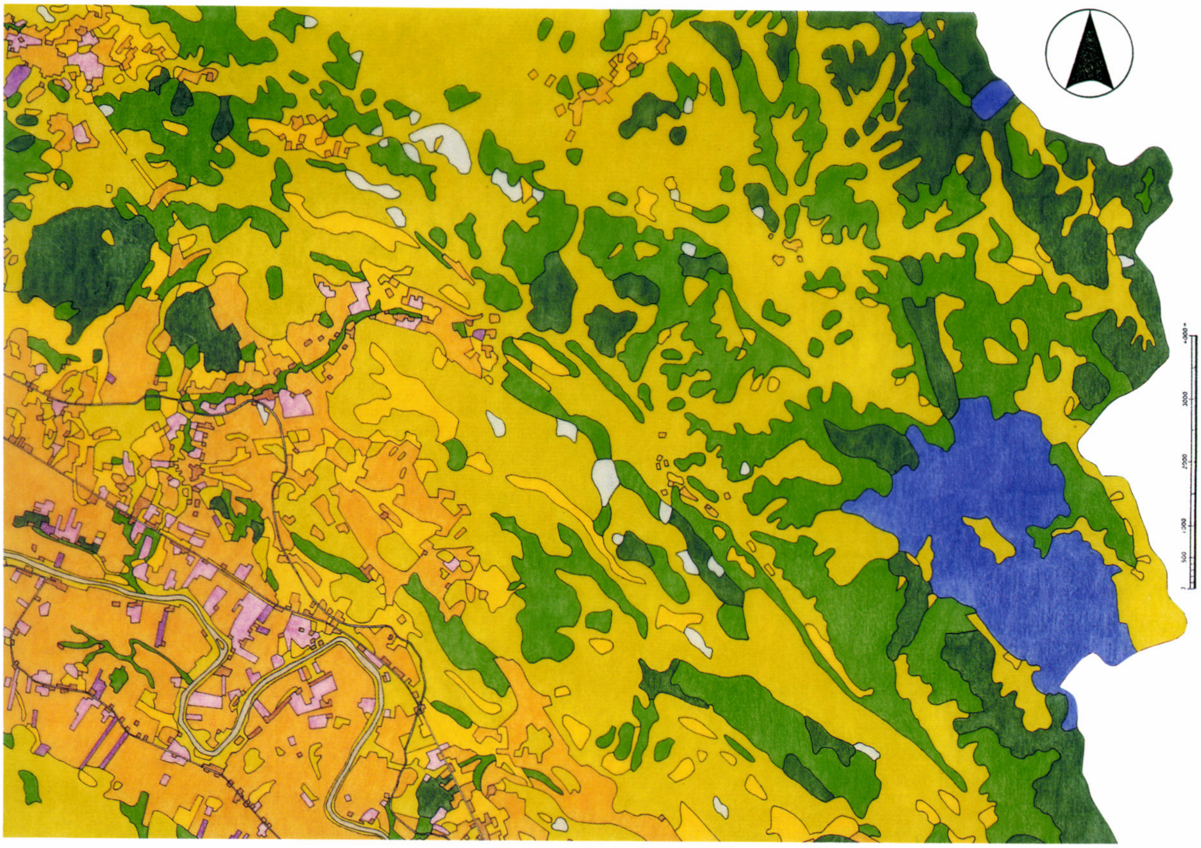

Fig. 1-e (1994)

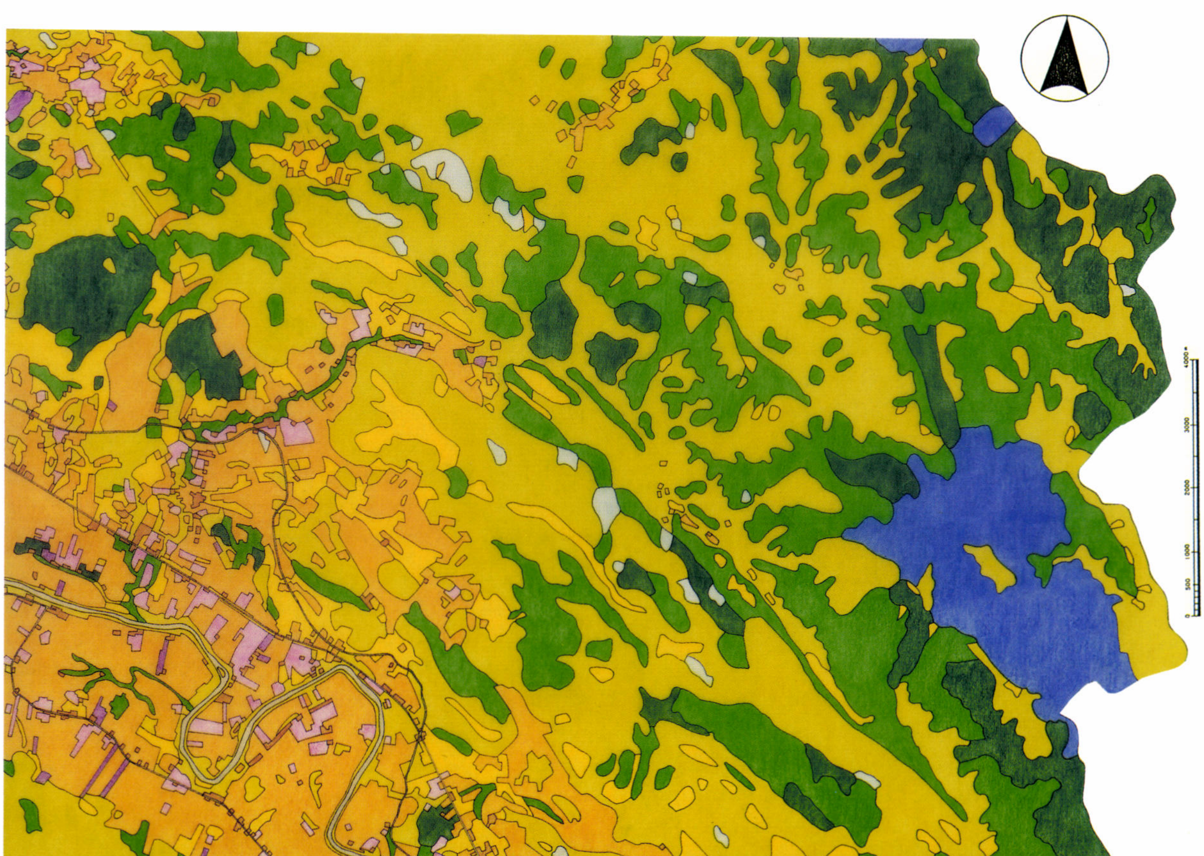

Fig. 1-d (1986)

cate that the forest covers in mountainous areas have not been changed to other types of land use to as great an extent as in the flat areas. As a result, the study site was divided by topographical characteristics (mountainous areas and flat areas) in order to better understand the changes of land use and land covers.

The villages of Nong Bang and Lam Ma Ke are located in the Mae Klong Watershed area. Nong Bang is located close to the forest between Lam-Ma-Ke and the mountains. Lam-Ma-Ke is located between the flat area and Nong Bang and is near a highway.

Mountainous Area

During 1954, 1968, 1976, 1986 and 1994 the percentage of agricultural land in the mountainous area was respectively 0.22%, 0.15%, 0.49%, 0.73% and 2.99%. The villagers that were interviewed indicated that during the second world war, people were living in the mountainous areas. Approximately twenty years ago, the population there shifted to Nong Bang village. The reasons for the move are unclear. Due to the migration to the flat areas, only a small amount of forest land was converted to agricultural land in the mountainous areas as mentioned above. Recently some of Nong Bang villagers have started to cultivate land on calm slopes in the mountainous areas. Villagers have made use of roads to access their farmland in the mountainous areas and some of them have commuted from Nong Bang village to their farmland in the mountains.

Even though the settlement in this area has moved down to the flat area only twenty years ago, forest covers have been degraded throughout the period from 1954 to 1994. During 1954, 1968, 1974, 1986 and 1994, the percentage of high density forest has been recorded as 20.29%, 9.37%, 7.51%, 6.29% and 5.71% respectively in the mountainous region. The medium and low density forest areas were also degraded over the study period. However the total area of secondary forest increased dramatically from 31.03% in 1954 to 50.56% in 1994. The percentage of secondary forest for 1974 was 29.70% and for 1986 it was 44.57%. Fig. 2 shows changes of forest types in the mountainous area. These trends clearly show that even in the mountainous areas, forest have been degraded continuously.

Flat Area

More deforestation has occurred in the flat region than in the mountainous region. During the period of 1954 to 1974, the gradual decreases in forest land use were mirrored by increases in the amount of land used for farming. However, between 1974 and 1994 the decreases in forest land use occurred rapidly, as did the increase of farming land use. This indicates that forest land use types in the flat area have been converted to the farming land use types. The data also showed that the area used for orchards increased from 1% in 1974 to 2% in 1986 to 7% in 1994. Fig. 3 and 4 show the changes of forest types and farming land uses in the flat area over the study period.

Comparing the types of changes in the forest covers in the mountainous and flat areas, it is clear that topographical factors play a key role in how the land use and land covers change in this watershed area.

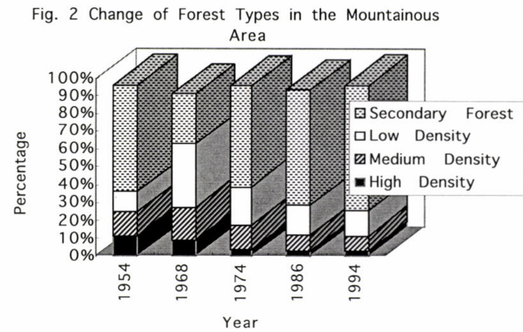

Fig. 2 Changes of forest types in the mountainous area.

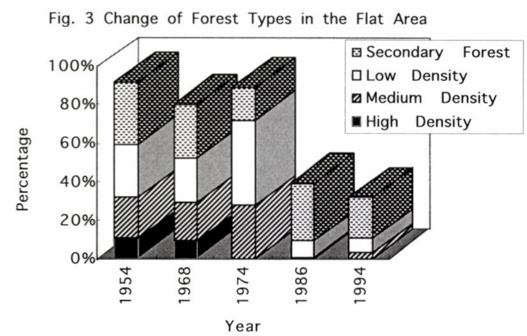

Fig. 3 Changes of forest types in the flat area.

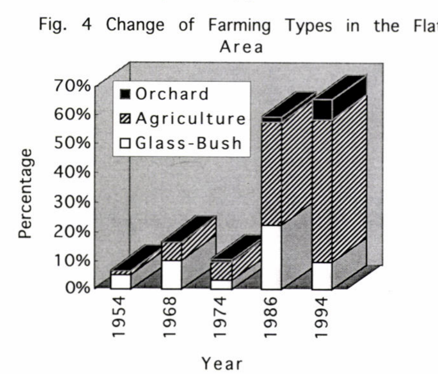

Fig. 4 Changes of farming types in the flat area.

LAND USE AND LAND COVER CHANGES IN KANCHANABURI

After reviewing the trends in the land use and land cover changes in Lintin, Mae Klong watershed area, it is clear that anthropogenic factors resulting from agricultural activities are the driving force behind the changes. In order to more fully understand the background of the land use and land cover changes in the study area, government statistics about land use of the agricultural sector in Kanchanaburi Province were reviewed. (The information in Fig. 5 was supplied by the Office of Agricultural Economics, 1975-1991 and shows general land use trends in Kanchanaburi.) From this graph we see that forest area in Kanchanaburi has continuously decreased. Both the study in Lintin and the statistics provided by the government indicate that as the forest area continued to decline, the area in the flat region was converted to agricultural land. Government land use statistics shown on Fig. 5 categorized the degraded forest in the mountainous area into the Unclassified Group. Fig. 6, based on information from Agricultural Statistics from the Office of Agricultural Economics, 1976-1993 shows temporal changes of major crops in Kanchanaburi Province. The graph indicates that

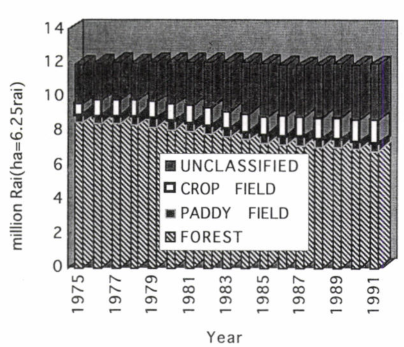

Fig. 5 General land use in Kanchanaburi.

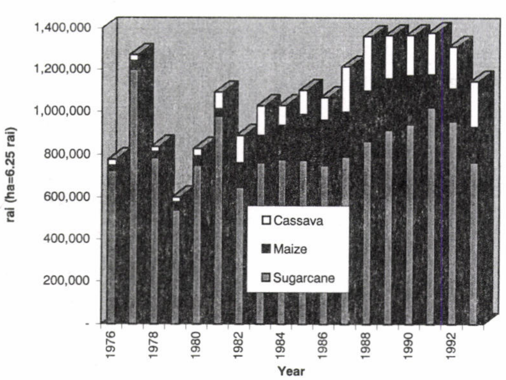

Fig. 6 Change of Major Crops Area in Kanchanaburi.

the major crop produced in the Kanchanaburi Province has consistently been sugarcane, accordingly manufactures are located in this province. Since 1982, there has been an increase in the amount of maize and cassava produced. A similar trend is occurring in Lintin. Even though changes in land use and land cover are caused by a complex network of factors, government statistics and the case study in Lintin indicate that both physical terrain and the agricultural sector play a significant role in how and where the changes occur.

SOCIO-ECONOMIC BACKGROUND OF MAE KLONG

In order to better understand land use dynamics in the flat area, socioeconomic conditions in the study area must be considered. The conversion of forest area to agricultural land in the flat area is a direct result of the population increase in the two nearby villages. To see how these anthropogenic influences effect on the land use and land cover changes, a questionnaire survey was carried out in the Nong Bang and Lam Ma Ke villages. In addition, the survey was designed to explain changes of socioeconomic conditions in the past. The questionnaire and the interviews were given to ten households in Nong Bang and nine households in Lam Ma Ke. The results of the questionnaire showed that Nong Bang village was established about sixty years ago. Most of the villagers are originally from the local area in the Thongphaphum District of Kanchanaburi Province. In the survey, villagers were asked to record the number of households found during a specific year such as during childhood, when married or when their children were born. (As the answers were based on memory, a variance was used when plotting the results) As shown in Fig. 7, the number of households in Nong Bang has increased rather slowly; there were approximately forty households ten years ago but now there are about fifty-seven households. Lam Ma Ke village was established in the 1950's about twenty years after Nong Bang village was established. The survey also showed that many of villagers in Lam Ma Ke migrated from other districts and provinces. The number of households increased significantly, especially from 1976 to 1986 and from 1990 to 1996. There were approximately sixty households in 1976 and one hundred eighty households in 1996. The interviewees indicated that the villagers were able to obtain their lands from various sources. This included 1) land given out by the government, 2) land borrowed from other people, 3) land given to them by their parents (or inherited land), 4) land purchased from the others, and 5) land taken after forest encroachment. When Nong Bang village was established land was provided by the government. Later, land use changes in Nong Bang occurred slowly compared to that in Lam Ma Ke village. Most of the land was transferred from parents to their children. In only a few households was the land

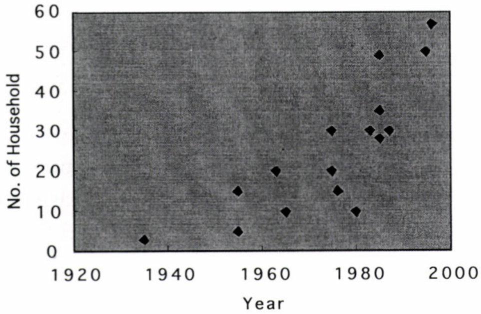

Fig. 7-a No. of Households (Nong Bang)

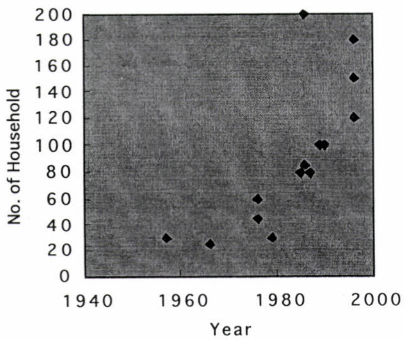

Fig. 7-b No. of Households (Lam Ma Ke)

purchased. The government did not provide land to the villagers in Lam Ma Ke. They obtained their lands by exploiting forests when the village was established. Some of the villagers had no land and were therefore required new land. This was especially true for those who had recently migrated to the village.

The different trends in household numbers and locations of the two villages were reflected in the types of land use changes. Nong Bang is located in a narrow valley and therefore farm land can not be readily expanded. This condition also restricts the number of additional households. On the other hand, Lam Ma Ke is located in a flat area, and was able to expand its farm land according to the increase in its population. Because Lam Ma Ke is quite accessible, it attracted people from the Nong Bang village and beyond. Due to heavy migrations during the period from 1974 to 1986, the Lam Ma Ke village witnessed a severe increase in the amount of land used for farming, especially for agriculture. The greatest number of migrations occurred in 1986. These changes in forest area in the flat region are clearly visible in the aerial photographs used to make the time series land use maps.

The remaining agricultural land use in Nong Bang and Lam Ma Ke were studied and shown in Table 2. In Nong Bang, most of the land consists of orchards, followed by cash crops, land leased to others, paddy fields and finally, land used for residences. In Lam Ma Ke, the order is slightly different, more land is used for cash crops, then paddy fields, followed by mixed farm land, orchards, and again the least amount of land is used for residences.

