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A simulation system for regional forest management using forestry and economic models

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Abstract : This study examines the consequences of harvesting strategies in forestry management, using simulations to investigate the effects of implementing two different forestry subsidy systems on timber production and carbon stock. An existing Local Yield Table Construction System (LYCS), a wood conversion algorithm (WoodMax), a silvicultural cost model and a system dynamic model were used in the simulations to test the applicability of different subsidies to the thinning operation. Using forest inventory data, the simulation output was used to calculate, among other factors, timber production, carbon stocks and stumpage price. The outputs of simulations based on two scenarios were analyzed and differences were found, with the timber yield of Scenario 1 (the Japanese traditional forestry subsidy) being greater than that of Scenario 2 (based on a long-rotation silvicultural regime), where subsidy rules were more relaxed. The harvested timber in Scenario 1 was produced mainly by clear-cutting and the stumpage value in the prediction period for the simulation was greater in Scenario 1 than Scenario 2. In contrast, it was predicted that the carbon stock would be greater in Scenario 2 than in Scenario 1.

Key words : carbon stock, harvesting strategy, yield prediction, subsidy, system dynamics

I Introduction

Sustainable management of the carbon stock held in the forested areas of Japan is important for maintaining forestry profits and the sustainability of large forest areas at a global scale, in accord with the Kyoto protocol (3). Recommendations for adopting adaptive management procedures, including the Plan-Do-Check-Act (PDCA) cycle, are based on scientific consensus (*6*). Previous analysis of the outcomes of private forest management in Japan have established a correlation between the extent of various silvicultural practices (planting, weeding, pruning, pre-commercial thinning, production thinning) and the level of national subsidy available (*8*).

This study aims to investigate the consequences of the application of management strategies in relation to specific forestry subsidy systems by simulating their effects on timber production, carbon stocks and other factors. The simulation output can also be used to assess the influence of investments in forestry and carbon stock and the validity of these simulations in respect of the PDCA cycle used in regional forest management systems.

II Method

Study site: The study site was a forest plantation in Morotsuka town, in the Miyazaki Prefecture. The forest inventory data for this region are linked to a geographic information system. This contains data layers relating to private forests and is updated annually by the Miyazaki Prefectural government and the Mimi river valley forest association. The targeted areas were forest plantations of *Cryptomeria japonica* between 30 and 50 years of age.

Analytical tools: The forestry and economic models used in this study were as follows. For estimation of carbon absorbed by forests, we referred to the J-VER guidelines (*1*). These make use of the Local Yield Table Construction System (LYCS), which simulates timber growth and carbon stock (*1*). This growth model is applicable to the main tree

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Tohru Nakajima, Takuya Hiroshima (The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-8657, Japan), Hideshi Noda, Mitsuo Matsumoto, Hidesato Kanomata, (Forestry and Forest Products Research Institute, 1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan) Development of a simulation system for regional forest management using forestry and economic models species (*12*). By combining LYCS with a wood conversion algorithm (*11*) and a harvesting cost model (*10*), we can predict carbon stock, harvested timber volume and forestry income. The harvesting and silvicultural practice records of the study site, including details of incomes, costs, and labor, were used to estimate forestry profits and labor requirements for harvesting and silvicultural practices. The unit price of subsidies was based on the standard silvicultural system (*7*). The labor requirements for performing various silvicultural practices, including harvesting, were also available from the historical records of the Mimi river valley forest Association. Using the estimated timber production with the system dynamics model described in (*13*), it was possible to estimate the stumpage value taking into account the improved lumber logistics.

Data analysis: Two subsidy system scenarios were considered: In Scenario 1, the traditional subsidy system was applied to stands less than 35 years old (*8*). In Scenario 2, the subsidy system was applied to stands of any age. Scenario 1 was based on the traditional Japanese forestry subsidy system that has been applied to non-commercial silviculture: i.e. stand establishment including planting, pruning, weeding and pre-commercial thinning. However, in order to fulfill Japan's international pledge under the Kyoto Protocol in a global context (*3*), a new subsidy system has been proposed that can be applied to non-commercial silviculture, and also to commercial thinning conducted in stands of any age. This will promote thinning and restrict large-scale clear cutting by supporting a long-rotation regime (*2*). This proposed system was implemented in Scenario 2.

The input data used for the models included the stand condition (stand age, site index and tree species), the thinning plan (thinning intensity, number of thinnings and the thinning age) and the timber price. The future standing volume, timber volume and forestry profits could be generated as model output. Data from the 20 sampling plots, including stand age, average dominant tree height and stand coordinates in the study area (including the Mimi river region) were also available. By substituting the stand age and average dominant tree height into the stand height curve (*5,12*), the site index class (calculated to two decimal places) could be estimated as follows.

$$S = (a - H/(1 - L\exp(-kt)))/b \qquad (1)$$

H: Stand height (m), t: Stand age (yr), S: Site index class, $M,\ L,\ k,\ a,\ b$: parameters derived from previous studies (*12*)

$$SI = (a - bS(1 - L\exp(-40k))) \qquad (2)$$

SI: Site index.

