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Carbon sequestration in forests

Abstract

In the process of photosynthesis, forests convert carbon dioxide and water into biomass and release oxygen, therefore, they may absorb a large amount of carbon dioxide. This effect is called the **carbon sequestration** effect of forests. Forest carbon sequestration is closely related to the **age composition** of forests. General forests can be divided into young forests, middle-aged forests, near-mature forests, mature forests and over-mature forests according to their ages. The mature forests and their biomass basically stopped growing, and the absorption and release of carbon were basically balanced. The age structure of a forest depends not only on the development and evolution of the forest itself, but also greatly affected by external disturbances.

We designed carbon sequestration models for different species of trees, which fully considered factors that affect carbon sequestration, such as temperature, season, leaf area, and forest fires. Based on the designed model, we also calculated the **total carbon sequestration** of a forest over 100 years. By comparing with real statistical data, we found that the model is in line with objective data. Additionally, in this part of the model design, due to the high forest coverage in California, we selected forests in California as the verification site for analysis. In addition, the correctness of our model is verified by comparison with the database of California forests.

In addition, we also designed a model in line with the concept of forest management, which has a detailed description of forest management strategies. However, due to the different conditions of each forest, our model may have some limitations. Meanwhile, by using **Richard's equation**, we have iteratively calculated the forest system, and the results of the calculation are as follows. In addition, we not only considered the carbon sequestration value of forests, but also elaborated on other aspects of forest values, including humanistic value and tourism value.

At the same time, we have explained to people the necessity of **rational felling** according to the model, which can increase the carbon sequestration value and economic value of the forest to the greatest extent. Our management strategy is mainly as follows: rational harvesting will not affect the forest ecosystem seriously and the process may not cause damage to the structure and function of the forest ecosystem. In addition, our harvesting management considers not only the harvest of wood, but also factors such as maintaining the inherent biodiversity of the forest, the composition and combination of tree species, forest facies and forest landscapes and their performance. This is because our model states that the value of trees is greatest when the value of trees reaches around 50 years old, when the value of felling trees is greatest for society.

For the transition point, we also considered natural factors, including biodiversity. Biodiversity factors affect the rate of change in forests, which affects transition points. At the same time, we also consider human factors, including economic development, which also affect the evolution of forests. In addition, land use and land use dynamics also affect the transition point.

Key words: Heat transfer, Thermodynamic system, CFD, Energy conservation

Contents

1 Introduction

1.1 Background

Climate change in recent years has had a huge impact on human production and life [1, 2, 3, 4]. An important factor affecting climate change is the concentration of greenhouse gases (carbon dioxide) in the atmosphere, therefore, how to effectively reduce the concentration of greenhouse gases has become an important research directions for human response to climate change[5]. However, it is not enough to just reduce greenhouse gas emissions, we should also find methods to increase carbon storage in the biosphere [6]. The carbon sequestration ability of forests can be considered from **the photosynthesis efficiency of plants, leaf area index, plant biomass, plant productivity and other aspects.** [7, 8, 9]

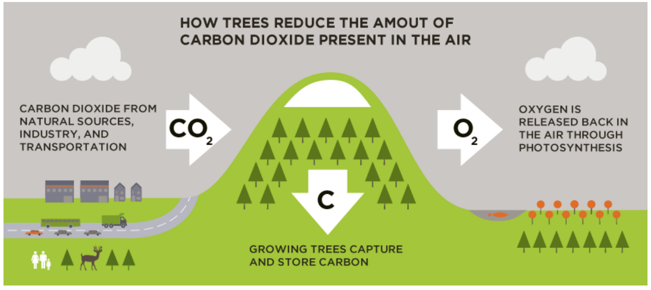


Figure 1: The process for Carbon Sequestration [10]

Forests are a major component of the global carbon cycle and can effectively reduce the concentration of greenhouse gases in the atmosphere [11, 9]. In general, the ability to predict changes in the forest carbon cycle (particularly net primary productivity and carbon storage) is increasingly dependent on multiple biological influences such as forest distribution and tree species [12]. The biosphere can store large amounts of greenhouse gases into plants, and large plants such as trees will play a particularly important role in this process. That's because trees and forests can turn huge amounts of carbon dioxide into tree products, which can be used by us a second time. These tree products include a series of wood products such as wooden furniture, paper, planks. In addition, according to the theory of carbon sequestration, about 90% of the carbon will be fixed in the soil, which means that despite forest fires, most of the sequestered carbon dioxide will be not released again. Therefore, how to manage the forest rationally is particularly important.

At the global level, forest management strategies that harvest trees properly and plant them in a timely manner are more conducive to carbon storage [13, 14, 15]. But over-cutting or reducing the planting of new saplings can limit carbon storage. Therefore, for a qualified forest management plan,i t is particularly essential to find a balance between the use of forest resources to generate profit and the value of trees as carbon sequestration [14]. For a reasonable forest management plan, people must consider the local topography, the type and age of the trees to enhance the value of the forest.

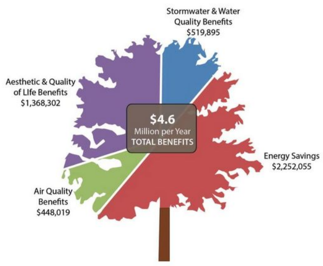


Figure 2: Forest management strategy

1.2 Literature Review

In general, forests use photosynthesis to store carbon including carbon dioxide and the carbohydrates produced by photosynthesis will be for their own growth. In previous researches, there were four models for estimating the carbon sequestration capacity of tree species.

1. **Estimation of carbon sequestration capacity of garden tree species by leaf area index**

   Based on the leaf area index of a single tree, people can derive a tree ecological benefit model with morphological characteristics as variables [16, 17]. The general form of this equation is:

   $$Y = ab \tag{1}$$

   $$b = \pi c d^2 / 4 \tag{2}$$

   Y is the daily carbon fixation and oxygen release value of a single tree, a is the daily carbon fixation and oxygen release value per unit leaf area and b is the total surface area of the plant, c is the leaf surface index, and d is the crown width. With the increase of the leaf area index, the carbon sequestration of trees also increased under the condition of certain crown width.

2. **Estimating carbon sequestration capacity of trees from biomass**

   Plant biomass increases as plants convert the carbon dioxide into organic matter [18]. When using the biomass method, the biomass conversion factor (BEF) method is generally used to establish the relationship between biomass and accumulation. Among them, (BEF) is the ratio of biomass to wood volume in the forest. This method is based on establishing the relationship between biomass and accumulation, so as to estimate the carbon storage of plants. Generally speaking, forests with large accumulations also have larger carbon sequestration per unit time.