Table 2 Differences of agricultural land uses between two Villages

Nong Bang Land Use Type	%	Lam-ma-ke Land Use Type	%
paddy	10	paddy	36
crops	28	crops	44
orchard	38	orchard	6.2
residence	8.4	residence	5.2
lease to others	16	mixed farmland	7.9

CONCLUSION

Because Thailand has experienced nationwide economic growth and a rapid increase in its population during the past decades, it has also lost a great deal of its forests. Although there are many national statistics about the deforestation in Thailand, no suitable model to explain the process of this phenomenon has been established. Land use maps made five times over forty years clearly show the actual progresses of degradation of forests and deforestation in Mae Klong watershed area. The results of this study show that anthropogenic activities based on a socioeconomic sector are the main driving factors changing land use and land cover types. The topographical features also played a key role, as they determined where land use and land cover changes would not occur. Because of the physical characteristics of the high land forest area, most of the changes were made in the low land region. Although farming could not be carried out on the sloping terrain, some degradation of the forest land there did occur because of anthropogenic activities, like logging. A new projection model showing future forest resources must incorporate both socioeconomic and topographical factors.

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Article

People's Perceptions and Methods to Evaluate a 360° Panoramic Coppice Forest Scene

Nobuhiko Tanaka*[1] and Katsue Fukamachi*[2]

ABSTRACT

This study was carried out in order to determine what factors in slightly different photographs are influential when evaluating scenic coppices. For the analysis, a 450° photographs was taken with a rotatory camera. This photo was sequentially broken down into forty-seven photos of the coppice landscape. Each photo contains horizontal and gradual differences of the same location taken at the same time.

Two questionnaires were then devised and distributed. The first was designed to establish categories based on compositional similarities. The second was designed to rate the photos based on the subjective comparison between each photo and its neighboring photo in the sequence.

The results from the first questionnaire show that the five main factors used in determining the appropriate category for the photos are: 1) brightness, 2) main elements in the landscape other than trees, 3) conspicuous trees, 4) presence of artificial things, and 5) stand density. These factors are used in both independently and in conjunction with one another.

The conclusion drawn from the second questionnaire is that the evaluation scores fluctuated according to changes in the horizontal constitution of the forest scenes. In addition, it shows that the five factors above played a key role in the evaluation process.

Keyword : scenic landscape analysis, compositional difference, coppice forest, rotatory camera, Tochigi Prefecture

INTRODUCTION AND BACKGROUND

In order to identify desirable forest scenic landscapes, various types of questionnaire surveys, using photographs or slides as media, have been performed in the past few decades (for example, DANIEL and BOSTER 1976, BROWN and DANIEL 1986, RIBE 1990, OISHI *et al.* 1994, and TADA *et al.* 1996). It has been pointed out, however, that the results of these surveys have been based on the quality of the photographs or slides, and not on the evaluation of the forest scenic landscape itself. Therefore, it is important to clarify how compositional differences will affect the evaluation results of questionnaires. Currently, few studies are being conducted on this topic.

TANAKA *et al.* (1994) quantitatively suggested that slight compositional differences among photographs or slides have an affect on evaluation results, even when these are taken from the same place. In that study, forty seven photographs and forty seven slides were taken from the same place but the composition was changed horizontally and gradually. Fifty people were then surveyed. The results showed that the evaluation scores fluctuated as the composition changed horizontally. How much the scores fluctuated depends on how well the main landscape subject fits into the composition.

The photographs and slides, used in that study, contain various landscape elements such as coniferous forests, farm sites, roads, and a house. It is a study that does not

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compare the compositional differences among forest scenes but compares compositional differences among various types of landscapes. Therefore, it is still uncertain how much compositional differences among forest photographs will affect the evaluation results of a questionnaire.

The purpose of this study is to determine what factors are influential when evaluating coppice scenes containing slight and gradual compositional changes. Photographs taken from the same location are used. The results were obtained from two different questionnaires.

PROCEDURES

This study is divided into the following three parts (Fig. 1):

1. Taking and processing photographs for questionnaires.
2. Developing two kinds of questionnaires (for categorizing and for a paired comparison).
3. Analyses of results.

Taking and Processing Photographs for Questionnaires

(1) The Forest Site

To begin with, a 360° panoramic photograph was taken of a coppice scene at 4:30 p.m. on April 7, 1995.

This coppice forest is located in Ichigai Town, Tochigi Prefecture, Japan (Fig. 2). The most dominant tree species in the forest is Japanese oak (*Quercus serrata*). Other species such as *Carpinus tschonoskii* and *Prunus sp.* are present. This forest has a rectangular shape, and is approximately four hundred meters in length and twenty five meters in width. It is located on a slight slope and the terrain is rugged.

The forest is privately owned, and according to the owner, the stand age is approximately twenty five. The forest is well maintained by the owner because he sells the fallen leaves as material for compost. As a result, the forest floor is almost void of vegetation and fallen matter.

(2) The Camera and Photographs

A rotatory camera (SOLECTA PANOSCOPE 35; Fig. 3) was used (see Table 1 for technical data, TAKAO (1991)). A 450° panoramic photograph, 90° of which is overlapped, was taken using this camera (Fig. 4). Because the rotatory camera can take a 360° panoramic picture within one frame, it avoids chromatic variances that can occur when a panoramic photo is created using several photos from a traditional camera. This is an obvious advantage when evaluating the photos for the questionnaire.

Using the panoramic photograph as a master picture,

Fig. 2 Location of Ichigai Town, Tochigi Prefecture

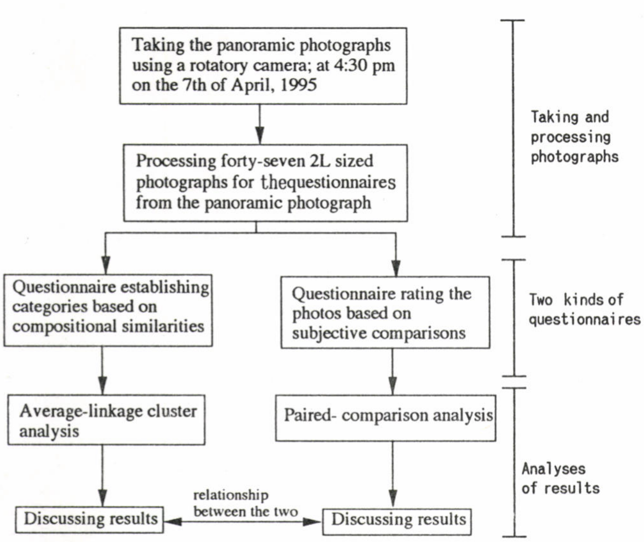

Fig. 1 Outline of this study

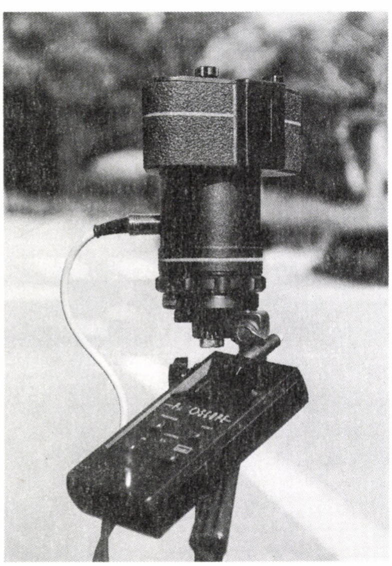
Fig. 3 A rotatory camera

Table 1 Techmical data of rotatory camera (SOLECTA PANOSCOPE 35)

Focal length	35mm
Lens opening	f2.8-f22
Shutter speed	1/15-1/1000
Vertical angle of view	36 deg. (23 deg. upwards and 13 deg. downwards)
Rotation angle	96 deg. -810 deg. (90 deg. interval)

Fig. 4 A 450° panoramic photograph

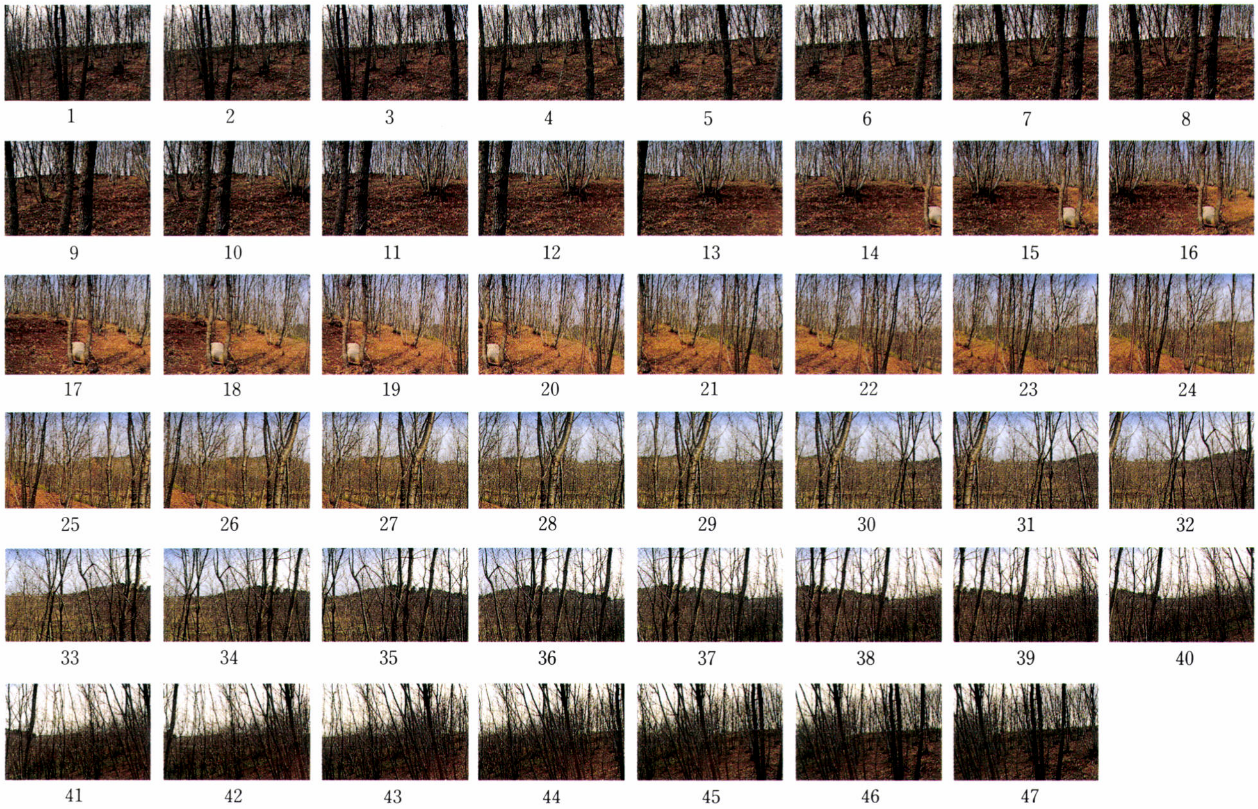

Fig. 5 47 photographs

forty seven scenic photographs, the composition of which changes horizontally and gradually (7.66° interval), are processed (Fig. 5, 1~47).

The size of these photographs is 2L size. This size was chosen to maintain consistency with an existing survey (TANAKA *et al*. 1994).

The number of the photographs was chosen for the following three reasons: 1. the number was not considered to be too extensive of the examinees, 2. The same interval photographs can easily be processed, and 3. the compositional change among the photographs will change only slightly.

Questionnaires

Two different surveys were conducted in this study. The first one was carried out to establish categories based on compositional similarities. The second one was designed to rate the photos based on a subjective comparison between each photo and its adjacent photo in the sequence.

(1) The Questionnaire to Establish Categories Based on Compositional Similarities

The questionnaire to establish categories based on compositional similarities was performed using forty seven photographs. The questionnaire was given to thirty examinees who work for a Japanese national research institute, the Forestry and Forest Products Research Institute. It is, therefore, assumed that, because the employees of this institute have more interested in and knowledge of coppice scenes than do members of the general public, the results will be more substantiated. Characteristics of the examinees are shown in Table 2.

In the questionnaire, each examinee is asked to divide the forty seven photographs, which are not distributed in any particular order, into groups. They are asked to form the groups based on compositional similarities of the photographs. The examinees are asked to divide photographs as precisely as possible, and they are allowed to form as many groups as they deem necessary. No time limit was given and the questionnaire was distributed one by one in order to avoid informational exchange between the examinees.

After the dividing task was completed, the examinees were asked what are the compositional characteristics of each group.

Once the questionnaires were finished, the number of times every two pictures where categorized in the same group was determined. This has been labeled the similarity distance and is calculated by using the following equation:

$$Rij = 30 - Pij$$

i = photo number = 1～47
j = photo number = 1～47
30 = number of examinees
Rij = 0～30
Pij = 0～30
Rij = the similarity distance between photo i and photo j
Pij = the frequency that the examinees divided photo i and photo j into the same group

Table 2 Breakdown of examinees by sex, age, and job

Sex	Male	Female	Total	
	18	12	30	
Age	20-29	30-39	40-49	Total
	15	8	7	30
Job	Researcher	Clerical worker	Part-time assistant	Total
	15	11	4	30

The results were then compiled into the matrix in Table 3.

Using the matrix, compositional similarity is categorized by average linkage cluster analysis. This type of analysis was designed by SAS INSTITUTE INC. (1990), and SAS statistical software was used.

(2) The Questionnaire Rating the Photos on a Subjective Comparison between Each Photo and Its Adjacent Photo in the Sequence

This questionnaire was done using the same photographs with the same examinees. It is based on a survey used in TANAKA *et al*. (1994).

This questionnaire was carried out by comparing each photo to its neighboring photo based on the examinees' scenic preferences (*i.e.*, photo 1 to photo 2, photo 2 to photo 3,....., photo 46 to photo 47, and photo 47 to photo 1). The examinees were asked to rate the photographs by assigning a number (the first photo was always rated as 100).

For example, if the examinee felt that the latter photograph was twice as good as the former one, it would be rated as two hundred; and if the latter was half as good as the former, it would be rated as fifty. The examinees were asked to be subjective in their rating of the photos. These scores must, therefore, be modified and standardized before a summary can be made of individual scores.

The individual scores were modified using the following equation:

$$Yi(j) = \log(Xi(j)/100)$$

and standardized by using the following equation:

$$Zi(j) = (Yi(j) - \bar{Y}i) / Si$$

$Xi(j)$ = score of photo j compared to photo j-1
j = 1～47 (photo 0 means photo 47)
i = examinee = 1～30
$Yi(j)$ = modified score
$\bar{Y}i$ = average from $Yi(1)$ to $Yi(47)$
Si = standard deviation from $Yi(1)$ to $Yi(47)$
$Zi(j)$ = standardized score.

The standardized scores of each photograph were

Table 3 A matrix of similarity distance

	No1	No2	No3	No4	No5	No6	No7	No8	No9	No10	No11	No12	No13	No14	No15	No16	No17	No18	No19	No20	No21	No22	No23	No24	No25	No26	No27	No28	No29	No30	No31	No32	No33	No34	No35	No36	No37	No38	No39	No40	No41	No42	No43	No44	No45	No46	No47
No1	0																																														
No2	9	0																																													
No3	11	10	0																																												
No4	14	9	9	0																																											
No5	17	10	12	8	0																																										
No6	18	12	14	9	7	0																																									
No7	21	17	17	14	9	8	0																																								
No8	25	21	20	18	14	12	8	0																																							
No9	26	23	21	19	17	15	12	5	0																																						
No10	27	25	23	24	23	21	20	13	9	0																																					
No11	27	25	23	24	23	21	21	15	11	3	0																																				
No12	29	29	27	28	28	27	26	24	22	14	11	0																																			
No13	29	29	28	29	29	29	28	26	24	18	16	8	0																																		
No14	29	29	29	28	29	29	28	25	24	21	20	12	9	0																																	
No15	29	29	29	29	29	29	28	28	27	26	26	19	17	10	0																																
No16	29	29	29	29	29	29	28	28	27	26	26	19	17	11	3	0																															
No17	29	29	29	29	29	29	28	28	27	26	26	18	15	11	4	2	0																														
No18	29	29	29	29	29	29	28	28	26	25	25	18	18	14	7	5	3	0																													
No19	28	27	27	27	27	27	28	25	24	23	23	21	22	18	10	9	10	8	0																												
No20	27	27	27	27	27	27	26	26	26	25	25	22	21	18	12	11	12	11	6	0																											
No21	28	28	28	28	28	28	27	26	26	25	25	24	23	24	23	23	24	23	20	16	0																										
No22	28	28	28	28	28	28	27	28	27	26	26	27	26	27	26	25	26	25	23	19	5	0																									
No23	29	29	29	29	29	29	28	29	29	29	29	27	27	27	27	27	27	27	27	23	9	8	0																								
No24	28	28	28	28	28	28	27	28	28	28	28	28	28	28	27	27	28	28	25	23	11	11	8	0																							
No25	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	28	29	29	27	26	20	17	14	10	0																						
No26	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	28	29	29	28	28	25	23	20	17	8	0																					
No27	29	29	29	29	29	29	28	29	29	29	29	28	28	28	27	27	28	28	28	27	23	21	19	16	10	5	0																				
No28	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	27	25	23	22	14	10	9	0																			
No29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	25	24	17	11	13	4	0																		
No30	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	25	24	17	11	12	5	2	0																	
No31	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	27	27	24	18	14	13	6	5	5	0																
No32	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	27	27	25	24	23	23	19	18	18	14	0															
No33	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	26	27	25	22	24	21	18	18	16	3	0														
No34	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	26	25	25	22	23	22	19	19	17	7	5	0													
No35	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	27	28	26	23	25	23	21	21	19	8	6	6	0												
No36	28	30	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	30	29	27	27	27	19	18	16	13	0											
No37	28	30	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	30	29	28	28	29	22	21	19	17	5	0										
No38	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	29	29	29	25	25	22	21	11	7	0									
No39	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	27	28	25	25	20	16	10	0								
No40	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	28	29	26	26	21	17	11	2	0							
No41	28	29	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	29	24	20	16	8	7	0						
No42	26	28	28	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	29	24	22	20	15	14	10	0					
No43	25	27	28	29	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	29	27	25	22	18	17	11	7	0				
No44	23	27	26	28	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	29	26	25	25	21	20	15	9	5	0			
No45	12	19	21	21	24	25	27	28	28	28	30	30	30	30	30	30	30	30	29	29	29	29	30	29	30	30	30	30	30	30	30	30	30	29	29	27	26	27	27	27	24	20	17	14	0		
No46	13	19	22	22	25	26	27	29	29	29	30	29	29	29	29	29	29	29	30	29	29	29	29	29	30	30	29	30	30	30	30	30	30	30	29	27	26	27	27	27	25	22	19	16	5	0	
No47	9	15	18	20	23	24	26	28	28	29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	29	26	25	26	26	26	25	21	19	17	11	7	0

then totaled and averaged respectively. The accumulated final score of photo j is found using the following equation:

$$Ac(j) = Ac(j-1) + Av(j) \quad (Ac(0) = 0)$$

$Av(j)$ = totaled and average score of photo j
$Ac(j)$ = accumulated final score of j

The accumulated final score was then used in the analysis.

