Dynamic visual simulation of growth and management of Chinese Fir Based on Structured Forest Management

Shen Kang¹,Yang Tingdong¹*,Zhang Huaiqing¹,Zhang Lili²
1.Research Institute of Forest Resource Information Techniques, Chinese Academy of Forestry
2. Experimental center of subtropical Forestry, Chinese Academy of Forestry
Email: shenkangmail@qq.com

Abstract: Based on the theory of Structure-based Forest Management, this paper studies the growth-management process of a forest considering the healthy state of the forest structure, and realizes three-dimensional visual simulation of this process based on unity3D. According to the angle scale, size ratio, crowding degree and other quantitative indexes of forest structure proposed by the theory of Structure-based Forest Management, the Spatial Structural function model and urgency management of forest were established to quantify the state of forest structure from many aspects. The growth equation of Chinese fir was fitted by the single tree growth equation based on the Hegyi competition index and forest density. Pre-thinning timbers are selected according to the rule that the cutting volume is less than the all growth volume in stand and size of competition index, and then the top 30%, 50% or 80% of pre-thinning timbers are extracted by rule sampling on the basis of pre-thinning timbers, and the stand structure function after thinning is also calculated. The minimum value of thinning plan is taken as the actual thinning plan. Our results show that according to the growth period of 5 years, the growth and management of sample plot 5 were simulated for next 10 years. As in this case, based on the structured forest management, the dynamic visual simulation method of Chinese fir stand growth-management can realize the visual simulation of Chinese fir stand growth and management, which is a good way to show the forest growth management, and has a good demonstration role in improving the forestry informatization.

Key words: structural parameters; stand growth; forest management; visual simulation

1. Introduction
There are two research fields in forest management: forest growth simulation and forest management [1-4]. In the aspect of forest growth simulation, from line analysis and non-linear analysis[5], to Big Data analysis [6], the accuracy of forest growth fitting is gradually improving; in the aspect of forest management, from "one size fits all" clear cutting management to selective thinning management [7-9], and then to sustainable development [10-11], the connotation and mode of forest management are gradually enriched. However, the influence of forest growth and management is mutual and continuous. A simple consideration of one aspect is not fair for a correct understanding of forest management. Therefore, this study attempts to study forest management from the perspective of growth and management interaction.

In recent years, the theory of forest management is becoming more and more mature and systematic, which shows that the theory of forest management is no longer only considering the management mode from the perspective of average stand information (such as average
DBH, average tree height), but also more detailed to consider the management decision (such as Structure-based Forest Management[12.19]) from the perspective of single tree competition[13-14]. The highlight of structured forest management is to optimize forest structure, guiding forest management with forest structure and evaluating forest status in real time[15]. However, the traditional chart method makes the theory of structured forest management lose a lot of luster. There are natural advantages in the presentation Forest of 3D visualization[16-18], so it has a good role in the performance and development of Structure-based Forest Management.

In this article, it is mainly described from the following chapters. The first chapter introduces the previous achievements and existing problems to lead to the specific content of this study; the second chapter is the general situation of the research area and the acquisition and processing of data; the third chapter specifically introduces how to construct the management function and the process and visualization method of forest growth & management through the structured forest theory; the fourth chapter shows the growth and management through specific sample plots visual simulation results of battalion and related discussion. The fifth chapter is the summary of this study; And the last chapter is the acknowledgment.

2. Study Area & Data

The study area is located in Huangfengqiao(HFQ) State-owned Forest Farm, Youxian County, Hunan Province, ranging from 113°04´ to 113°43´E and 26°43´ to 27°06´N, with the lowest elevation of 115 m and the highest elevation of 1270 m. It belongs to the subtropical monsoon climate with an average temperature of 17.8 C and annual precipitation is 1410.8 mm in volume. It also is a key demonstration base for promoting large-diameter timber of Chinese fir in Hunan Province, with 90.07% in forest coverage.