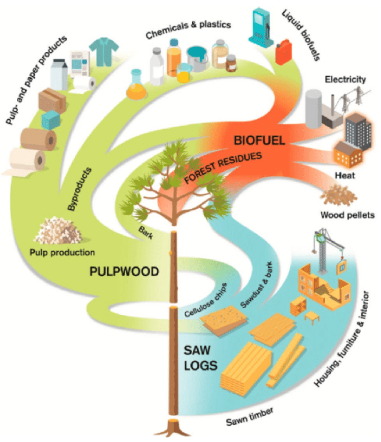


Figure 3: Forest biomass conversion [19]

3. **Calculating the carbon sequestration capacity of plants through productivity**

   Introduced in the National Forestry Standard (LY/T1721-2008), the carbon sequestration formula of plants is:

   $$G_{cs} = 1.63 * R_{Carbon} * A * B_{year} \tag{3}$$

Among them, G_{cs} is the annual carbon sequestration of plants, R_{Carbon} is the carbon content in carbon dioxide, the value is 27.27‰, A is the forest structure area, and B_{year} is the net productivity of the area. This method estimates the amount of carbon sequestered by forest communities in one year. The higher the net productivity per unit of forest structure area, the greater the carbon sequestration of the community.

4. **Estimation of plant carbon sequestration capacity by photosynthetic efficiency**

   According to the carbon fixation mechanism, the daily assimilation amount of photosynthesis of forests can be measured, and then the amount of stored carbon dioxide and the amount of oxygen released by forests can be calculated [20, 21]. In the diurnal variation curve of tree photosynthesis, its assimilation amount is the area enclosed by the net photosynthetic rate curve and the horizontal axis of time. Based on this, the calculation formula for the net assimilation of tree species on the day is:

$$P = \sum_{i=1}^{j} [(P_{i+1} + P_i) \div 2 \times (t_{i+1} - t_i) \times 3600 \div 1000] \tag{4}$$

   P is the total daily assimilation of tree species, P_i is the instantaneous photosynthetic rate of the initial measurement point, P_{i+1} is the instantaneous photosynthetic rate of the next measurement point, t_i is the instantaneous time of the initial measurement point, t_{i+1} is the time of the next measurement point, j is the number of tests [21]. The method of estimating the amount of carbon sequestration by the measured photosynthetic efficiency of tree species is applicable to the months of June to August each year, and the estimated daily carbon sequestration amount is the peak throughout the year.

1.3 Restatement of the Problem

According to the acquirement [6], we need to develop a carbon sequestration model required by the International Carbon Management (ICM) Organization to determine the amount of stored carbon that forests and their products are expected to sequester over time. At the same time, we also need to establish a model for forest management, because the value of forest is not only in the amount of carbon sequestration, but also in its humanistic and social value. The model designed will simultaneously take into account the impact of different forest values on forest management decision makers. In the decision-making model for designing forests, we will also provide the essential scope of application and the realistic factors, which may include: forest fires, climatic conditions, geographical conditions and other impacts. Taking into account the different conditions of different forests, there will be transition points in the forest management plan, and we will also take into account the design of real model. Since the 10-year deforestation cycle may be long, we will also discuss strategies for transitioning from the 10-year cycle to the new time in a way that is available to human needs. At the end, a non-technical newspaper articles on rational tree felling will also be provided to explain our management strategy and the advantages of the strategy we have developed.

2 Assumptions and Justification

2.1 Assumptions of carbon sequestration per tree

1. **Assumption the process of photosynthesis in one day**

   Since the amount of carbon sequestered by trees in different time periods of the day is different, we need to design a piece-wise model to assume the amount of carbon sequestered by trees in a day. The distribution of carbon sequestration by real trees in a day is as follows:

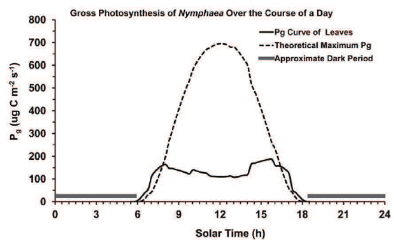


Figure 4: Distribution of carbon sequestration by trees in a day

2. **Assumption the surface of leaves**

   Light is the essential condition for photosynthesis, and leaves are an important organ for plants to receive sunlight. The ability of receiving light depends on the surface of leaves. Based on the laws of nature, trees sprout in spring (March to June), dense foliage in summer (June to September), fall leaves in autumn (September to November), and no leaves on branches in winter (November to March), thus the surface of leaves will change during the changing of the season or month. According to it, a model can be assumed that the maximum surface of leaves is 1)

Figure 5: Changes in the surface of leaves throughout one year

3. **Temperature assumptions for the Model**

   Temperature is also an important factor affecting forest carbon sequestration, because the process of plant carbon sequestration is essentially a chemical process, which requires the catalysis of enzymes, and the catalysis of enzymes is greatly affected by temperature. changes with the seasons of the year, which in turn affect the carbon sequestration of forests. Figure 4 shows the relationship between the rate of photosynthesis and respiration and the temperature.

4. **Assumption of the forest Fire**

   Forest fires will cause serious damage to various organs of trees in a large area, making trees unable to perform photosynthesis, thereby reducing the amount of carbon sequestration in forests. Furthermore, Forest fires may also alter the ability of mycorrhizal fungi to sequester soil carbon on short- and long-term timescales. Wildfires reduce the abundance of ectomycorrhizal fungi, and the decline in fungal abundance persists for years after the fire.

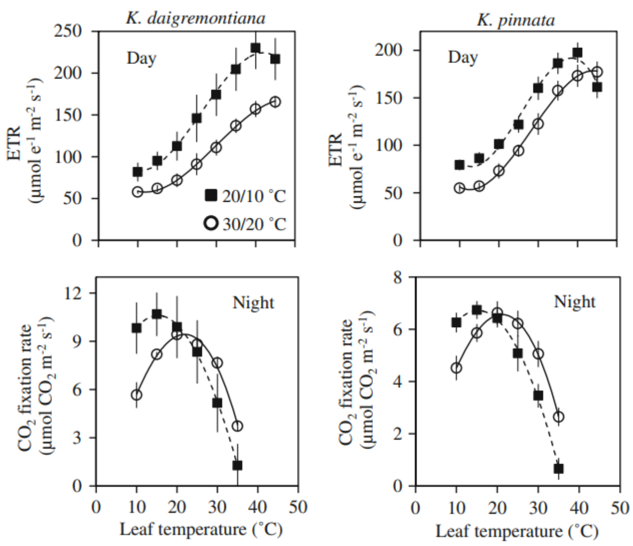


Figure 6: The effect of temperature on photosynthesis[22]

3 Notations

3.1 Notations for Model I

Symbol	Function	Unit
A	absorption of CO2	mg
L	surface of leaves	m^2
T	the rate of carbon sequestration against month	mg/h
P	total daily carbon sequestration of trees	mg
Pi	instantaneous photosynthetic rate at time ti	mg/h
Pi+1	instantaneous photosynthetic rate at time ti+1	mg/h
W	Molar mass of carbon sequestration	mg
Y	the daily carbon sequestration per tree	mg
a	the daily carbon sequestration per unit area	mg/m^2
d	the crown width	m^2
C	total carbon sequestration by a tree in a month	mg
M	total carbon sequestration of forests of a year	mg