RESULTS

Results on the Questionnaire Establishing Categories Based on Compositional Similarities

The results that established categories based on compositional similarities are shown in Fig. 6. In order to interpret these results, we must first explain the higher branches in the cluster dendrogram (HORI and SUZUKI, 1988). Explaining the meanings of these branches will clarify how people establish categories based on compositional differences among coppice scenes.

Nine branches, Branch A to Branch I, with a cluster distance higher than 0.6, are the main focus of the study. The following five main categories, determined by the results given by at least half of all examinees, have been created, based on compositional similarities.

Factor 1: Level of brightness among the photographs (twenty seven out of thirty examinees chose this factor),

Factor 2: Presence and proportion of landscape elements other than trees, (such as scenery outside forest or proportion of ground) (twenty six out of thirty examinees chose this factor),

Factor 3: Single conspicuous trees (for example, isolated coppice trees or trees standing nearest the front) (sixteen out of thirty examinees chose this factor),

Factor 4: Presence of small artificial things (such as bags for fertilizer or bags for fallen leaves) (fifteen out of thirty examinees chose this factor),

Factor 5: Differences in stand density (fifteen out of thirty examinees chose this factor).

Relationships among the nine branches and the five factors are shown in Table 4. Also, the characteristic of each cluster group or category is shown in Table 5. According to the results in these tables, most branches contain more than one factor. It is therefore evident that multiple factors are considered when categorizing the composition of individual coppice photos. However, the

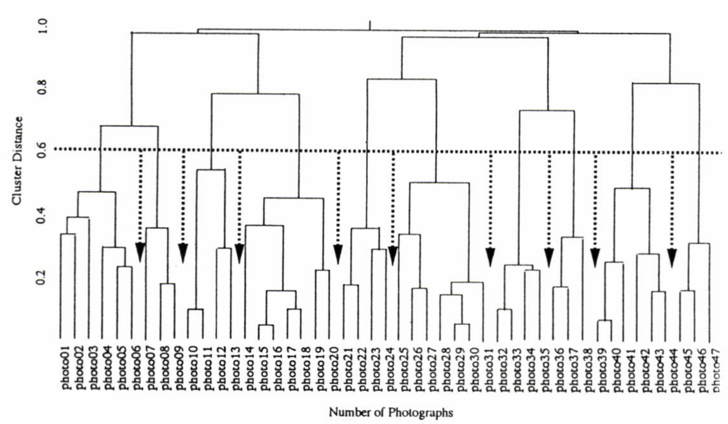

Fig. 6 Categorical results

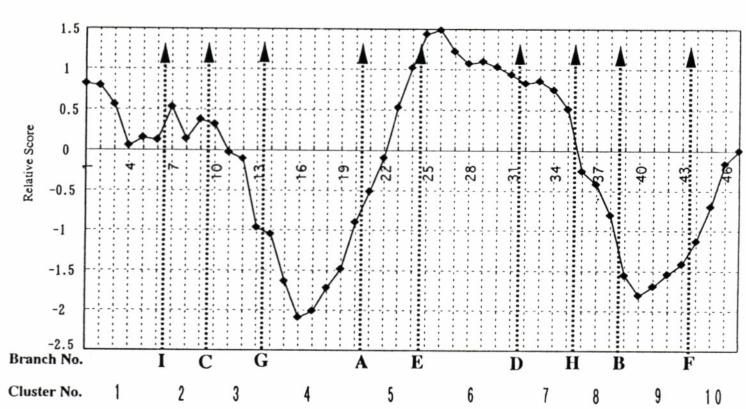

Fig. 7 Evaluation results

Table 4 Relationsship between the nine branchs and five factors

No.of Branches	Main Factor	Details
Branch A	Factor 4	Presence of a small artificial thing (bags for fallen leaves) (-photo 20); and lack of it (photo21-)
Branch B	Factor 2 Factor 5	A landscape element other than trees (scenery outside the forest) is seen well (-photo 38); and vice versa because of a dense forest (photo 39-)
Branch C	Factor 3 Factor 4	Presence of conspicuous trees (standing nearest the front), lack of a small artificial thing (bags for fertilizer) (-photo 09); and presence of more conspicuous trees (coppice trees) and an artificial thing (bage for fertilizer) (photo 10-)
Branch D	Factor 1 Factor 3	Bright and presence of a conspicuous tree (a cherry tree standing nearest the front) (-Photo 31); and vice versa (Photo 32-)
Branch E	Factor 2 Factor 3	A landscape element (proportion of ground) is seen well and lack of a conspicuous tree (a cherry tree standing nearest the front) (-photo 24); and vice versa (photo 25-)
Branch F	Factor 1 Factor 2 Factor 5	Dark, dense stand, and a landscape element (proportion of ground) is not seen well (-photo 43); and vice versa (photo 44-)
Branch G	Factor 3 Factor 4	Presence of a small artificial thing (bags for fertilizer) and conspicuous trees (isolated coppice stand) (-photo 13); and presence of another artificial thing (bag for fallen leaves) and lack of conspicuous trees (photo 14-)
Branch H	Factor 1 Factor 2	Relatively brigth, main landscape elements other than trees (scenery outside the forest) are rice paddies (-photo 35); and relatively dark, main landscape element other than the forest (scenery outside the forest) is a coniferous forest (photo 36-)
Branch I	Factor 3	Presence of conspicuous trees (Japanese oaks standing nearest the front) (-photo 06); and vice versa (photo 07-)

Table 5 Characteristics of each cluster group

Cluster No.	Photo No.	Characteristics				
		Brightness	Main elements in the landscape other than trees	Conspicuous trees	Presence of artificial things	Stand density
1	1-6	relatively dark	forest floor	none	none	sparce
2	7-9	moderate	forest floor	Japanese oaks standing nearest the front	none	sparce
3	10-13	relatively bright	forest floor	isolated copice stand	a bag for fertilizer	very sparce
4	14-20	bright	forest floor	none	a bag for fallen leaves	sparce
5	21-24	bright	forest floor and outside view (farms and deciduous forests)	none	none	moderate
6	25-31	bright	outside view (farms and deciduous forests)	a cherry tree standing nearest the front	none	relatively dense
7	32-35	relatively bright	outside view (farms and deciduous forests)	none	none	relatively dense
8	36-38	relatively dark	outside view (farms and coniferous forests)	none	none	relatively dense
9	39-43	dark	forest floor and outside view (farms and coniferous forests)	none	none	dense
10	44-47	relatively dark	forest floor	none	none	moderate

Table 6 Relationsship between compositional evaluation and compositional characteristics

Group No.	High or low score	Photograph No.	Brightness	Main elements in the landscape other than trees	Conspicuous trees	Presence of artificial things	Tree density
Group 1	high	1-10, 47	relatively dark to moderate	forest floor	none or Japanese oaks standing nearest the front	none	**sparce**
Group 2	low	11-22	**relatively bright to bright**	forest floor	none or isolated coppice stand	*a bag for fertilizer or a bag for fallen leaves*	**sparce or very sparce**
Group 3	high	23-35	**bright to relatively bright**	outside view (farms and deciduous forests)	none or a cherry tree standing nearest the front	none	Moderate to relatively dense
Group 4	low	36-46	*relatively dark to dark*	*outside view (farms and coniferous forests) or forest floor*	none	none	*moderate to dense*

Bolod: Good characteristics
Italic: Bad characteristics

highest branch, Branch A, is made up of only a single factor. As a result, a conspicuous and effective factor can become a single determining factor. In addition, most examinees, who chose this factor, feel that its conspicuousness makes it unfit in natural forest scenes.

Results on the Questionnaire Rating the Photos Based on Subjective Comparisons between Each Photo and Its Neighboring Photo in the Sequence

The result of this questionnaire is shown in Fig. 7. The relative scores fluctuate above and below zero. There are very discernible maximum points, photo 1 and photo 26, and minimum points, photo 16 and photo 40.

The focus in this study is whether the relative score is higher or lower than zero. As shown in Table 6, the forty seven photographs were divided into four groups based on this factor. There are two groups which have scores higher than zero, group 1 and group 3, and also two groups which have scores lower than zero, group 2 and group 4.

Table 6 also shows the relationship among these four groups and the main five factors. After classing the photographs, the examinees claimed that each factor has both positive aspects and negative aspects. In Table 6, the cells written with bold font indicate positive aspects and cells written with italic font represent negative aspects.

The results in Table 6 show that group 1 has one positive characteristic group 3 has two positive characteristics and group 4 has three negative characteristics. Accordingly, the scores are positive, positive, and negative respectively.

Group 2, however, is more complicated because it has two positive characteristics and one negative characteristic. The relative score of group 2 is negative. As indicated earlier, the presence of artificial things is one of the strongest factors used that results in a negative effect. Therefore, it can be assumed that this single negative factor outweigh both the two positive factors combined. However, further study is needed to confirm this.

CONCLUSION

As a result of this study, we conclude that several factors are used to establish categories based on slightly different compositions of coppice photographs. The following five key factors have been recognized: 1. brightness, 2. main elements in the landscape other than trees, 3. conspicuous trees, 4. presence of artificial things, and 5. stand density. Furthermore, these results indicate that both single factors and multiple factors are taken into account at the same time.

The result also shows that the evaluation scores of the forest scenes fluctuate as the composition of photographs changes horizontally and gradually, even though they were taken from the same place and at the same time. Comparing the relationship between evaluation scores and compositional aspects shows that there is a close relationship between the two. However, if one photograph has both positive and negative aspects scoring, it becomes complicated. However, the results of this study show that even one extremely influential factor can outweigh a combination of two less influential factors in determining a final score. Further studies are required to substantiate this claim.

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Impact of Windthrow Risk on the Management of Forest Estates in the Canterbury Region in New Zealand

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ABSTRACT

A model was constructed to address the harvest scheduling problem under risk of occurrence of catastrophic events. The model was made up of an optimization and a simulation model. The optimization model provided an optimal harvest pattern under deterministic conditions. The simulation model modified the optimal harvest pattern according to a function of random risk assessing the performance of the system through net present value (NPV). The model was run a large number of times estimating mean, standard deviation and a frequency distribution for NPV.

The model was run for a case study considering a forest estate of 8,412 ha located in Canterbury in New Zealand. The random component of the system was windthrow occurring at different times and with different intensities. Storms were generated randomly over a planning horizon of 50 years considering an average return period of 28 years between two successive storms. The intensity of damage was assumed to be proportional to the historical damage. As a result, NPV after taxes regarding the management of the forest estate was reduced 11 percent on average. Windthrow brought about economic losses due to reduced harvest following windthrow, reduced recovery (80%), increased total establishment costs, and the fact that trees were harvested before optimal rotation.

Keyword: forest estate modelling, catastrophic risk, windthrow, recovery operations

INTRODUCTION

Wind is the most important risk factor in plantation forestry in New Zealand. Wind damage is by far much more important than fire which accounts for only a small proportion of the total loss of forests in New Zealand (SOMERVILLE, 1989a). In contrast, windthrow has accounted for at least 50 000 ha of catastrophic damage to stands over 5 years-old since the turn of the century (SOMERVILLE, 1995). Surprisingly, until 1989 windthrow had been largely overlooked by scientists and managers probably because of its rare occurrence. Managers used to think that wind damage was an unlucky event that probably it would not happen again and that anyway management cannot do anything about it. Today, managers' perceptions have evolved in the face of new research that suggests that wind damage is an important production factor which will happen again and that through appropriate silvicultural practices it can be ameliorated (SOMERVILLE, 1989a).

Wind damage brings about losses due to toppling of recently planted trees, stem malformation, changes in wood properties, growth retardation and attritional windthrow and stem breakage in stands (SOMERVILLE, 1989b). Toppling and especially windthrow can be considered the main sources of wind damage to plantation forestry in New Zealand.

Windthrow and stem breakage have occurred over a high proportion of the territory of New Zealand. However, this has been more accentuated in the Wellington, Canterbury, North Auckland, and Manawatu regions. From all these regions, Canterbury is the one that has suffered the most serious damage (SOMERVILLE, 1989b).

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Even though recovery can be performed, significant economical losses are brought about because of windthrow. Among the most direct reasons are: reduced recovery due to breakage, harvested trees before planned rotation age, increased harvesting and establishment costs, etc. Some indirect reasons for economical losses can be also pointed out such as decreased prices due to sudden supply, industry not prepared to absorb supply, lower prices for salvage timber, etc. (BOWN, 1996).

Because windthrow implies economic losses, managerial tools are required to assess the impact of such events on the financial position of an organization over time. Current models planning the evolution of forest estates address risk mostly in a deterministic fashion. These models behave properly when risk can be considered as an average rate per year and therefore a constant attritional area of the forest is partially or completely affected. However, windthrow is different in nature because the phenomenon does not occur every year in small proportions. It does happen rarely but when it strikes a high proportion of the forest can be partially or completely destroyed. Under these conditions current models fail to appropriately represent the forestry system and therefore a new approach is needed.

The aim of this research was to examine the harvest scheduling problem including random risk and compare the results with a deterministic solution in a case study.

METHOD

The method is divided in two parts: Stochastic Modelling and Estate Modelling. Basically, the stochastic component refers to a function of distribution of probability able to represent randomly the occurrence of windthrow. Estate modelling refers to the development of a mathematical model able to represent a forest estate over time. Both components are integrated in order to achieve the research objectives.

Stochastic Modelling

A probability distribution able to represent the damage caused by windthrow at the forest level was created using historical data from Canterbury. The function describes frequency and intensity of windthrow over time. The development of this function was based on the approaches followed by REED and ERRICO (1986) in Canada and MANLEY and WAKELIN (1989) in New Zealand.

Occurrence

For the purposes of the study, occurrence might be understood as the time interval between two successive windthrow events. This time span is obviously not a constant behaving as a random variable. However, an average return period can be assumed in order to represent the phenomenon in the long term. A 28 year return period was assumed.

BUONGIORNO and GILLES (1987) proposed an exponential probability distribution to represent the occurrence of catastrophic events which behave according to a return period. That is, the function is able to generate random time intervals between two successive catastrophic events which in average after a large amount of observations are equal to the return period.

The function is completely defined by the parameter "m" which is the mean rate of catastrophic events per year. Then, the probability "p" of having a catastrophic event during a period of time "T" is:

$$\mathrm{P}(0 \leqq t \leqq T) = 1 - \exp(-mT) \qquad (1)$$

Rearranging terms and expressing "T" as a function of its probability gives equation (2). Thus, a random number "R" can be generated with a uniform distribution of probability and applied over formula (2) in order to calculate random time span between two successive windthrow events.

$$T = [-\ln(1-R)]/m \qquad (2)$$

where; T is the time interval between two successive windthrow events and
R is a random number on a 0-1 scale

The function was used several times in order to generate as many windthrows as required to complete the planning horizon given for the estate modelling. Fig. 1 shows the probability "P" of having a windthrow with an average 28 year return period, within "T" years.

Intensity

MANLEY and WAKELIN (1989) reported that the probability of a stand being windthrown is not constant throughout the life of a stand increasing with age. This trend has been supported by MILLER and QUINE (1991) in the UK. Table 1 shows the proportion of forest windblown by the 1975 storm at Canterbury. This function was used to determine the intensity of damage during simulation.

The intensity of damage was integrated into the model by multiplying the area of each stand by its corresponding proportion of area being windblown each time a windthrow took place (Table 1). For instance, if the age of a forest stand was 22 years old, 85% of that stand was blown down while the remaining 15% stayed unaffected. The damaged area was assumed to be immediately replant-

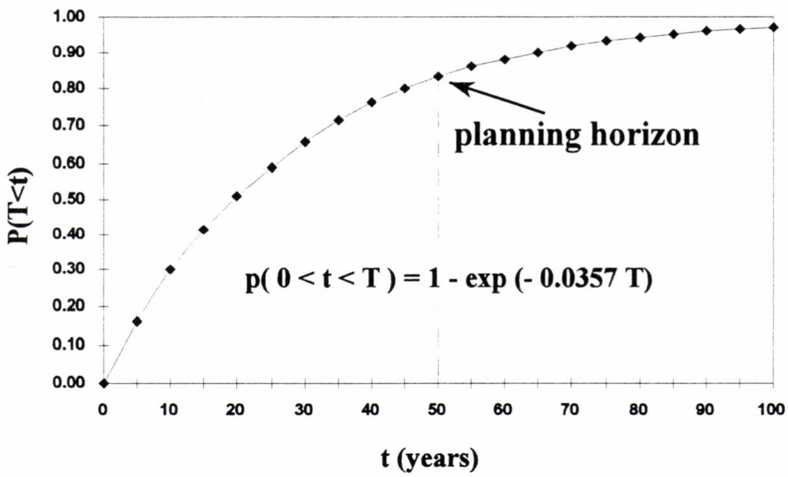

Fig. 1 Probability of having a windthrow within t years

Table 1 Area of forest being damaged by the 1975 storm at Canterbury

Age	*Proportion area windblown Canterbury*
1-5	.00
6-10	.00
11-15	.00
16-20	.53
21-25	.85
26-30	.87

Source: SPBL, pers.comm., (1995)

ed after recovery operations while the undamaged area grew according to its yield table.

