

Forest management scheme based on simulated annealing algorithm

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Abstract. Climate change is posing a great threat to human survival, and the technology to achieve carbon sequestration with forests is gaining attention which focuses on effective and balanced forest management. To measure the combined value of the forest, mathematical expressions for forest products, biodiversity, potential carbon sequestration, recreational and cultural uses are constructed separately. Then, using the preference factor weighting method, an expression for the radius of influence of the forest can be constructed from the above expressions. The forest is abstracted as a rectangular area, and the integrated value of the forest is reflected by drawing a circle with the impact point as the center and the impact radius as the radius. This is intuitive and transforms the problem of forest management plan into a layout problem. Using the simulated annealing algorithm to solve, the forest management plan is obtained.

Keywords: Radius of influence, Simulated annealing algorithm, Preference factor weighting method.

1. Introduction

Forest resources are Forests are important natural resources that play a significant role in the rational regulation of natural climate and the economic development of society[1]. As an important main body of terrestrial ecosystem, forest not only can play the function of providing forest products and forest by-products, but also can play the function of containing water and regulating climate, which is an important natural resource, social resource and ecological resource[2]. Scientific and reasonable forest management is of great significance for optimizing forest structure, improving forest quality, and finally realizing sustainable forest management [3]. Climate change poses a certain threat to life in nature. In order to slow down the impact of the gas, people have to reduce the emission of greenhouse gases such as carbon dioxide. But this is far from enough, so we need to take a completely new approach - carbon sequestration, using the biosphere to store carbon dioxide in plants, soil, and water environments. From this, we know that forests will slow down climate change. In addition, forest products evolved from forests can also sequester carbon dioxide during their life cycle, and even the combination of carbon dioxide sequestration from forest products and carbon sequestration from regrowth of young forests can make it possible to produce more carbon dioxide in a short time. carbon sequestration. But over-harvesting is also undesirable, so we need to find a balance to generate more carbon sequestration and ultimately reduce climate change[4].

2. Determination of forest management plan

2.1. Flowchart of Ideas

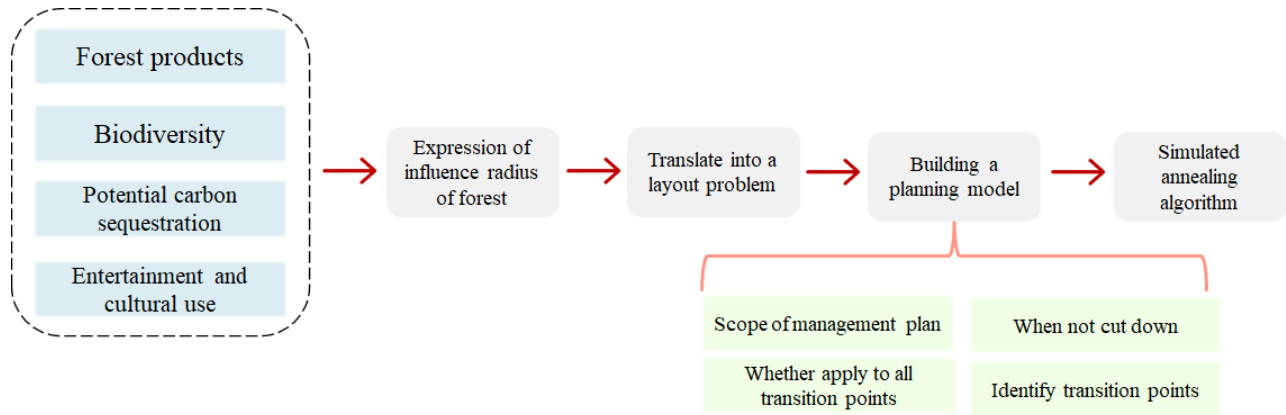


Figure 1. Flowchart of ideas.

2.2. Construction of Mathematical Expressions

Forests play an irreplaceable role in mitigating climate change, controlling soil erosion and land degradation, and protecting biodiversity[5]. As one of the important measures for mitigating climate change, protect and enhance the forest carbon sinks, reducing deforestation and forest degradation caused by the carbon content related to be incorporated into many international convention on climate change[6].