The selected sample plots were measured by routine tree-surveying methods, including diameter at breast height, tree height, crown height, crown width, height under living branches, growth status and relative position of trees (x, y, z). According to the interval of one year, the survey data of 2012-2017 were collected. Five sample plots with the same status index were summarized as shown in Table 1.
Table 1. Sample plot survey data in HFQ

| ID | Area/m²  | Age/a  | Num | DBH/cm   | H/m    | CW/m   | UBH/m   |
|----|----------|--------|-----|----------|--------|--------|----------|
| 1  | 60*60    | 17~22  | 533 | 7.1~15.9~35.6 | 4.3~11.4~23.8 | 0.45~3.17~3.8 | 1.2~6.14~13.6 |
| 2  | 50*80    | 24~29  | 363 | 13.3~23.4~38.3 | 8.4~17.0~29.5 | 1.3~3.82~4.2 | 1.7~11.13~19  |
| 3  | 50*50    | 11~16  | 310 | 5.9~15.2~30.6 | 5.3~11.6~19.8 | 0.85~3.03~4.0 | 2.5~6.22~13.1 |
| 4  | 50*80    | 10~15  | 953 | 3.2~12.12~26.8 | 3.2~9.6~17.8 | 0.5~2.5~3.8 | 1.3~5.65~13.7 |
| 5  | 50*50    | 16~21  | 231 | 10.5~21.21~34 | 6.7~14.97~19.9 | 1.6~3.8~7.5 | 2.6~8.1~14.2 |

Note: a~b~c, a is the minimum, b is the average and c is the maximum.

Figure 2. Distribution Map of Relative Position of Trees in Five Survey Sample

3. Methodology

3.1. Construction of Spatial Structural Function

According to Hui Gangying’s study of Structure-based Forest Management[19], a healthy stand structure can be described by four structural parameters: angle scale, size ratio, mixing degree and crowding degree, which is represent the distribution of stand, the competition of stand and the isolation of stand species, the degree of forest nutrition and the size of tree nutrition space. According to the results of previous studies, the healthy stand structure can be quantitatively expressed in this four parameters. Because the mixed degree of Chinese fir plantation is zero, the parameters of mixed degree are eliminated and the spatial structure function is established. As shown in the following formula, the smaller value of the spatial structure function Q(g), the closer the stand structure is to the healthy level.

\[
Q(g) = |\bar{W} - 0.5| + \frac{\bar{U}_a}{\bar{U}_{a-o}} + |\bar{C} - 0.9|
\]

Where g is the sample forest vector, which is included multiple attributes of stand; \(\bar{W}\) is the Average Angle scale; \(\bar{U}_a\) is the Size Ratio after structural adjustment; \(\bar{U}_{a-o}\) is the Size Ratio before structural adjustment; \(\bar{C}\) is the Average Crowding Degree.

3.2. Dynamic visual simulation of Growth & Management
The spatial structure characteristics of forests affect the growth of forests, and also determine whether management measures are needed. In order to achieve a healthy structure of forests, it is necessary to conduct multiple management of forests. In this paper, Rivasj JC’s single tree growth equation, which is improved, is used as the driving equation of stand growth[20]. The dynamic interaction between stand growth and forest management is realized by combining the optimal thinning management plan selection of rule sampling method, and meets the dynamic needs of managers. The process of management dynamic visualization simulation is as follows:

Firstly, initialize stand scenarios. By reading the Excel data table, we set the coordinates of Chinese fir position as \((x, y, z)\), the initial DBH of single tree as \(D_0\), the tree height as \(H_0\), the crown width as \(CW_0\), and the height under living branches as \(UBH_0\), then the tree position as \(Tree\_Position= (x, y, z)\), the X-Z plane zoom coefficient as \(Tree\_XZ=D_0*D^{-1}\) (\(D\) is the DBH of the original model), and the zoom coefficient in the Y direction as \(Tree\_Yscale=H_0*H^{-1}\) (\(H\) is the height of the original model).

Secondly, the judgment of stand management and the choice of optimal management plan. Based on the spatial structure parameters, the urgency of forest management was analyzed, and the thinning is determined to implement or not, according to the analysis results and the actual considerations of managers. Once thinning is beginning, the preliminary selection of timbers is made by comparing the size of competition index, and the chain of thinning management plans are established. Then, on the basis of pre-thinning of the 30%, 50% and 80% are extracted by regular sampling and the value of stand structure function after thinning is calculated. The minimum value of thinning plan is taken as the actual thinning plan, and the thinning attribute of the tree is set to 1 (cut=1), \(Tree\_Position= (x, y, z)\), \(x, y, z\) is set to infinite distance, and the tree stump model downloaded from Asset Store in Unity3D is used to replace the original position of the tree.

