Harvest Regulation Based on Sustainable Management of Forest Resource

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Abstract By the support of ForStat2.0, beginning with the real production, uncut age series，stable yield restriction，target area error restriction，and total volume and to construct the real age series，target age series，regular period，the upper limit of restriction at the end of period, each of them determined the structure of that linear programming model. The result of the experimentation in Mangui Forest Bureau proved that, the cut area and volume dropped by stages, and the preserved volume moved up in conk, as a result, the sustainable forest age structure was reached.

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1 Introduction

Forest Harvest regulation is one of the core issues of forest management and the key technology of the limits control of the current deforestation(Wu,2003).In the natural state, if there is no large natural variability or disasters, forests should convergence to the sustainable forest resource structure with probability 1 (Li,2009).

From the perspective of space forest age, forest harvest regulation is to seek a best transferring path of forest age vector, and attain the goal. In this sense, forest harvest regulation is an issue of linear programming optimization. A Japanese researcher promoted linear programming forest harvest regulation model type I in 1980, which has two obvious disadvantages. First, cutting volumes were not always “uniform flows", which means that cutting volume of every stage can’t be guaranteed to be approximately the same mount. In some cases, calculation result is largely different from the cutting volume. The second, forest accumulation can’t be adjusted to the target value, so this model is rarely used in the practice (Lang et al., 2005).

Based on former forest harvest regulation models (Tang et al., 2003), a bran-new forest harvest regulation linear programming model is promoted in the paper. This model type is suitable to the actual situation，because some options are added, such as production stabilization, target age-class acreage and total accumulation, and acreage error of target forest age-class (specified error) is permitted in the model**.**

2. Principle of Forest Harvest Regulation Linear Programming Model

Set $\vec{w}_t = (a_{10}, a_{20}, \ldots a_{p0})$ to realistic forest age vector, $\vec{w}_\tau = (b_1, b_2, \ldots b_r)$ to target forest age vector, $n = \max(p, r)$ to the maximum age-class, $c = (c_1, c_2, \ldots, c_n)$ to accumulation of every hectare at the age-class, decision variable arrangement of every age-class cut(clear-cut) by q stages (1 stage equals to 1 age-class), every stage and age-class cutting acreage(decision variables) and retention acreage can be the following matrix respectively:

$$X_{n\times q} = \begin{pmatrix} x_{11} & x_{12} & \ldots\ldots x_{1q} \\ x_{21} & x_{22} & \ldots\ldots x_{2q} \\ \ldots\ldots & \ldots\ldots & \ldots\ldots \\ x_{n1} & x_{n2} & \ldots\ldots x_{nq} \end{pmatrix} \qquad A_{n\times q} = \begin{pmatrix} a_{11} & a_{12} & \ldots\ldots a_{1q} \\ a_{21} & a_{22} & \ldots\ldots a_{2q} \\ \ldots\ldots & \ldots\ldots & \ldots\ldots \\ a_{n1} & a_{n2} & \ldots\ldots a_{nq} \end{pmatrix} \quad (1)$$

The reality stand age vector: $\vec{w}_t = (a_{10}, a_{20}, ...a_{p0})$ That formed the extended matrix of retained area is $\tilde{A} = \vec{w}_t + A$ by 0 means method in A.

Supposed that retained forest stand rises 1 level with probability per stage; to limit afforestation to keep up with harvest, that is to make all felling area to be the retained forest stand in this stage in age 1.See main parameters of forest harvest regulation in Figure 1.

0stage	1 stage	2 stage	3 stage…………………………	q stage	Target-value
a_{10}	x_{11} a_{11}	x_{12} a_{12}	…………………………………	x_{1q} a_{1q}	b_1
a_{20}	x_{21} a_{21}	x_{22} a_{22}	…………………………………	x_{2q} a_{2q}	b_2
………	………	………	…………………………………	………	……
………	………	………	…………………………………	………	b_r
a_{n0}	x_{n1} a_{n1}	x_{n2} a_{n2}	…………………………………	x_{nq} a_{nq}	

Note: The elements of unfilled matrix can be cleared automatically.

