

Study on forest land change dynamics based on CA-Markov and FORECAST models

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Abstract. In order to study the dynamics of forest land change in Sichuan province, this paper developed a CA-Markov model to estimate the total amount of CO₂ stored in the region in the future 100 years. Then, the visualization results of forest land change are combined with forest comprehensive value to provide suggestions for forest managers in the region. Finally, this prediction model was used to study the impact of different rotation periods on forest carbon sinks of specific tree species in the study area.

Keywords: The dynamics of forest; CA-Markov model; FORECAST model.

1. Introduction

Forests and woody forest products are important components of the carbon cycle in terrestrial ecosystems, and the topic of their carbon stocks has been included as an important issue in the United Nations Framework Convention on Climate Change. We developed a forest value-based decision evaluation model and other related models as a way to develop appropriate management strategies for forests [1].

The rise of greenhouse gases has brought a huge threat to the living environment of human beings, and forests play a very important and irreplaceable role in mitigating climate change [2-5]. Forests sequester carbon in their own ecosystems and forest products produced by trees, and during the regeneration of young forests, they will also absorb a large amount of carbon dioxide due to photosynthesis. How to formulate management plans reasonably to maximize forest benefits? It has become a problem for all countries and even all mankind [6, 7].

This paper selected Sichuan Province, China, for the analysis. First, a CA-Markov model was developed to predict the dynamics of forest land change in Sichuan Province over 100 years, and the total CO₂ stored in the region over 100 years was estimated to be $8785 \times 10^8 t$. Subsequently, the results of forest land change visualization were combined with the forest comprehensive value to make recommendations for forest managers in the region. Finally, the FORECAST model was used to investigate the effects of different rotation periods on forest carbon sequestration for specific tree species in this study area.

In summary, the model constructed in this paper can estimate forest carbon sequestration dynamically in a more prepared way and performs very well in different regions. Secondly, it provides forest managers with forest management strategies from multiple perspectives and contributes to the maintenance of ecosystem stability and the promotion of peak carbon neutrality.

2. CA-Markov Model

2.1 Establishment of a dynamic prediction model for forest land types

The dynamic degree of forest use can quantitatively describe the quantity, speed and difference of forest use area change in a certain area, and its expression is as follows [8, 9]:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \quad (1)$$

Among them: U represents the area of a certain forest use type; a, b is the time node of the start and end of the study; T is the total time.

The CA simulation system is composed of states, fields, cells and transformation rules [10]. Generally, a 5x5 Moore field is used as a filter. Show:

$$S_t + 1 = f(S_t, N) \quad (2)$$

In formula (2), f is the cell transformation rule of the local space; S is the geometry of the finite and discrete state of the cell; $t, t+1$ is different time points; N is the adjacent region of a cell, they are all nonlinear, and it is difficult to accurately predict them only by using the local transformation rules of CA.

Markov is a stochastic system. The prediction of land use change conforms to the conditions of Markov chain. The ratio of mutual conversion between different land types is the state transition probability. Using this probability, the Markov model can be established. The formula is as follows:

$$P = \begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P_{n1} & P_{n2} & \cdots & P_{nn} \end{bmatrix} \quad (3)$$

$$S_t + 1 = P \times S_t \quad (4)$$

In formula (3), $0 \leq P_{ij} < 1$ and $\sum P_{ij} = 1$. $P_{ij}(i, j=1, 2, \dots, n)$ represents the transition probability of the land type from transitioning to j in the time cycle period; P is the transition probability matrix of each type; n is the number of land use types; S_t, S_{t+1} are the land use status at time t and time $t+1$.

2.2 Model verification

2.2.1 Extended kappa coefficient

The kappa coefficient test used in this paper includes four extended kappa indices [11]. We use the extended kappa coefficient to verify the accuracy of the simulated and actual forest data, and then obtain the accuracy of the CA-Markov model in simulating the forest utilization planning in Sichuan Province. If it meets the requirements, it can better simulate the forest utilization in the area in the expected year.

