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A GIS-based interactive spatial decision support system for integrating the management of protected and productive forests of lakeside area

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Abstract: Protected forests require management strategies that differ from productive forests, but it is necessary to integrate management of both forests from a landscape perspective. This integration is necessary for protected forests to be managed in the most economical and sustainable way possible, and to make sure that management of adjacent productive forests does not negatively affect protected forests. Traditional approaches to forest management planning do not offer this integration because they lack a holistic and spatial approach. In this paper the author describes the development of a spatial decision support system using GIS, and harvest schedule/allocation model, which allows simulation of potential forest resource management activities from a landscape perspective. This approach combines landscape perspective with improved analytical tools. It enables resource managers to design and demonstrate the long-term conservation outlook of forest resources under alternative management strategies with multiple objectives.

1 Introduction

In order to deal with sophisticated issues of integrating forest resources management with environmental, and social values and objectives in a sustainable manner, more holistic and spatial approaches than traditionally applied is necessary to manage forest ecosystem from a perspective of stands (Baskent and Jordan, 1995; Forman, 1995). By taking a landscape perspective, combined with improved analytical tools to support the consensus-based management decision-making, it may be possible to benchmark forest management practices to meet an adequate scale or level of potential impacts caused by silvicultural and harvesting activities (Kurttila, 2001; Murray, 1999). In this paper the author describes the development of a GIS-based timber harvest scheduling system oriented toward the sustainable forest management combined with raster GIS. It offers image processing capabilities and a harvest schedule/allocation model, and allows simulation of differences in terms of the size of timber harvest units, the total area harvested, intervals of harvest rotation, and the spatial distribution of harvest areas. The emphasis is on providing visual feedback of the outcome. The proposed approach enables resource managers to have the flexibility to design and demonstrate a long-term conservation outlook of forest resources under alternative management strategies with multiple objectives.

2 Classification schemes of forest management areas

This procedure classifies forest management areas into functionary categorized units according to management strategies. In this paper, three functional categories- Static Management Zone (SMZ), Conservative Management Zone (CMZ), and Productive Management Zone (PMZ) were defined (Figure 1). SMZ was established to maintain forest ecosystems. SMZ is composed of natural stands, broad-leaved second growth, wildlife habitat and original vegetation, and timber harvesting should be avoided. However, essential cares must be given for its public benefits. CMZ was established to maintain the forestland condition for forest management operations. In CMZ, slope distribution, landslide and river networks were considered. Slope distribution limits logging operations and affects the growth of regenerated trees. In order to avoid spreading out of the existing landslide and its soil loss, it may be proper to set up a buffer zone. River network should be extracted and then a buffer zone should be set up in order to protect riparian areas. In order to classify conditions of CMZ, such as the upper limit of slope, the width of buffer and the form of river network, various conditions based on the surveyed data were considered. CMZ should have limitations on the harvesting method, and especially clear-cutting should be avoided. PMZ was the remaining zone excluding SMZ and CMZ from unrestricted forests. PMZ should be kept sustainable for timber production by way of the right tree on the right site through positive management.

3 Framework of HARVEST simulations

HARVEST provides visual and quantitative means to predict spatial patterns of forest openings produced with alternative harvest strategies (Gustafson, 1999). The HARVEST approach was adopted allowing flexible input of parameters that relate to standards and guidelines for timber management areas where various management goals were assigned (Gustafson

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and Crow, 1999). HARVEST is a cell-based (raster) model and produces landscape patterns which have spatial attributes resulting from initial landscape conditions and potential timber management activities (Borgesa and Hoganson, 2000). By setting control parameters into simulation, we are able to specify the time and place for the harvest schedule/allocation, including such conditions as types of forest cover, topography, and wildlife habitat.