3.2 Notations for Model I

Symbol	Function	Unit
A	saturation value of cumulative growth	–
B	initial parameter of growth	–
k	growth rate	–
m	allometric growth parameter	–
r	discount rate	–
x	current probability of getting the best value	–
dx	random probability	–
T	temperature of annealing method	–
dT	reduction rate of T during iteration	–

4 Sub-model I: Carbon sequestration model for one tree

4.1 The model of photosynthesis in one day

The carbon sequestration is based on the photosynthesis in plants, which is a process that absorbing carbon dioxide from the external world and forms organic matter for storage in the body of the plant.

$$CO_2 + H_2O \rightarrow (CH_2O) + O_2 \tag{5}$$

According to our previous assumptions, the designed model is as follows:

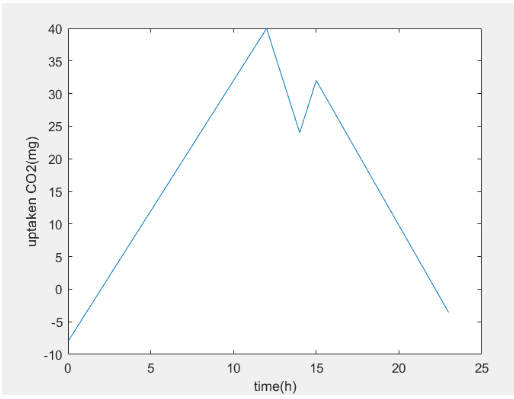


Figure 7: The simulated amount of carbon sequestered by trees in a day

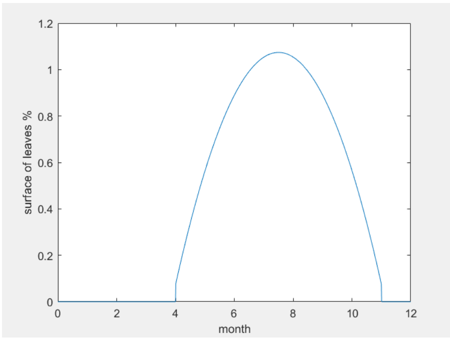
In order to simplify the model, the curve can be assumed to be a linear diagram, which means that the function can be approximately to a linear function, which is shown in the above figure.Thus, the linear function can be represented as a step function, which is shown below

$$A_{CO_2abs} = \begin{cases} \text{4t-8 } 0 < t < 8 \\ \text{-8t+136 } 12 < t < 14 \\ \text{8t-88 } 14 < t < 15 \\ \text{(-40/9)t+293/3 } 14 < t < 24 \end{cases} \tag{6}$$

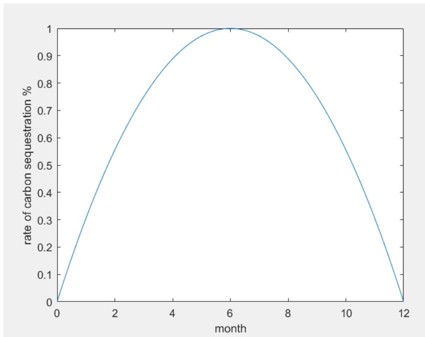
(Assume the parameter shown in Figure 1 b=-8 mg, d=40 mg, e=24 mg and f=32 mg).

4.2 The model of seasons and temperature to the surface of leaves

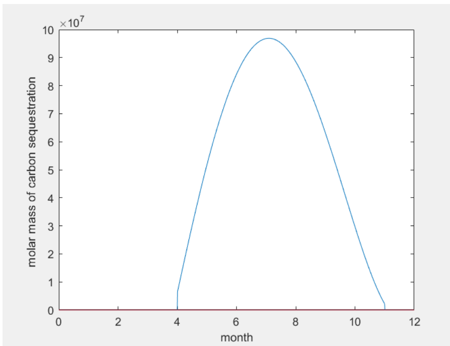
According to the assumption above, we think that the amount of carbon sequestration will change with the change of seasons. During winter, the respiration of trees will decrease, so the amount of carbon sequestered by trees will also decrease. In addition, we also considered the effect of temperature on plant respiration. According to geographical knowledge, temperate climates rarely exceed 30 degrees, even in hot summer, thus according to the above, the model about the carbon sequestration and the month is similar to the model of the surface of the leaves and the month. The spring begins to warm, the carbon sequestration rate begins to increase, the summer carbon sequestration rate reaches the maximum, the autumn begins to cool, the carbon sequestration rate begins to decrease, and the winter is the coldest, and the carbon sequestration rate reaches the minimum. A model can be assumed, which is shown below, too. (Assumed that the maximum rate of carbon sequestration is 1 and the rate of carbon sequestration is zero when the temperature at 0 degree)



(a) The relationship between tree leaf area and month



(b) The relationship between rate of carbon sequestration and month



(c) The relationship between the mass of carbon sequestration and month

Figure 8: The relationship between carbon sequestration and month, leaf area

Assumed that the maximum surface of leaves is 1. According to the model of photosynthesis, surface of leaves is proportional to the carbon sequestration. Thus, the surface of leaves model can be used to estimate the daily carbon sequestration per tree in other month, when the maximum surface of leaves is assumed to 1 in the summer. The equation is shown below:

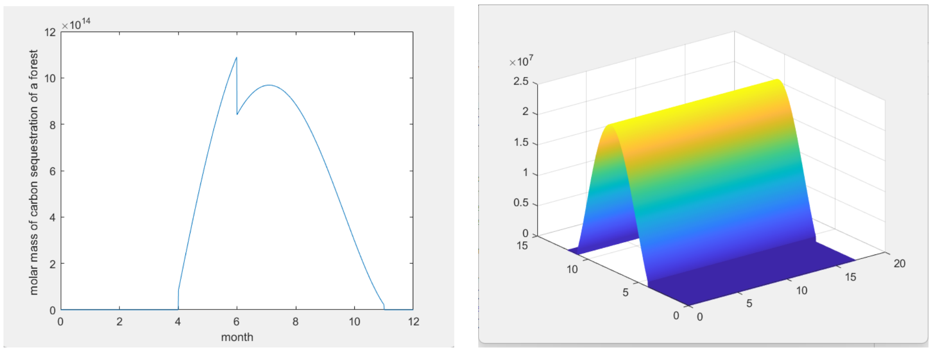
$$C = W * 30 * L \tag{7}$$

Where C is total carbon sequestration by a tree in a month, L is the surface of leaves against the month. Similar to the surface of leaves, the rate of carbon sequestration, which is influenced by the temperature, is assumed to have a linear relationship with total carbon sequestration of a month, and the maximum rate is also set to 1 in the summer. The equation is shown below

$$C = W * 30 * L * T \tag{8}$$

4.3 Forest Fire model

The previous model focus on the carbon sequestration of one tree. In order to calculate the carbon sequestration of forests in different regions, the forest area of different regions is required. The forest area can be affected by forest fires, especially in seasons and areas with frequent forest fires. The sequestration of forests = the carbon sequestration of one tree*forest surface. The following figure shows that the relationship between month, forest surface and the carbon sequestration of forests of a month.