2.2.2 Model validation

We use the land use maps in 2000 and 2010 to predict the distribution of land use in 2020 according to the CA-Markov model, as Figure 1. The predicted forest coverage in Sichuan Province in 2020 is roughly consistent with the actual situation in the area, and the VIDLIDATE module in the IDRISI software is used to test the accuracy of the predicted land use and the actual land use. The four expanded kappa coefficients are: $k_{no} = 0.8382$; $k_{standard} = 0.8334$; $k_{location} = 0.8295$; $k_{locationstrata} = 0.8$, the kappa coefficient = 0.8364 which proves that the model we established has a good prediction effect and can be used for the prediction of forest land change.

2.3 Model prediction

We used the CA-Markov model to predict various forest coverage in Sichuan Province, and obtained the transition matrix of forest land area, as shown in Table 1. In order to show the results directly, we made a map of regional forest cover and transfer in Sichuan Province in 2120, as shown in Figure 2.

Put the forest cover area in 2120 into InVEST model, and finally get 2424×10^6 t of carbon storage in 2120. By converting the carbon storage into the formula, sichuan province will store 8785×10^8 t CO₂ in the next 100 years.

Table 1. Woodland Area Transfer Matrix

Woodland species	Conversion type				Area increase
	Woodland	Shrub	Open woodland	Woodland	
Woodland	46139	6209	3140	144	3679
Shrub	9043	29462	1623	136	-3076
Shrub	3986	1395	11807	47	-622
Woodland	143	122	43	416	19

