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Short communication

The application of “Wood Max” for total optimization of forestry profits based on joint implementation silvicultural practices [*1]

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In this research, we aimed to develop a simulation system connecting wood conversion algorithms (woodmax) to maximize forestry income with a Local Yield Table Construction System (LYCS). Considering the harvesting costs in the study area, we used specific and total optimization through joint implementation of harvesting to maximize forestry profits at sub-compartment level and at total management unit level. By comparing specific and total optimization, we estimated the economic merit of joint implementation of harvesting in this study site. This simulation system could be useful in decision making for rational harvesting planning in local area forest management strategies.

Key words：Forestry profits, GIS, LYCS, Woodmax

Ⅰ. Introduction

With declining prices for timber produced from plantation forests in Japan, the importance of unmanaged forests is increasing. A previous sampling ground survey throughout Japan suggested that more than half of the area under plantation forest in Japan has not been thinned for 10 years (Matsumoto *et al.*, 2007 : Nakajima *et al.*, 2005, 2006a, 2006b, 2007), and an increase in mature sugi (*Cryptomeria japonica*) and hinoki (*Chamaecyparis obtusa*) stands is evident. Approximately half of all Japanese plantation forests are more than 40 years old and could be thinned to harvest timber (Forestry Agency, 2005). In abandoned plantation forests, the volume of dead wood is increasing while forest environmental functions are decreasing. It is therefore important to advance suggestions for rational harvest planning and to expand managed forestland. In this research, we aimed to develop a simulation model that connects wood conversion algorithms to maximize forestry profits with the potential of forest resources. Using this simulation system, we estimated the optimum harvesting strategies and analyzed the economic merits of total optimization of harvesting by joint implementation of thinning or clear cutting.

Ⅱ. Methods

1. Study site

The targeted area was the First Memorial Forest of Ise Jingu in Kumamoto Prefecture, Japan. In this forest, ground survey data from sample plots, forest inventory data, forest roads, timber harvesting records including harvesting cost, log volumes, numbers of logs, etc. were linked to a GIS.

The forest area is 65 ha, of which *C. japonica* occupies 33 ha, and *Chamaecyparis obtusa* 32 ha. We focused on the *C. japonica* plantation forest in the study site. The *C. japonica* stands are more than 40 years old, and have reached the final stage in the silvicultural process. Hence, it is important to consider future harvesting strategies in these forests.

2. A tool for harvested timber simulation

In this study, we used the algorithm “woodmax” (Nakajima *et al.*, 2008, submitted). The framework of the algorithm is shown in Fig. 1.

To include information about stand conditions, we considered the diameter distribution, average stand height, and stand age in the algorithm. For information about the timber market, we considered log prices (yen/m^3), which depend on log length and top-end diameter, in the algorithm. Based on the stand condition data and curves for relative taper and relative height by diameter, this algorithm is able to estimate top-end diameter, which depends on log length. We estimated log volume with formula (1) and converted log volume to stumpage price using log prices.

$$V = d^2 l \qquad (1)$$

where, V is log volume (m^3), d is top-end diameter (m) and l is log length (m).

A top-end diameter was estimated based on a relative taper-curve, DBH class, and tree height. We applied a relative taper-

