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Establishment of Optimal Timber Harvesting Model by Using Goal Programming

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Abstract

The total yield of *Pinus koraiensis* stands was reviewed along forest function by using goal programming, which is one of the operations research techniques. The 4 kinds of management goals are set to identify timber production in the Research Forest of Kangwon National University. As a result, scenario 1 was estimated the best timber production over 2,073 ha area and also 588 ha in the third quarter was showed the most timber harvest. The rate of timber harvest was separated by 10 to 50 percent in non-timber forest function in the scenario 1 and that model was applied to the Research Forest of Kangwon National University. The structure of the area and volume is showed to be balanced quarterly when rate of timber harvest at 10 to 20 percent.

Key Words: goal programming, forest functions, *Pinus koraiensis*, timber harvesting, forest management

Introduction

The forest functions in Korea are divided into six functions according to the sustainable forest management principle. These functions are timber production, watershed forest, protection of forest disaster, natural environment conservation, forest recreation and living environment conservation. The forest management plan was set up according to the forest function for sustainable forest management but substantial forest management act is incomplete.

Korea is occupied mostly of trees with age-class III and IV, therefore forest management plans must consider various forest functions and that is reflected on decision making. In the past, the purpose of forest management plans were concentrated on timber harvesting, but recently, multiple forest plans have been established for covering environmental problems.

Development of forest information system with the application of geographic information system and forest management plan for multiple forest management was studied by Eun-Sik Park (1998).

In this study, goal programming (GP) was used that is usually used as methodology for multiple forest management.

The work of Mitchell and Bare (1981) is composed of 6 main factors and 50 detailed factors for the New Mexico area and it determines the priority of management by applying GP.

Mendoza (1987) studied the applicability and the theoretical verification of GP. Howard (1991) configured the GP model and mathematical algorithm to consider ecological problem, and environmental problem, timber production which were faced with forestry aspect. Romero and Rehmen (1989) applied GP on multiple forest management and afforestation plan.

In the case of Korea, Cheol Soo Jang (1991) first applied GP to solve the decision making problem and to establish

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the resource management method.

The ultimate goal of the establishment of systematic and scientific forest management plan to moves away from past forest management pattern and to achieve sustainable forest management by targeting on the Research Forest of Kangwon National University.

Materials and Methods

Study site

The site of the study is the Research Forest of Kangwon National University. It is located between Chuncheon-si Dongsan-myeon and Hongcheon-gun Bukbang-myeon, Republic of Korea. The total area is 3,146 ha (Table 1). It is not only a natural deciduous forest and *Pinus koraiensis* but also has good quality forest.

This site has 635 species of plant resource and 172 species of woody plants (Research Forest of Kangwon National University, 2010), the coniferous forest is 789 ha (26%), while the deciduous forest is 2,236 ha (73%). Total volume of 584,529 m^3 is composed of the coniferous 175,166 m^3 (30%) and the deciduous is 409,166 m^3 (70%).

Forest function division in the Research Forest of Kangwon National University

The Research Forest of Kangwon National University was divided into each functions for sustainable forest management and optimal timber harvesting.

The factors about external and internal is set by functional through a survey of experts. Weights each functions were applied then forest functions are divided.

Goal programming

GP was introduced by A. Charnes and W.W. Cooper. Decision making can be applied in many conflicting goals, sub-goals and one goal and a number of sub-goals. But if many conflicting goals exist, achieving all of the goals at the same times are impossible.

In this case, GP can get the most reasonable solution according to importance priority of the goals. GP model used by Hyun-gyu Won in 2009 was used in this study for optimal decision making.

Methods

Setting management goals for optimal regulated timber harvesting

Four types of management goals were set for finding out timber production according to goals of the Research Forest of Kangwon National University.

Goal 1. Timber production forest induces sustainable age structures. Goal is set to minimize size variation of each age class.

Goal 2. Change in timber production of each business quarter shouldn't exceed 10 percent. Goals are set so that timber harvesting is not concentrated in one quarter.

Goal 3. Non timber forest keeps 30% of harvesting area. The other forest function goals are not timber production, so the other forest function goals are set to optimize each functional parts.