The estimated site index was used to provide the objective variables in a multiple regression model. Site indices in each sub-compartment were derived from the Digital Elevation Model (DEM: Grid size: 10 m × 10 m), proposed by the Geographical Survey Institute. We obtained the following multiple regression model by selecting variables derived from the DEM using a step-down procedure method described previously (4). Variables including slope, solar radiation, flow accumulation, curvature, the wetness index, distance from a ridge, and shaded relief were calculated using ArcGIS 9.3 (ESRI).

$$SI = -0.0048\ [\text{Solar radiation}] + 0.1148\ [\text{Flow accumulation}] - 0.0699\ [\text{Curvature}] + 19.6 \qquad (3) \qquad (R^2=0.71)$$

The final age at cutting was chosen to maximize the present net value of forestry profits. The discount rate was then estimated in relation to a value considered to be reasonable to society; in this case we assumed a value of 3.0 % representing the average long-term yield of Japanese government bonds (*14*). Although the thinning plan was included in the input data, it could be modified according to a particular stand density control strategy. A thinning plan that maximized the net present value was selected. The thinning ratios were varied by 5 % increments from 20 % to 40 % in line with the existing standard silvicultural systems (*7*). The number of thinnings was varied between zero and three, and the thinning age by increments of 5 years between the initial stand age and the final age at cutting. Using various thinning plans in the LYCS, we were able to simulate forestry profits obtainable under a range of harvesting strategies and this was used to select the cutting plan that maximized the present net value of forestry profits for each sub-compartment.

The total harvesting area and the quantity of harvested timber were calculated by summing the respective values based on the harvesting plans calculated for each of the two existing subsidy scenarios. The subsidies were estimated by summing the silvicultural and thinning subsidies derived from government subsidy unit prices. The total forestry profits could then be estimated from the forestry income and the subsidy. The carbon stocks were also estimated by substituting stand volumes derived from the LYCS into the following formula (4):

$$C = E\,D\,V(t) \quad (4)$$

where C: carbon stock (tonnes ha^{-1}), E: a biomass expansion factor, D : wood density (tonnes m^{-3}), $V(t)$: stand volume ($\mathrm{m}^3\,\mathrm{ha}^{-1}$)

These variables, including E and D, were derived from a previous study (*1*). For each silvicultural practice, labor requirements were calculated by multiplying the amount of labor required per hectare by the area over which the silviculture would be practiced, these figures were based on the estimated optimal silvicultural regime and the age distribution of trees in the study site. For descriptive purposes, the prediction period was set at 25 years. The benefits of applying these simulations to the Plan-Do-Check-Act (PDCA) cycle (*9*) for forest management systems are discussed below.

III　Results and Discussion

Figure 1 shows the differences in volumes of harvested timber in the two scenarios. In Scenario 1, the traditional Japanese model, the harvesting yield of clear-cutting timber was greater than that of thinning timber. Figure 2 shows how the subsidies varied depending on the scenario. The subsidies in Scenarios 1 and 2 were allocated mainly to clear-cutting and thinning, respectively (Fig. 1). The results (Fig. 1a) suggest that a managed decrease in the clear-cutting area would not cause an immediate decrease in the required subsidy (Fig. 2a) as weeding would still be required for 5 years after planting in the clear-cutting area. Fig. 3 shows the monthly variation and moving average of the stumpage value in the two scenarios. Harvesting productivity is improved by an increase in the log volume derived from stand growth (*10*), with the stumpage value in 2025 in Scenario 1 and 2 rising to 4,975 yen and 4,743 yen, respectively. The timber output in Scenario 1 is mainly derived from clear cutting of a larger log volume and higher timber quality; the stumpage value in scenario 2 was lower than for scenario 1.

Figure 4 shows the response of carbon stock in each of the two scenarios. The predicted carbon stock was more stable in Scenario 2 than in Scenario 1. A comparison of the two scenarios clearly shows that the carbon stock under Scenario 1 would be smaller than for Scenario 2 with the differences ranging between 0 and 658.3 Kt, resulting mainly from clear-cutting. According to the carbon accounting system under the Kyoto Protocol, all carbon stock held as standing timber is counted as being released into the atmosphere by clear-cutting (*3*). Therefore, the larger clear-cutting area in Scenario 1 would affect a dramatic decrease in the carbon stock when this carbon accounting is applied.