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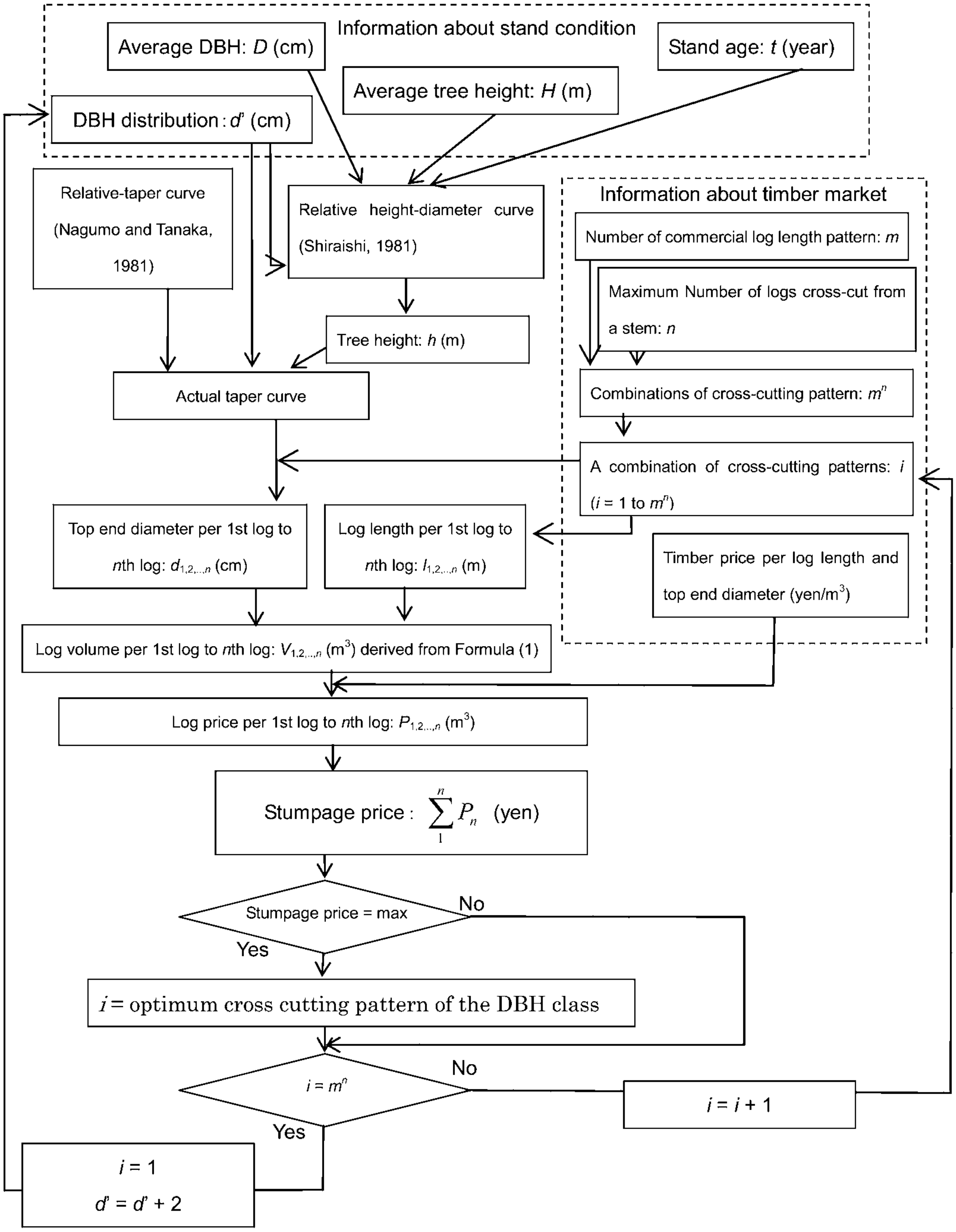

Fig. 1. Framework of the algorithm to estimate stumpage prices from stand conditions and timber market conditions

curve obtained from the University Forest in Chiba, the University of Tokyo by Nagumo and Tanaka (1981). The tree height of each DBH class could be estimated by the relative height-diameter curve obtained by Shiraishi (1981).

We can calculate the top-end diameter at an arbitrary height with the actual taper-curve based on the relative taper-curve. The parameters in the relative taper curve and relative height-diameter curve were not developed in Kumamoto Prefecture, but were relativized for application to other areas. We assumed that these parameters could be used to estimate the tree height distribution and taper of *Cryptomeria japonica* plantation forests in Kumamoto Prefecture. This procedure is applied to all log length combinations from the first log to the last log for each DBH class.

Using formula (1), we can calculate the log volume per first log to *n*th log based on length combinations and the top-end diameter derived from actual taper curve. The log price can be calculated by multiplying the log volume to log price per log length and top-end diameter. The stumpage price is the sum of these log prices. If the stumpage price is at a maximum, we identified the length combination as the optimum cross-cutting pattern for this DBH class. Finally, the algorithm performs this procedure for all length combinations.