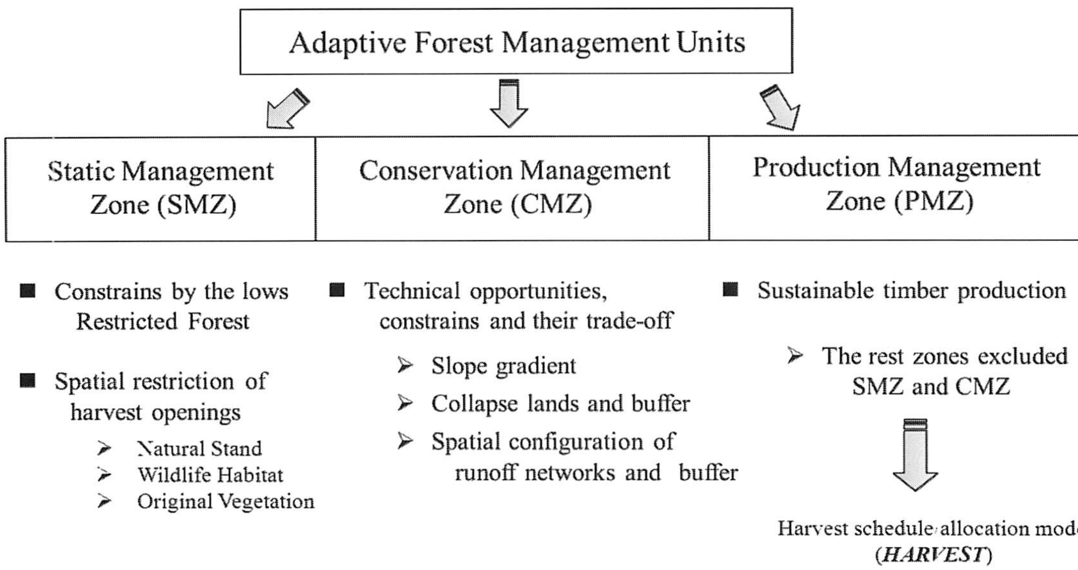

Figure 1: Standards applied to the zonation into three functional management units

4 Study area and methods

The area chosen for the study was a plantation forest tract of about 1,000 ha located in the northwest side of Lake Biwa, Shiga Prefecture. The area planted with Cryptmeria japonica amounts to 532 ha and the volume of its stands is about 120,000 m^3 (Figure 2).

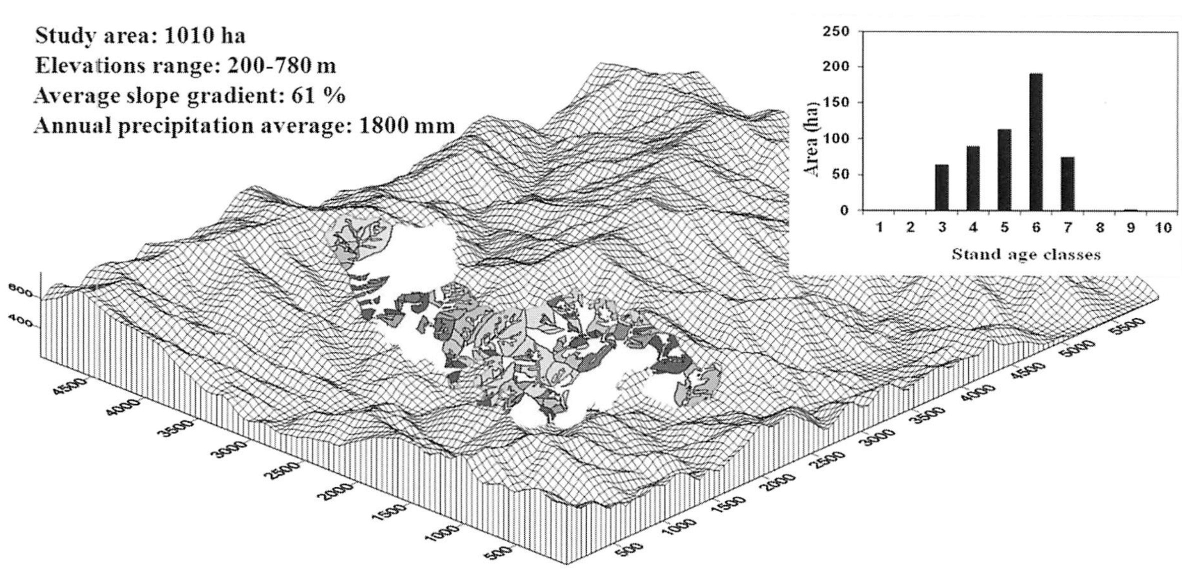

Figure 2: Overview of the study area overplayed compartment boundaries and stand age information