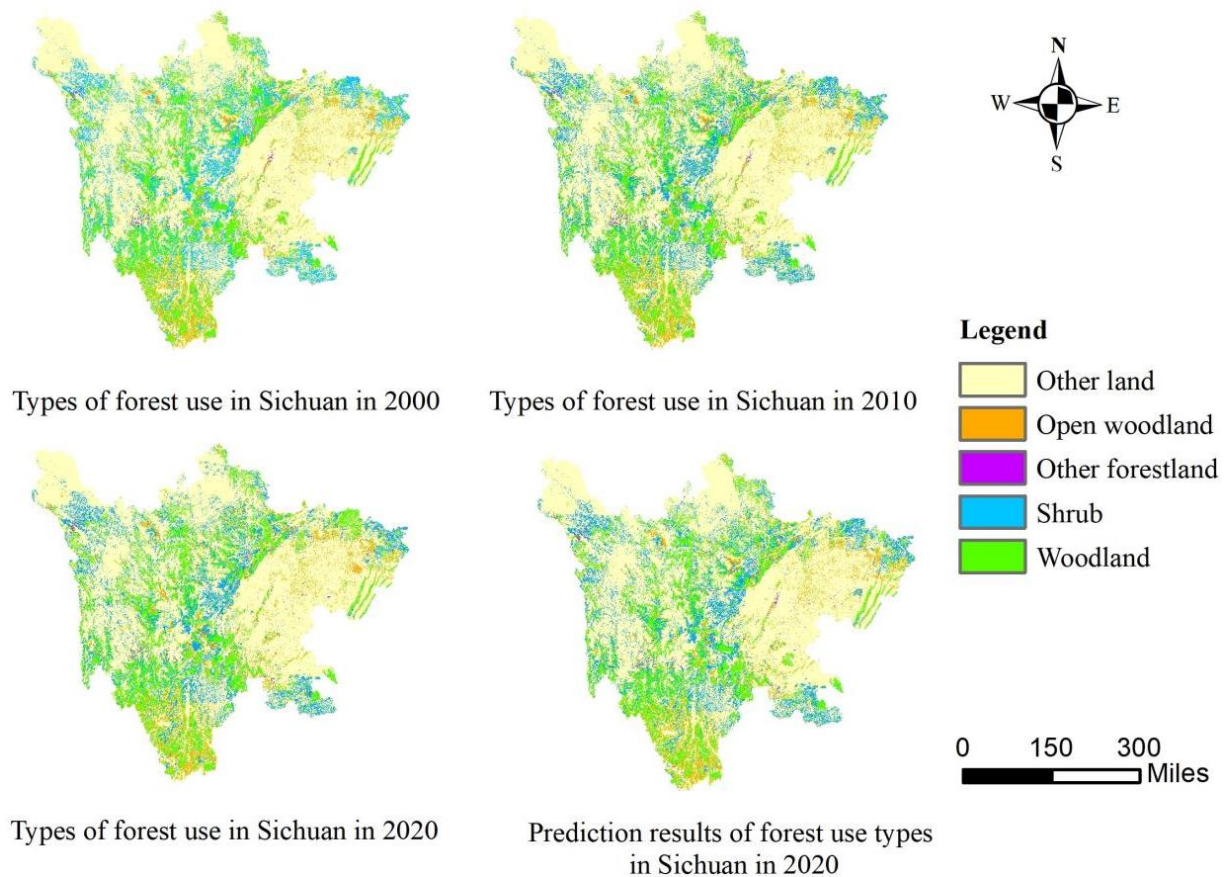


Figure 1. Prediction of Forest Land Change in Yunnan Province

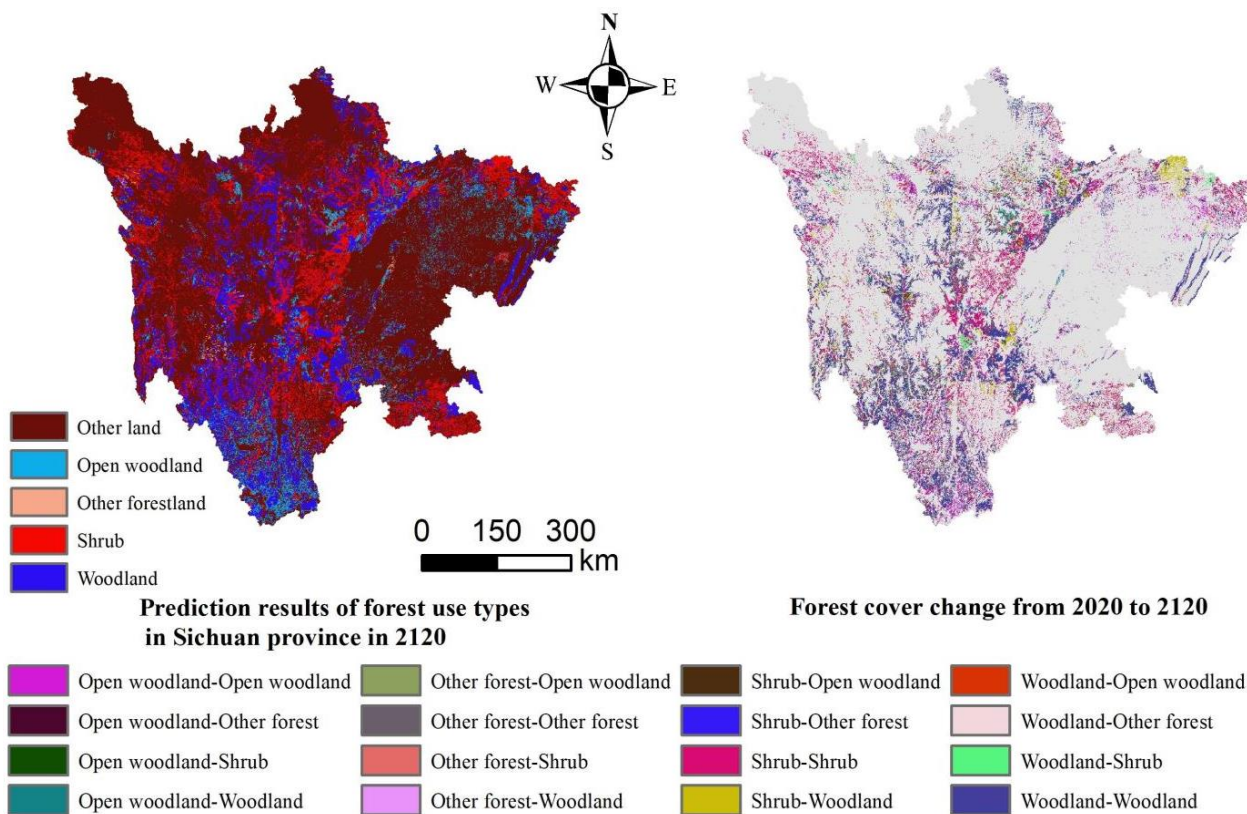


Figure 2. Forest area transfer map

2.4 Sichuan Forest Management Strategy

From the visualization results and Table 2, it can be seen that most of the forest distribution in Sichuan Province is forest land, and the transfer of forest types also focuses on the conversion of other types of forest land to forest land, which will affect the environment and biodiversity. Considering the complex and diverse topography and rich soil types in this area, we believe that the deforestation of forest land should be increased, and more shrubs and sparse woodland should be planted in the regeneration of forests. Considering the transition to a new timeline management strategy, we will further consider the impact of rotation periods on the carbon sequestration capacity of forests.