3. Procedures

Estimation of log volume

Comparing estimates with observed log volume in the study site, we checked the accuracy of the estimated log volume using the "woodmax" algorithm. We input the following stand condition data measured in the final cutting area (Table 1) into "woodmax", and analyzed and modeled the relationship between the error ratio and stand density (yield index: Ry: Matsumoto, 1990) in each stand.

Table 1. Stand condition data measured in the final cutting area

Compartment	Sub-compartment	Area (ha)	Average height (m)	Average DBH (cm)	Stand density (stems/ha)
3	I 1	1.55	13.3	17.7	1428
3	I 1	1.01	14.2	23.6	1268
3	I 1	1.87	15.1	23.2	1006
3	Ro	0.96	16.8	25.1	724
3	Ro	0.96	15.8	29.7	819
4	Ri	1.04	14.2	20.9	1038
6	Ha1	3.28	16.7	24.3	1372
6	Ha1	1.77	16.9	25.1	1422
10	Ha1	1.25	14.0	21.0	1793
18	Chi1	2.37	16.7	25.1	1089

The model of this relationship for estimating log volume and stand density was then introduced into the Local Yield Table Construction System (LYCS : Shiraishi 1986 ; Matsumoto 1997) with "woodmax" to estimate harvesting income and costs as described below.

Estimation of harvesting income

"Woodmax" can also estimate stumpage prices based on log prices. In this study, we used the log prices for the study site given in Table 2, together with the Local Yield Table Construction System (LYCS), which can predict stand information, such as average DBH, tree height, and yield index. The stand information will be useful for estimating log volume with "woodmax". Thus, we combined "woodmax" and LYCS, and predicted future log volume and forestry income.

Table 2. Log prices for the study site

Log length (m)	Top-end diameter (cm)	Log price (Yen/m³)
2	10～22	4,500
	24～30	4,600
	32～	5,300
3	10～14	9,800
	16～22	10,000
	24～	11,000
4	10～14	7,600
	16～22	10,000
	24～	11,000

Estimation of harvesting costs

The harvest cost model used the following formula.

$$C = a_0 + (a_1 + a_2 x_1 + a_3 x_2) V \qquad (2)$$

where,

C : harvesting cost (yen)
V : harvested log volume (m^3)
x_1 : distance from forest road (m)
x_2 : average harvested log volume (m^3)
a_0, a_1, a_2, a_3 : parameters

The harvesting cost was modeled by considering three factors. First, log volume derived from harvesting records; harvesting the larger log volume is relatively time-consuming and costly. Second was distance from forest roads. Generally, the longer the distance between a cutting area and a forest road, the higher the harvesting cost. This factor was derived from GIS data by calculating the distance between the forest road and the centre of a cutting area. Third was average log volume. If this is large, the harvesting efficiency could be high. This factor was calculated by dividing the harvested log volume by the number of harvested logs derived from harvesting records.

Considering these factors, we used the quasi-Newton method because it is adaptable to nonlinearity (Nakagawa and Koyanagi, 1982). Finally, we checked the adjustability of the harvesting cost model by comparing the estimated harvesting cost with observed harvesting cost.

Optimization of harvest planning

Specific optimization of the harvesting strategy

We input the observed stand data for average DBH, tree height, and stand density into LYCS and combined these data with "woodmax". In this procedure, the future forestry profit depending on harvesting planning strategies was estimated. The final cutting age was input as 50 years, which is the standard final cutting age in the study site. We changed the thinning ratio of between 20% and 40% by 5%. We also changed the number of thinnings from zero to two, and the thinning age between initial stand age and final cutting age by 1 years. Inputting these various thinning plans into the LYCS, we simulated forestry profits under all strategies for harvesting. After this procedure, we selected the cutting plan that maximized forestry profits as the optimum harvesting strategy for each sub-compartment. In sub-compartments where optimum forestry profits were negative, the final cutting age in the stand was raised to 55 years.