Risk Analysis

Risk analysis is one of the most important and widely used applications of discrete-event simulation. Usually, the objective is to assess the desirability of a proposed investment, based upon some financial decision criterion such as net present value (NPV).

Application of the risk analysis method results in a cumulative distribution being generated for the decision criterion. As a result we can foresee not only the expected value of the decision criterion but also the likelihood of realizing a much higher or a much lower value (GOTTFRIED, 1984).

Determining the number of random events required for the desired confidence level is one of the most important considerations in discrete-event simulation. This is a two-step process. First a trial is run with 100 simulations and its mean (average) and standard deviation are calculated. Then, based on these statistics the desired confidence interval for the mean and the number of simulations required to achieve this may be estimated based on a t-distribution (GOTTFRIED, 1984).

Number of observations required $n = \left(\frac{t \times s}{x \times Y}\right)^2$ (3)

where:

- t = the t-statistic based on the desired confidence level
- s = the calculated standard deviation for the NPV in the trial run
- x = desired percentage range for the mean (e.g. 0.01 is 1 percent)
- Y = the calculated mean for the NPV in the trial run

While the NPV distribution was not symmetrical about the mean, the results of this formula were taken as a reference and arbitrarily doubled to ensure an adequate number of runs.

Forest Estate Modelling

Fig. 2 shows a diagram of the system proposed to address catastrophic risk. The system approaches the harvest scheduling problem under risk in the long term (strategic level) and therefore excessive details in the description of the forest estate are avoided. The system is based on a simulation and an optimization model (Model III). These models were created and configured to be compatible and to use common input information. This common forest description is made up of two components; namely, a description of a function of distribution of probability regarding windthrow damage (occurrence and intensity); and a description of the forest estate (areas by age

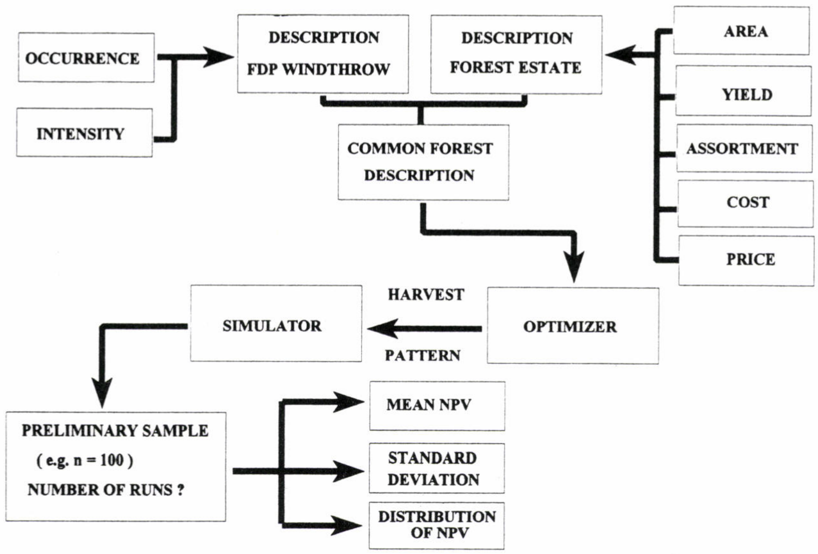

Fig. 2 Description of proposed system to address catastrophic risk at the forest level.

class within crop types, yield and log assortment, costs, prices and some financial parameters). This information is used by the optimization model in order to find an optimal solution under deterministic conditions. The simulation model reshapes the optimal solution under deterministic conditions according to "proportional rates" regarding the distribution of damage.

A preliminary sample of one hundred runs may be used to estimate a large enough number of runs in order to appropriately represent risk. The simulation model is run again for the number of runs required and based on this information, mean, standard deviation, and distribution of NPV are generated.

A frequency distribution for NPVs may be useful to support decisions because it provides an explicit quantification of risk. Management decisions involving forest estates have in the past usually been made using deterministics data. This methodology allows decision makers to predict not only the expected value but also the likelihood of realizing a much higher or a much lower value.

CASE STUDY

The model was ran using data for a portion (8,413 ha) of the forest estate owned by Selwyn Plantation Board Limited (SPBL). SPBL is a local authority trading enterprise, essentially a limited liability company owned by local government organizations. The main objective of the company is to operate as a successful business consistent with the principles of conservation and the provision of shelter on the plains of Canterbury. SPBL's estate is mostly *Pinus radiata* D. Don (radiata pine) planted largely in the Canterbury Plains. The forest estate was divided into six crop types according to differences in site productivity and management (Table 2).

There are some characteristics that make the Canterbury plains quite susceptible to wind damage. First of all, the soils are shallow and intensive cultivation in the past favoured topsoil removal. This condition brings about scarce root development facilitating uprooting. Moreover, the topography is extremely flat which favours high wind speeds as a result of a lack of barriers. Finally, the location of the Canterbury plains in the rain shadow of the Southern Alps increases the chances of strong winds.

SPBL deals frequently with windthrow that brings about significant financial losses. Unfortunately, this frequency or average return period for major wind events can not be statistically estimated because data recording gust speeds for New Zealand extends back only to 1919. However, SPBL uses a 28 year return period for its silvicultural planning because there have been 3 major storms in 83 years. We chose this for an average return period of major storms, testing it later in a sensitivity analysis.

Windthrow has a negative influence on a cash flow because it increases costs and depress revenues. After windthrow, the damaged area is harvested (recovery operation) and the site is prepared to be planted with seedlings. Since most trees are lying on the ground, recovery operations are more expensive. Moreover, a high volume of waste brings about higher establishment costs (site preparation, planting, weed control, etc.). Revenues decrease as a result of smaller volume recovered, smaller products, appearance of products, lack of markets able to absorb a large production in a short time, etc. To give some idea of the magnitude of the problem, SPBL reported that since the

Table 2 Area of forest by site, management and age class used in the case study

Age (years)	Area by croptype Radiata Pine (ha)									Total
	Hills			Plains			Sands			
	Tended	Untended	Sub	Tended	Untended	Sub total	Tended	Untended	Sub	(ha)
1-5		694.3	694.3		288.0	288.0		135.5	135.5	1,117.8
6-10		1,269.9	1,269.9		482.4	482.4		158.9	158.9	1,911.2
11-15	0.9	206.6	207.5	953.7	56.8	1,010.5	43.2	49.6	92.8	1,310.8
16-20	354.9	207.7	562.6	1,799.1	54.5	1,853.6	256.9	97.7	354.6	2,770.8
21-25	27.6	51.8	79.4	498.1	159.4	657.5	139.3	22.2	161.5	898.4
26-30		6.1	6.1	195.4	48.3	243.7	90.1		90.1	339.9
31-35							10.7	3.1	13.8	13.8
36-40				0.6		0.6	1.5		1.5	2.1
40+		0.5	0.5	24.9	0.3	25.2	4.3	17.8	22.1	47.8
Sub	383.4	2,436.9	2,820.3	3,471.8	1,089.7	4,561.5	546.0	484.8	1,030.8	8,412.6

Source: Studholme (no date).

turn of the century, 90 percent of all timber harvested in the Canterbury plains has been following windthrow (STUDHOLME, no date).

From the management point of view, the problem is very critical because it is not possible to predict when the next windthrow will strike, what its magnitude, and also how it will affect the future supply of timber and age class distribution of the forest estate. However, the phenomenon is not completely uncertain and some empirical knowledge has been collected over the years. In affected areas, trees can be either blown down or broken. Blown down trees are usually not damaged and they can be recovered in a period of less than five years. Historically, most broken trees were not susceptible to economical utilization but they needed to be felled in order to decrease the risk of harvesting operations and for establishment purposes. It has been estimated that approximately 1 of each 5 trees was broken during the 1975 storm at Canterbury (Selwyn Plantation Board, pers. comm., 1995).

Several assumptions were made to carry out the study:

- all simulations were over a 50-year planning horizon;
- time was aggregated into 5-year-periods in order to reduce the number of decision variables and because the model assumes that the period of recovery is the same as the aggregation of time;
- no price penalty was assumed for timber blown down and harvested in relation to unblown harvested timber;
- twenty percent of the timber volume was assumed to be lost due to windthrow;
- costing was kept constant;

Some fundamental data-sets, such as discount rate, costs and prices were collected, based on personal communications with staff from SPBL. The following values were used:

- a rate of return equal to seven percent
- an administration cost of NZ$122/ha/annum
- discounted tending costs ranging from NZ$ 900/ha to NZ$ 1,400/ha
- harvesting and transport cost ranging from NZ$ 30/m^3 to NZ$ 40/m^3
- timber prices ranging from NZ$ 50/m^3 for pulpwood to NZ$ 210/m^3 for clearwood

The harvest scheduling problem was optimized subject to volume and regulation constraints. Volume constraints were set up in such way that the volume from one period to the next did not vary more than 10 percent. Also, regulation constraints were set up to achieve at the end of the planning horizon at least 1,500 ha in each of the first four age classes.

RESULTS

The optimized solution produced a NPV after taxes of NZ$ 43.208 million (deterministic solution). This value did not include windthrow risk and it represents the upper limit in the NPV distribution. A forest estate simulator was used to generate NPVs under different sequences of catastrophic windthrow (stochastic solutions). The simulator was run 1,100 times estimating an average NPV after taxes under stochastic conditions of NZ $ 38.278 million. This corresponds to an average reduction of NPV after taxes of 11 percent compared with the deterministic solution.

A standard deviation for the NPVs was estimated even though the distribution was not symmetric around the mean. This value was estimated to be NZ $4.236 million. The minimum value found was NZ $ 24.152 million and the maximum was NZ $ 43.301 million.

Fig. 3 shows the frequency distribution associated with 1,100 NPVs considering NZ $ 2 million classes. The overall trend of the distribution is decreasing in relative frequency (probability) from right to left which means that there are better chances in getting NPVs closer to the stochastic maximum than to the stochastic minimum.

The lowest NPVs are related to a large number of windthrows along the planning horizon with the first windthrow usually occurring at period 1 (0-5 years). Progressively higher NPVs are found with a decreased number of windthrows and/or with the first windthrow occurring later in the planning horizon up to the point where no windthrow takes place. There are difficulties in generalizing the causes that explain the variation between NPVs under stochastic conditions. However, number of windthrows and their time of occurrence account for a great deal of the differences.

Sensitivity Analysis

The uncertainty associated with certain parameters such as establishment costs, recovery, and price discounts for recovered timber, was analyzed through sensitivity analysis. The system was very sensitive to increases in establishment costs. In fact, NPV was reduced on average 0.22 percent for each 1 percent increase in the establishment cost. Similarly, NPV was reduced 0.50 percent on average for each 1 percent decrease in the recovery factor of windblown timber. A price drop of recovered timber also significantly affected the NPV. In fact, NPV was reduced 0.4 percent on average for each 1 percent price decline following windthrow.

The sensitivity of the solution was also analyzed in relation to the return period. A trial was conducted for a return period 5 years longer and 5 years shorter than 28 years. The average NPV for 23, 28 and 33 years was almost the same. In fact, variation on average NPV between 23 and 28 years was - 1.8 percent; while between 28 and 33 years was + 1.7 percent. The range in which NPV moved for 23, 28 and 33 years was also very similar. This information suggests that the solution is not very sensitive to small variations in the return period.

Rotation Age

The effect of windthrow damage over rotation age was analyzed. Under deterministic conditions the optimal rotation age was found when trees are harvested at 28 years old while under stochastic conditions when trees are harvested at age 25. As could be expected, wind risk has reduced optimum rotation age by three years (Fig. 4).

In this case, the expected value should be the NPV of a 25 year rotation, and the gambling case should be that of a 28 year rotation because of the existence of wind risk. Risk averse decision makers should prefer a 25 year rotation because it maximizes profit given the risk, but risk lovers prefer a 28 year rotation because it maximizes profit regardless of the level of risk. Risk neutral decision makers may choose between 25 and 28 years.

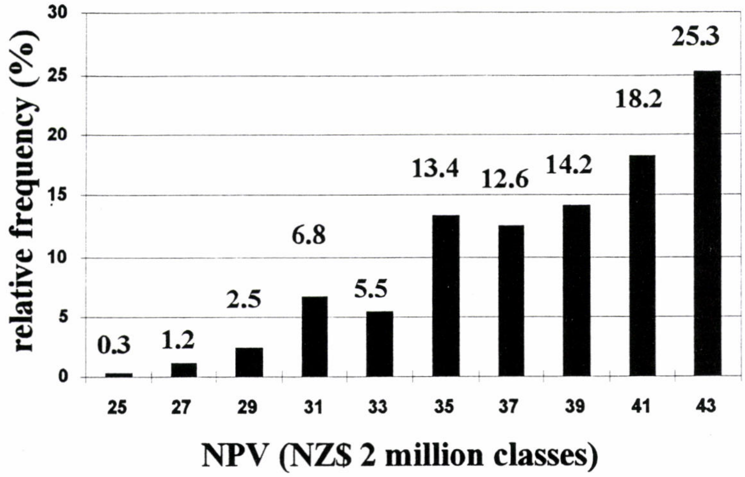

Fig. 3 NPV distribution under windthrow risk

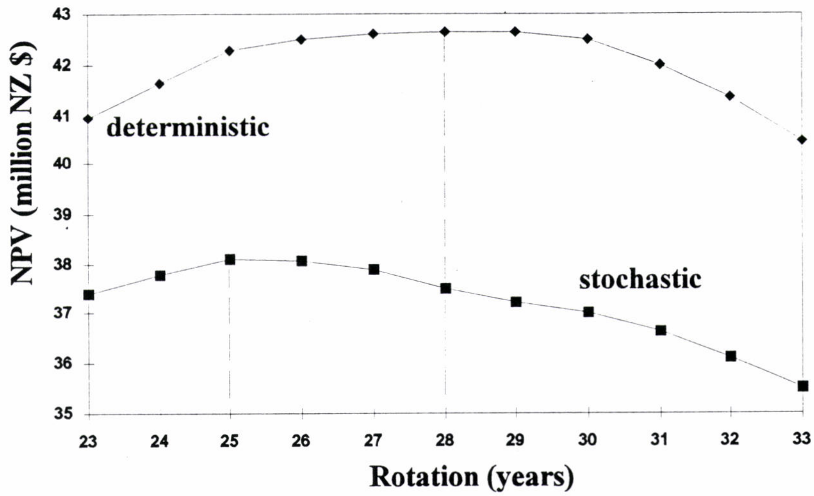

Fig. 4 Average NPVs under deterministic and stochastic conditions for different target rotations

MARTIN (1995) using a stand model at Canterbury reported that land expectation values (LEV) for rotation ages 23 to 27 are all very similar. However the risk associated with these expected returns was minimized at age 23 and maximized at age 26. The findings reported by MARTIN (1995) at the stand level as well as the findings reported in this research at the forest level suggest that rotation age should be shortened by three years. This is a result that management can use to reduce its exposure to risk.

DISCUSSION

Windthrow brings about economic losses due to reduced harvesting in the periods following windthrow, reduced recovery, increased total establishment costs (a large area must be replanted following windthrow) and the fact that trees are harvested before optimal rotation age. The financial performance of the system was reduced 11 percent on average because of windthrow over a 50 year planning horizon.

A frequency distribution for NPV was demonstrated to be useful to support decisions because it bounds the losses which could be expected and provides an explicit quantification of risk. Before, decision makers regardless of their risk stance undertook decisions based on poorer knowledge of the risks involved as well as more uncertain impacts of such decisions over the management of forest estates. Now, it is possible for decision makers to predict not only the expected value but also the likelihood of realizing a much higher or a much lower value. Also, sensitivity analysis can be used to explore the performance of the system under variation in the production factors. In this way managers would be able to analyze the impact of their decisions to minimize risk.

The overall trend of the distribution showed to be decreasing in relative frequency (probability) from right to left which means that there are better chances to achieve higher NPV outcomes than lower ones. The lowest NPVs are related to a large number of windthrows along the planning horizon with the first windthrow preferentially occurring at the very beginning of the planning horizon. Progressively higher NPVs are found with decreased number of windthrow and/or with the first windthrow occurring later up to the point where no windthrow takes place and obviously where NPVs under stochastic conditions equal the NPV under deterministic conditions.

According to the results of the study, NPV distribution is very sensitive to a variation in recovery factor and establishment costs and therefore managers should look closely to strategies to increase recovery and control establishment costs. A small increase in the recovery factor could significantly reduce the overall risk. This could be done by recovering and finding suitable use for broken trees (chips, poles, pulplogs, small sawlogs, etc). Similarly, new establishment techniques aimed to reduce costs, assisted by an improved recovery (less waste in the ground), would reduce the overall risk.

The system was not very sensitive to small changes in the return period. This is important because usually the estimation of the return period is quite difficult as a result of the lack of historical records. Thus, there is no need for a very accurate estimation of the return period to obtain acceptable results.

Risk has reduced rotation age as would be expected.

The NPV profile is a result that management can use to central and reduce its risk exposure.