(a) The relationship between month and the carbon sequestration

(b) The relationship between month, forest surface and the carbon

Figure 9: The model of carbon sequestration in trees considering forest fires

According to the data, the forest area of California is approximately 13000000 m^2, and assuming that each fire will burn 3,000,000 m^2 of forest area, and it will take about half a year for the forest to recover. The above figure shows the relationship between month and the carbon sequestration of forests of a month, when considering the forest fire.

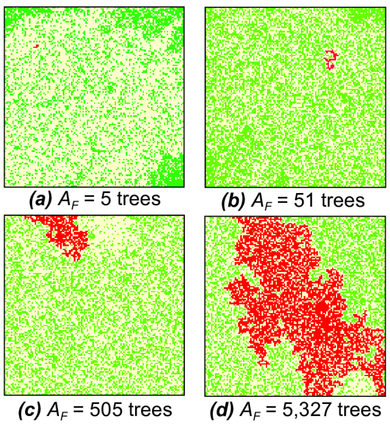


Figure 10: Four examples of typical fires in the forest-fire model [23]

In addition, we also calculate the total carbon sequestration of forests of 100 years. Because we know the amount of carbon sequestered by the forest in one year, we can know the total amount of carbon sequestered in 100 years.The total carbon sequestration of forests of a year is simulated in Matlab. Finally, according to the simulation, we get a result of $4.3165 * 10^{15}$ in one hundred years.

5 Forest management model

5.1 The forest growth model based on Richard's equation

Plant growth follows a "growth curve", the most common of which is a sigmoidal function, also known as the logistic function.

$$y = \frac{1}{\frac{1}{k} + ab^x} \tag{9}$$

The equation illustrates the formula for logistic function. Similarly, the Richards equation also gives a good description of the three phases of plant growth: initial growth, exponential growth, and steady growth. It can be described by the following differential equations.

$$\frac{dV}{dt} = \eta V^m - \gamma V \tag{10}$$

$$V(t_0) = V_0 \tag{11}$$

The solution takes the form shown in the following equation.

$$V(t) = (\frac{\eta}{\gamma})^{\frac{1}{1-m}}(1 + \frac{\gamma c}{\eta} e^{\gamma(m-1)t})^{\frac{1}{1-m}} \tag{12}$$

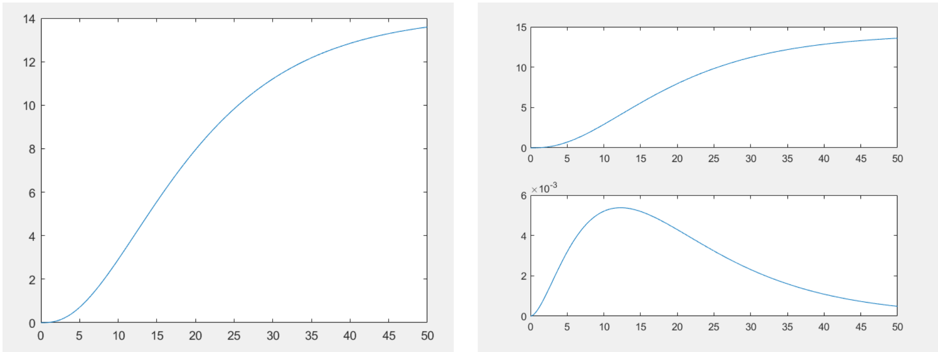
Set parameters to simplify formula writing as shown in the following equations.

$$V(t) = A(1 - Be^{-kt})^{\frac{1}{1-m}} \tag{13}$$

$$A = (\frac{\eta}{\gamma})^{\frac{1}{1-m}}, B = -\frac{\gamma}{\eta}c, k = \gamma(1-m) \tag{14}$$

In the above equations, "A" is the saturation value of cumulative growth, "B" is the initial parameter of growth, "k" is the growth rate, and "m" is the allometric growth parameter.

This model was applied to the first generation of sand camphorated pine at the Zhanggutai Test Base. Its growth and volume model can be found to conform to the formula shown in above equation. A table of parameters for the growth model of camphorated pine was obtained by analyzing the data at different sites and ages. Trees entered a period of rapid growth from year 6, corresponding to the exponential growth region in the S-shaped curve. And to saturation zone at approximately 21 years. The volume varies with the change of height and chest diameter. It entered the exponential growth zone at year 12, and its annual growth reached its highest value at year 29.



(a) The age-dependent curve of the height (b) The relationship between month, forest surface and the carbon

Figure 11: The final results for the forest growth model based on Richard's equation

The above figures show the age-dependent curve of the height of camphorated pine varying with "year" on the horizontal axis and "meter" on the vertical axis. The plot of tree volume against age is shown in the fist figure(1). Where the horizontal axis is "year" and the vertical axis is m^3. second figure(2) is a curve of the annual volume growth of camphorated pine with the horizontal axis as "year" and the vertical axis as $m^3/year$.

The value model of a single tree can be derived from a certain discount rate and management costs as shown in the following equation.

$$W = v(t)e^{-rt} - p(t) \tag{15}$$

Where P(t) is a function of time (management cost). r is the discount rate.

$$\frac{v'(t)}{v(t)} = r \tag{16}$$

The above equation shows the criteria "t" needs to meet when it reaches its maximum.

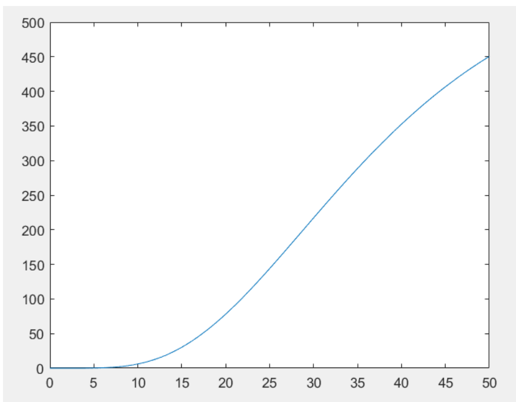


Figure 12: The value of one camphorated pine

The value of trees is estimated based on the volume of camphorated pine and current market prices. It is about $2,000 dollar/m^3$. The result is shown in the figure. The horizontal axis is year and the vertical axis is price.

5.2 Long-term optimal value model based on annealing algorithm iteration

Simulated annealing simulates the annealing process of a metal. That is, as the temperature decreases, the particle becomes stable. It is a random algorithm. This method is used to find out what probability to fell trees to obtain the maximum economic value within 500 years. Since the actual situation in different regions is quite different, here assume the value of trees is proportional to the volume, that is, $value = 2000 * volume(2,000 dollar/m^3)$.

5.2.1 Conditional hypothesis

Firstly, the trees were divided into 50 groups according to their age. The smallest tree is 1 year old and the largest is 50 years old.

1. **Planting and felling**

   This model assumes that the trees in a fixed area are certain. The probability of being felled is 100% when the tree reaches the age of 50. Replace a new tree of age 1 if it is cut.

2. **Age**

   After each iteration, all trees grow older. For example, if the number of three-year-old trees in the first year is 5, the probability of being felled is 0.2. The number of four-year-old trees in the second year is 4.