I. Considering forest products as economic value, the expression of economic value generated by forest products in unit time can be obtained:

$$M_1 = \mu \sum n_i \quad (1)$$

Note: In the formula, μ represents the profit rate, n_i represents the sales of different forest products

II. Biodiversity:

The forest area (10,000 hectares) and the tree cover rate of the forest largely determine the biological diversity of the forest. Let the product of the forest area and the tree cover rate be M , and the value of the biodiversity is M_3 , Conduct a refined quantitative analysis of this problem by establishing the functional expressions of M and M_3

To facilitate the solution, we use the range transformation:

$$x'_{ij} = \frac{x_{ij} - \min_{1 \leq i \leq n} \{x_{ij}\}}{\max_{1 \leq i \leq n} \{x_{ij}\} - \min_{1 \leq i \leq n} \{x_{ij}\}} \quad (2)$$

Normalize the value of M_3 corresponding to different M , then M is between $[0,1]$.

Let M be x and M_3 be $y=f(x)$, where $y \in [0,1]$. The closer y is to 1, the stronger the biodiversity. y and x should satisfy the following conditions:

i. The greater the product of forest area and tree cover, the stronger the biodiversity, that is, y increases with x .

ii. When the product of forest area and tree coverage is 0, the initial value of biodiversity is a Changshu in the interval $(0,1)$, that is, $f(0)=y_0 \in (0,1)$

iii. When the product of forest area and tree coverage is large, and gradually tends to positive infinity, biodiversity will tend to 1

An exponential growth model that meets the above conditions as follows:

$$y=f(x)=(1-y_0)(1-e^{-\beta x})+y_0, \quad y_0 \in (0,1) \quad (3)$$

Take the initial value of biodiversity as 0.13 , that is, in the above expression, take $y_0=0.13$. Combined with the actual situation, estimate that the range of β is between $-0.00028 \sim -0.00018$, and take β as -0.00023 . The resulting function expression is as follows:

$$y=0.87 \times (1 - e^{-0.00023x}) + 0.13 \quad (4)$$

III. Seeing Potential Carbon Sequestration as Potential Value

The potential value of potential carbon sequestration is mainly determined by biodiversity, and biodiversity is mainly related to M (M is the product of forest area and tree cover). The larger the M , the stronger the biodiversity. To this end, Construct the following mathematical expression for the potential value:

$$M3 = 2 - e^{\frac{M}{M_2/r}} \quad (5)$$

Note: In the formula, M_2 is biodiversity, r is correction factor

IV. The benefits of entertainment and cultural use per unit time can be expressed by the following formula:

$$M_4 = \Sigma(d_1 \times x_i + d_2 \times y_i) \quad (6)$$

$$d_1 + d_2 = 1$$

Note: In the formula, d_1, d_2 are coefficients, x_i represents the benefits generated by different recreational uses, y_i represents the benefits generated by different cultural uses.

2.3. Construction and solution of forest management plan model

2.3.1 The Influence Radius R of the Forest

The forest impact is comprehensively measured by the impact radius to determine the forest management plan that balances the forest value in various ways.

Assuming that there are n impact points in the forest, with the impact point as the center, the impact on surrounding forest products, biodiversity, potential carbon sequestration, recreation, cultural use can be measured. Draw a circle with the influence point as the center and the influence radius R as the radius (see Figure 2).

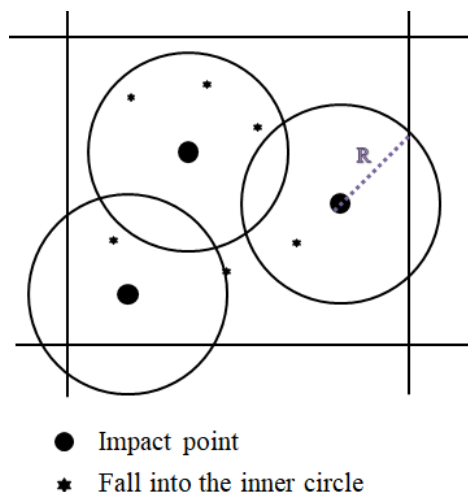


Figure 2. The area of influence of the point of influence.

If an area falls within the circle, the value of forest products, biodiversity, potential carbon sequestration, recreation, cultural use, etc. in that area of the forest is determined by that impact point. If an area falls in multiple circles at the same time, the value of forest products, biodiversity, potential carbon sequestration, recreation, cultural use in that area is determined by multiple impact points.