3. Analysis of the effect of different rotation periods on total biomass carbon

3.1 Introduction to FORECAST Model

The FORECAST model is developed based on the principle of mixed model, which fully combines the advantages of process model and mechanism model, and is based on the laws of material production and nutrient cycling in the entire forest ecosystem.

In the model, the system can create 3 site conditions (good, medium, and poor) and (*S*) represent them with a site index. We take the Chinese fir plantation in Sichuan Province as an example. Through the tree height growth data under different site conditions, the corresponding growth process can be fitted by the model, which $SI=17, 21, 27$ represents the average height of dominant trees under the three site conditions of poor, medium and good in Sichuan Province. The effects of different management measures on carbon sequestration were studied by coupling different site conditions and stand growth characteristics.

3.2 Simulation Scenario Settings

In order to enhance the comparison of the results, we reviewed the literature and set the simulation scenarios as poor site and good site conditions ($SI=17, 27$), with rotation periods of 15 years (short rotation period), 25 years (normal rotation period), and 50 years (Long rotation period), the afforestation density is $2500trees\cdot hm^2$, and the simulation time span is 150 years (corresponding to 10, 6, and 3 complete rotation periods, respectively).

3.3 Result analysis

As shown in Figure 3, in terms of annual carbon sequestration, regardless of site conditions, the overall change trend of biomass carbon and soil organic carbon in different rotation periods is decreasing with the extension of the rotation period, which is due to Due to the inherent characteristics of tree species planted in this forest, different rotation periods have a certain impact on the dynamic characteristics of carbon sequestration. The short rotation period is the stage in which the carbon sequestration capacity increases rapidly. Combining factors such as competition and less litter, the consumption of the site is more serious; while the long rotation period is a process of decreasing carbon sequestration ability, but due to the influence of litter accumulation and understory vegetation development, it is more favorable for the restoration of the site.

Based on the above analysis, we believe that when the degree of differentiation of the stand is poor, the rotation period should be extended to improve the forest's own site conditions and realize the transition between different site stages of the forest.

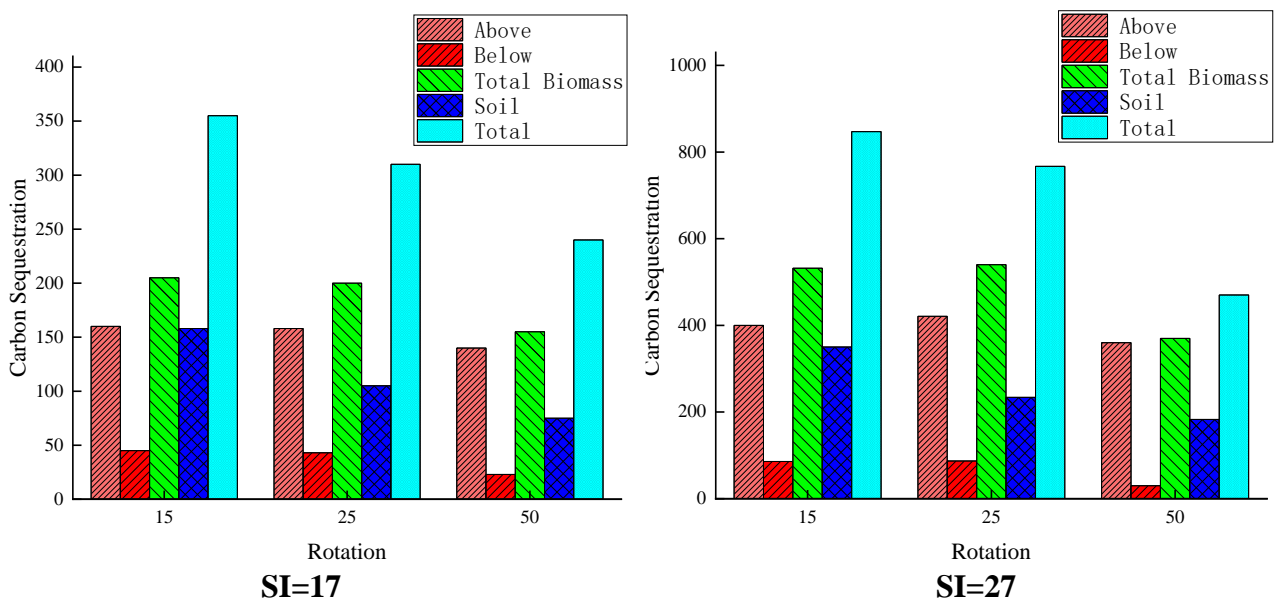


Figure 3. Effects of different rotation periods and site indices on carbon sequestration

