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Research on Forest Management in the Context of Carbon Sequestration

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Abstract: *As resources are exploited around the world, the environment is being affected as never before, and one of the more serious problems is global warming. This paper presents a more comprehensive study of forest management plans in areas such as the Cariboo Forest. First, the paper fit the relationship between tree age and volume using logistic regression, and then estimate the forest's maximum carbon storage $Csum$ using the biomass conversion factor method along with a modified Leslie model. In this paper, three aspects of economic benefit, social demand and carbon storage are balanced, and a forest decision-making model based on multi-objective linear programming is established. This paper applies the model to the Cariboo Forest area and optimizes the carbon sequestration assessment model using the first-order decay method (FOD), taking into account the carbon release from wood products.*

Keywords: *Multi-objective linear programming; Leslie model; Carbon sequestration; First-order decay method*

1. Introduction

The United Nations Intergovernmental Panel on Climate Change (IPCC), in its fourth assessment report, states that the global average surface temperature will increase by approximately 0.74℃ over the next 100 years [1], and that the main cause of the increasing global greenhouse effect is carbon emissions from fossil fuel burning energy consumption.

Figure 1 shows a diagram of the major sources and sinks of CO_2. Some of the carbon dioxide peopel emit from fossil fuels and land use change is absorbed and stored in the oceans, land and soil. Only the remainder - about half of global emissions - remains in the atmosphere.

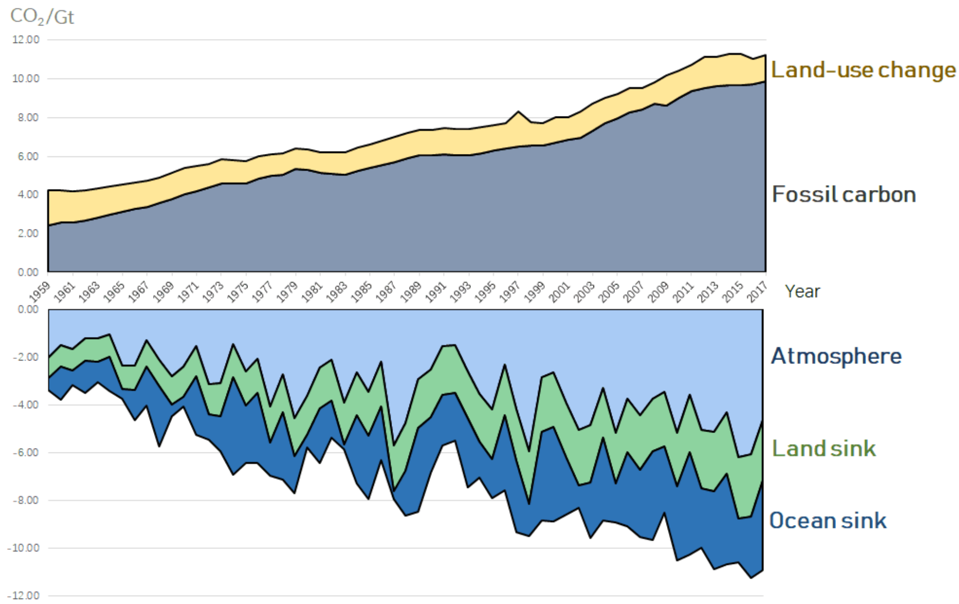

Figure 1: Balance of sources and sinks

Forests are the mainstay of terrestrial ecosystems and an important part of the Earth's biosphere. Although the global forest area accounts for only 27% of the land area, the above-ground vegetation

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carbon pool stores about 80% of the global above-ground carbon stock [2], and forests have been widely recognized and confirmed as an important "carbon sink". However, the fact is that only 10% of the world's forests are under effective management [3].

2. Model preparation

2.1. Delineation of regions and forest carbon stock components

Before model building, it should determine the ecological zone division under study. Taking into account the differences in climate temperature and humidity and the changes in the distribution of tree species in different regions, the paper build the predictive model of biomass by considering the sections with similar climatic conditions and adjacent physical geographic areas as a whole. Such a division not only makes the model more reliable and practical, but also makes it more extensive in analyzing the specifics of various types of forests.