Each impact point in the forest has a consistent impact on its area, and the felling of trees is mainly carried out in the area that does not fall into any circle. Therefore, the problem is transformed into:

I. Determine the impact radius of the forest, so that the deforestation amount of the forest is between 15% and 26% .

II. How to determine the radius of influence

III. Solving the model when the number of influence points of the forest is known

IV. Solving the model when the number of influence points of the forest is unknown

2.3.2 Preference Coefficient Weighting Method to Determine the Influence Radius

In the above, the mathematical expression has been constructed for the effects of forests on forest products, biodiversity, potential carbon sequestration, recreation, and cultural uses, respectively.

Multi-objective is not conducive to solving the problem, so we use the preference coefficient weighting method to convert the multi-objective problem into a single-objective problem, and its expression is:

$$M = k_1 M_1 + k_2 M_2 + k_3 M_3 + k_4 M_4 \quad (7)$$

The expression here reflects the combined effects of forests on forest products, biodiversity, potential carbon sequestration, recreation, and cultural uses, which we call comprehensive values. Here k_1 , k_2 , k_3 , and k_4 have two meanings: one is to act as a preference weighting coefficient, and the other is to act as a correction coefficient to ensure forest products, biodiversity, potential carbon sequestration, entertainment, and cultural uses. The quantized values of the four expressions of are approximately equal numerically.

The increase in the influence radius of the forest is roughly proportional to the increase in M when the forest size is small. Because we consider the influence point in the forest, the influence point can be regarded as a small-scale forest, so it can be considered that the increase of the radius of influence to be sought is related to M , and its expression is:

$$R = k_5 \times M + b \quad (8)$$

2.3.3 Solving the Model When the Number of Influence Points of the Forest Is Known

On some higher power or more complex polynomial function to find the most value of the problem, the derivative, find the stationary point, find the extreme values, etc. are relatively tedious, it is easy to make mistakes in the calculation. Therefore, the use of computer-aided verification of the maximum value of the function, the correctness of the minimum value, become an The computer-aided verification of the correctness of the function's maximum and minimum values has become an effective problem solving method. The computer-used simulated annealing algorithm program design, which becomes the key to solve the problem quickly[7]. In view of the complexity of forest management, the simulated virtual forest environment is usually used as the experimental area, and the simulated annealing algorithm tool is used to operate and manage the forest[8]. Simulated annealing algorithm is one of the most widely used and most stable heuristic algorithms in forestry field. It is of great significance to study the optimization and enhancement of search performance of the algorithm to improve the search performance of other heuristic algorithms and the compiling level of forest management schemes[9]. By constructing the objective function reasonably, it also has a good effect on solving a large number of combination and arrangement problems in forest management[10].

Simulated annealing is a general probabilistic algorithm used to find the optimal solution to a problem in a large search space. The idea of modern simulated annealing algorithm originates from the annealing process of solid: heating the solid to a high enough temperature, and then slowly cooling: when heating, the particles inside the solid become disordered with the increase of temperature, the internal energy increases, and slowly Cooling makes the particles gradually tend to order again. Theoretically, if the cooling process is slow enough, at any temperature in the cooling, the solid can reach thermal equilibrium, and when cooled to a low temperature, it will reach a state of minimum internal energy at that low temperature. The analogy between the physical annealing process and the simulated annealing algorithm is shown in Figure 3.

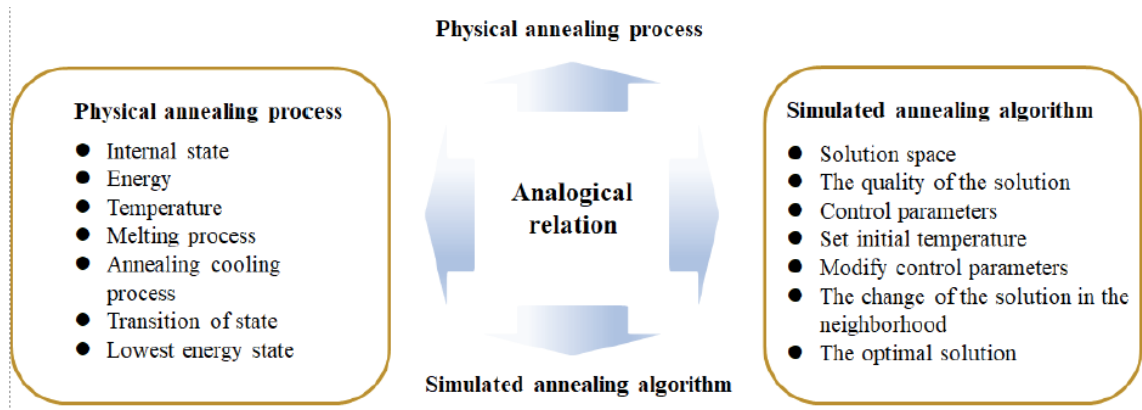


Figure 3. Analogue diagram of physical annealing process and simulated annealing algorithm.