Stream network pattern was identified according to the following procedure. Flood runoff lines were extracted by the GIS's *RUNOFF* function from DEM (10m x 10m mesh), and then classified into watershed areas. In this way, runoff lines were extracted by fixed watershed area. Next, some runoff patterns were compared with the river systems in a 1:25,000 topographic map based on its shape. Results indicated that the simulated stream network in a watershed area of 1 ha was closely similar to the first order stream pattern in the map. In the same way, watershed areas of 4 ha and 25 ha similar to the second and third order streams, respectively. The watershed area of 50 ha also simulated to the perennial stream in the map. Using the *BUFFER* function, a buffer zone was set up around the stream lines ranging from 10 m to 100 m with a 10 m interval. Stream networks and its buffer zone were mapped as CMZ, and the remaining part as PMZ. 40 maps in total were prepared as conditions for CMZ. All sorts of maps were combined and then classified the area into CMZ and PMZ with 600 (= 3x5x40) conditions in total.

5 Harvest schedule/allocation simulations

Harvest schedule/allocation simulation was planned through HARVEST on the condition that the ratio of PMZ area should surpass 80% of the planting areas. The objective of harvest schedule/allocation was determined: the present short-term (rotation interval: 40 years) plantation management should be shifted to a long-term (rotation interval: 80 years), and sustainable one. In order to realize it, age class structure of stands must be changed gradually from the current pattern of the concentration in 3 to 7- year stand class to even out throughout the classes. The simulation period was set for 80 years (= 16 working periods). The targeted area for harvesting was decided to be 25 ha during every working period. The minimum allowable age for cutting was 40 years at the beginning, and then extended gradually in order to avoid plural harvesting at the same place during simulation. As for parameters for each harvesting patch, the mean area of cutting was set at 1.0 ha with reference to private forest management systems conducted in Shiga Prefecture (Shiba, 1997). The maximum patch was 2.0 ha and the minimum was 0.01ha (= resolution of GIS data; its pixel size was 10m). Harvested patches were supposed to be regenerated promptly after the final cutting.

6 Resulting patterns of forest openings

The relationship between the ratio of the PMZ area and the total area for harvesting were examined. Then the number and the mean area of harvesting patches were quantified. All the harvesting patches were counted during simulation. There were two processing methods for patch territories in a raster map. Cells that were in contact diagonally were identified to check if they were the same patch or not. In this paper, when cells with the same attributes shared, vertically and horizontally, at least one side, they were identified as the same patch, while those in contact only diagonally were identified as different patches. This processing method was common with HARVEST. The mean area of harvesting patches was calculated using the equation of the total harvesting area divided by the number of harvesting patches. From a landscape perspective, changes in number, size and shape of the patches were measured in the planting areas. Change in patch structure will be proven through this analysis. The total number of patches was counted in the planting areas. Concerning the patch size, its mean area was calculated by dividing the total area for planting by the total number of patches. The edge density and fractal dimension were measured as indices of change in patch shape (Shiba, 2001). The length of the edge was calculated from its total length after defining the edge as a part of its neighboring and yet separate patch. The edge density was calculated through the equation of the total planting area divided by the length of the edge. The edge density means the length of the edge per fixed area. An increase in the edge density means its relative increase in edge environments (Forman, 1995). The fractal dimension was calculated by means of setting up a minimum fractal dimension (= 1.0) from the relationship between a pixel area (= 100 m^2) and the length of the edge (= 40 m) of a unit pixel.