Goal 4. Optimization of timber harvesting. Setting tim-

Table 1. The area and stock of the Research Forest of Kangwon National University

Forest type	Species	Area (ha)	Stock (m^3)	Stock/ha (m^3)
Natural forest	*Pinus densiflora* forest	32	10,307	322
	Broadleaved forest	2,236	409,166	183
	Total	2,268 (74%)	419,473	505
Artificial forest	*Pinus koraiensis*	522	115,665	222
	Larix leptolepis	210	57,212	272
	Pinus rigida	3	501	167
	Abies holophylla	10	412	41
	Larix gmelini	12	2,078	173
	Total	757	175,868	875
Total		3,061 (100%)	584,529	191
Total area				3,146 ha

Table 2. Weights corresponding to each management goal in management scenarios

Management goals	Management scenarios					
	1	2	3	4	5	6
Goal 1	W1[a]	W1[a]	W2	W3	W2	W3
Goal 2	W2	W3	W3	W2	W1[a]	W1[a]
Goal 3	W3	W2	W1[a]	W1[a]	W3	W2
Goal 4	W4	W4	W4	W4	W4	W4

W1[a] (=1000) > W2 (=100) > W3 (=10) > W4 (=1).

ber production goal to minimize deviation of the timber production in each harvesting quarter.

Establishment of optimal timber harvesting model for GP

Each management scenarios has weight about 4 goals (Table 2). Each management scenarios has to set from end of 2010 to 2059 (total 50 years). Second, every 10 years is one business quarter so it constitute a total of 5 quarter. Third, harvesting is possible from III age class. Fourth, 5types of harvesting plan and non harvesting plan was set in goal 4.

Scenarios were set with different weight from goal 1 to goal 4. As seen in table 1, alternative 1 and 2 are set with most weight on goal 1, alternative 3 and 4 on goal 2, alternative 5 and 6 on goal 3. Weight was applied to show distinct differences according to priority. The ranking system (1 ranking=1,000 > 2 ranking=100 > 3 ranking=10 > 4 ranking=1), used in de Oliveira's (2003) work is used in this study.

Establishment of GP model

There are 6 total constraints, which are objective function constraint, area constraint, age class of timber production constraint, harvesting area each forest function constrain, harvesting change constraint and non-negativity constraint.

Minimize Z=

$$W_1\sum_{m=1}^{M}(d_m^- + d_m^+) + W_2\sum_{m=1}^{M}(e_m^- + e_m^+) + W_3\sum_{m=1}^{M}(a_i^- + a_i^+) + W_4\sum_{m=1}^{M}(q^- + q^+)$$

Constraints

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} C_{ijkm}X_{ijkm} + q^- - q^+ = H_t, \forall t = 1,2\ldots, T$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} X_{ijkm} = A_t, \forall t = 1,2\ldots, T$$

$$\sum_{m=1}^{M}\left\{\sum_{j=1}^{J}\sum_{k=1}^{K} X_{4jkm} + d_m^- - d_m^+\right\} = N_m$$

$$\sum_{i=1}^{I}\left\{\left(\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} X_{ijkm} + a_i^- + a_i^+\right)\right\} = \beta_i A_i$$

$$\sum_{m=1}^{M}\left\{\left(\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} C_{ijkm}X_{ijkm}\right) - (1-\alpha)\right.$$

$$\left.\left(\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} C_{ijkm+1}X_{ijkm+1}\right) + (e_m^- - e_m^+)\right\} = 0$$

$$d_m^+, d_m^-, e_m^+, e_m^-, a_i^+, a_i^-, q^+, q^-, c_{ijkm}, c_{ijkm} \geq 0$$

Z: Objective function

W_1, W_2, W_3, W_4: weights about deviation of goals

d_m^+, e_m^+, a_i^+, q^+ : (+) deviation of management objectives

d_m^-, e_m^-, a_i^-, q^- : (-) deviation of management objectives

C_{ijkm} : harvesting volume per unit area (contributing factors)

X_{ijkm} : operation areas (decision variables)

i: forest function devision (i=watershed forest, recreational forest, disaster prevent forest, Timber production forest)

j: age class (j=1...5)

k: forest types (k=coniferous, broadleaves, mixed forest)

m: management plan (m=1...6)

t: business quarterly/functions/age class/any combination of forest types ($t \in \{i, j, k, m\}$)

H_t : total timber production

A_t : total area

N_m : harvesting area of timber production forest

β_i: limited percentage of harvesting area of each functions (β_i=0.3, 0.3, 0.3, 1.0,)

A_i: area of each functions

α : allow rate of quarterly timber production change (α =0.1)

The first formula of constraints calculates total harvested production when harvested during total management planning period by using harvested area (X_{ijkm}), volume per unit area (C_{ijkm}). The second formula concerns the present area; the total area (X_{ijkm}) that takes decision making for harvested management, including non management, is the same as the real area (A_t). The third formula is for inducing sustainable age class of timber production. Timber production forest area that is managed on planning period has to be maintained the same each quarter.