As can be seen from the above, identifying a forest management plan that balances the various ways in which forest values can be translated into a layout issue. Build programming modelsto solve progressively.

A forest can be thought of as a rectangular area. Now the problem can be briefly described as in this rectangular area, there are x_i small circles with radius r and y_i large circles with radius R . Now put these circles in the rectangular area so that the distance between the centers of the large circles is approximately equal and as large as possible so that there is no overlap between the campus and the great circle.

The small circle refers to the area in the forest that does not fall within the range of the impact point, and the trees in this area can be felled. The great circle is the circular influence area generated by the influence point as the center and the influence radius as the radius.

The objective function is:

$$g = \sqrt{\prod_i \prod_j [(l_i - l_j)^2 + (l'_i - l'_j)^2]} \quad (i \neq j) \quad (9)$$

The advantage of using g as the objective function is to make the center distances between the major circles approximately equal and to make them as large as possible. Therefore, we use the maximum g as the objective function to establish a planning model:

$$\left\{ \begin{array}{l} R \leq l_{yi} \leq l - R \\ R \leq l'_{yi} \leq l' - R \\ r \leq l_{xi} \leq l - r \\ r \leq l'_{xi} \leq l' - r \\ \sqrt{(l_{yi} - l_{yj})^2 + (l'_{yi} - l'_{yj})^2} \geq 2R, i \neq j \\ \sqrt{(l_{xi} - l_{yj})^2 + (l'_{xi} - l'_{yj})^2} \geq R + r \end{array} \right. \quad (10)$$

Among them, the subscript x represents the center coordinate of the small circle, and the subscript y represents the center coordinate of the large circle. In order to simplify the problem, first we only consider the layout of the large circle, and then arrange the small circle on the periphery tangent to the large circle to meet the moderate aggregation amplification effect.

It is difficult to construct an efficient algorithm for the layout problem, but we can use the flexibility of the simulated annealing algorithm with memory to efficiently find an approximate optimal solution for the great circle layout.

2.3.4 Solving the Model When the Number of Influence Points of the Forest Is Unknown

Consider the forest as a rectangular area, let the area of the rectangular area be S , and the area of all the great circles in the rectangle be S_1 .

If the number n of the influence points of the forest is known, that is, when the influence radius is calculated, $(S-S_1) \div S \times 100\%$ is between 15%-26%.

$$S_1 = n \times \pi \times R^2 \quad (11)$$

So the length of the radius of influence is:

$$\sqrt{\frac{0.74S}{n\pi}} < R < \sqrt{\frac{0.85S}{n\pi}} \quad (12)$$

At this point, forests and their products are sequestering more carbon dioxide over a period of time. Since R is known, expressions for forest products, biodiversity, potential carbon sequestration, recreation, and cultural uses of the forest can also be solved. Forest management plans can be derived in various ways that balance forest values.

2.3.5 Solving the Model When the Number of Influence Points of the Forest Is Unknown

Consider the forest as a rectangular area, let the area of the rectangular area be S , and the area of all the great circles in the rectangle be S_1 .

If the number of influence points of the forest is known, that is, when calculating the influence radius, $(S-S_1) \div S \times 100\%$ is between 15%-26%. It can be seen that S_1 should be between [4440000, 5100000].

Assuming that the length of the rectangle is 2000 m, 3000 m, the width is 1500 m, 2000 m, when the initial temperature is 97 °C, the final temperature is 3 °C, and the Markov chain length is 60000, the obtained approximate The optimal solutions are shown in Figure 4 and Figure 5, respectively.

When the length is 2000m and the width is 1500m, the influence radius R is 350m, and the number of influence points is 6, which is more reasonable. The coordinates of the six centers are:

(350,350)、(350, 1050)、(1050, 350)、(1050, 1050)、(1750, 350)、(1750, 1050).