3. **Price**

   The price function in the model is the sums of felled trees for each age group multiply their values separately. To maximize continuous earnings, the model estimates the earnings over 500 years, and wants to reach maximum.

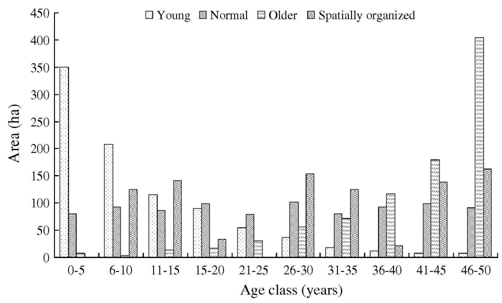
5.2.2 Initial value setting

Before each iteration starts, set all the 100 trees to 0 ages. The probability of trees being cut is 100% for each age group. Calculate the total return after 500 years. Randomly generating a four-bit probability “dx” (between zero and one). “x[i]+dx[i]*T” is the probability of being cut for each age group in the next iteration. i=0 for the first iteration. T is the temperature of annealing method, which decreases with the number of i increasing. After each iteration, “T=T*dT” is assigned. In this case “dT” is set to 0.997. T will decrease to 0.223 after about 500 iterations, and reach 0.049 after 1000 iterations. Considering the precision of random dx and the number of parameters, more accurate results can be obtained in about 1000 iterations. If dT is relatively small, the temperature changes too fast, and the model approaches a value quickly, but not the maximum, because “x[i]+dx[i]*T” is already less than the accuracy (0.0001).

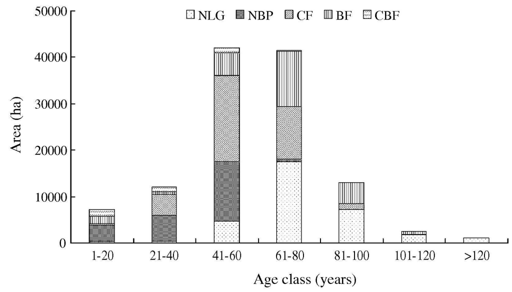
The age distribution of the four hypothetical datasets and the real dataset NLG = natural Larix gmelinii dominated forests, NBP = natural Betula platyphylla dominated forests, CF = coniferous forests, BF = broad-leaved forests, and CBF = coniferous and broad-leaved mixed forests.

5.2.3 The final results for the model

The blue line in the following, which shows that after 897 iterations, the function tends to be the best solution: 450000. At this time, the probability of trees that should be felled approached

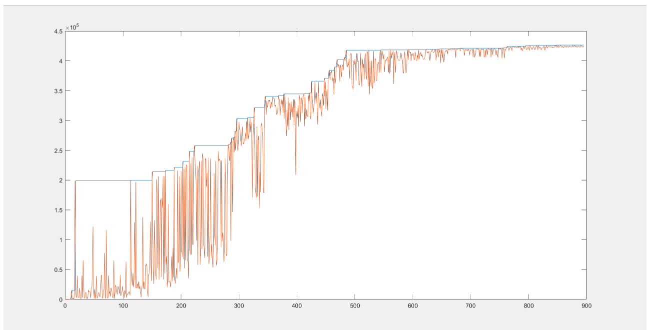


(a) Four hypothetical datasets



(b) The real dataset

0 in the 1-49 age range, and the probability of a 50 year old tree being cut is 100%. Its actual numerical expression is that the trees are cut every 50 years to obtain the maximum benefit. Consider sustainable development for forests. The forest can be further divided into smaller areas and felled in turn.



(c) The result of annealing method

The red line is the value of each iteration with the current optimal probability x[i] as the center and a random generation probability dx[i] as the "radius". Initially, the maximum dx value tends to 1 to fully obtain the income under different parameter combinations. As the number of iterations increases, the randomness decreases and the income approaches the maximum value.

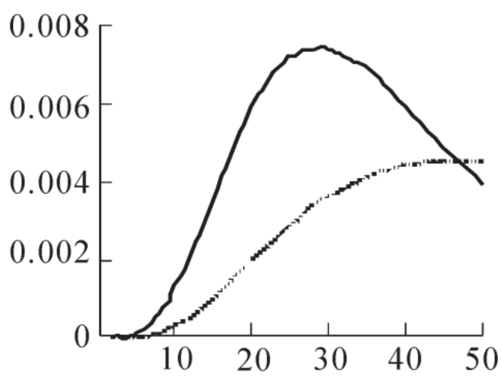


Figure 13: The average growth value (The dotted line: Current volume/age Unit: $\mathrm{m}^3/year$)

The above figure shows the average growth value (The dotted line: Current volume/age). This validates the result: more trees are expected for 50 years, because their average growth is the largest.

6 Problems and strategies of Forestry Economic Development

As a special natural resource, forestry resources have multiple functions such as ecology and economy, which play an important role in promoting the development of human society and the development of the national economy. Therefore, the forestry manager should pay more attention to study the unfavorable factors which may affect the forestry economy, and effectively promote the development and improvement of the forestry economy.

6.1 Scope of the management plan for the Forest management

The first model is only suitable for forests in mid-latitudes, which means the forest must grow in environments with obvious climate change and have the habit of deciduous. By taking the data of camphorated pine, the second model is suitable for semi-arid areas with less annual mean precipitation and colder climate. The main types of soils are grass-fixed sandy soil and mobile sandy soil with less nutrients.

6.2 Supplement to the transition point of the management of forests

For the action of human being, economic development led to industrialization and urbanization, pulling labor from rural to urban areas. For example, industrial policies that subsidized manufacturing led to a shift to urban sector manufacturing and service jobs, resulting in land abandonment and forest regeneration. Furthermore, land cover changes is an important transition point for the forest management. Most forest evolution is caused by the transition of fallow-successive vegetation.

$$LC = \frac{U_b - U_a}{U_a} * \frac{1}{T} * 100\% \tag{17}$$

In the formula, LC represents the degree of land use change, U_a is the area of a particular land use at the beginning of year "a", U_b is the area at the end of year "b", and T is the length of time. When the unit of T is set to year, LC represents the degree of individual land-use dynamics in the year. The degree of integrated land-use change was defined by the combined numerical change of all land-use categories in the area during the study period. The formula used is as follows:

$$LC = \frac{\sum_{i=1}^{n} \triangle LU_{i-j}}{2\sum_{i=1}^{n} LU_i} * \frac{1}{T} * 100\% \tag{18}$$

L_{Ui} represents the area of category i at the beginning year of the study,$\triangle LU_{i-j}$ represents the amount of category i converted to other categories; T represents the length of the study. When the unit of T was set as a year, LC indicated the degree of annual integrated land use dynamics.

If we consider rubber plantations as forest cover, all sites show a significant increase in land cover with woody vegetation, however, at the expense of agricultural land conversion at the expense of intensively cultivated upland and active fallow. Finally, land use dynamic is also a transition point for the forest management. Land use dynamics reflect local political economy, ecological succession, and interactions between humans and resources in a coupled system of humans and the environment. Forest area continues to decline at a much slower rate, converting to shrubland or pasture. Inappropriate species used in reforestation programs and insect attacks slow forest regeneration. Logging and fencing had a major impact on forest biomass and regeneration of forest near villages. An equation can be basically used to reflect the land use. In order to quantify the land change across the sites, the following formula was used to calculate annual land use dynamics.