Total optimization of harvesting strategy

Next, we calculated total optimum harvesting strategies, considering the joint implementation of thinning and clear cutting among sub-compartments. The constrained conditions for joint implementation were as follows: first, joint implementation of thinning was conducted with neighboring sub-compartments; second, joint implementation was conducted in the same age class of a sub-compartment; and third, joint implementation of harvesting could not be done in sub-compartments across a mountain ridge. These constrained conditions were derived from a questionnaire survey given to the forest owners in the study site. We calculated all combinations of joint implementation of harvesting, and selected the cutting plan that maximized forestry profits as the optimum harvesting strategy for each sub-compartment. Finally, we compared the forestry profits from this total optimization with the forestry profits using specific optimization.

Ⅲ. Results and discussion

Figure 2 shows the relationships between yield index (Ry) and the ratio of observed log volume to estimated log volume.

The relationships could be modeled with a second-order curve, suggesting that the ratio of observed log volume to estimated log volume in high-density stands is relatively low because the timber quality was reduced by severe competition among trees in high-density stands. The second-order curve was introduced into "woodmax" for further estimation of forestry profits.

Figure 3 shows the comparison between observed and estimated harvesting costs using the following cost model.

$$C = 150000 + (8x_1 - 19000x_2 + 9000)V \qquad (3)$$

where,

C: harvesting cost (yen)

V: harvested log volume (m^3)

x_1: distance from forest road (m)

x_2: average harvested log volume (m^3)

The coefficient determined from this relationship is 0.97. The constant term and slope of the regression line were nearly 0 and 1, respectively. A comparison of the harvesting cost estimated using the formula (3) with values observed in the study site showed that the values were almost identical, with an average difference of about 7.6%. This means that if we can estimate the log volume, distance from a forest road, and average log volume, the harvesting costs could be accurately predicted.

Figure 4 and 5 shows a comparison of forestry profits based on specific optimization and total optimization in the study area. Total optimization improved forestry profits by more than 352 thousand yen in this study site. Thus, this study enabled us to estimate the economic merit of implementation of harvesting strategies. A previous study suggested that forest owners are mostly concerned about the economic merits of joint implementation of harvesting (Nakajima *et al.* in press). Therefore, this study might provide a decision-making system for forest owners by showing them the economic merits of joint implementation of harvesting.

Ⅳ. Conclusion

We developed a simulation model for forestry income by combining the LYCS and "woodmax". Based on this model and harvesting records in the study site, we also estimated harvesting costs. This allowed us to estimate the economic merit of joint implementation of harvesting in the study area. If we can provide a model showing the economic merit for joint implementation of harvesting with other forest owners using the simulation system, it might be possible to expand the managed plantation forest area through consensus with forest owners.

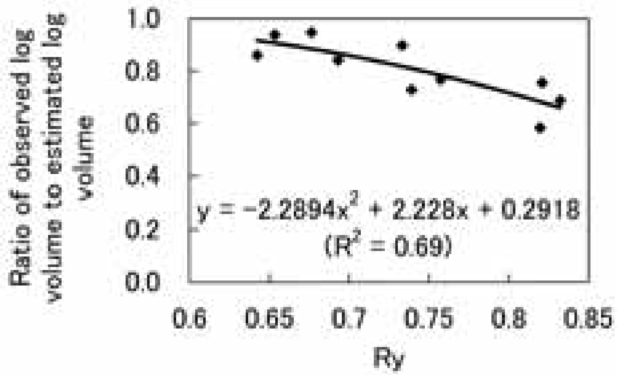

Fig. 2. Relationships between yield index(Ry) and ratio of observed log volume to estimated log volume