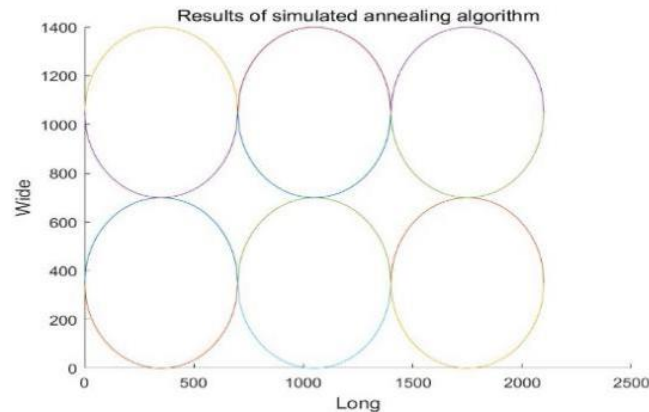


Figure 4. Results of simulated annealing algorithm.

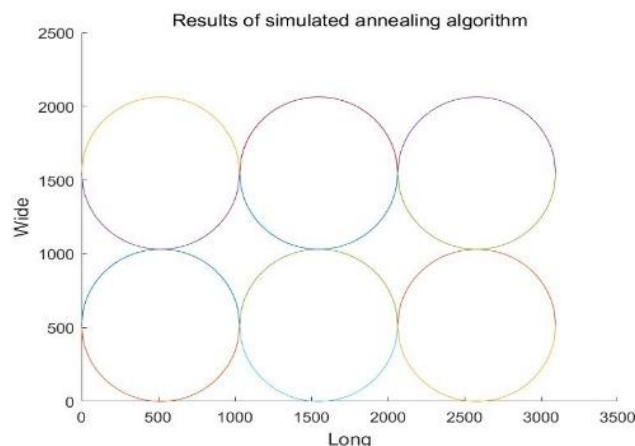


Figure 5. Results of simulated annealing algorithm.

When the length is 3000m and the width is 2000m , the influence radius R is 516m , and the number of influence points is 6 , which is more reasonable. The coordinates of the six centers are:

(516,516)、(516, 1548)、(1548, 516)、(1548, 1548)、(2580, 516)、(2580, 1548).

In both cases, forests and their products store more carbon dioxide over a period of time. Since R is known, expressions for forest products, biodiversity, potential carbon sequestration, recreation, and cultural uses of the forest can also be solved. Forest management plans can be derived in various ways that balance forest values.

2.4. Conclusion of forest management plan model

2.4.1 Scope of the Management Plan

If the influence radius of the forest is known, it is assumed that the influence point is at the vertex of the rectangle, and the influence range of the influence point is represented by a large circle.

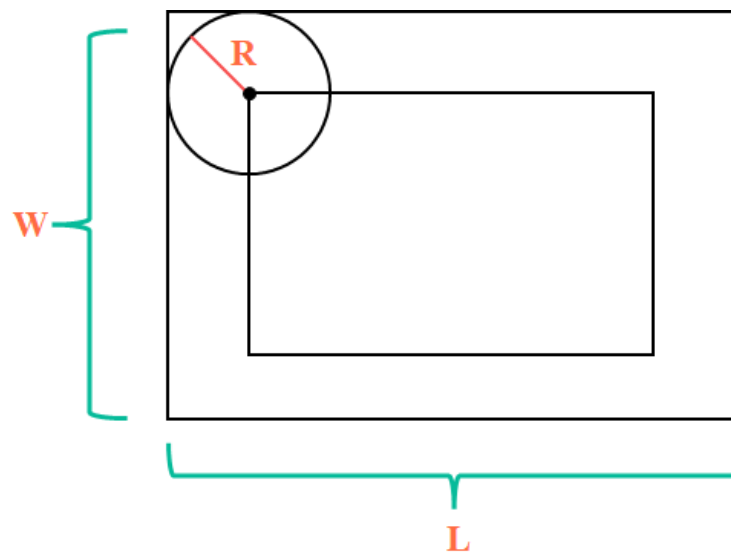


Figure 6. Schematic Diagram of Forest Assumptions.

Let the area of the rectangle representing the forest be S_2

The area of the rectangle circumscribing the great circle is S_3

If $(S_3 - S_2) \div S_2 \times 100\% > 85\%$, then the forest falls within the scope of our management plan and is the type that our model mainly discusses.