The fourth formula shows the harvested area based on forest function. It is applied rate of limit β_i=0.3 about non-timber forest functions area.

The fifth formula is applied rate of change (α=0.1) for limit 10% of change of harvest on quarterly. The last formula is non-negativity constraint (all variables are same or bigger than 0). LINGO6.0 was used for analysis of Optimization Model.

Results and Discussion

As a result of forest function division, *Pinus koraiensis* and *Larix leptolepis* are applied on timber production function. Another sites are divided into forest recreation function, Disaster Prevention function and Watershed function (Fig. 1). Priority of function is selected 250 m Grid unit. Also weights are applied in function. Then it is

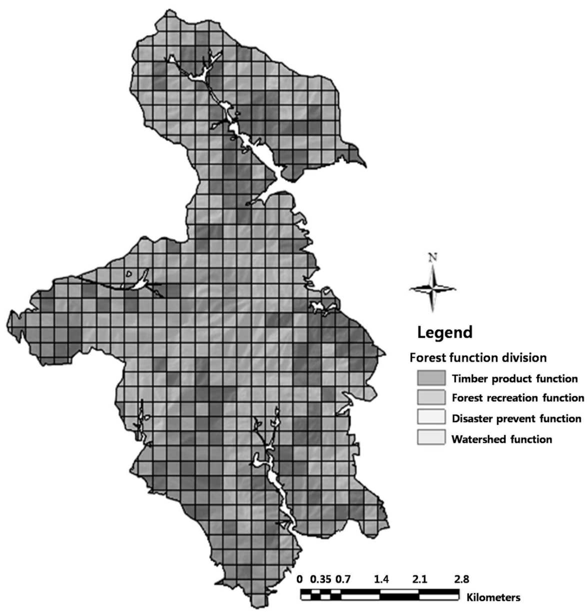

Fig. 1. Forest function division of Research Forest of Kangwon National University.

Table 3. Area and rate of each forest functions on the Research Forest of Kangwon National University

Division	Total	Watershed function	Timber product function	Forest recreation function	Disaster prevent function
Area (ha)	3,155.8	1,158.6	767.0	478.0	752.2
Rate (%)	100	36.7	24.3	15.1	23.8

Table 4. Harvesting area for each quarter management scenarios (unit: ha)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1 Quarter	506	377	125	377	408	205
2 Quarter	538	588	677	288	498	538
3 Quarter	588	221	342	677	285	348
4 Quarter	539	377	288	322	488	256
5 Quarter	532	135	88	186	377	126
Total	2,703	1,698	1,520	1,850	2,056	1,472

possible to estimate about relevance and potential or resistance and risk of functions.

A shown in Table 3, Watershed function is 36.7% of total area, timber production function is 24.3% of total area, disaster prevent function is 23.8% of total area and forest recreation function is 15.1% of total area.

As shown in the results of the GP model analysis, most of the total area of 2,073 ha was harvested in scenario 1 (Table 4), and in the third quarter, a total area of 588 ha was harvested. A total of 1,698 ha, 1,520 ha, 1,850 ha, 2,056 ha and 1,472 ha was harvested in scenarios 2, 3, 4, 5 and 6, respectively. In all scenarios except for scenario 1, the quarterly harvest areas are random (Fig. 2).

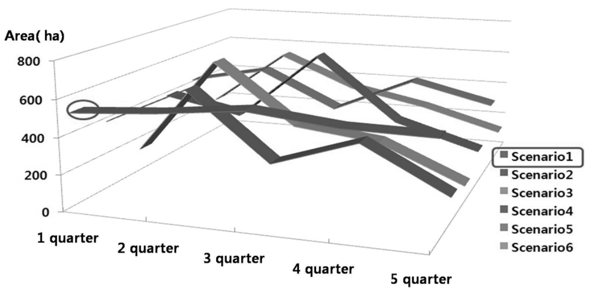

Fig. 2. Harvesting area each quarter scenarios.

Also, based on the results of quarterly harvested volume, scenario 2 harvested the most volume with 274,672 m^3 (Table 5, Fig. 3).

Through the GP model, we concluded that the most suitable scenario is scenario 1 (Fig. 4).