The paper divide the forest carbon stock C_{sum} into the carbon stock of the forest area and its wood products, and define the formula for C_{sum} as follows.

$$C_{sum} = C_{forest} + C_{wood} \tag{1}$$

Where C_{forest} represents the carbon stock of forest stands and C_{wood} represents the carbon stock of woody products.

2.2. Wood forest products

Carbon in woody forest products formed after forest harvesting is not emitted immediately, but gradually over the following years or decades, and some of the carbon in woody forest products may also be preserved for a long time [4]. Forests that are used in situ as fuelwood have their stored carbon returned to the atmosphere in a relatively short period of time through decomposition or combustion. As for various woody forest products, the rate of emission is related to the use and service life of the product.

Referring to the IPCC default algorithm, the change in carbon stock for manufactured wood forest products is defined in the following equation.

$$C_{w-cha} = \sum_{i=1}^{5} \Delta C_i = 0 \tag{2}$$

Where $C_{w\text{-}cha}$ represents the sum of carbon stock changes of all types of woody forest products, and $DeltaCi$ represents the carbon stock changes of type i woody products. This shows the framework of the carbon stock model for forests and their wood products as follows Figure 2.

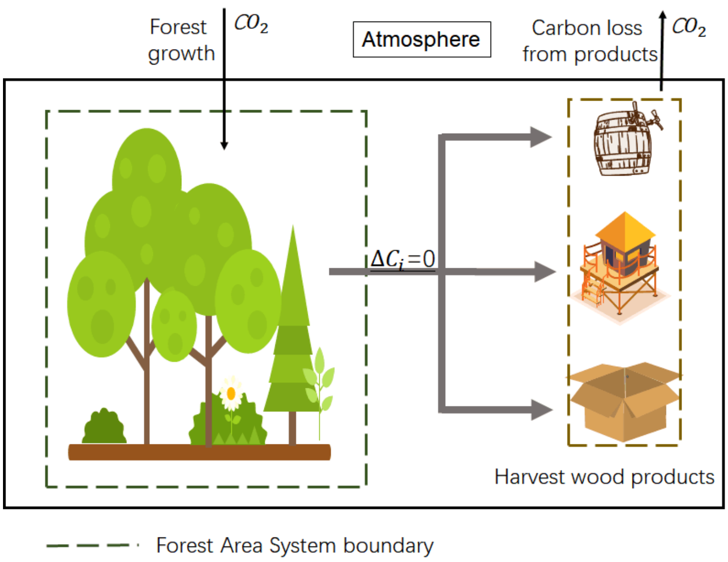

Figure 2: Carbon stock flow framework for forests and their products

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In the above it has given the carbon stock change equation for woody forest products with reference to the IPCC default method, which shows that the carbon stock of woody forest products does not change, which is a simpler system of measurement methods.

Considering the actual situation of different forests, making all the harvested logs into sawn timber and man-made boards may be limited by factors from species and economy, etc. The above simplified formula can be obtained from the following equation based on the data and situation splitting of the study area.

$$C_{w-cha} = \Delta C_1 + \Delta C_2 + \Delta C_3 + \Delta C_4 + \Delta C_5 \tag{3}$$

The change in carbon stock of wood products can be obtained, then the C_{wood} formula for carbon stock of woody forest products in this model is defined as follows.

$$C_{wood} = C_{log} + C_{w-cha} \tag{4}$$

Where C_{log} represents the carbon stock of the logs.

2.3. Modeling of biomass and timber volume

There are many methods to determine the age of trees, but they are often less accurate or difficult,whereas the diameter at breast height of trees is easier to measure. According to the survey, there is a strong correlation between the age of a tree and its diameter at breast height [5]. Taking poplar trees as an example, the relationship between diameter at breast height and tree age can be fitted to find the most suitable equation as Logistic equation, and the calculated correlation coefficient is 0.996 and the mean square of residuals is 0.032, and the results are shown in Figure 3 below.