If $(S_3 - S_2) \div S_2 \times 100\% < 85\%$, the forest does not belong to the scope of our management plan, and there should be selective discussion.

$(S_3 - S_2) \div S_2 \times 100\% > 85\%$ to a certain extent reflects the forest's influence on the surrounding area. When the forest's influence is larger, it is more suitable to discuss various ways of balancing forest values, our model will be relatively accurate. If forests have a small area of influence, our model may be less accurate when discussing forest management plans in various ways to balance forest values. So our model mainly discusses $(S_3 - S_2) \div S_2 \times 100\% > 85\%$ forest.

2.4.2 When the Forest Is Not Deforested

It can be seen from the above model that when $(S - S_1) \div S \times 100\%$ cannot be between 15% and 26% , it is necessary to consider whether the forest can be cut down.

There are two situations at this point:

Case 1: $(S - S_1) \div S \times 100\% < 15\%$

In this case, it means that the influence radius is large, the influence range of the influence point is large, and the influence range of an influence point can include more than 85% of the rectangle . Taking the influence point at the vertex of the rectangle as an example, the area of the great circle representing the influence range is larger than that of the rectangle, and more than 85% of the rectangle is largely covered by the great circle, as shown in Figure 7 .

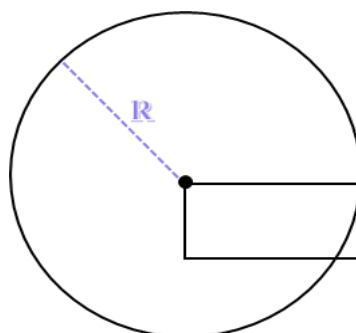


Figure 7. Case1: $(S-S_1) \div S \times 100\% < 15\%$.

The area of such forests is small, but there are more trees in the forest, the distribution of trees is relatively dense, and the forest has a large impact on forest products, biodiversity, potential carbon sequestration, recreational, cultural uses, resulting in a radius of impact larger. At this time, the forest can be cut down appropriately.

Case 2: $(S-S_1) \div S \times 100\% > 26\%$

In this case, it means that the number of influence points in the forest is small, and the influence radius is small, so that most of the forest is not within the influence range of the influence points, as shown in Figure 8.

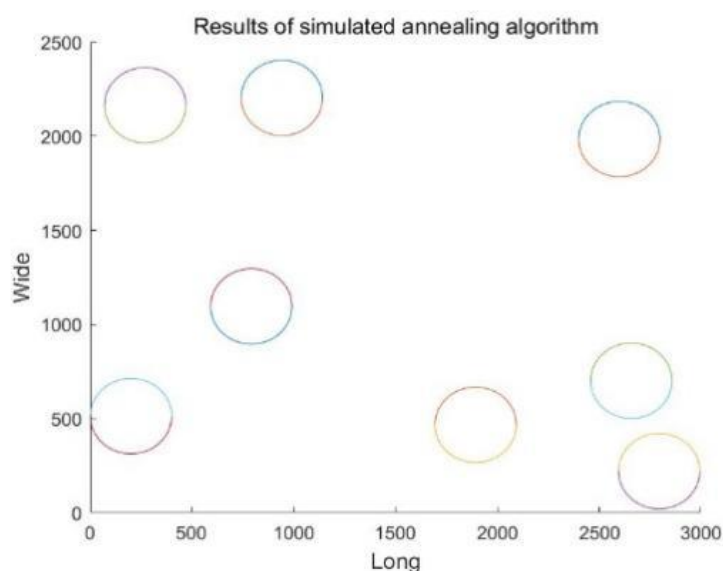


Figure 8. Case 2: $(S-S_1) \div S \times 100\% > 26\%$.

This type of forest has fewer trees and a more sparse distribution of trees, and the forest has less impact on forest products, biodiversity, potential carbon sequestration, recreational, cultural uses, resulting in a smaller impact radius. Do not cut down the forest at this time, otherwise it may cause great damage to the forest.

2.4.3 Conversion points for all forests

There are transition points that apply to all forests.

Take the value of the transition point as $(S-S_1) \div S \times 100\%$.

When $(S-S_1) \div S \times 100\%$ is between 15%-26%, further solving using our model yields forest management plans in various ways that can balance forest values.

When $(S-S_1) \div S \times 100\%$ is not between 15%-26%, it is necessary to consider whether the forest can be cut down.