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Article

Classification and Choices of Management Regimes for Marginal Timber Plantations

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ABSTRACT

As a result of increasing costs of forest management and reduced prices for timber, the area of forest land where timber plantations are managed with the expectation of profitability has declined significantly. This has made large areas of plantations 'marginal' in an economic sense. Marginal plantations can be classified into three categories ; 1) Timber plantations with no stumpage value, 2) Timber plantations with stumpage value lower than the cost of conventional high input regeneration, and 3) Timber plantations with negative expected NPVs for the next rotation. In an optimization model for even-aged forest management, forest owners should first decide the method of regeneration, assuming that the forest is clear-cut now, and then make a decision on the final cutting. Rational economic choices for management differ depending on the category of plantation. In particular, the constraints which apply to the method of regeneration have different effects in each class. For marginal plantations where stumpage value is low, the tendency for risk aversion is not significant. Given the uncertainty of timber prices in the future, it can be a rational choice for forest owners not to harvest marginal plantations immediately, but to keep the option to harvest at any time in the future. Finally, the choices for partial cutting are discussed and the question of adequate restrictions on the method of harvesting and regeneration are considered.

Keyword : marginal timber plantation, forest management, forest economics, Japan, uncertainty

INTRODUCTION

The area of timber plantations in Japan has expanded to about 10 million hectares. This constitutes about 42% of the forest area and 27% of the total land area in Japan. One third of the plantations were planted in the 1960s, one quarter in the 1970s, and about 18% in the 1950s. Only about 11% were planted before 1950. The area of potentially harvestable timbered land will significantly increase in the near future.

Currently, a large proportion of forest owners believe that plantation management is 'unprofitable', and many are reluctant to continue managing their forests. The profitability of plantations has significantly declined over the last two decades in Japan (OKA, 1996). Labor costs have increased in terms of yen and more dramatically in terms of US dollars. The growth rate of wages in Japan has been higher than in timber exporting countries, resulting in a comparative disadvantage for labor intensive forestry in Japan. The currency exchange rate has favored imports, and consumer preferences have changed in favor of imported timber as people have become accustomed to it. Thus, imports of timber have increased and local stumpage prices of timber have declined throughout the 1980s and in the first half of the 1990s.

Although a large area of timber plantations has been established, the increased cost of forest management and reduced stumpages have had the effect of reducing the area of plantations which can be expected to be profitable. Thus, a large area of plantations are economically marginal. Therefore, the area of plantations that should con-

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tinue to be managed needs to be reconsidered, and alternatives for the areas which are no longer economic should be developed.

During the course of socio-economic development and population increase in Japan, both labor and capital inputs to control forests had been increasing for more than a century. It is not necessary, however, that human control of forests keep expanding. Some people prefer semi-natural forest landscapes, and others believe, from both an ecological and economic point of view, that natural forests including secondary forests have been excessively converted to plantations (KUMAZAKI, 1989). Furthermore, an increasing number of people suffer from pollen allergies in the flowering seasons of the major plantation species, i.e. sugi (*Cryptomeria japonica*) and hinoki (*Chamaecyparis obtusa*). The government had been subsidizing the conversion of natural forests into timber plantations, but in response to the changing public interest in forests, it has decided to stop encouraging conversion of natural forests into timber plantations. If it is assumed that the demand for local timber will not increase significantly, we might be at a turning point in history where we can reduce the input to forest resources and begin to re-naturalize the forest.

The objective of this paper is to evaluate the management choices for timber plantations on marginal lands and at the standard cutting age, 50 years old, or older. In this paper, marginal plantations are 'marginal' in the economic sense. The choices for management considered here should be financially acceptable to the forest owner and environmentally acceptable to society.

CLASSIFICATION OF MARGINAL TIMBER PLANTATIONS

What kind of costs and benefits are being considered when people say that timber plantation management is unprofitable? We are going to show that marginal timber plantations can be classified into three categories of unprofitability. Inputs required in the past to establish existing plantations are regarded as sunk costs.

1) Type I: Timber plantations with no stumpage value

These are plantations which do not have a positive stumpage value. In other words, the value of the harvest would not cover the logging cost. This is seldom the case for mature plantations fully stocked with commercial species of average quality, but it may include plantations which have been damaged by unexpected natural events such as wind and snow storms, or plantations which were established on inappropriate sites. These plantations have low quality timber and/or are located in areas which are difficult to access with heavy machines.

For example, if the price of sawlogs at the sawmill gate is as low as the average for medium sized larch in 1995, that is 12,900 yen/m^3 or 28% lower than the average for small sized sugi in the same year (FOREST AGENCY, 1996), and if the logging cost for the stand is as high as the average for hinoki in 1994, that is 11,303 yen/m^3, and the transportation cost is 2,885 yen/m^3 (FOREST AGENCY, 1995), then the total cost for logging and transportation is greater than the price at the sawmill gate, which means the stand has no stumpage value. Logging costs can exceed 20,000 yen/m^3 (FOREST AGENCY, 1995), and in these circumstances, the total costs for logging and transportation are likely to exceed the average price of medium sized sugi at the sawmill gate (22,200 yen/m^3 in 1995 (MAFF, 1996)). In these cases, the forest owner would not cut timber unless it was for conversion or stand improvement purposes (see Table 1).

2) Type II: Timber plantations with a stumpage value lower than the cost of conventional, high input regeneration

These plantations have a positive stumpage value, but the total cost of conventional regeneration is expected to exceed the net revenue from the harvest. Here, the total cost includes the cost for land preparation, seedling, planting, weeding, precommercial thinning, and other direct costs for timber plantation management during a rotation, except interest on the capital. In this paper, 'regeneration cost' means these total costs of regeneration, including self-employed labor.

The total cost of conventional regeneration is extremely high in Japan. It is estimated to be about 2.3 million yen/ha for sugi and hinoki plantations on average in 1991 prices (MAFF, 1993). Consider a stand of 50 year-old sugi on a third class site which yields 280m^3/ha of sawlogs, and which is located on steep terrain about 500 meters from the nearest forest road. The total cost for logging and transportation is 12 thousand yen/m^3, or 3.4 million yen/ha. If the timber is not sold for more than 20 thousand yen/m^3 on average, or 5.7 million yen/ha, the value of the harvest does not cover the expense of regeneration, even if the cost of regeneration is supposed to be constant in the future.

Examples of type II marginal plantations include many of the larch plantations. Consider an average case for larch where the price at sawmill gate is 12,900 yen/m^3, the cost of logging and transportation is 8,277 yen/m^3, and the effective volume is 200m^3/ha. Then, the net revenue from the harvest is 0.92 million yen/ha, which is lower than the cost of regeneration.

3) Type III: Timber plantations with negative expected NPVs for the next rotation

Marginal plantations of type III have positive stumpage values and the net revenue of the harvest exceeds the expected total cost of conventional regeneration. How-

Table 1 Prices and management costs for major plantation species in Japan

	Sugi (*Cryptomeria japonica*)	Hinoki (*Chamaecyparis obtusa*)	Larch (*Larix kaempferi*)
Existing area of plantation (million ha in 1995 *1)	4.5 mil ha	2.5 mil ha	1.1 mil ha
Planted area from 1990 to 1994 (ha/5 year period *2)	89,018 ha	119,416 ha	17,695 ha
Average price at sawmill gate (yen/m³ in 1995 *3)	22,200 yen/m³	53,500 yen/m³	12,900 yen/m³
	(diameter : 14-22 cm,	length : 3.65-4.00 m	for sugi and hinoki)
	(diameter : 14-28 cm,	length : 3.65-4.00 m	for larch)
Range of logging costs	1,175-23,650	2,056-41,050	2,949-9,620
and transportation costs	926- 6,000	1,431- 4,465	1,298-3,626
for harvested stands	(Average total cost for logging and transportation)		
(yen/m³ in 1994 *4)	11,041 yen/m³	14,188 yen/m³	8,277 yen/m³
Average of total regeneration cost in 1991 prices without interest and subsidy (million yen/ha in 1991 *5)	2.2 mil yen/ha	2.4 mil yen/ha	1.0 mil yen/ha

Source: *1. FOREST AGENCY (1995) : State of Forest Resources
*2. FOREST AGENCY (1992, 1994, 1996) : Forest Statistices Handbood
*3. MAFF (1996) : Timber Demand and Supply Report
*4. FOREST AGENCY (1995) : Stumpage Price Survey Report
*5. MAFF (1993) : Forest Management Cost Survey Report

Note : Average of potential cost for logging and transportation for the whole area of plantation is higher than the average for harvested stands, because there is some evidence that the stands with easy access are more likely to be harvested than the stands with hard access (SHIRAISHI, 1994).

ever, the net revenue to the forest owner is too low, after subtracting the cost of regeneration, so the next planting is not considered to be economic. More precisely, in this case the expected NPV (net present value) of the next rotation, starting with the next planting and ending at its harvesting, is negative.

Currently in Japan, the NPV for the next rotation of a large proportion of plantations is expected to be negative under the current price systems and the conventional management regime. Suppose seedlings of sugi are replanted following harvest, if the cost and prices remain constant at 1995 levels, the internal rate of return for the next rotation will be less than 2% on a moderate site. Therefore, if forest owners do not expect a rise in the price of sugi in the future, and the guiding rate of interest for forest owners is higher than 2%, plantations of sugi on moderate sites would be classified as type III.

Classification as type I can be made using current prices only. Classification as type II is determined by current prices and expected regeneration costs, which can be estimated with reasonable accuracy. Classification as type III depends on the expected net return of the next rotation, which is quite uncertain.

It should be noted that these plantations might change their status in the future, for example, from type I to type II, or from type II to type III, by revaluation or by growth of the timber, and prime timber lands can be managed profitably.

Unfortunately, a firm estimate of the area of each type of marginal plantation in Japan is difficult to make. It is sure, however, that a substantial area of plantations in Japan are now marginal and this area is increasing, although the majority of plantations may be classified as type III.

DECISION STEPS IN AN OPTIMIZATION MODEL FOR EVEN-AGED FORESTS

In even-aged forest management systems, most important decisions for the next rotation, including the selection of species to grow, should be made in combination with the decision of the final harvest, no matter how it is hard to estimate and compare the future benefits of each possible regeneration system. If we want to control the species composition of the forest, the best opportunity is at final harvest. In even-aged management systems, this is the only opportunity (OKA, 1995).

The forest owner's decision about the final harvest must consider the method of regeneration and its cost, although the benefits of regeneration will not be obtained until the next rotation. Given a piece of bare land after a clear-cut, the income from the previous harvest does not directly affect the choice of regeneration method, at least in optimization models.

The income from the previous harvest may indirectly affect the choice of regeneration method because of the difference it makes to the forest owners' financial status, expectation for the value of the next harvest, and perhaps his feelings for the land. If the forest owner is in debt, for example, he is less likely to choose a more expensive regeneration method. However, his financial condition is only partly determined by the income from the timber harvest. Furthermore, expectations about future prices are not only determined by the current price, but also by the long term trends in price and by the long term prospect for changes in technology and the market.

In optimization models for even-aged forests, forest owners should first decide the method of regeneration considering the expected cost and benefit during the next rotation, assuming that the forest is clear-cut now and that the forest owner's financial condition after harvest is known. The decision about the final cutting can then be made, with the method of regeneration determined in advance. The decision about harvests in the future can be tentative.

ECONOMIC CHOICES FOR THE TREATMENT OF EVEN-AGED MARGINAL TIMBER PLANTATIONS

At the beginning, it is assumed that all plantations will be managed by conventional even-aged forest management systems for as long as they are managed. There are three management choices : (a) clear-cut followed by conventional regeneration by planting, (b) clear-cut followed by natural regeneration, i.e. minimum-cost regeneration, or (c) leave it to natural processes without harvesting, which means to cease timber management until the conditions for management change significantly.

Note that actions (a) and (b) do not have to be done immediately. Forest owners may not fix a time to harvest, but might wait until a favorable time. In such cases, the distinction between choice (a) or (b) and choice (c) is only the changeable intention of the owner, which might be observed by the difference in reactions to predictable damage to the timber.

Although the regeneration method in choice (b) is defined as natural regeneration, it may be assisted by human intervention. The important point is that the cost of regeneration in choice (b) is considerably lower than the cost of conventional regeneration by planting. In other words, regeneration in choice (b) is low input regeneration, compared with high input regeneration in choice (a).

In some cases, forest owners are legally obliged to replant after harvesting. Moreover, many forest owners believe that planting is their duty after clear-cut, even if it is not a legal requirement. There is also social pressure for forest owners to plant seedlings after harvesting.

Now, the economic choices for the treatment of each category of marginal plantation will be evaluated (see Table 2).

1) Type I : Timber plantations with no stumpage value

Principally, the third choice, "leave it to natural processes without harvesting" is the only economic treatment for this type of plantation. If, and only if, the re-establishment of the plantation is likely to be successful not only in physical terms but also in economic terms, it should be planted all over again. It is also possible that this type of forest might change status to type II or type III, following revaluation or further growth of the forest. The decision to "leave it to natural process without harvesting" can be tentative.

2) Type II : Timber plantations with stumpage values lower than the cost of conventional high input regeneration

The second choice "clear-cut followed by natural regeneration, or minimum-cost regeneration" is financially the best choice for this type of forest. For economic purposes, plantations should be harvested before trees begin to die, if the stumpage value is significantly larger than the

Table 2 Classification of marginal timber plantations

	Relationship of cost and revenue	Choices of management regimes with and without duty to replant: Without duty	With duty
Type I	Stumpage value = 0	No operation	No operation
Type II	0 < Stumpage value < Cost of regeneration by planting	Cut and natural regeneration	No operation
Type III	Cost of regeneration by plantiong < Stumpage value and Cost of regeneration by planting > Expected discounted revenue during the next rotation	Cut and natural regeneration	Cut and plant

expected cost of regeneration. Note that the regeneration cost can be arbitrarily small, if there are no constraints on the method of regeneration. The optimal cutting age for this type of forest might be quite old, because the growth in timber value begins at older ages and rents for such forest lands must be low if the rent is determined by value of the land for timber production.

If the forest owner must plant again after harvesting, however, the net result of harvesting is an economic loss. In such cases, the third choice "leave the forest to natural processes without harvesting" is the best choice for the forest owner.

3) Type III : Timber plantations with negative expected NPVs for the next rotation

Choice (b) is financially the best choice for this type of the forest. However, if planting is compulsory after harvesting, the second best choice for the forest owner is the first choice "clear-cut followed by planting". Even though expected net present worth of the next rotation is negative, the expected net income through the combination of clear-cut and replanting is positive, and is better than to do nothing (OKA, 1995).

According to the decision steps for even-aged management, the regeneration method should be decided before the decision to harvest. If natural regeneration is selected, the distinction between type II and type III forests is not significant. On the other hand, if the forest owner is obliged to replant after final harvest, the distinction between type II and type III is crucial.

EFFECTS OF A DUTY TO REPLANT AFTER CLEAR-CUT

It is shown above that an obligation to replant after harvesting will affect a forest owner's decisions about the level of timber production and the state of the forest in the future. If replanting is required, plantations of type II will never be harvested, as long as it remains as a type II forest. For type III forests, the owners are forced to continue plantation management for the next rotation, even though they cannot expect sufficient return from it. In these cases, a longer rotation age will be selected, because the expected net present worth of the next rotation is negative, and hence, it is rational for the owner to postpone it.

It should also be noted that if replanting is a duty and the net present worth of the next rotation is negative, the forest value including the value of the standing trees and the forest land can be lower than the value of the standing trees only. These negative effects on forest value should be reflected in the property evaluation for taxation. The same is true for type II marginal plantations, where timber use value becomes null by the duty.

The effect of the duty to replant is to make type II marginal plantations drop out of the category of production forests, to make the rotation of type III plantations longer, and consequently, the level of timber production lower, while the area of stands in older age classes increases.

Recently, substantial areas of private forest land have been planted after harvesting with funding from public forest improvement corporations and the Forest Development Corporation under a proceeds-sharing system. This kind of transfer of management suggests that the owners of such forest lands believe that expected NPV for the next rotation of plantation management is negative. The total area planted by public forest improvement corporations and the Forest Development Corporation was 164,648ha during the period from 1985 to 1994, and the area planted privately in the same period was 301,672ha (FOREST AGENCY, 1996). Funding of regeneration by public corporations removes the financial burden of regeneration from the private owners of marginal timber lands, and is similar to the case of minimum-cost regeneration.

Thus, we conclude that marginal plantations of type I and type II which must be replanted at the owners expense will not be managed for timber production, as long as their status does not change significantly. However, most marginal plantations should be harvested before the standing trees decay. This is the rational choice for the forest owner based on a financial analysis.

The remaining problems to be discussed are harvest scheduling in relation to the prospects for future values, and adequate determination of the constraints on the methods of harvesting and regeneration of plantations to be harvested. After this, the management of marginal plantations which should be harvested will be considered.

HARVEST SCHEDULING WITH CONSIDERATION OF RISK AND UNCERTAINTY

The relative costs of harvesting and regeneration compared to timber sales are higher for marginal plantations than for prime timber lands. Stumpage values for marginal plantations do not begin to improve until the trees are older, so the economic cutting age tends to be higher than in prime timber lands (RYUKO, 1989). This is even more apparent if planting after harvesting is required of the forest owner, because his timber sales income, net of regeneration cost, turns positive at a higher age than is the case without such duty. In a deterministic model, therefore, it is rational to set the cutting age for marginal plantations higher than the standard cutting age for prime timber lands.

The risk of wind and pest damage is higher in long rotation systems. If the owner decides to harvest the timber sooner, his income is guaranteed. The decision to harvest later makes the income less certain because the risks of wind or pest damages, or price changes are greater. If the owner has an immediate need for income from his timber lands, even if the absolute profit may be small, he may choose to harvest immediately to ensure an income.