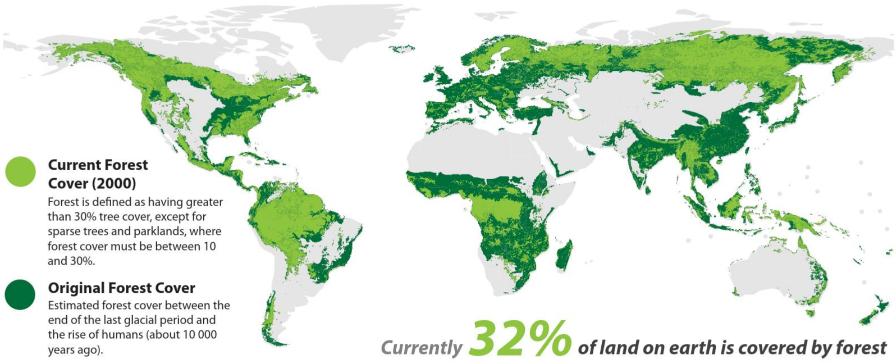


Figure 14: The amount of and type of forest cover has changed over time

6.3 Problems of Forestry Economic Development

6.3.1 Unreasonable structure of forestry

The development of primary, secondary and tertiary forestry industry is uncoordinated. Especially, the primary accounts for a relatively high proportion of the forestry industry, while the secondary and tertiary industries are relatively backward in development. As a result, its overall economic strength will be reduced. Coupled with the lack of forest resources, the construction of forestry bases is relatively backward. Due to the limited nature of forest resources, the total amount of forest resources has certain deficiencies. Especially after the ban on cutting down forests privately, the resources of artificial forests are very limited. Meanwhile, the investment in forest resources is large and the cycle is relatively long in contrast, which affects the enthusiasm of manager to invest, such as whether the trees can be cut down when they grow up, which also affects the development of forest resources.

6.3.2 The concept of forest management is lagging behind

Since many of the current forest managers have not changed their old concepts, which is still based on planting, protecting and cutting trees. They may not consider other added value of the forest. Moreover, forest managers generally lack professional management personnel, which leads them to pay the government to bear the operating costs. However, the government's forest management funds may be limited, which will also lead to serious shortage of forest management and infrastructure costs.

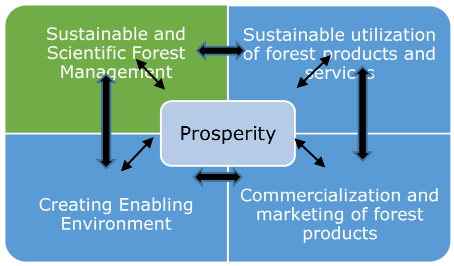


Figure 15: The concept of forest management

6.4 Improvement Countermeasures for Forestry Economic Development

6.4.1 Pay attention to protecting the ecological benefits of forestry resources

On the premise of ensuring its ecological benefits (carbon sequestration), efforts are also made to improve its economic and social values. In the process of developing the forestry economy, the laws of nature and economic development must be observed, and priority can be given to the development of fast-growing commercial forests and high-yield forests, shrub raw materials, economic forest bases and fodder forest bases. At the same time, it is necessary to continuously promote the in-depth development of forestry products in combination with local climatic conditions, and improve the utilization rate and added value of forestry products. At the same time, it can also promote the popular eco-tourism and forest tourism, as well as the development of forest products and the domestication and breeding of wild animals. At the same time, the government should also issue relevant policies on the forestry economy to increase support and guidance for the forestry industry, cultivate and discover valuable products and enterprises, continuously optimize the management methods of forestry-related industries and improve the forestry industry's presence in the forestry market.

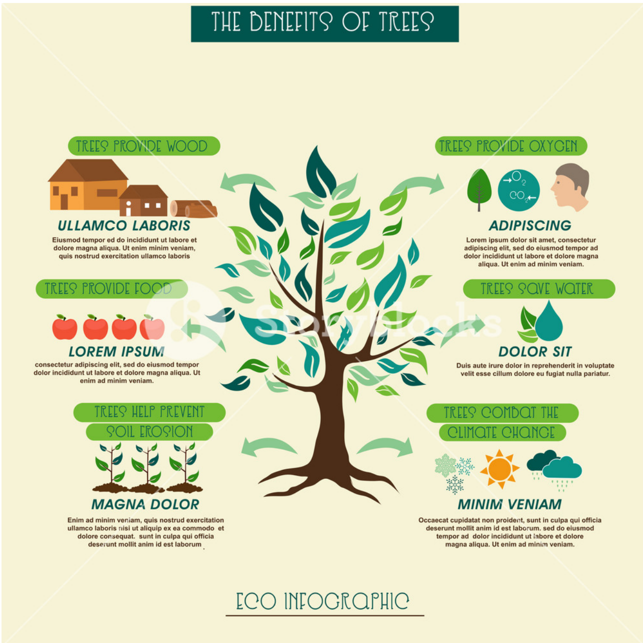


Figure 16: Forest biomass conversion [24]

6.4.2 Attach importance to the technical work of forestry

Secondly, the government should also attach importance to the technical work of forestry industry practitioners and improve their technical capabilities. Through the full combination of government and the forestry practitioners, the economic benefits of the forestry industry will be improved on the basis of continuous improvement concept. Focusing on forestry ecological construction, continuously adjust and solve problems such as forest species and tree species, and technical problems such as drought resistance and survival to improve the scale and level of the forestry industry

6.4.3 Follow the rules of forestry development and economic development

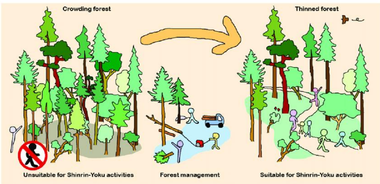


Figure 17: Rational tree cutting may improve economic value

In addition, forest managers should also follow the rules of forestry development and economic development to achieve coordinated development of primary, secondary and tertiary industries. The government should actively implement relevant policies and strengthen the guidance and support for the forestry industry. Meanwhile, efforts should also be made to realize the industrialized management of forestry, and continuously improve the competitiveness and vitality of the forestry industry in the market. The economic development of the forestry industry also needs a series of supporting measures, such as introducing socialized services, improving the circulation speed of forestry products and constantly expanding the market. Efforts should be made to establish a modern forestry industry system with reasonable layout, good economic benefits and competitiveness in the market. In addition, in some cases, the appropriate cutting of some trees can also increase the overall economic value of the forest.

6.5 Strategic Advice for the forest managers

Assume that the trees in the forest will achieve the greatest economic benefit in five years. The economic benefits stabilized after five years. Managers can consider increasing the ecological benefits and ornamentality. The increase of ecological benefits contributes to long-term development, make forests more stable and more resistant to changes in external conditions. The increase in ornamental can attract tourists and increase managers' income. For those using forests, it is possible to preserve the logs by dry storage method, chemical treatment and so on, and to purchase trees in demand for 10 years at harvest time.