4. Sensitivity Analysis

In order to test the sensitivity of the model, we use the CA-Markov model to predict the forest cover in other regions, and test whether the accuracy of the model changes with the change of the region. We chose Hubei Province, which has a large topographical difference from the above area [12], and still used the land use maps in 2000 and 2010 to predict the land use distribution in this area in 2020, and the comparison map between the prediction and the actual forest land cover. As follows.

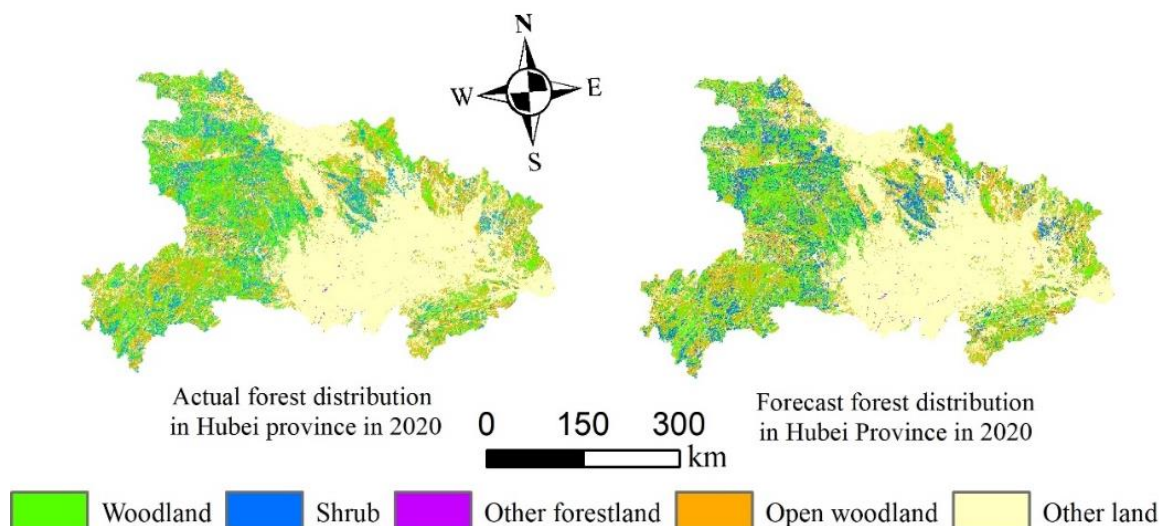


Figure 4. Forest land coverage map in Hubei Province

from Figure 4 that the predicted forest land coverage is almost consistent with the actual distribution; through the accuracy test of the predicted forest land and the actual forest land, four kappa coefficients are obtained: $k_{no}=0.8433$; $k_{standard}=0.8274$; $k_{location}=0.8315$; $k_{locationstrata}=0.8243$, the kappa coefficient = 0.8364, which proves that the C AM arkov model we established has high sensitivity.

5. Evaluation of the model

5.1 Strengths

The CA-Markov model effectively combines the advantages of the spatial prediction technology of the CA model and the long-time series prediction simulation of the Markov model, which helps to improve the accuracy of the research and can more accurately predict the change of forest area.

The FORECAST model is developed based on the mixed model principle, fully combining the advantages of the process model and the mechanism model, and is based on the material production and nutrient cycle laws of the entire forest ecosystem.

Moreover, The FORECAST model can also be used to evaluate the impact of management measures such as artificial tending, fertilization, and the treatment of cutting residues on carbon sequestration. The model can be effectively used in forest planning to achieve a better evaluation of forest value.

5.2 Weaknesses

The CA-Markov model's prediction of forest coverage is based on the premise that the overall forest utilization trend has no drastic changes. If natural disasters occur in the forest, the prediction results will be poor.

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