Thirdly, dynamic changes of stand growth. Based on Unity3D key frame technology, tree growth is divided into several stages at certain intervals, each stage is represented by a key frame. Under the simulation of the growth equation of variable growth rate based on competition index, we set the DBH of Chinese fir to \(D_i\), the tree height is set to \(H_i\), the crown width is set to \(CW_i\), and the height under living branches is set to \(UBH_i\) in the i key frame. At this moment, the tree location \(Tree\_Position= (x, y, z)\), the X-Z plane scaling coefficient is \(Tree\_XZscale=D_i/(D_{i-1})^{1/(i>1)}\), and the scaling coefficient in the Y direction is set to \(Tree\_Yscale=H_{i-1}\) (\(i>1\)).

Finally, taking the structural characteristics of healthy stand and the DBH of target stand as the stopping conditions, the steps 2 and 3 is recycled until the management objectives were met.

4. Results and Discussions

4.1. Analysis on the Urgency of stand management

According to the research conclusion proposed by Hui and others[14], One, make the spatial distribution orientation of healthy stand as random as possible, i.e. \(W=[0.475-0.517]\); Two, reduce the competitive pressure of stand, i.e. \(\frac{\bar{b}_a}{\bar{b}_{a-0}}=(0-1)\); Tree, the value of stand crowding
is in the middle, i.e. $\bar{C} = [0.9 - 1.1]$. According to these three conditions, the thinning of pure forest stands can be divided into four situations: No Management, Proper Management, Need management and must management.

4.2. Single tree growth equation fitting based on Hegyi competition index and stand density

On the one hand, the growth of single tree is affected by the adjacent surrounding trees, and the growth performance is negatively related to the competitive advantage of the surrounding trees. On the other hand, the growth status of single tree is related to the stand density on the stand level. Therefore, by improving the research results of rivasj JC[20] and others on the growth of single tree, the DBH growth fitting of this study is carried out, and the parameter equation is shown in formula (2):

$$D(i, t + 1) = D(i, t) + \exp \left( a + \frac{b}{At} + c \ast CI_i \right) + d \ast (\ln(M))^{-1}$$  \hspace{1cm} (2)

Where $D(i, t+1)$ is DBH of the No.i tree at $t+1$ year; $D(i, t)$ is DBH of the No.i tree at $t$ year; $At$ is the age of stand; $CI_i$ is the competition index of Hegyi in No.i tree; $M$ is stand density; $a$, $b$, $c$, $d$ are parameters.

The data of successive years' investigation of the four plots are processed, and the data of abnormal values with large fluctuation are eliminated. Then, the non-linear analysis is carried out through the ForStat 2.2 software developed by China Academy of Forestry Sciences. The growth equation results of fitting DBH are shown in Table 2. The upper and lower limits of 95% confidence interval of parameter $a$, $b$, $c$ and $d$ values do not exceed 0, indicating that the fitted parameter values are available.

Table 2. Fitting Growth Equation Results Based on Nonlinear Method

| Parameter | Value | Asymptotic standard deviation | Lower limit | Upper Limit |
|-----------|-------|-------------------------------|-------------|-------------|
| a         | 0.8482| 0.0702                        | 0.7106      | 0.9859      |
| b         | -5.4322| 0.3235                      | -6.06638    | -4.7981     |
| c         | 0.0137| 0.0022                      | 0.0930      | 0.0180      |
| d         | -15.8408| 1.0516                    | -17.9022    | -13.7793    |

The data shows that the correlation of $b$, $c$ and $d$ is low in table 3, which shows that the function structure is reasonable, the correlation of $a$ and $d$ is high, but $d$ is related to variable $M$(stand density), so $a$ and $b$ cannot be combined. To summarize, the equation of DBH growth of Chinese fir is fitted. We also drew the distribution map of D-H, D-CW and H-UBH according to the data collected(Figure 4). It is clearly find that there is a clear correlation between them. Therefore, we finally calculate the exact formula between them through linear regression analysis. The $R^2$ of D-H, D-CW and H-UBH were 0.7908, 0.5418 and 0.5786, which indicated that the correlation between DBH and height of tree was higher respectively, and that between DBH and crown ,height of tree were lower. Lastly, We got the growth equation of tree height, branch height and crown diameter by the growth equation of DBH and the relationship between DBH and tree height, branch height and crown diameter.