The specific logistic fitting equation is defined as follows.

$$L = \frac{13.679}{1 + 3.3476 \cdot e^{-0.2099D}} \tag{5}$$

This paper can also use the tree diameter at breast height for tree volume estimation. Again, taking poplar as an example, the volume vs. diameter at breast height regression model was obtained with the help of Box-cox transformation. The fitted curves are shown in Figure 4 below, and the average relative error of the calculated regression is 1.22%, which verifies the high accuracy of the fit. The equations of the regression curves are as follows.

$$v = \left(-0.015 + 2.4948 \cdot L\right)^{1/0.35} \tag{6}$$

Where v represents the wood volume of poplar and L represents the diameter at breast height of poplar.

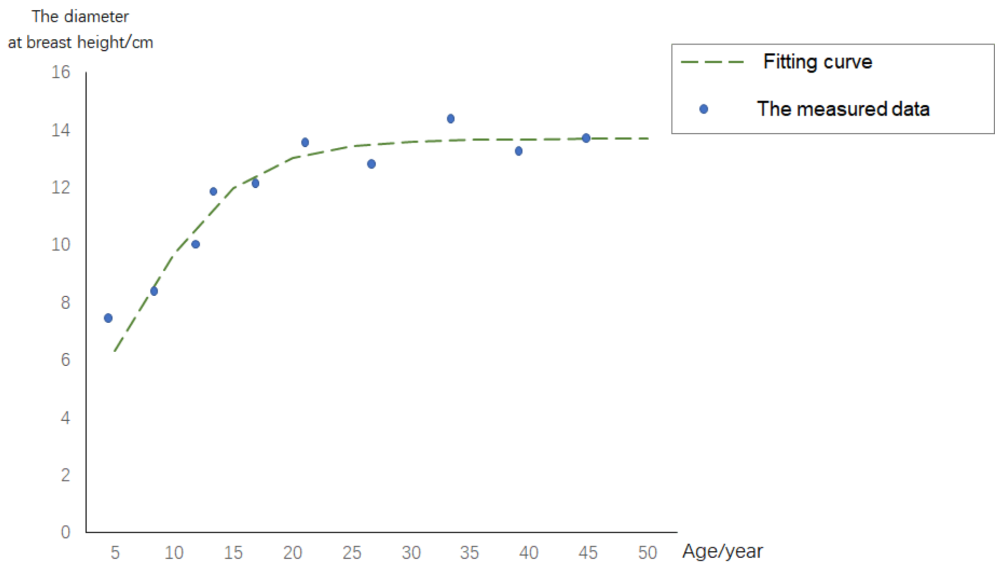

Figure 3: Age vs. diameter at breast height curve fit

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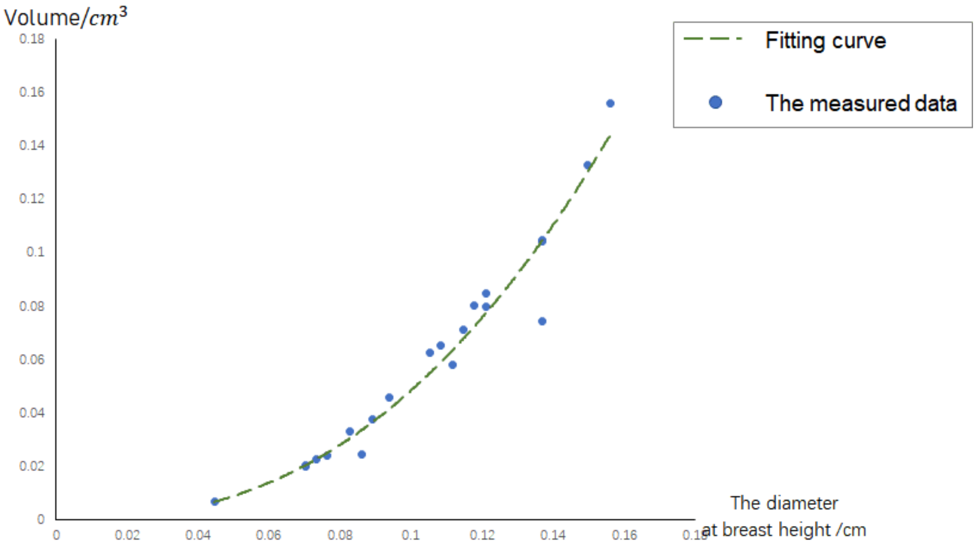

Figure 4: Curve fit of volume vs. diameter at breast height

Where v represents the wood volume of poplar and L represents the diameter at breast height of polar.