On the other hand, if the owner has enough income from other sources, he may choose to postpone the final harvest. While the risks of wind and pest have only negative effects on the forest value, future price changes may have a positive influence on the timber value. Timber prices may rise significantly, and even in the worst case, standing timber would not usually be valued negatively. It means that there is an upper limit for the loss of property value caused by price changes and natural disaster, which is higher on prime timber land, where large revenues are expected from the timber harvest. The limit is lower for marginal timber land.

In marginal plantations, where the owner cannot expect a large net income in the near future, the tendency for risk aversion might be minimal, because the smaller the magnitude of the risk relative to one's income and/or wealth, the less one is concerned with risk. This is commonly observed amongst private forest owners in Japan at present. By deciding not to harvest now, the owner has the option to harvest at any time in the future, unless the forest is damaged severely by wind, pest, or other destructive forces. For many forest owners, this option may be more important than attaining the small amount of income that is available immediately.

Thus, in addition to the effects of relative costs and returns, the decline in the relative importance of income from timber reduces the risk aversion of forest owners, and hence, extends the delay until harvest. Furthermore, consideration of risk and uncertainty exaggerates the difference in the economic cutting period between prime timber land and marginal timber land, because the upper limit for the potential loss of property value as a result of price change and natural disaster is lower on marginal land.

CONSIDERATION OF CASES WHERE PARTIAL CUTTING IS APPROPRIATE

For simplicity, only even-aged forest management has been considered so far in this paper. Now, the cases for partial cutting should be examined. There are many partial cutting systems, including a variety of selection systems, shelterwood systems, and small scale strip cutting systems (OGANE, 1981). However, partial cutting systems are, for simplicity, categorized in this paper as : (d) partial cutting followed by planting, and (e) partial cutting followed by natural regeneration.

As above, natural regeneration following partial cutting may be assisted by human intervention. The important point is that the cost of regeneration in choice (e) is considerably lower than the cost of regeneration by planting in conventional two-storied plantation systems, which is a typical system of choice (d). In other words, "natural" regeneration (choice (e)) is highly dependent on natural processes.

The comparative total costs of harvesting and regeneration for all options are assumed to be as follows;

$$\begin{matrix} C(\mathrm{a}) \\ C(\mathrm{d}) \end{matrix} > C(\mathrm{e}) > C(\mathrm{b})$$

where $C(\mathrm{a})$ is the total cost of clear cutting and replanting per unit value of harvest, $C(\mathrm{b})$ is the total cost of clear cutting and minimum-cost regeneration per unit value of harvest, $C(\mathrm{d})$ is the total cost of partial cutting and the next planting per unit value of harvest, and $C(\mathrm{e})$ is the total cost of partial cutting and natural regeneration per unit value of harvest. The relationship between $C(\mathrm{a})$ and $C(\mathrm{d})$ is not clear.

$C(\mathrm{a}) > C(\mathrm{e})$ and $C(\mathrm{d}) > C(\mathrm{e})$ means that regime (e) is financially better than choices (a) and (d) if the next rotation is assumed to be unprofitable.

ENVIRONMENTAL CONSIDERATIONS AND RESTRICTIONS ON THE METHOD OF HARVEST AND REGENERATION

What kind of constraints, if any, on the method of harvest and regeneration are appropriate for the public interest? Although $C(\mathrm{e}) > C(\mathrm{b})$, partial cutting may be better than clear cutting in terms of environmental effects, or natural regeneration after clear-cutting may be perceived negatively by the public and be restricted. In these circumstances, choice (e), which is the second best financially, is an alternative.

If natural regeneration after partial cutting is allowed, or if a socially acceptable method of minimum-cost harvesting and regeneration is established, some parts of marginal timber plantation of type II can be harvested. The decline of values of type II and III plantations would then be minimized, and the reluctance to harvest due to the duty of unprofitable planting would also be minimized. In this case, the economically feasible level of timber production would be higher, at least for the 50 years' planning horizon, than in the case where natural regeneration is not allowed.

For marginal plantations of type II, if choice (e) is not allowed, choice (c) will be selected. Partial cutting and natural regeneration may convert the forest to a mixed forest, in which the volume of timber stock is lower than the original timber plantation, but biodiversity will be increased. From the ecological or environmental point of view, and considering the long term effects, it is not clear which is better; choice (e) or do nothing and leave the timber plantation to natural processes.

For marginal plantations of type III, if choice (e) is not allowed, choice (a) or (d) will be selected. From the ecological or environmental point of view, and considering the long term effects, again, it is not clear which is better; choice (e) or to continue the conventional monocultural plantation management.

If a reliable technique of natural regeneration or minimum-cost regeneration for plantations were established, choice (e) would be better than choices (a) or (d) for the management of marginal plantations. Unfortunately, we have not yet established any reliable silvicultural guidelines for this.

CONCLUSIONS AND POLICY IMPLICATIONS

Some people, including many foresters, may be emotionally opposed to reducing the human control of nature and perhaps implicitly believe that once timber plantation established, they should be managed as timber plantation indefinitely. It should be remembered, however, that about a half of the existing area of softwood plantations in Japan were newly established between 1950 and 1980, when there was an exceptionally large amount of surplus labor in forested regions in Japan. Management of timber plantations over such a large area may be achievable only in unusual historical conditions.

The area of forest land where the next rotation can be expected to support the owner financially has been significantly reduced because of the changes in the socio-economic conditions for forestry. If the demand for local softwood products does not significantly increase in the long run, and conventional high-cost management cannot be continued in marginal areas, the natural choice will be to switch to management systems which are more dependent on the autonomic functions of the forest ecosystem, while making wise use of the trees already planted.

However, we do not have enough knowledge about the ecological processes of low-input labor-saving regeneration after partial or clear-cutting of plantations in Japan. There is a wide range of harvesting and regeneration systems that could be used, and a wide variety of sites where they could be applied.

Where natural regeneration is undertaken, the process of regeneration should be carefully monitored. The change from timber plantation to mixed forest by partial cutting and natural regeneration will hopefully be slow enough to avoid the risk of rapid environmental changes, as well as allowing the best use of standing trees in plantations.

In recent years, the annual harvested area of plantations has been less than 1% of the total plantation area. In addition, economic cutting ages of marginal plantations are higher than for prime timber plantations, as demonstrated above. In many cases, a cessation of timber harvesting is reasonable for marginal plantations, particularly if the stumpage value does not cover the expected cost of regeneration. By comparison, most areas of prime timber land will be planted after harvesting if there is a reasonable subsidy. Therefore, even if natural regeneration of timber plantation was allowed, it is unlikely to cause changes over a large area in a short period. With careful monitoring, it may be possible to learn and improve the methods for harvesting and regeneration to maintain forest ecosystem health.

There may be a gradual cessation of management of marginal timber plantations in the future. Forest owners should expect to continue to have some responsibility for regeneration after final harvesting, especially in areas with important environmental values. The process of change should be ecologically sound and acceptable by the forest owner as well as by society. Silvicultural techniques which require lower inputs and are more dependent on the natural processes of the forest ecosystem should be developed for marginal plantations by carefully monitoring the effects of forest operations on the forest.

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Article

Suitability of Long Rotations in Snow Risk Areas
—— A Stochastic Simulation of Timber Plantations ——

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ABSTRACT

In this study, we evaluate the risk of snow damage to sugi plantations in Japan. We examine the optimal rotation age (ORA) which maximizes the land expectation value (LEV), and the economic effects of snow damage. We considered two types of stem breaking damage. One is the thinning type and the other is the domino type of damage. In the case of the thinning type, if there are subsidies or higher prices, long rotations are suitable. This is because the damage ratio is lower in stands. In the case of the domino type damage, the ORA is similar to cases without damage. Snow risk has two apparently contradictory effects. One is a rotation shortening effect - harvest before the stand is damaged by snow. The other is a rotation lengthening effect, i.e. harvest later to recover, the increased management costs of snow damage. If the probability of snow damage is high for matured stands, a shorter rotation is advantageous, even in cases of thinning type damage. This is similar to the case of forest fire in preceding studies. However, if the probability of snow damage is lower for mature stands, the rotation shortening effect is often cancelled out by the rotation extending effect of increased management costs. Furthermore, if damage ratios in the stands over 30 years old are sufficiently low, even where there is domino type damage, the ORA is higher than in stands without damage under subsidy or higher price. From this, it is clear that the damage ratio at older ages is a key factor determining rotation age.

The decrease in LEV following domino type damage is twice as much as that of thinning type damage. In cases, where the probability of domino type damage and damage of older stands can not be reduced to reasonable levels at a reasonable cost, natural forest management may be more appropriate than plantation management.

Keyword : the risk of snow damage, land expectation value, stochastic simulation, optimum rotation, damage ratio by age class

INTRODUCTION

Plantation forestry is exposed to several kinds of risks, including those caused by natural disasters, such as windthrow, snow damage, freezing damage and drought. Snow damage is the most serious risk to plantation forestry in Japan. According to a summary of damage to forests due to natural disasters over 30 years ("The Statistics of National Forest Insurance", Forest Agency, 1965 to 1994), the total damaged area was 243,000 ha by snow, 208,000 ha by fire, 94,000 ha by freezing, and 76,000 ha by wind. This paper concentrates on the risk of snow damage.

Many studies on snow damage have been done in Japan. Most evaluated silvicultural methods to establish sugi (*Cryptomeria japonica*) or hinoki (*Chamaecyparis obtusa*) plantations in snowy regions. Sugi and hinoki are the most common softwood species for plantation establishment in Japan. Young plantations frequently suffer toppling, stem butt crookedness or death as a consequence of snow damage. In snowy areas, this damage can be so frequent that trimming, supplementary planting or propping up bent trees is needed to grow timber commercially. In the middle-aged plantations, stem breakage and uprooting occurs. Such damage does not occur so frequently, even in snowy areas, but the economic loss is serious if it does occur.

As far as the silvicultural techniques are concerned,

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longer rotations seem appropriate for snowy regions (FUJIMORI, 1987), because the risk of damage is lower in older plantations. In the long rotation system, forest owners can save recovery cost for the young stands per unit of harvest. However, if a long rotation is chosen, the possibility of damage increases, since it takes longer for a forest to be harvested. BUONGIORNO and GILLESS (1987) presented a simple simulation model considering the risk of fire, and showed that shorter rotations were more appropriate. REED and ERRICO (1985) also found a similar result. Both studies assumed that the whole stand would be destroyed by fire if it occurred, and that there are no difference in the probability and extent of damage among age classes of the forest. We have different assumptions on some of these points.

In this study, we evaluate the risk of snow damage. We examine the optimal rotation age (ORA) which maximizes the land expectation value (LEV), and the economic effects of snow damage on plantation forestry. Recently, the average age of harvesting of plantations has become older because of changes in the economic background, such as decreasing log prices and rising labor costs. Therefore, it is important to investigate whether long rotations are appropriate in the presence of risks, and to clarify when they are appropriate. Since few attempts have so far been made to evaluate these matters, this study might throw new light on the study of risk analysis.

STUDY AREA AND CONDITIONS

Honshu island, the main island of Japan, can be roughly divided into two parts by the amount of snowfall. On the Pacific side, there is usually little snow but if there is heavy snowfall and strong wind the snow damage can be serious. On the Japan Sea side, there is a lot of snow but relatively little damage. This is because a snow resistant variety of sugi has been planted and damage prevention techniques were introduced earlier.

Satomi village and Tanagura town were selected as the study sites. The towns are located in northern Ibaraki and southern Fukushima, respectively, and both are in a similar climatic zone on the Pacific side of Japan (Fig.1). This area has abundant sugi plantations. It has snowfalls several times every year and stem bending damage sometimes occurs. It suffered severe snow damage in the winter of 1980 - 1981 and there was stem breakage, which is the typical type of snow damage in Japan. We focus on sugi plantation to analyze the effects of snow damage on forest management, because sugi is the most common plantation species in this area. This study is representative of the characteristic snow damage on the Pacific side.

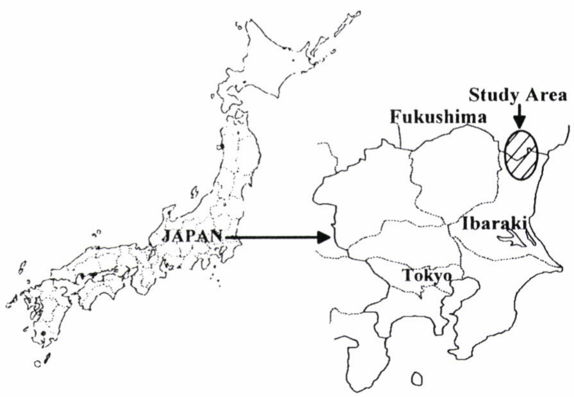

Fig. 1 Location of the study area

Types of Snow Damage

There are two types of snow damage. One is stem bending which is the result of the snow load causing the tree to bend. This occurs in stands between 6 and 15 years old. Stem of some young trees are bent, but most trees survive because uprooting occurs rarely. The damage is repaired by picking up the bent trees by rope. On average, the operation takes 6.7 man-days per hectare. This type of damage occurs 7 times in 25 years, according to a forest owner in the study area (KUBOYAMA, 1994).

The other type of damage is stem breakage. This only occurs rarely but causes serious damage. There is only one record of it in the study area in 30 years, but some local old men recalled two or three events this century. WATANABE *et al* (1986) reported that it seems to occur approximately once per 20 years. However, the probability of its occurrence is unclear, so for the sensitivity analysis, we assumed four levels of probability, once per 5, 10, 20, and 40 years. This type of snow damage causes not only stem bending among 6 to 15 year old trees but also causes stem breakage and uprooting among trees over 10 years old. The stem breakage and uprooting kills the trees, making them virtually worthless. Trees killed by stem breakage need to be removed to prevent secondary disasters.

The cost of the operation to pick up young trees is assumed to be the same as in the case of stem bending damage. The cost of removing trees with broken stems over 10 years old is calculated from "the record of remarkable snow disaster of Fukushima prefecture in the winter of 1980 to 1981" (1983). Fig.2 shows the ratio of destroyed trees by age class. This distribution is similar to the results obtained by other studies. The ratio is high among trees below 35 years old compared with trees above 35 years old. This is one of the reasons some researchers support longer rotations in snow risk areas. In our simulation model, we determined the proportion of broken stems in a stand on

Table 1 Schedule of tending and harventing

Age	1	2~8	13	18	25	30	40	50	60	70	80
Operation	Planting and Weeding	Weeding	Improvement cutting	Improvement cutting	Improvement cutting	Thinning	Thinning or Harvesting	Thinning or Harvesting	Thinning or Harvesting	Thinning or Harvesting	Harvesting
Number of standing tree (before thinning)	350		2850	2175	1698	1360	947	724	587	495	429
D.B.H of dominant trees (cm)							24.9	29.2	33.1	36.6	39.7
D.B.H of sub-dominant trees (cm)						15.7	19.5	23.0	26.1	28.8	
Thinned volume (m^3/ha)						72.4	69.4	65.4	60.8	56.2	
Harvested volume (m^3/ha)							428.7	515.7	592.0	658.6	717.2

Note : Removing trees is additionally needed when snow disaster occurs.

the basis of this distribution.

We also divided stem breakage into two classes of stand damage. The first class is the type of scattered damage that has an effect in the stand like thinning. This type of damage only requires a sanitary operation for its repair. The second class is the type of damage which causes a small cluster of trees to collapse, like a small scale clear cut. To be repaired, both a sanitary operation and replanting are required. These two classes of damage are referred to as the thinning type and domino type, respectively. In the simulation, we assume that either type can occur.

Forest Management Regime

We assume that the forest owner establishes their sugi plantation by planting seedlings on one hectare of bare land and follows the schedule of tending and harvesting shown in Table1. This schedule is based on the yield table for sugi stands on moderate sites (Forest Agency and Forestry Institute, 1955), as well as on the results of interviews held in the study area. When the stand is harvested, seedlings are replanted in the following year, and the forest owner continues management under the same schedule.

Economic data for the simulation was collected in the study area. Reforestation costs were obtained from the Forest Owner's Cooperative of Satomi village for 1993. Logging costs are those from a typical moderate case; clear cutting 50-year-old sugi with a yarding distance of 200 m in Tanagura town. Revenues from thinning and harvesting are estimated using volumes from yield tables and the market price of roundwood summarized by Maebashi Regional Forestry Office.

STRUCTURE OF THE SIMULATION MODEL

Snow damage, both stem bending and stem breakage is assumed to be random events which are observed in the distribution of the damage occurrence (Kuboyama, 1994). To assess the effects of such stochastic snow damage, we developed a simulation model following a Monte Carlo approach. In the model, we calculate land expectation value (LEV) for a range of rotation ages to examine how snow damage influences the value of a plantation and how the plantation should be managed to maximize the expected net return. We use a discount rate of 2.6%. This rate reflects the long term real discount rate calculated from the average rate of return from government bonds over 10 years and the average rise in the consumer price index between 1972 and 1993. Inheritance and land taxes are not considered in this study.

The names and definitions of the variables used in the simulation model are as follows:

t = current year (t = 1, .., 560)

r = discount rate = 0.026

y = tree age (y =1, .., h)

h = rotation age

($y = t$ for $t < h$, $y = t-h$ for $h < t < 2h$,...)