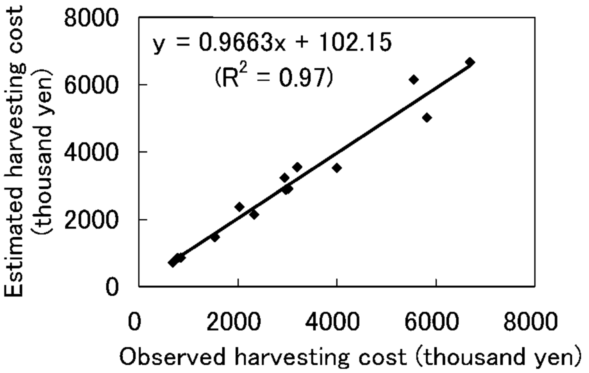

Fig. 3. Comparison between observed and estimated harvesting costs

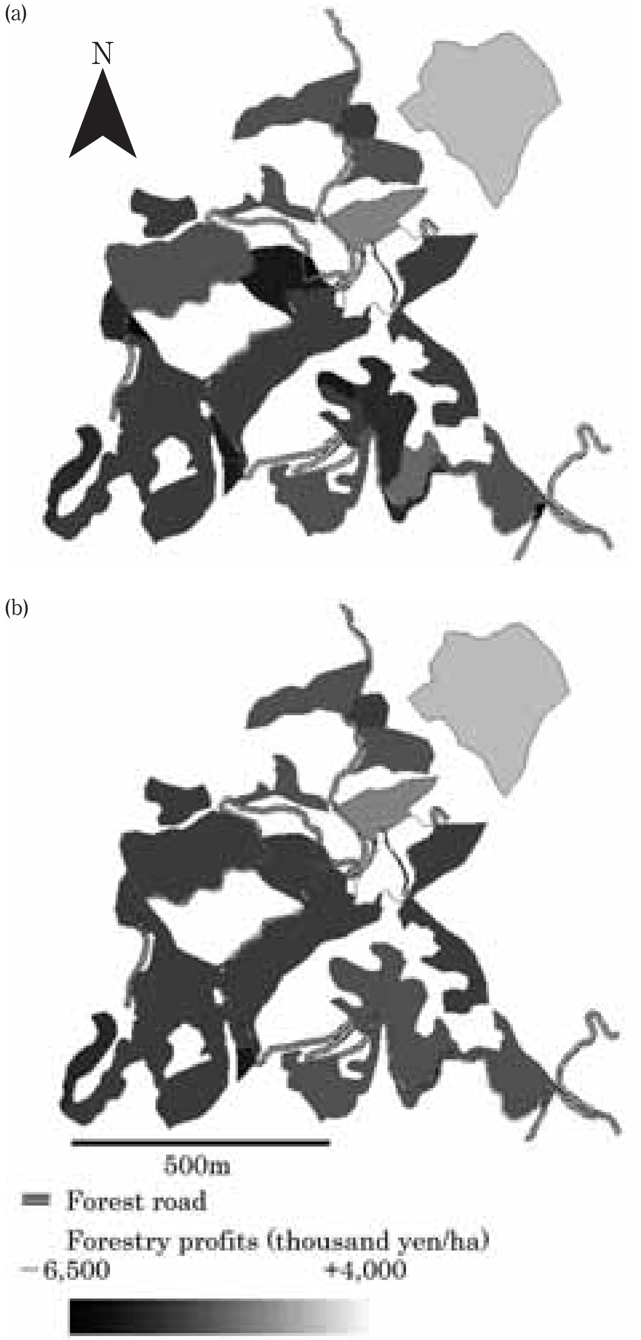

Fig. 4. Comparison of forestry profits based on (a) specific optimization and (b) total optimization in the study area

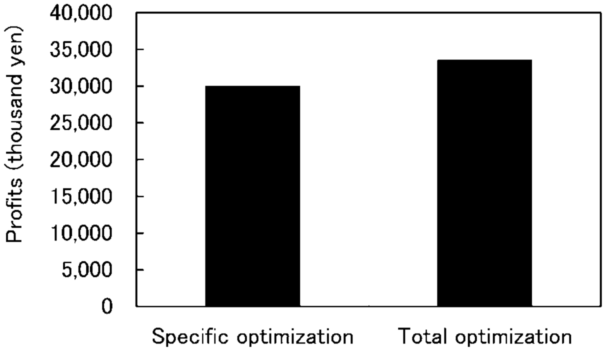

Fig. 5. Comparison of forestry profits based on specific optimization and total optimization

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