2.4. Tree population change matrix

It is assumed that the harvesting interval in forest management plan is one year, i.e., trees of appropriate diameter at breast height are harvested in a cycle of one year. Referring to the Leslie model of population distribution, it defines the following equation for the transformation relationship of trees of different ages.

$$n_{i,t+1} = \begin{cases} \sum_{j=1}^{s} F_j \cdot n_{s,t}, (i=0) \\ p_{i-1} \cdot n_{i-1,t}, (i \neq 0) \end{cases} \tag{7}$$

Where $n_{i,t+1}$ represents the number of trees of age i in t+1 year,ni ,t represents the number of trees of age i in t+1 year, F_j represents the compensation rate after felling of trees of age i, p_{i-1} represents the survival rate of trees of age i-1, and S represents the maximum age of trees.

3. Establishment of model

3.1. Multi-objective linear programming model

Under the condition that the price of wood products does not fluctuate too much, the model can be constructed as follows.

$$\begin{cases} \max f_1(x) = P_{r_{i1}} \cdot x_1 + P_{r_{i2}} \cdot x_2 + P_{r_{i3}} \cdot x_3 \\ \max f_2(x) = C_1 \cdot x_1 + C_2 \cdot x_1 + C_3 \cdot x_1 \end{cases} \tag{8}$$

s.t.

$$x_1 + x_2 + x_3 = 100\% \tag{9}$$

$$x_1, x_2, x_3 \geq 0 \tag{10}$$

The first equation, max $f_1(x)$, represents the maximum level of forest economic benefits, which consists of the values of three types of forest products. p_{ri1}, p_{ri2}, and p_{ri2} represent the prices of the wood products of that type, and x_1, x_2, and x_3 represent the allocation ratio of the wood products of that type. The second equation max $f_{2(x)}$ represents the maximum level of forest carbon stock, where C_i represents the carbon sequestration factor, which is obtained from the statistics of wood product lifetime. And the formula for C_i is given as follows.

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$$C_i = \ln(pl) \tag{11}$$

Where pl denotes the lifetime of the woody forest product. Lifetime is the period of time that the final product is being used in a state of use before it is recycled or disposed of, and is the duration of use or average use of the product [6].

The first equation in the above constraint indicates that the proportions of the three wood products sum to a constant 1. The second equation indicates that the proportions assigned to the different wood products are all non-negative.

Then give the evaluation function of the linear weighting method as follows Eq.

$$\max h(F(x)) = \lambda_1 \cdot f_1(x) + \lambda_2 \cdot f_2(x), (x_1 + x_2 = 1) \tag{12}$$

Where the weighting factor is a value of λ_1 and λ_2 dynamics, which should be adjusted according to the climatic conditions of different regions.

3.2. Environmental condition scoring sub-model

In order to smooth the transition between different forest management plans to fit as many forests as possible, the paper will develop a scoring sub-model based on the entropy approach for different environmental conditions and explore the transition points of management plans.

Since different trees require different optimum conditions for growth, the paper set three different optimum temperatures to rate the environment in different regions, with a full score of 100 for each region. if the average score of the three conditions does not reach 70, then the environment in that region is not suitable for tree growth.

The paper selected climate data from five regions and used the entropy weighting method to determine the weights of different indicators. The results of the calculation of the weights of each indicator are shown in Figure 5 below.