D_t = damage type (D_t takes 0, 1 or 2, representing no damage, stem bending snow and stem breakage, respectively)

$d(y, D_t)$ = damage ratio at age y ($d(y, 0) = d(y, 1) = 0$)

(cf. Fig.2 ratio of stems broken by age class)

$n_t(y, D_{t-1}, D_{t-2}, \ldots)$ = number of standing trees per hectare

$p(y)$ = average price of logs harvested from forest at

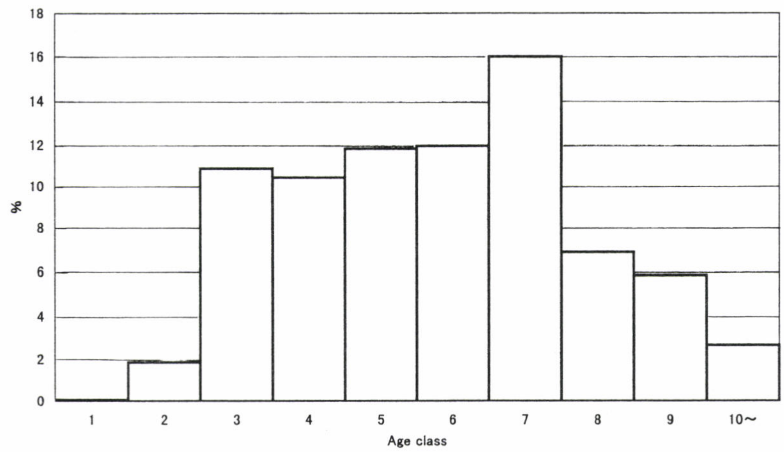

Fig. 2 Distribution of the ratio of broken stems by age class
Note: Data collected in the Abukumagawa planning unit of the National Forest in the fiscal year of 1980.

age y (Yen per cubic meter)

$T_t(y, n_t)$ = thinned volume at age y (cubic meters per hectare)
(cf. Table 1., schedule of thinning)

$H_t(y, n_t)$ = harvested volume at age y (cubic meters per hectare)

R_t = revenue obtained at year t (Yen)

L = log production cost at final harvest (Yen per cubic meter)

L' = log production cost at thinning (Yen per cubic meter)

Here we assume : $L'_t = 1.2 \cdot L_t$

$CR_t(y)$ = reforestation and tending cost at age y (*Yen per hectare*)

$CS_t(y, D_t)$ = costs of repair following a damage event (Yen per hectare)

r, h, p, L, and L' are assumed to be constant for the period of our simulation.

At the time of thinning, the number of standing trees is mostly a function of age y. However, it can be changed by stem breakage:

$$n_t = (1 - d(y, D_{t-1})) \cdot n_{t-1} \qquad \text{for } D_{t-1} = 2.$$

For example, the standard number of trees in a stand between 30 years old and 39 years old is 1,360 stems per hectare. If there are 892 stems left following stem breakage by snow, the thinning due at 40 years (if the planed rotation age is more than 50 years) will be skipped, because there are fewer remaining stems than the target residual stocking for the thinning operation (947).

The volume from thinning and harvesting operations depends on the number and age of standing trees. The revenue and LEV are determined by the following formulations:

$$R_t = H_t(y, n_t)(p(y) - L) + T_t(y, n_t)(p(y) - L')$$

$$LEV = \sum_{t=1}^{560} (R_t - CR_t(y) - CS_t(y, D_t)) / (1 + r)^t$$

Some other variables are added in the case of domino type damage: i means number of sub-compartment, which takes a value between 1 and s. $x_{i,t}$ is the area of the i th sub-compartment (ha).

At the start of the simulation, it is assumed that there is only one compartment, thus the initial value of "s" is unity. But after an event of snow damage causing stem breakage, a sub-compartment defined as a result of the recovery reforestation needed to repair the area of collapse. The area of the new sub-compartment is equal to the damaged area of the primary stand, and in the year following the disaster, y =1 for the sub-compartment. If there is further snow damage, both compartments can suffer damage, the extent of which depends on the age of each stand. The value of "s" then becomes three, and the area of the new sub-compartment is the summation of the damaged area in each compartment. This procedure is iterated on for every stem breakage event. Therefore, the final harvested volume, $H_{i,t}(y_i) \cdot x_{i,t}$, is a function of the area of each harvested sub-compartment. The area of stands, revenue, and LEV are calculated as follows:

$$x_{s+1,t} = \sum_{i=1}^{s} x_{i,t-1} \cdot d(y_i, D_t) \quad \left(\sum_{i=1}^{s} x_{i,t} = 1\right)$$

$$R_{i,t} = H_{i,t}(y_i) \cdot x_{i,t} \cdot (p(y_i) - L) + T_{i,t}(y_i) \cdot x_{i,t} \cdot (p(y_i) - L')$$

$$LEV = \sum_{t=1}^{560} \sum_{i=1}^{s} (R_{i,t} - CR_{i,t}(x_{i,t}, y_i) - CS_{i,t}(x_{i,t}, y_i, D_t)) / (1 + r)^t$$

The number of observations in the stochastic simulation is set at 300. Each run is calculated with different series of random numbers. This allows us to estimate the mean LEV and its interval with sufficient confidence. The time horizon is set at 560 years. This is also large enough to approximate the case of an infinite time horizon.

Deterministic solutions which assume no disasters or damage are also calculated. We call these the cases of no damage.

RESULTS

To evaluate various economic situations, we considered four scenarios and compared the results of the analyses. The four scenarios were; (1) basic case, using current levels of costs, prices, and the probability of snow damage; (2) subsidized case, which includes subsidies for planting, weeding, improvement cutting; (3) higher price case, which assumes a log price 2.5 times higher than the price in 1993; and (4) non-declining damage ratio case, which assumes that the damage ratio for a stand over 35 years old is constant at 6.8 % and which includes subsidies (MOLL and CHINNECK, 1992). For each scenario, a sensitivity analysis is also made to examine the effect of different probabilities of stem breaking snow damage on optimum rotation age (ORA) and land expectation value (LEV).

In the basic case, snow damage did not significantly affect ORA. The reduced damage ratio in forests over 35 years old did not change the ORA. This may be because the advantage of a longer rotation is canceled out by sharply diminished volume increments and ceiling price of timber in forests over 70 years old (Fig.3.)

However, the LEV was decreased significantly by snow damage, especially by domino type damage, even if the occurrence was only once per 40 years. In addition, most of the curves, except for No damage and T5, lie below the horizontal broken line, which represents the LEV for coppice management of hardwood forests to produce pulp. We assume that the coppice is managed under 30 year rotation and that the coppices suffer no damage from snowfall. The LEV for this regime was estimated from the data collected in Fukushima prefecture.

Fig.4 shows the results for the subsidized case. The subsidies cover more than half the reforestation costs; i.e. about two thirds of the total costs of planting, weeding, improvement cutting, and thinning trees to 30 years old. It also covers a large part of the costs of sanitary logging and reforestation of damaged areas. This shifts the LEV for each scenario well into the positive and above the LEV for

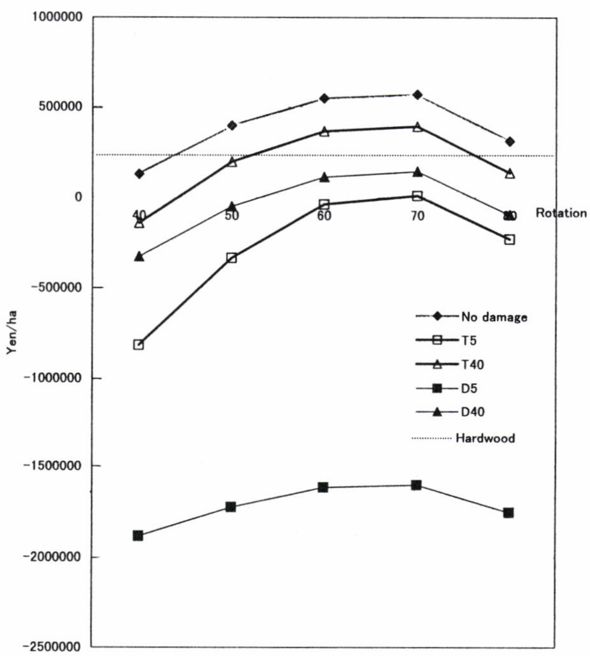

Fig. 3 Changes in LEV with rotation age for the basic case
Different scenarios are shown, including the scenario where there is no damage (-◆-). The squares represent cases where snow damage occurs every five years on average. The triangles represent cases of damage every 40 years. The solid symbols (D in the legend) represent domino type damage. The unfilled symbols (T in the legend) represent thinning type damage. The broken line represents the LEV of hardwood forest managed under a coppice system for pulp production.

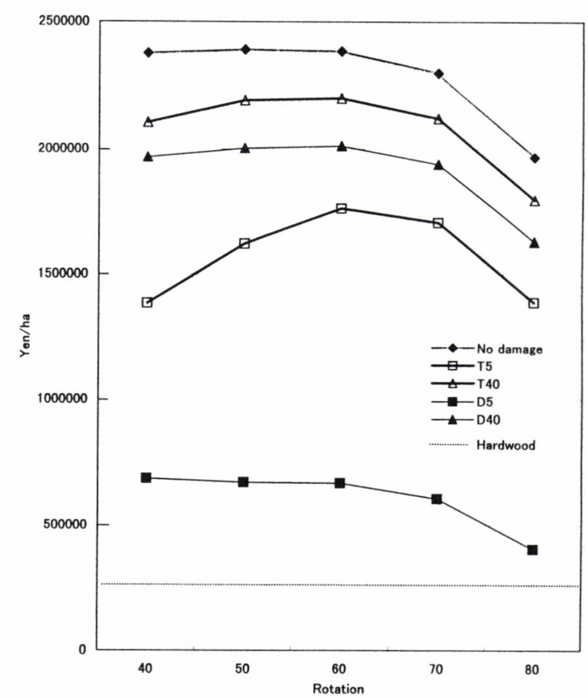

Fig. 4 Changes in LEV with rotation age for the subsidized cases.
Symbols as per Fig. 3

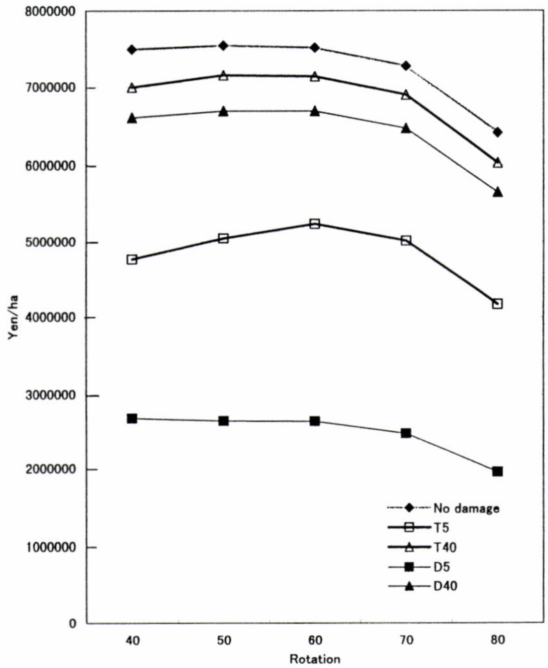

Fig. 5 Changes in LEV with rotation age under higher prices.
Symbols as per Fig. 3

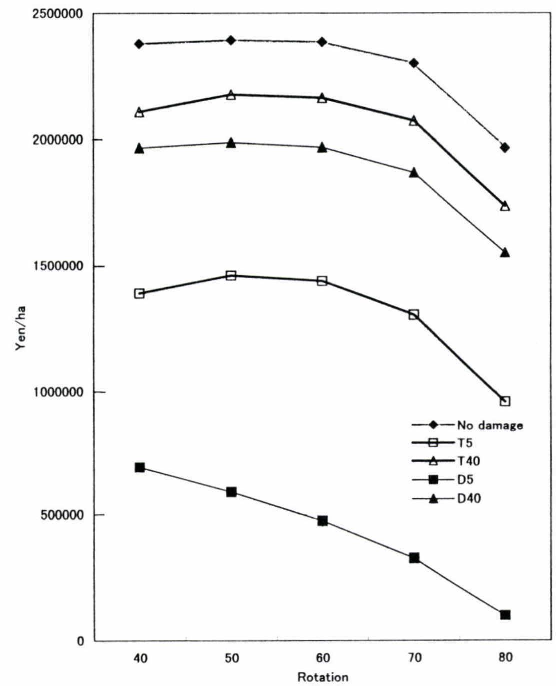

Fig. 6 Changes in LEV with rotation age for constant damage ratios.
Symbols as per Fig. 3

hardwood. The ORA for the no damage case and the domino type cases are 50 years, but the ORA for thinning type cases are 60 years. This suggests that frequent thinning increase the ORA. This shows the suitability of the longer rotation in snowy areas with thinning type damage.

Fig.5 shows the results for the higher price case, in which we assume log prices 2.5 times higher than the 1993 price. This assumption seems unreasonable, but it compares to 1963, when the ratio of the average value of standing timber of sugi divided by reforestation cost without interest was 8.0. In this model, this ratio is 8.5, although under current price structures, the ratio is 2.9. Since the ORA is determined by the relative value of revenue over cost, if revenue, cost and interest rates are constant, it can be assumed that forest owners of the early 1960's decided their harvesting schedule on a similar basis to the assumptions of the higher price cases. Therefore, the result of the simulation for this scenario may reflect the situation in early 1960's.

Fig. 6 shows that the ORA became lower as the price increased. These results are similar to those of the subsidized cases. The ORA is about 50 years for the case of no damage, but the ORA for the case of T5 is 60 years. It suggests that frequent thinning type damage keeps ORA at a higher level.

Various parameters were assumed to be constant through the simulation. We can change them, however, and observe how they affect LEV and ORA. For example, if we use an increased/decreased discount rate, both the LEV and ORA will be decreased/increased. However, the direction of changes in ORA caused by varying the probability of snow damage do not change. The same is true when other simulation parameters, such as log price, timber growth, logging cost and reforestation cost are changed. For example, higher log prices make the ORA of the no damage case lower. The risk of snow damage keeps the ORA high under some conditions. On the other hand, higher reforestation costs make the ORA for the no damage case higher and the risk of damage makes it even higher. There are some difference on the degree of change of ORA by the snow risk between the case in which ORA of no disaster case is relatively low and the case in which ORA of no disaster case is high. The lower ORA in the no damage case, the changes in ORA caused by snow damage risk are observed clearly.

Resistance to damage depends on the shape factor of each tree. The shape factor is often expressed as stem height-to-diameter ratio, H/D ratio in short. The relationship between damage ratio and H/D ratio has been shown in several studies. A high H/D ratio is correlated with high risk, and results from high planting density and inadequate improvement cutting or thinning during younger ages. In addition, this ratio tends to stay high once it exceeds 90. Therefore, in stands over 30 years old in which the H/D ratio exceeds 90 and there has been inadequate tending, it is possible that the damage ratio will remain high, even in

Table 2 Summary of results of simulations

		Basic case	Subsidized case	Higher price case	Non-declining damage ratio case
No Damage	ORA	70	50	50	50
	LEV	568	2392	7541	2392
Thinning Type (T5)	ORA	70	60*	60*	50
	LEV	9	1758	5237	1458
Domino Type (5)	ORA	70	40	40	40*
	LEV	-1605	687	2681	687

Note: The unit for LEV is thousand yen per ha. '*' indicates significance at 90% confidence level.

stands over 40 years old. Based on this, we considered the scenario in which the damage ratio of a stand over 40 years old remained at 6.8%, which is the same as the ratio of 36 to 40 years old stand. The result for this, non-declining damage ratio case is shown in Fig.6. Shorter rotation is advantageous under this condition, and the LEV is significantly reduced in each scenario.

DISCUSSION

There are two contradicting effects of the risk of snow damage. One is the rotation shortening effect, where it is advantageous to harvest a stand before it will be damaged by snow. The other is the rotation extending effect, to cover the increased management costs caused by snow damage. If the risk of snow damage to stands of higher ages is low, extended rotations can be expected to improve the cost benefit ratio.

In the cases of thinning type damage under subsidy or higher prices, long rotations are suitable (Table 2). This result is dependent on the condition that the damage ratio is lower in stands of higher ages. Thinning type damage increases the cost of sanitary operations and decreases the volume of thinned timber, but it is not likely to have a serious effect on final harvest. As a result, the rotation extending effect is more significantly than the rotation shortening effect. However, in the basic case, the change in the ORA from the risk of snow damage is not observed. The ORA for stands without damage is 70 years and already high. Since the LEV declines steeply after 70 years, the rotation extending effect does not apply. Consequently, the peak of LEV does not shift above 70.

In the case of domino type damage, the ORAs are similar to the case of no damage in each of the first three scenarios. This may be because if there is damage before the final harvest, the damaged part must be cleared and replanted. Therefore, the change to the LEV caused by delaying the harvest is smaller and hence the rotation extending effect is weaker than in the thinning type damage. If the probability of snow damage in older stands is low, the rotation shortening effect and rotation extending effect are almost offset with each other. Furthermore, if the damage ratio in stands over 30 years old is sufficiently low, for example about half the ratio shown in Fig.2, the ORA becomes higher than in the case of no damage under the scenarios with subsidies or higher prices. By contrast, if the probability of damage is high in older stands, such as in the non-declining damage ratio case, a shorter rotation is advantageous, as with cases of forest fire considered in earlier studies. From these results, it is clear that the risk of damage at higher ages is one of the key factors determining rotation age.

Typhoons also cause stem breakage, uprooting and domino type damage among stands of relatively high age classes. Since the damage ratio is over 10 percent even in stands of 80 years old, short rotations are recommended where there is a risk of typhoons. The risk of fire damage is higher in young stands in Japan. In this case, longer rotations are recommended.

The decrease in the LEV for the cases of domino type damage was twice as much as that for thinning type damage. This means that the loss of forest value by snow damage is much greater in domino type damage than that in thinning type. In other words, the cost of managing forests prone to this type of damage is quite high.

POLICY IMPLICATIONS

Two approaches for mitigating or avoiding the risk of snow can be considered. The first approach is to prevent domino type damage and to reduce the damage ratios of older stands. Silvicultural methods which can be used for this include reduced planting density, proper arrangement of planting formation, promotion of initial growth by appropriate weeding and improvement cutting, and density control through thinning, especially in young stands. If the probability of domino type damage and damage to older stands cannot be reduced to reasonable levels at a reasonable costs, natural forest management may be more appropriate than plantation management. This is the second approach.