Fig. 1. Schematic of forest harvest regulation

Following are 7 groups of constraints in stages:

1.1 Uncut constraints:

$$x_{j,i} = 0 \quad 1 \le j \le I_1, 1 \le i \le q \qquad (2)$$

Where I_1 is the upper limit of uncut age. Obviously the first I_1 lines of decision variable of matrix X front will be assigned to zero. The methods of dummy decision variables to be adopted to solve the design of decision variables in forest harvest regulation.

1.2 The cut area constraints

Clearly, the cut area of each stage and age must be less than or equals to that of the former stage and age, which is

$$x_{j,i} \le \tilde{a}_{j,i-1} \quad 1 \le j \le n, 1 \le i \le q$$

It regards $\vec{w}_t$ (a realistic forest age vector) as a column vector for the zero staging.

1.3 The state transferring equation of age area constraints

(1) Constraints to afforestation area, the resulting calculation formula for the each stage 1 age-class reservations area:

$$a_{1,i} = \sum_{k=1}^{n} x_{k,i} \quad 1 \le i \le q \qquad (3)$$

Formula (3) denotes the i-phase 1 age-class reservations area equals to the sum of the age-class cutting (afforestation) area.

(2) Calculation formula for other age-class reservations area:

Obviously, the j stage, the i age-class reservations area equals to the j-1 stage, the i-1 age-class reservations area (to i age-class) minus the present felling area of i age-class, which is:

$$a_{j,i} = \tilde{a}_{j-1,i-1} - x_{j,i} \qquad 1 < j < n$$
$$a_{n,i} = \tilde{a}_{n-1,i-1} + a_{n,i-1} - x_{n,i} \qquad 1 \le i \le q \qquad (4)$$

The second formula in (4) denotes the largest age-class is no longer transferring the age-class. $a_{i0}, 1 \le i \le n$ is the known real area in each age class, so it can be seen as a zero stage, each age-class retained area.

1.4 Stable yield restriction constraints:

$$\sum_{j=1}^{n} x_{j,i+1} * c_j \le (1+k\%) * \sum_{j=1}^{n} x_{j,i} * c_j$$
$$\sum_{j=1}^{n} x_{j,i+1} * c_j \ge (1-k\%) * \sum_{j=1}^{n} x_{j,i} * c_j \qquad (5)$$

Where $k\%$ is the allowable error from the former and latter timber production.

1.5 The end of regular period constraint

(1) Target age-class constraints:

$$a_{jq} \le (1+u\%)*b_j \quad 1 \le j \le n$$
$$a_{jq} \ge (1-u\%)*b_j \qquad (6)$$

$u\%$ is the allowable error of target area,

b_j is target area in j age-class.

(2) The end of the total volume constraints:

$$\sum_{j=1}^{n} a_{jq} * c_j \ge v * \sum_{j=1}^{n} a_{j0} * c_j \qquad (7)$$

v is the end of the total volume which is a multiple of realistic total volume, when v>1, it needs more and more harvest.

According to the problem requirements (options) and the constraints above, we can get the equations or inequalities with the constraints of practical problems. The objectives function as follow:

$$Z = Max \sum_{i=1}^{q}\sum_{j=1}^{n} x_{ij} c_j \qquad (8)$$

A general type of linear programming has been got by collating.

Demand $x = (x_1, x_2, ...x_h)$, under the following conditions:

$$\begin{aligned} &\beta_{11}x_1 + \beta_{12}x_2 + ...+ \beta_{1h}x_h \le [=][\ge] b_1 \\ &\beta_{21}x_1 + \beta_{22}x_2 + ...+ \beta_{1h}x_h \le [=][\ge] b_2 \\ &... \\ &\beta_{m1}x_1 + \beta_{m2}x_2 + ...+ \beta_{mh}x_h \le [=][\ge] b_m \\ &x_1 \ge 0, x_2 \ge 0, ...x_h \ge 0 \end{aligned} \qquad (9)$$

For the objective function: $z = c_1x_1 + ... + c_px_p$ is to be a maximum.