7 Results

Changes in the ratio of the PMZ area under each condition were examined. As for the slope distribution, the ratio of the PMZ area decreased to 99.8 %, 98.3 % and 90.3 % as the mapping condition on the slope changed from 100 % to 90 % and 80 %, respectively. For landslides, the ratio of the PMZ area decreased gradually as conditions on the width of a buffer expanded. In the 30 m buffer zone, the ratio of the PMZ area was less than 80 %. As for the river networks, the ratio of the PMZ area changed greatly in each fixed watershed area. The ratio of the PMZ area decreased substantially in the watershed area of 1 ha; it decreased to 22.6 % with a buffer zone of 100 m. On the other hand, the ratio of PMZ area decreased little by little in the watershed area of 50 ha: it only decreased to 89.4 % with a 100 m buffer zone. 62 conditions out of all the conditions surpassed 80 % of the PMZ area, and only one condition out of 62 surpassed 90 %. Age class structure of stands changed to an almost even level throughout classes from the current concentration in the 3 to 7-year class of stands through simulation (Figure 3). The targeted area for harvesting (= 25 ha) was achieved in the 7 to 13-year class and the harvesting area decreased gradually in the below 6-year class. This result suggests that adjacency constraints were controlled by harvesting patches. Stands in the 15 and 16-year class were arranged only in the areas of 3.60 ha and 0.98 ha respectively because those with allowable cutting age for harvesting were not readily available during each working period. Despite being far short of the harvesting area for 15 and 16- year class, the total harvesting area on average amounted to 315 ha (Table 1). This figure was equal to 78.7 % of the area targeted for harvesting, so it can be interpreted that the age class structure of stands is approaching a normal level based on the assumption of sustainable forest management. The total area for harvesting and the ratio of the PMZ area didn't seem to be correlated. This trend can be seen in the variation of coefficients on the total area for harvesting compared with the ratio of the PMZ area. Table 2 shows the comparison of landscape statistics.

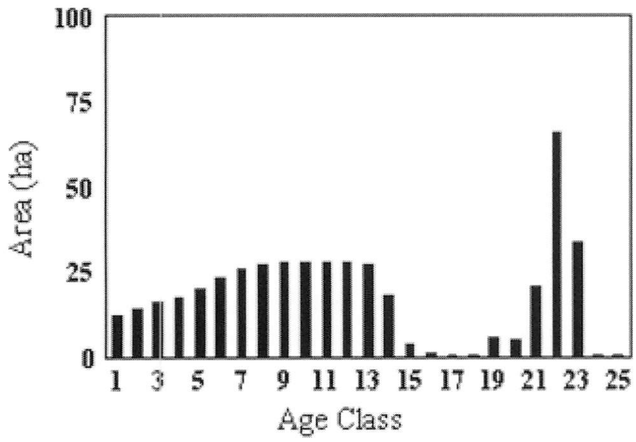

Figure 3: Stand age distributions after harvest scheduling simulation with a rotation length of 80 years

Table 1: Results of the landscape statistics after harvest scheduling simulation

Variable	Mean	SD	Minimum	Maximum	CV
PMZ area (ha)	445.5	14.7	426.4	479.2	0.033
Total harvesting area (ha)	315.0	23.1	288.8	345.4	0.073
Harvesting patch number (No.)	426	23.1	390	512	0.054
Harvesting patch area (ha)	0.74				

Remarks: SD(Standard Deviation), CV(Coefficient of Variation)

Table 2: Comparison of landscape statistics: patch abundance, patch size and patch shape

Variable	Condition	Mean	SD	Minimum	Maximum	CV
Total patch number (No.)	present	218	40.7	165	341	0.187
	after simulation	1,061	67.9	906	1,306	0.064
Mean patch area (ha)	present	2.1				
	after simulation	0.42				
The length of edge (km)	present	155.2	10.3	139.2	182.6	0.066
	after simulation	336.2	10.0	316.9	360.1	0.030
Edge density (m/ha)	present	348.6				
	after simulation	754.9				
Fractal dimension	present	1.071				
	after simulation	1.066				

Remarks: SD(Standard Deviation), CV(Coefficient of Variation)