There is a substantial area of plantations in Japan which were established where the risk of snow damage is high, such as in snowy regions or high altitude areas. In these places, natural forest management may be more suitable. Natural forests tolerate not only snow disaster but also other natural disasters, such as diseases and insects (SHIDEI, 1993 and FUJIMORI, 1995). In addition, natural forests have lower management costs than plantation forestry. To make it an attractive option for forest owners, it is important to establish operation systems which are able to produce high quality timber from the natural forests. It may also be important to provide subsidies for natural forest management. Such reforms would allow the environmental functions of the forest to be improved by ensuring that different forest types will be established in suitable places.

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Article

Management of Natural Mixed Forests in Northern Hokkaido using the Control Method: 30-year Report

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ABSTRACT

An experiment implementing the control method of forest management was implemented in Hokkaido Univercity's Nakagawa Experimental Forest in 1966, to investigate management options for natural forests in northern Hokkaido. Thirty years have passed since the experiment began. This report presents the results which have been assessed to date. The working circle area in the experimental forest covered 110.3 ha, and was a natural mixed forest with a slight majority of coniferous trees (average growing stock: 225 m^3). The experimental forest was divided into 10 blocks and the management period defined as 10 years. In the first management period, many low-quality trees were found, and the growth rate in each block ranged between 2.1% and 0.8%. In the same period the total number of trees decreased from 42,438 to 40,154. The growth rate in the second management period ranged from 1.1 to 3.1%, reflecting an improvement in stand structure, but the number of trees decreased from 37,039 to 35,311. Trees planted in areas of poor natural regeneration are growing well and thus an increase in the number of trees and a further increase in growth rate are expected in the third management period.

Keyword: control method, forest management, natural mixed forest, Hokkaido Univ. forest

INTRODUCTION

An experimental forest managed using the control method was established in Hokkaido University's Nakagawa Experimental Forest (located in Nakagawa-gun, Kamikawa Subprefecture) in 1966 to investigate options for managing natural mixed forests in northern Hokkaido.

The control method was designed by a Frenchman, A. Gurnaud, in 1847, and was further developed by H. Biolley, who applied it to a natural mixed forest of European spruce and fir in Switzerland. The method is conducted as follows: the forest is divided into blocks which are completely enumerated at short intervals to observe changes in growth and stand structure during a specified period. Yield is controlled to gradually improve the growing stock, taking growth into consideration (OKAZAKI 1951). However, due to natural and social conditions, there are many challenges in managing forest for the highest possible yield. This is the case, in particular, with natural mixed forests in cold regions with heavy snowfall such as northern Hokkaido, in which bamboo grass thrives on the forest floor. The following report presents results of forest management to date.

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OUTLINE OF THE EXPERIMENTAL FOREST

The experimental forest covers an area of 124.33 ha (working circle: 110.3 ha). The management period was set at 10 years, based on various management conditions, and the forest was divided into 10 blocks. Most of the slopes in the forest face west and their gradients are moderate. However, the topography is complex and there are numerous small swamps. The forest is 40 to 220m above sea level and the soils are generally acidic and brown. The annual mean temperature is 4.9℃, but the temperature range is large: the maximum is 36℃ and the minimum is -40℃. The annual mean precipitation is 1,650 mm and accumulated snowfall reaches 2m. The forest has inland-type meteorological conditions, and is located in one of the coldest regions with the heaviest snowfalls in Hokkaido. The forest is mainly a mixed forest of coniferous and broad

-leaved species, including coniferous species such as white fir (*Abies sachalinensis*), Ezo spruce (*Picea jezoensis*) and Glehn's spruce (*Picea glehnii*) and broad-leaved trees such as white oak (*Quercus crispula*), Japanese linden (*Tilia japonica*) and maple species (*Aceraceae*). The density indicates that most of the forest is in an intermediate stage of stand development. The growing stock when the experimental forest was established was 225m³ per ha, a relatively high level. By comparison the average growing stock of a natural mixed forest in Nakagawa Experimental Forest was 166m³. The undergrowth is mainly made up of large, thriving 2-3-m bamboo grass, which results in poor regeneration.

The following survey system was used. Firstly, the standing tree volume was determined from a complete enumeration of each block at the beginning of each management period. The trees with a diameter at breast height over 15cm were measured. Trees to be cut were selected following the Soviet tree class-division system, a system used for natural mixed forests which classifies trees into three classes: I -- upper-story trees with good character; II -- lower-story trees with good character; III-class "a" trees -- those preventing I- and II-class trees from growing; and III-class "b" trees -- including insect-damaged, fungi-damaged and frost-cracked trees with poor character. Class III trees were selected to be cut.

Until 1972, logging was mainly conducted by horses and men, however changes in the labour market, extended road networks (currently 86m per ha) and increased machanisation.

Manual planting was conducted in areas of poor regeneration areas and open areas where poor-character, old and rotten trees grew sporadically. There were approximately 50 planting sites, ranging in size from 0.03ha to 0.50ha, with an average of 0.18ha. The total planting area was 15.05ha (white fir: 14.37ha, Glehn's spruce: 0.52ha, Ezo spruce: 0.16ha), accounting for approximately 13% of the total experimental forest area. Planted trees are growing well (OHGANE *et al*. 1988).

DEVELOPMENT AND RESULTS OF THE FIRST FOREST MANAGEMENT PERIOD

The original growing stock in each block in the first management period (1967 to 1976) is shown in Table 1. The original growing stock ranged form 173m³ per ha (No. 2 block) to 287m³ per ha (No.6 block), and averaged 225 m³. A frequent, small amount of cutting had been conducted since the late 1910s, but many poor-character trees remained. The ratio of coniferous trees in the forest ranged from 67% (No.2 block) to 46% (No.10 block), indicating that the forest had slightly more coniferous trees than broad-leaved trees in general. In terms of volume ratio by diameter class, large-diameter trees (over 55 cm in breast-height diameter) accounted for 5 - 20% of total volume, medium-diameter trees (35-50 cm) 49 - 55% and small-diameter trees 30 - 42%. Overall, large-diameter trees accounted for less than 4% of all trees, medium-diameter trees 24 - 29% and small-diameter trees 67 - 74%. The stand structure was similar in all blocks.

For this forest stand, trees were cut using the Soviet system described above. The yields of each block are shown in Table 2. The cutting rate in each block ranged from 7% (No.1 block) to 27% (No.5 block), largely due to differences in the stand density of each block, the number of class III trees, and the state of regeneration. The ratio of volume removed compared to original growing stock was almost identical for both coniferous and broad leaved trees. However, the ratio of volume removed in large-diameter trees was significantly greater than that removed in small and medium-diameter trees in all blocks.This was because there were many large trees that were fungi-damaged or

Table 1 Growing stock in each block at the start of the first management period

Block	Area (ha)	Number of trees	Standing tree volume (m³)	Number (/ha)	Volume (m³/ha)	Volume ratio (%) Conifer	Volume ratio (%) Broad-l.	Volume ratio by diameter class (%) >55cm	35~50cm	15~30cm	Number ratio by diameter class (%) >55cm	35~50cm	15~30cm
1	14.14	4,339	2,664	307	188	63	37	16	53	31	3	27	70
2	8.72	2,498	1,511	286	173	67	33	16	51	33	3	24	73
3	14.69	5,183	3,338	353	227	60	40	20	49	31	4	26	70
4	10.64	3,994	2,453	375	231	54	46	14	51	35	3	27	70
5	11.07	4,296	2,577	388	233	59	41	11	54	35	2	28	70
6	5.60	2,799	1,605	500	287	59	41	8	54	38	1	27	72
7	8.17	2,924	1,555	358	190	57	43	5	53	42	1	25	74
8	6.72	2,670	1,631	397	243	49	51	15	51	33	3	27	70
9	12.91	4,260	2,750	330	213	50	50	13	55	32	3	29	68
10	17.62	7,191	4,751	408	270	46	54	16	54	30	4	29	67
Total	110.28	40,154	24,835	364	225	—	—	—	—	—	—	—	—

frost-cracked, and many wolf trees which were categorised as class III trees. The dry wood volume of each block ranged from 1 to 10m³ per ha in the first survey of growing stock, and there were differences among blocks. At the end of the first management period, the dry wood volume ranged between 2 and 11m³ in each block, and the ratio of dry wood in the original growing stock ranged from 1% to 5%.

Table 3 shows the total growing stock, which is the sum of the growing stock at the end of the first management period and the volume cut during the management period. Growth during the same management period was obtained by subtracting the growing stock at the beginning of the management period from the growing stock at the end of the management period.

Table 4 shows annual and percentage growth rates, calculated from the original and final growing stock in the first management period. These results indicate that although the blocks were generally similar in terms of structure and other aspects, differences were observed in annual and percentage growth rates between blocks. Annual growth per ha ranged from 2.2m³ (No.8 block) to 4.1m³ (No.7 block) and percentage growth rate ranged from 2.3% (No.2 block) to 0.8% (No.6 block). The growth rate of coniferous trees was slightly higher than that of broad-leaved trees (OHGANE *et al.* 1988).

DEVELOPMENT AND RESULTS OF THE SECOND FOREST MANAGEMENT PERIOD

Table 5 shows the growing stock in each block during the second management period of 1977-1986. Compared with the original growing stock in the first management period, both the number of trees and the standing tree

Table 2 Yield of each block in the first management period

Block	Total yield (m³)	Yield per hectare (m³)	Yield ratio compared with original growing stock (%)					
			Total Yield	Species		Diameter class		
				Conifer	Broad-l.	>55cm	35~50cm	15~30cm
1	195	14	7	7	9	10	8	5
2	189	22	13	15	8	16	14	9
3	405	28	12	12	12	21	12	7
4	601	57	25	23	27	46	25	16
5	694	63	27	26	28	64	27	16
6	219	39	14	13	15	25	14	10
7	230	28	15	14	15	36	16	11
8	209	31	13	13	12	20	13	9
9	622	48	23	22	23	40	21	18
10	1,081	61	23	18	26	37	21	19

Table 3 Final growing stock in each block at the end of the first management period

Block	Number of trees	Standing tree volume (m³)	Number (/ha)	Volume (m³/ha)	Volume ratio (%)		Volume ratio by diameter class (%)			Number ratio by diameter class (%)		
					Conifer	Broad-l.	>55cm	35~50cm	15~30cm	>55cm	35~50cm	15~30cm
1	4,796	3,106	339	220	61	39	19	53	28	4	27	69
2	3,297	1,853	379	212	65	35	20	48	32	4	21	75
3	5,556	3,650	377	248	59	41	22	49	29	4	27	69
4	4,119	2,763	386	260	56	44	14	55	31	3	31	66
5	4,690	2,957	425	267	60	40	13	55	32	3	29	68
6	2,745	1,734	489	310	60	40	10	56	34	2	30	68
7	3,052	1,856	373	227	58	42	6	59	35	1	30	69
8	2,652	1,766	396	263	50	50	17	53	30	3	29	68
9	4,465	3,023	344	234	49	51	15	55	30	3	31	66
10	7,066	5,091	401	289	46	54	19	54	27	5	31	64
Total	42,438	27,799	385	252	—	—	—	—	—	—	—	—

Table 4 Annual and percentage growth rates for the first management period

Block	Annual growth per hectare (m³)	Growth rate (%)		
		Conifer	Broad-1.	Total
1	3.9	1.7	2.6	2.1
2	3.9	1.9	3.0	2.3
3	2.4	1.0	1.1	1.0
4	3.2	1.8	0.9	1.4
5	3.4	1.6	1.3	1.5
6	2.3	1.0	0.6	0.8
7	4.1	2.4	1.9	2.2
8	2.2	1.2	0.7	0.9
9	2.6	1.2	1.3	1.2
10	2.8	1.3	0.8	1.0

Table 5 Growing stock in each block at the start of the second management period

Block	Number of trees	Standing tree volume (m³)	Number (/ha)	Volume (m³/ha)	Volume ratio (%)		Volume ratio by diameter class (%)			Number ratio by diameter class (%)		
					Conifer	Broad-1.	>55cm	35~50cm	15~30cm	>55cm	35~50cm	15~30cm
1	4,591	2,911	325	188	61	39	19	52	29	4	26	70
2	3,019	1,663	346	191	63	37	20	47	33	3	20	76
3	5,132	3,245	349	221	59	41	20	50	31	4	26	71
4	3,410	2,161	321	203	57	43	11	56	33	2	30	68
5	3,896	2,263	352	204	61	39	9	55	36	2	26	72
6	2,439	1,516	436	270	60	40	10	56	34	2	29	69
7	2,737	1,626	335	199	58	42	6	59	35	1	30	69
8	2,401	1,556	357	232	50	50	16	53	31	3	28	69
9	3,706	2,401	287	186	50	50	13	56	31	3	30	67
10	5,708	4,010	324	228	49	51	17	55	28	4	31	65
Total	37,039	23,352	336	212	—	—	—	—	—	—	—	—

volume in No.2 block increased significantly, and the tree volume in No.7 block slightly increased, but in other blocks, the number and volume of trees generally decreased. Consequently the total number of trees in the entire experimental forest decreased from 40,154 at the beginning of the first management period to 37,039 (a decrease of 7.8%) at the beginning of the second management period, and the total tree volume decreased from 24,835 to 23,352m³ (a decrease of 6.0%). As can be seen from the changes in the number of trees in each diameter class in Tables 1 and 5, cutting during the first management period caused a shift in the diameter class distribution. Small-diameter trees grew to medium-diameter trees, and medium-diameter trees grew to large-diameter trees. Only a few secondary stands grew into the small-diameter class. This was because bamboo grass thrived on most forest floors of the experimental forest, making natural regeneration poor.

In the second management period of these experimental forests, the same selection system used in the first management period was adopted to select trees to be cut. The objective was to improve the stand structure of each block, as shown in Table 6. Both the annual and percentage growth rates per ha in the second management period, shown in Table 7, were greater than those for the first management period. The growth rates were greater in seven of the blocks, except blocks 1, 4 and 7. In particular, the growth rates of blocks 3, 6, 8, 9 and 10, which were low in the first management period, more than doubled.

Table 8 shows the growing stock for each block at the biginning of the third management period, which began in 1987. Compared with the growing stock (in Table 5) at the beginning of the second management period, the number of trees in the entire forest decreased from 37,039 to 35,311 (a decrease of 4.7%), which was less than the previous 7.8% decrease. By contrast, the growing stock increased slightly from 23,352 to 23,722m³. The ratio of dry wood in each block was also lower than in the previous period, ranging from 1.2% to 2.7%.

Table 6 Yield of each block in the second management period

Block	Total yield (m³)	Yield per hectare (m³)	Yield ratio compared with original growing stock (%)					
			Total Yield	Species		Diameter class		
				Conifer	Broad-l.	>55cm	35~50cm	15~30cm
1	677	48	23	22	26	22	25	21
2	247	28	15	10	23	17	15	13
3	800	54	25	21	30	31	24	22
4	386	36	18	17	20	26	18	15
5	302	27	13	12	16	23	11	14
6	280	50	19	16	23	29	17	17
7	309	38	19	20	18	48	19	15
8	311	46	20	19	21	37	18	15
9	399	31	17	17	16	35	16	10
10	665	38	17	19	14	19	17	14

Table 7 Annual and percentage growth rates in the second management period

Block	Annual growth per hectare (m³)	Growth rate (%)		
		Conifer	Broad-l.	Total
1	2.2	1.0	1.2	1.1
2	4.9	2.6	2.5	2.6
3	4.5	2.0	2.0	2.0
4	2.5	1.4	1.0	1.2
5	4.5	2.3	2.2	2.2
6	4.7	2.0	1.4	1.7
7	3.7	2.2	1.4	1.9
8	6.5	3.0	2.6	2.8
9	5.8	3.7	2.6	3.1
10	5.4	3.4	1.4	2.4

Table 8 Growing stock in each block at the start of the third management period

Block	Number of trees	Standing tree volume (m³)	Number (/ha)	Volume (m³/ha)	Volume ratio (%)		Volume ratio by diameter class (%)			Number ratio by diameter class (%)		
					Conifer	Broad-l.	>55cm	35~50cm	15~30cm	>55cm	35~50cm	15~30cm
1	4,282	2,544	302	178	62	38	20	49	31	4	23	73
2	3,033	1,799	348	206	66	34	24	44	32	4	20	75
3	4,657	3,034	317	207	62	38	20	50	29	4	26	70
4	3,000	2,045	282	192	59	41	13	58	29	3	32	65
5	3,796	2,463	343	222	62	38	14	56	30	3	29	67
6	2,034	1,500	363	268	63	37	14	60	26	4	35	61
7	2,539	1,619	311	198	60	40	8	61	31	2	31	67
8	2,675	1,680	398	250	51	49	17	55	28	3	27	69
9	3,766	2,745	292	213	52	48	19	56	24	5	32	63
10	5,529	4,293	314	244	52	48	23	53	24	6	32	62
Total	35,311	23,722	320	215	—	—	—	—	—	—	—	—

CONCLUSIONS

Thirty years of implementing the control method of forest management in a forest with high growing stock and many trees of poor form resulted in a gradual improvement of stand structure. However, there was a concurrent reduction in the number of trees, which is a serious concern.

The artificially planted trees in areas of poor regeneration began to have an impact on the forest structure during the third management period. For example, there was a significant decrease in the number of trees in block 1 between the first and second management periods and a corresponding decrease in the growth rate, but in the third management period approximately 800 trees planted 30 years earlier were incorporated into the small-diameter class. Consequently the growth rate in the third management period rose to 3.6%. This is also likely to be the case in other blocks which are scheduled to be surveyed after 1997. Therefore, the next report on this forest, due in about 10 years, should show a considerable change in the forest structure.

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