3. Forest Harvest Regulation Test

Mangui Forestry Bureau harvest experimental forest is 20-year-old (Li et al.,2008)deciduous forest, which was divided into commercial forest in 1996. To optimize adjustment of the experimental field for forest harvest regulation, parameters designed as:

1. Adjustment of the number of stages: 7, the adjustment period is 140 years; the limit of uncut age-class: 2.

2. The target area restrictions: the allowable error between the end of regulation period area and the target area is less than 10%, the output difference between pre-and post stage is less than 15%.

The Output: adjusting the number of stages: 8; uncut age-class: 2;the target area restrictions: the allowable error between the end of regulation period area and the target area is less than 10% , the output difference between pre-and post stage is less than 15%. (see Table 1 ~ 4).

The objective function value (the total accumulation of harvesting) = 13669272 m^3。

Table 1. The optimal harvesting area table in each stage

Age-class	stage1	stage2	stage3	stage4	stage5	stage6	stage7	stage8
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	6447	921	9512.6	0	583.8	0	0
4	0	0	0	0	8081.6	914.9	0	0
5	0	0	8091	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	10226.2	0	0	0	0	0	0	0
8	7368	10508.8	4931.2	4638.9	3020.6	6516.7	6403.3	5442.8
sum	17594.2	16955.8	13943.4	14151.5	11102.2	8015.4	6403.3	5442.8

Table 2. The optimal harvesting accumulation table in each stage

Age-class	stage1	stage2	stage3	stage4	stage5	stage6	stage7	stage8
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	651147	93021	960770	0	58961	0	0
4	0	0	0	0	969790	109788	0	0
5	0	0	1124679	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	1595282	0	0	0	0	0	0	0
8	1223088	1744467	818572	770061	501416	1081776	1062947	903505
sum	2818370	2395614	2036272	1730831	1471207	1250526	1062947	903505

Table 3. The end of each stage reservations area table

Age-class	stage0	stage 1	stage 2	stage3	stage 4	stage 5	stage 6	stage 7	stage 8
1	921	17594.2	16955.8	13943.4	14151.5	11102.2	8015.4	6403.3	5442.8
2	6447	921	17594.2	16955.8	13943.4	14151.5	11102.2	8015.4	6403.3
3	10131	6447	921	17594.2	16955.8	13943.4	14151.5	11102.2	8015.4
4	12894	10131	0	0	8081.6	16955.8	13359.6	14151.5	11102.2
5	8289	12894	10131	0	0	0	16040.9	13359.6	14151.5
6	25788	8289	12894	2039.8	0	0	0	16040.9	13359.6
7	21183	25788	8289	12894	2039.8	0	0	0	16040.9
8	7368	10956.8	26236	29593.8	37848.9	36868.1	30351.4	23948.1	18505

Table 4. The end of each stage retained accumulation table

Age-class	stage 0	stage 1	stage 2	stage 3	stage 4	stage 5	stage 6	stage 7	stage 8
1	29472	563013	542587	446188	452848	355269	256493	204905	174170
2	489972	69996	1337157	1288644	1059696	1075514	843765	609170	486650
3	1023231	651147	93021	1777011	1712540	1408281	1429302	1121319	809555
4	1547280	1215720	0	0	969790	2034701	1603152	1698180	1332260
5	1152171	1792266	1408209	0	0	0	2229691	1856984	1967059
6	3790836	1218483	1895418	299848	0	0	0	2358018	1963861
7	3304548	4022928	1293084	2011464	318206	0	0	0	2502387
8	1223088	1818834	4355175	4912577	6282920	6120108	5038331	3975385	3071880
sum	12560598	11352388	10924651	10735732	10796001	10993873	11400733	11823962	12307821

4. Conclusion

1. By the support of ForStat2.0, beginning with the real production, to construct the real age-class p , the target age-class r, regulation period q, the upper limit of uncut age-class I1, stable yield restriction k, target area error restriction u, the end of period total accumulation restriction v , each of them uniquely determined the structure of that linear programming model. From the experiment result of Mangui Forestry Bureau, felling area and accumulation descend by stages, retained accumulation ascends, and finally a sustainable forest age structure can be attained.

2. The harvesting area descends by stages, the harvesting accumulation gradually decreased, the reservation accumulation before the third stage before are on the decline, but after the fourth stage are on the rise.

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