Table 3. Asymptotic correlation coefficient of parameters

| Parameter | a     | b     | c     | d     |
|-----------|-------|-------|-------|-------|
| a         | 1.0000| 0.8292| -0.4111| -0.9909|
| b         | 0.8292| 1.0000| -0.4152| -0.8945|
| c         | -0.4111| -0.4152| 1.0000| 0.4161|
Table 1. Linear regression results of three tree factors (DBH-HDBH-CW, H-UBH)

| d     | -0.9909 | -0.8945 | 0.4161 | 1.0000 |
|-------|---------|---------|--------|--------|

\[ D(i, t + 1) = D(i, t) + \exp \left( 0.8482 - \frac{5.4322}{A_t} + 0.0137 \cdot C_{li} - 15.8408 \cdot (\ln(M))^{-1} \right) \]

Figure 3. Linear regression results of three tree factors (DBH-HDBH-CW, H-UBH)

4.3. Dynamic visual simulation of Growth and management in Chinese Fir

In this study, we simulated the growth and management of No. 5 sample plot in Huangfengqiao forest farm of you County for next 10 years. From the analysis of operational urgency of the initial stand scenario (as shown in Figure 4 up), it can be seen that the initial stand scenario (16a) of sample plot No.5 is “Proper Management”, considering the low level of management need, so that a continuous five-year simulation is carried out. The simulation results are as follows, it can be seen from Figure 4 (down) that the value of stand crowding degree becomes smaller, indicating that with the growth of the stand, the crown becomes larger, the competition pressure between trees increases, in addition, the average DBH increases by 3.58cm in this 5 years, and the urgency of management changes from “Proper Management” to “Need Management”. 
Thinning simulation is carried out for the sample plot No.5 at 21a (as shown in Figure 5). The red ball shows the preliminary selection of the timbers to be cut. The selection of the timbers to be cut is based on the size of the competition index and the principle that the volume of thinning wood amount of the forest shall not be less than the growth of the forest volume. The preliminary selection of the timbers to be cut are 23 plants. Actually, the result of thinning are 8 plants (Figure 6). The final thinning is based on the equidistant sampling, and the Spatial Structural function values of 30%, 50%, 80% and 100% of the pre-thinning are calculated respectively. The final thinning plan is determined by comparing the size of the function values. After thinning, the structure of the stand was analyzed again to serve for next time. It was found that the average DBH of the stand after thinning changed to 24.17cm, which indicated that the main thinning timbers were trees with smaller DBH. The thinning measures were very effective. The congestion degree of the stand after thinning increased by 0.031, and the stand was sparse compared with that before thinning. In order to reflect the continuous growth management effect, we continue to simulate the growth results for next 5 years, and then conduct thinning simulation again according to the urgency management. The results are shown in Figure 7, among which 22 trees are thinned.
Figure 5. Result of preliminary selection timbers (21 a)

Figure 6. Result of preliminary selection timbers (21 a)
5 Conclusions

Based on the theory of structure-based Forest Management, we study the growth and management process of a forest considering the healthy state of the forest structure, and propose a dynamic forest management visual simulation method of 3D rendering engine based on unity3D. Then, the three-dimensional reconstruction and simulation of the next 10-year growth & management results of the sample plots No.5 were carried out in the state-owned forest farm of Huangfengqiao, you County, Hunan Province. From the results of simulation, we preliminarily completed the simulation of stand growth and management precisely, and the effect of thinning management has a positive significance for the healthy development of stand structure. Further, We can provide technical reference for the Digital Forestry in China. However, forest management activities are not only simple thinning measures, but also replanting, pruning, fertilization and so on. Therefore, we also need to further simulate all kinds of forest management activities in the future research.

In addition, the growth and management of the forest influence each other. The growth of the forest determines when to manage and what kind of management activities to take, the management activities also affect the competitive advantage between the trees during growth. In this paper, we focus on the performance of growth in the stand structure, and using the stand structure to guide thinning. However, this study does not consider the significant impact of topography on the stand structure. As we all know, the trees on the height slope will affect the trees on the low slope, even if they are the same height. Therefore, in the aspect of growth
simulation, the terrain factor should be added in the future research.