7 Model Analysis and Sensitivity Analysis

7.1 The analysis of Simulated Annealing, SA

1. **Features of Annealing Algorithms**
   - Different from genetic algorithm, article swarm optimization and ant colony algorithm, Simulated annealing algorithm is not a swarm optimization algorithm and does not need to initialize the population operation.
   - The speed of convergence is slower. Because its initial temperature is generally set high, and the final temperature is set low, which means that it is considered that the material is at the lowest energy equilibrium point. Second, it accepts deteriorating solutions, not all in the process of convergence, which can be compared to the mutation in GA, so that it is not continuously converging.
   - Temperature management (start, end temperature), annealing speed (decay function), etc. All have an impact on the optimization results. For example, if the decay speed of T is too fast, the global optimal solution may not be found.

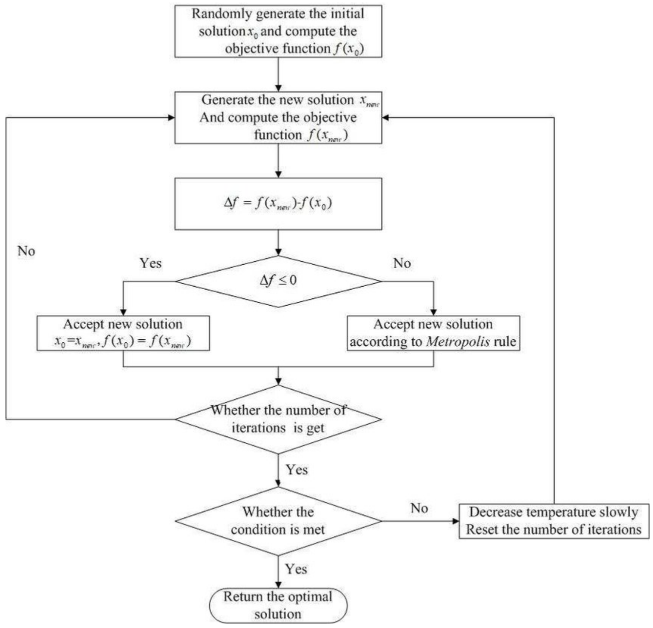


Figure 18: The flowchart of annealing algorithm

2. **Constraints of Simulated Annealing Algorithm**

   In this simulation model, we refer to the penalty function method, which is a commonly used technique for dealing with constraints, and it is very effective to deal with constraints in the simulated annealing algorithm. The idea of the method is to convert the constraints into a penalty function and construct a new objective function by adding it to the original objective function. When the constraints are not satisfied, the new objective function will be discarded by making the new objective function worse by the penalty function.

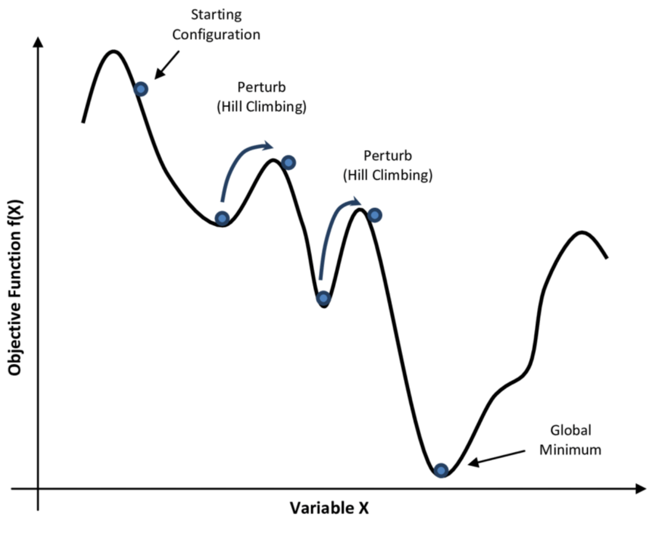


Figure 19: Simulated Annealing optimization of a one-dimensional objective function

There are two types of penalty function methods: the outer point method and the inner point method. The out-of-point method imposes penalties on the points outside the feasible region and does not penalize the points inside the feasible region, so that the iterative points will approach the feasible region D. The interior point method is to search inside the feasible region and the constraint boundary acts like a wall, which means the objective function cannot pass through to make sure the search point is limited to the feasible region, so it is only suitable for inequality constraints.The core algorithm formula is:

Consider the constrained optimization problem:

$$min : f(X) \tag{19}$$

Satisfy the constraints:

$$c_i(X) \leq 0 \tag{20}$$

The penalty function method transforms the problem into the following unconstrained problem:

$$min : L_k(X) = f(X) + \sigma_k \sum_i g(c_i(X)) \tag{21}$$

Among them:

$$g(c_i(X)) = max(0, c_i(X))^2 \tag{22}$$

In the above equations, $g(c_i(X))$ is called the external penalty function, and σ_k is called the penalty factor. In each iteration, when σ_k is increased, and then the unconstrained problem will be solved. The results of each iteration are combined into a sequence, and the limit of this sequence is the solution of the original constraint problem.

7.2 Analysis of carbon sequestration ability of different tree species

In our previous model, different factors such as photosynthetic efficiency, leaf area index, biomass and productivity were considered. At the same time, we also estimated the carbon sequestration and oxygen release capacity of different species of trees by consulting the data. This part of the analysis will be presented as supplementary information to the previous model.

CSPGA is the carbon sequestration per unit ground area, CSPLA is Carbon sequestration per unit leaf area, QRGA is the Oxygen release per unit ground area and QRLA is Oxygen release per unit leaf area. It can be seen from the above table that Locust has a relatively large amount of carbon sequestration per unit ground area and unit leaf area. Therefore, Locust is a suitable kind of trees for carbon sequestration. If peopel want to increase the carbon sequestration amount in a unit area, choosing to plant Locust is a great option. In addition, there is a positive correlation between the amount of carbon sequestered by trees and the amount of oxygen released.

8 Strength and Weakness

8.1 The advantages and disadvantages of Model I

For the strength, this model can roughly calculate the annual carbon sequestration of forests, and takes into account the effects of seasons, temperature, leaf area, and natural disasters on forest carbon sequestration. At the same time, this model also makes reasonable assumptions to simplify the model, such as assuming the change of photosynthesis in one day as a linear function, the effect of season on leaf area is simplified as a quadratic function, and the effect of temperature on carbon sequestration rate is assumed to be a quadratic function. Furthermore, At the same time,

Table 1: Carbon sequestration and oxygen release capacity of 10 different tree species

V	$CSPGA/gm^{-2}d^{-1}$	$CSPLA/gm^{-2}d^{-1}$	$QRGA/gm^{-2}d^{-1}$	$QRLA/gm^{-2}d^{-1}$
Ginkgo	29.48	6.38	21.45	4.64
Camphor	35.16	11.69	25.57	8.5
Magnolia	57.79	14.06	42.03	10.23
Willow	65.20	11.18	47.41	8.13
Ficus lobularis	44.36	7.46	32.26	5.55
Locust	102.10	22.39	74.25	16.28
Prunus	28.63	7.23	16.28	7.23
Yellow kudzu	67.2	13.63	48.88	9.91
Magnolia	29.4	9.05	21.4	6.58
Oleander	46.9	17.05	34.1	12.4

this model ignores the respiration of plant roots in winter, because root respiration is very weak at low temperature.