The number of the harvesting patches and the ratio of the PMZ area don't seem to be correlated either one of the two. This trend can also be seen in the variation of coefficients. And the result of the average patch area for harvesting was 0.74 ha, not reaching the targeted area of harvesting (=1.0 ha). Figures 4 shows the examples of stand age maps pre and post- harvest simulation respectively. Comparing both maps, large patches of the present landscape pattern were subdivided into smaller patches as a result of specifying harvesting patches in terms of space and time through simulation. It is a matter of course that harvest scheduling was limited to the PMZ area. The situation seemed to be that there were no or little harvesting parts, especially in northwestern, central and southeastern parts. One reason may be that the allocation of harvesting patches in these parts controls the total harvesting area. From another viewpoint, harvestings were scheduled continuously at limited sites so that no harvesting patches were subdivided due to the concentrated allocation of harvesting patches. This led to the result that the mean patch area for harvesting did not reach the targeted area of harvesting.

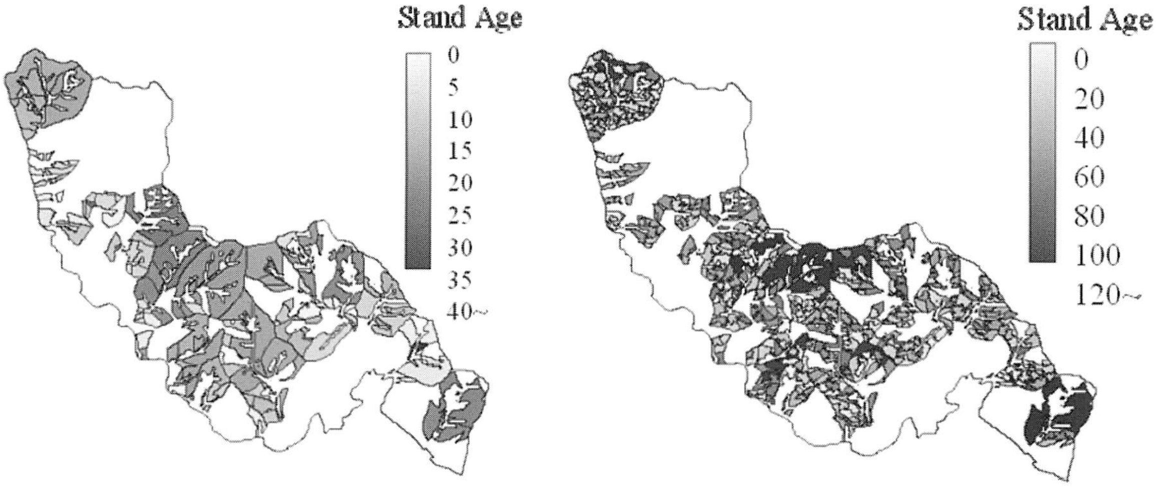

Figure 4: Comparison of stand age maps: pre (left) and post (right; rotation length of 80 years) - harvest scheduling simulations

With respect to the resulting patterns of forest openings, the total number of patches increased by 387 % from the current 218 to 1,061 post simulation. It can be said that no harvesting patches were subdivided nor fragmented because when harvesting patches were allocated, the number of harvesting patches was 426. As the total number of patches increased, the mean patch area decreased by 80 % from 2.11 ha to 0.42 ha. The length of the edge increased by 117 % from 155 km to 336 km and the edge density also increased by 117%. The fractal dimension increased by 0.4 % from 1.12 to 1.14. This result suggests that the patch shape tends to be less complex. The variation in coefficients on the total number of patches and the length of the edge are considered to converge into little values through simulation. The mean patch area and the edge density, depending on the total number of patches and the length of the edge, can be expected to show similar tendency because the ratio of forest areas was fixed pre and post simulation.

8 Discussions

The system capabilities were illustrated through examples of predicting changes in landscape patterns with spatial and temporal contexts resulting from initial landscape conditions and potential harvesting activities- economic, environmental and social benefits. The flexible management strategies were geared toward multiple objectives. Analyses of resulting patterns will act as a key factor for decision-making.

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