If deforestation is possible, use our model to solve further, resulting in a forest management plan that balances forest values in various ways.

If it cannot be cut down, the forest management plan of various ways to balance the forest value is: make $M=k_1M_1+k_2M_2+k_3M_3+k_4M_4$ to achieve the maximum value.

2.4.4 Use the Characteristics of Specific Forests and Their Locations to Identify Transition Points between Management Plans

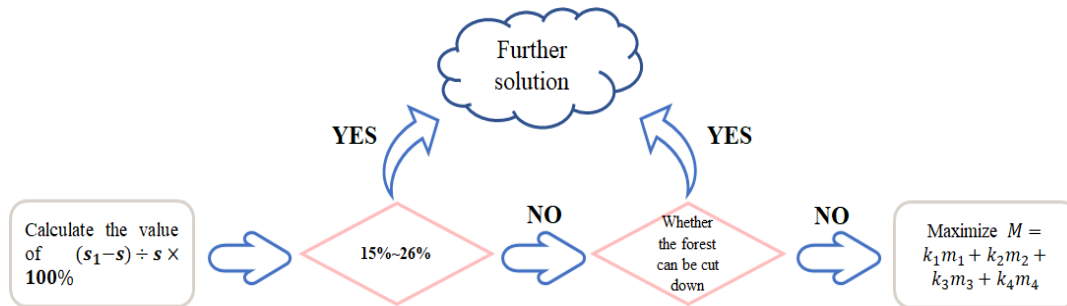


Figure 9. Flow chart of management plan determination.

Impact Points n and the influence radius R can be obtained from the relevant data of a specific forest.

Considering the forest as a rectangular area, the area S of the rectangle can be obtained from the location characteristics of the forest. For example, if the range of the longitude and latitude of the forest is known, the range is a rectangular area, and the three vertices of the rectangular area are taken as A , B , and C respectively. The geographic coordinates of the three vertices are :

$$A(x_1, y_1), B(x_1, y_2), C(x_2, y_1)$$

In order to calculate the area of the total area, take the center of the earth as the coordinate origin O , take the equatorial plane as the XOY plane, and take the plane where the 0 degree meridian coil is located as the XOZ plane to establish a three-dimensional Cartesian coordinate system. Then the Cartesian coordinates of the three points A , B , and C are:

$$A(R\cos x_1 \cos y_1, R\sin x_1 \cos y_1, R\sin y_1)$$

$$B(R\cos x_1 \cos y_2, R\sin x_1 \cos y_2, R\sin y_2)$$

$$C(R\cos x_2 \cos y_1, R\sin x_2 \cos y_1, R\sin y_1)$$

Among them, R is the radius of the earth and $R=6370\text{km}$.

The formula for the actual distance between points A and B is:

$$d_1 = R \arccos \left(\frac{|\vec{OA} \cdot \vec{OB}|}{|\vec{OA}| \cdot |\vec{OB}|} \right) \quad (13)$$

Use Matlab to calculate the actual distance d_1 between points A and B , and similarly obtain the actual distance d_2 between points A and C , then the total area of this area is $S = d_1 \times d_2$

The area of all the great circles in the rectangle representing the sphere of influence of the point of influence is S_1 .

$$S_1 = n \times \pi \times R^2 \quad (14)$$

If $(S-S_1) \div S \times 100\%$ is between 15%-26%. Further solving using our model yields a forest management plan that balances the various ways of forest value.

When $(S-S_1) \div S \times 100\%$ is not between 15%-26%, it is necessary to consider whether the forest can be cut down.

If deforestation is possible, use our model to solve further, resulting in a forest management plan that balances forest values in various ways.

If it cannot be cut down, the forest management plan of various ways to balance the forest value is: make $M = k_1 M_1 + k_2 M_2 + k_3 M_3 + k_4 M_4$ to achieve the maximum value.

2.4.5 Final conclusion

By discussing the model, the scope of the management plan is determined and the following conclusions are obtained:

(i) Logging is possible when the area covered by all circles is greater than 85%; logging is not possible when it is less than 74%.

(ii) There is a transition point for all forests: all areas covered by circles. This overpoint can be used to determine if the forest can be harvested.

(iii) From the data related to a specific forest, the number of impact points and the length of the impact radius can be found. Then, from the location characteristics of the forest, the area of the forest can be found, and thus its management plan can be determined.

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