For the weakness, this model does not consider the vertical distribution of leaves area. Because the leaves at the top of the tree will block the light of the leaves at the bottom, the light area of the leaves at the bottom will decrease, which will reduce the photosynthetic rate of the tree and reduce the amount of carbon sequestration. Furthermore, because the activity of plants in nature is complex, it is affected by many factors that are not considered by the model such as soil, animals, rainfall. Finally, this model is only suitable for forests in mid-latitudes, because leaves of plants in lower latitudes do not fall throughout the year, and the temperature does not change much throughout the year.

8.2 The advantage and disadvantages of Model II

This model combines data from the first generation of camphorated pine with the Richards equation to plot a curve of tree height and volume varying with age. It has a certain value for the growth state during the actual afforestation process. Simultaneously, the annealing algorithm replaces the number of deforestation per age group with the proportion, which limits the range of random selection to (0, 1), greatly simplifying the algorithm. By setting and optimizing the target values for 500 years, the maximum long-term economy can be achieved.

For the disadvantages, This model simplifies the income of a single tree, which is proportional to the volume of the tree. However, in reality, the price of trees is affected by supply and demand, maintenance costs, ornamental value and so on. Since the simulated annealing algorithm can accept the worse solution with a certain probability and obtain the global optimal. This model is still applicable after more detailed numerical value is obtained in the future.This model assumes that trees grow for 50 years without natural death and ignores the effects of biodiversity. In the future, forest simulation optimization system (FSOS) can be used. FSOS combines annealing, mountaining and genetic algorithms. The tree growth curve, landscape, wildlife protection and other factors are considered.

9 Non-technical newspaper articles

FOREST

Team # 2224167

Monday, February 21, 2022 Issue 1 Environmental Issue Weekly

The need for reasonable tree cutting

Analysis the value of trees

It is of great significance to strictly prohibit indiscriminate deforestation to further improve the efficiency of forest resource use and to rationally utilize forest resources. The forest system has many functions such as protecting our earth, providing us with pure oxygen, purifying the air necessary for our survival and absorbing toxic gases. The main component of the forest system is a variety of trees. The forest system is a very complex structure with a large number of populations. It is the largest of the terrestrial ecosystems on which we human beings live. Meanwhile, it is also a very important part of the biosphere and an environment that human beings absolutely cannot escape from providing people with various terrestrial resources. Human production and life are inseparable from forest resources, which occupy a very important position in the process of human survival and development. However, due to many factors, the world's forest resources are decreasing at a rapid rate. Facts have proved that if the forest resources are not used according to certain rules, it will lead to very serious consequences. Deforestation will lead to further deterioration of environmental pollution.

Forest

The most important natural resource in the world including the wood and the wood raw material

The importance of forest resources

Forests can save a lot of water resources and can also play the function of saving rainwater. If the forest is destroyed in a large area, it will directly lead to the intensification of soil erosion, global climate change, and a large increase in harmful substances in the air. getting drier. With the gradual reduction of forest resources, the absorption of carbon dioxide will drop significantly, resulting in more and more carbon dioxide accumulating in the atmosphere. Relevant statistics show that trees around the world absorb billions of tons of carbon dioxide every year, and carbon dioxide The reaction of raw materials produces a large amount of oxygen for our survival, which is the only natural source of oxygen for our human beings.

Defination

A forest is a land dominated by trees. Hundreds of definitions of forest are used worldwide, including factors such as tree density, tree height, land use, legal status, and ecological function. The Food and Agriculture Organization of the United Nations (FAO) defines a forest as "land of more than 0.5 hectares with tree heights of more than 5 meters and a canopy cover of more than 10%, or trees capable of meeting these thresholds in situ. Excluding those used primarily for agriculture or Land for urban use." Using this definition, the 2020 Global Forest Resources Assessment (FRA 2020) found that forests cover 4.06 billion hectares (10 billion acres; 40.6 million square kilometers; 15.7 million square miles), or about 2020 of the world's land area of 31%.

The effect of rational logging on the effective protection of forest resources

Scientific planning of forest harvesting

Principles

Selecting the most suitable felling objects according to scientific principles is a very important link in the mining process. The main contents to be planned are: forestry types and the division of mining areas, the total amount of trees extracted each year, the time of mining and the construction of structural space, the annual cutting area and total cutting amount, road construction and storage for wood transportation Construction of timber yards, etc.

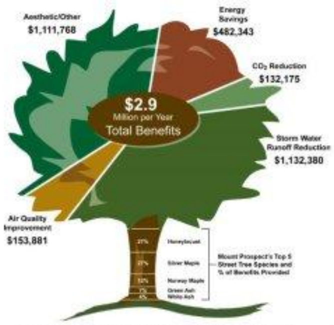
Procedure

Design strict forest harvesting procedures to ensure that the mining process is all reasonable and legal, which can play a great role in the rational exploitation of forest resources. Before mining, it is necessary to study the age of the mined trees in detail, and strictly follow the regulations to determine the mining. total work. Secondly, in the process of formulating the plan, we must adapt measures to local conditions and formulate corresponding mining work plans according to the characteristics of the region.

Different-term harvesting planning

Long-term harvesting planning. The time frame for long-term harvesting planning is 10 years. The main contents that need to be planned are: the planning of tree species in the forest. Planting and reasonable spatial distribution of trees do not affect the total annual mining of forest ecological structure and the proportion of mined trees occupied by various types of trees, the production quantity of trees and other forest products, the construction of roads used for wood transportation, and Some necessary repairs and maintenance, maintenance and repair of related equipment used for mining, etc.

The time frame for the **medium-term** harvesting plan is 5 years. The planning content includes: people need to divide the distribution of forestry types and the mining area. The total amount of trees to be mined each year will be controlled without affecting the forest environment, and the time division of mining will be considered at the same time,t including the distribution in terms of spatial distribution. In addition, the total amount of trees mined each year and the area of forest land mined each year, the construction of roads used to transport timber, some necessary repairs and maintenance will also be considered.



Annual harvesting plan. This plan is one of the most important bases in the planning process of forest mining operations. The main content of this plan is: we need to determine the areas to be mined, the types of trees to be mined, the methods to be used in the mining process, the intensity of mining, the total amount of mining, and the timing of mining and other factors.

Forest Management

Forest exploitation and forest protection are inseparable and they are not contradictory. The plan for forest exploitation must be formulated based on correct, scientific and rational principles, so as to maximize the protect forest resources.

Sustainability

Management of forest resources to meet environment,social and economic needs of today's society, withoutcompromising the ability of future generations to meet theirs.

Urban Forest Management Strategy

1

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