As a result of comparison in the non-timber forest function, the broad total harvest area is 3,003 ha at 50% rate of timber harvest (Table 6). However, the structure of the area and volume showed a balanced quarter when the rate of timber harvest is 10 to 20 percent (Fig. 5).

Conclusions

This study established the optimized forest regulation plans and set the required management goals of forest functions. The Research Forest of Kangwon National University is divided into each functions for sustainable forest management. In addition, non-timber forest function is exerted maximum and the change of timber harvest is not over 10% each quarterly.

According to Kangwon National University goal on forest timber production, we set to identify the four kinds of

Table 5. Harvesting volume for each quarter scenarios (unit: m^3)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1 Quarter	47,958	42,260	18,897	2,365	38,670	19,430
2 Quarter	58,689	54,741	39,987	13,648	47,200	50,991
3 Quarter	54,883	79,848	86,960	79,875	27,012	32,983
4 Quarter	59,665	66,003	13,765	8,569	46,252	24,169
5 Quarter	53,365	31,820	9,532	18,696	35,732	11,942
Total	274,560	274,672	169,141	123,153	194,865	139,514

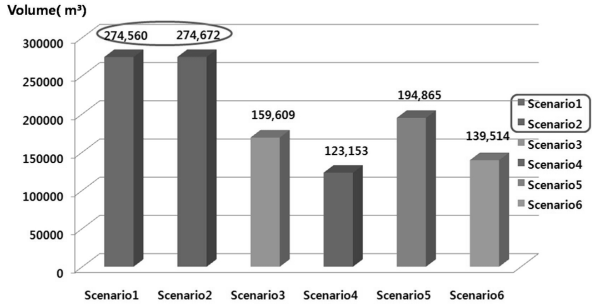

Fig. 3. Harvesting volume each quarter scenarios.

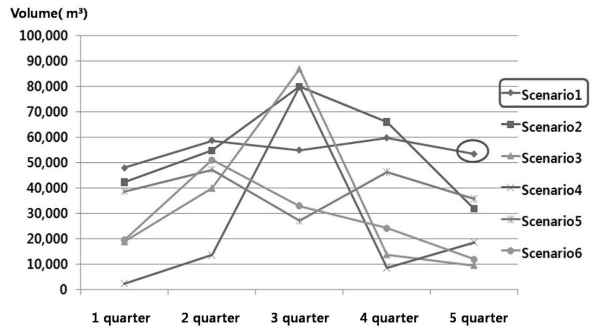

Fig. 4. Harvested total volume through Goal Programming.

Table 6. Harvested area according to the harvest rate of non-timber forest function (unit: ha)

	10%	20%	30%	40%	50%
1 Quarter	506	516	516	406	756
2 Quarter	538	558	458	238	538
3 Quarter	588	578	528	888	988
4 Quarter	539	559	609	839	489
5 Quarter	532	542	732	532	232
Total	2,703	2,753	2,843	2,903	3,003

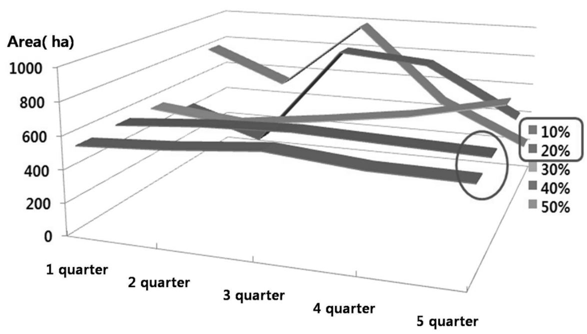

Fig. 5. Quater harvest area according to harvest rate.

management objective. As a result, the most of the total area of 2,073 ha was harvested in scenario 1, and in the third quarter, a total area of 588 ha was harvested.

The harvest volume stock in each quarter for sustainable forest management was 54,912 m^3 in every quarter (10 years). Using the averaged stock of 191 m^3 in the Research Forest of Kangwon National University that is shown as afforestation and harvesting has to run in 278 ha area on every years.

The Korea Forest Service has planned about forest resource in 170 ha of whole country. However the Research Forest of Kangwon National University is need extend management 1.6 times by the management plan of forest resource which is operated in Korea Forest Service. However, finding the suitable regulation timber harvesting plan is difficult because many hypotheses are put in and constraints are predicted.

But, in this study the established optimal timber harvest model even if functions needs were different and this paper is possible to establish relative management plan which was noticed in this paper.

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