References

[1] Damjan Strnad, Stefan Kohek, Simon Kolmanc 2018 Ecological Informatics. Fuzzy modelling of growth potential in forest development simulation. 48 80-88

[2] Victor Hugo Ferreira Andradea, Sebastião do Amaral Machadao, Afonso Figueiredo Filhoa, Paulo Cesar Botossob, Bruno Palka Mirandac, Jochen Schöngartd 2019 Forest Ecology and Management Growth models for two commercial tree species in upland forests of the Southern Brazilian Amazon. 438 215-223

[3] Pan Wana, Gongqiao Zhanga, Hongxiang Wanga, Zhonghua Zhaoa, Yanbo Huab, Ganggang Zhangac 2019 Ecological Informatics Impacts of different forest management methods on the stand spatial structure of a natural Quercus aliena var. acuteserrata forest in Xiaolongshan, China. 50 86-94

[4] Vladimir Shanin, Sauli Valkonen, Pavel Grabarnik, Raisa Mäkipää 2016 Forest Ecology and Management. Using forest ecosystem simulation model EFIMOD in planning uneven-aged forest management. 378 193-205

[5] Liyong Fu, Hua Sun, Ram P. Sharma, Yuancai Lei, Huiru Zhang, Shouzheng Tang 2013 Forest Ecology and Management. Nonlinear mixed-effects crown width models for individual trees of Chinese fir (Cunninghamia lanceolata) in south-central China. 302 210-220

[6] Sijia Li, Huaiqing Zhang, Yongliang Li, Tingdong Yang, et al. 2019 Forest Research. Dynamic Visual Simulation of Chinese Fir Stand Growth Based on Sample Library. 32(1):21-30

[7] Zhu Yuje, Dong-Xibing 2016 Journal of Beijing Forestry University Evaluation of the Effects of Different Thinning Intensities on Larch Forest in Great Xing’an Mountains. 12:29-38

[8] Huang Xueman, You Yeming, Lan Jiachuan et al. 2016 Acta Ecologica Sinica The effect of carbon storage and its allocation in Cunninghamia lanceolata plantations with different thinning intensities. 36(1):156-163

[9] Liu W Y, Lin C C, Su K H 2017 Forest Policy and Economics Modelling the spatial forest-thinning planning problem considering carbon sequestration and emissions. 78 51-66

[10] Robert G D’Eon, Daryll Hebert, Stephen L Viszlai 2004 Forestry Chronicle An ecological rationale for sustainable forest management concepts at Riverside Forest Products, southcentral British Columbia. 80(3):341-348.

[11] PAN Cun-de. 2006 Journal of Beijing Forestry University Sustainable forest management: from timber to biodiversity. 6:205-213.

[12] Li Yuanfa, Ye Shaoming, Hui Gangying, Hu Yanbo, Zhao Zhonghua 2014 Forest Ecology and Management. Spatial structure of timber harvested according to structure-based forest management. 322 106-116

[13] Aguirre O, Hui G Y, Gadow K v 2003 Forest Ecology and Management An analysis of spatial forest structure using neighbourhood-based variables. 183(1-3) 137-145

[14] Zhao Z H, Hui G Y, Hu Y B 2014 Canadian Journal of Forest Research Testing the significance of different tree spatial distribution patterns based on the uniform angle index. 44(11) 1419-1425

[15] Hui Gangying, Hu Yanbo, Zhao Zhonghua 2018 Forest Research. Research progress of structured forest management. 31(1) 85-93
[16] Andre O. Falcao, Manuel Prospero dos Santos, Jose G. Borges 2006 *Computers and Electronics in Agriculture* A real-time visualization tool for forest ecosystem management decision support. *53* 3–12

[17] En-Mi Lima, Tsuyoshi Honjo 2003 *Landscape and Urban Planning* Three-dimensional visualization forest of landscapes by VRML. *63* 175–186

[18] Chunming Cheng, Li Kang, Saihua Cai, Jiayao Li, Ruizhi Sun 2018 *International Federation of Automatic Control* Virtual Display and Interactive Experience Platform of Farming Culture Based on Unity3D. *51-17* 637-642

[19] Hui Gangying, Klaus von Gadow 2016 Principles of Structure-based forest management (Beijing: China Forestry Press) chapter 5 pp 253-254

[20] Rivas J JC, Gonzalez J G A, Aguirre O, Hernández FJ. 2005 *European Journal of Forest Research*, The effect of competition on individual tree basal area growth in mature stands of Pinus cooperi Blanco in Durango (Mexico). *124(2)* 133-142

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