Figure 5 shows the likely labor requirements related to the different scenarios. In this case, silviculture has a higher labor requirement in the traditional approach of Scenario 1 than in Scenario 2.

These simulations have potential applications in planning forest management and aiding decision-making by forestry policy makers under the PDCA cycle. After the planning stage, including securing required labor (Do), a number of factors, such as forest resources, stumpage price, and carbon stock could be monitored to assess the effects of the forest management plan (Check). Monitoring would provide valuable information for determining the level of subsidy for practical funding and would assist in setting the budget for improving forest management planning (Act). Incorporation of these outputs could be used further to simulate improvements in the forest management plan. This could take into consideration possible socio-economic conditions that might prevail in the future (Plan). By repeating these stages in the PDCA cycle, the effect of subsidies on forest management in maintaining economic and environmental sustainability at a regional level could be continuously and appropriately revised and checked. This would aid accountability relating to public investment in forests. Policy makers could use the information from the simulations to understand the influence of different subsidy scenarios on local forestry and thus select appropriate plans for meeting their management goals. There are a number of ways in which the simulation proposed in the present study would enable us to improve the subsidy strategy. Despite the uncertainties associated with future socio-economic conditions, these types of simulations could provide information about future tendencies by estimating changes in values in response to the level of subsidy.

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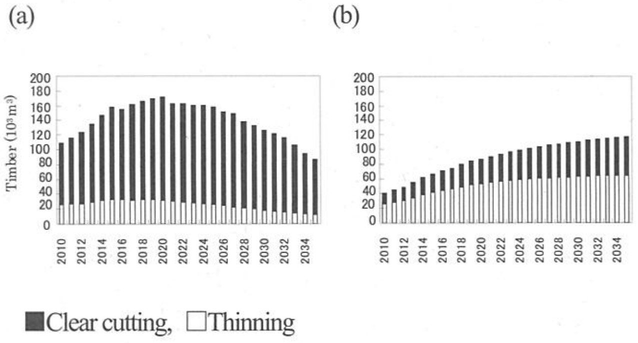


Fig-1. The clear-cutting and thinning harvested timber volume under (a) Scenario 1, and (b) Scenario 2.

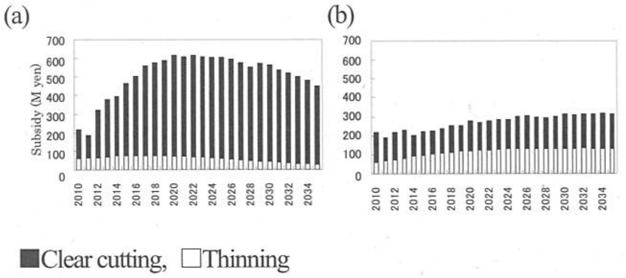


Fig-2. The silviculture and thinning subsidy under (a) Scenario 1, and (b) Scenario 2.

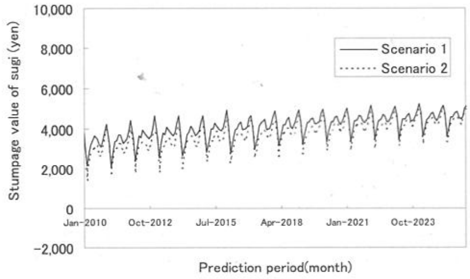


Fig-3. The stumpage value under (a) Scenario 1, and (b) Scenario 2.

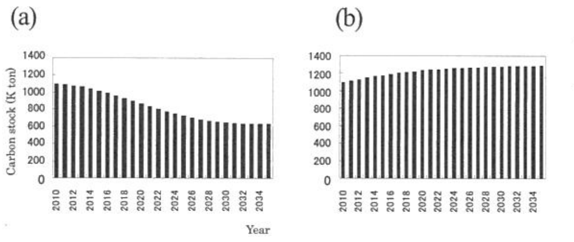
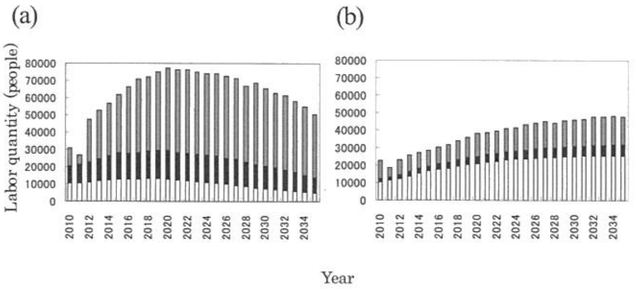


Fig-4. The carbon stock under (a) Scenario 1, and (b) Scenario 2.



▨Silviculture, ■Clear cutting, □Thinning

Fig-5. The labor requirements for silviculture, clear-cutting and thinning under (a) Scenario 1, and (b) Scenario 2.