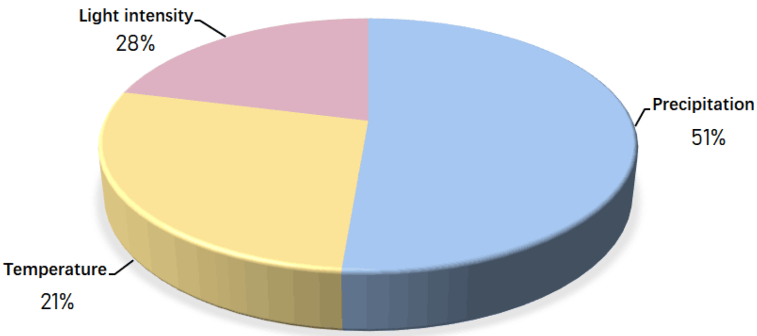

Figure 5: Weighting chart for each condition

3.3. Forest carbon stock prediction model

Using the prices of local forest products provided in [7], it calculated by the FDM model that paper accounts for 43% of forest products, furniture for 17%, and building consumables for 40%. This is combined with a typical life span of 10 years for paper, 40 years for furniture, and 60 years for construction consumables. That is, after 10 years the paper produced in the first year starts to reach its useful life and is burned or landfilled, and in the 40th and 60th years furniture and building materials similarly start to be disposed of. The paper found that about 30% of the forest products disposed of are burned and 70% are landfilled. Combined with the CSAM model, it can obtain the optimized model.

$$C_{wood} = C\log - (\Delta Cb + \Delta Cl) \tag{13}$$

ΔCb is the carbon stock released from incineration over 100 years and ΔCl is the carbon stock released from landfills over 100 years.

For incineration, all forest products are converted to carbon dioxide and enter the environment. For landfill, the process is very slow, and here it refer to the first-order half-life method to give an equation

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to calculate the amount of carbon storage entering the environment.

$$C_{(i+1)} = e^{-k} \times C_{(i)} \left[\frac{\left(1-e^{-k}\right)}{k} \right] \times C_{Innow(i)} \tag{14}$$

$$\Delta C(i) = C(i+100) - c(i) \tag{15}$$

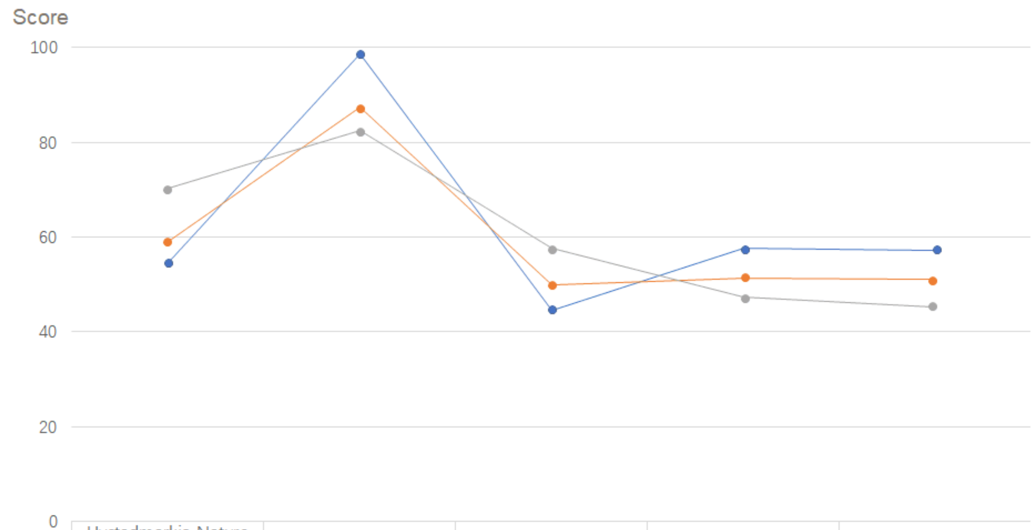
C_i and C_{i+1} are the carbon stock of woody forest products in the landfill part at the beginning of year i and i+1, respectively; k is the decay constant under the first-order decay method, k =ln2/tm, where *tm* is the half-life of woody forest products; C_{inflow} is the amount of carbon flowing into the solid waste landfill in year i; ΔC(i) is the increment of carbon stock of woody forest products in the landfill part in year i.

4. Model results

Taking the data of Cariboo Forest Region as an example, it calculated the optimal proportion of different forest products based on the model and compared it with the demand of the society in its current state, calculating the value of SC as 0.12. From an overall perspective: the value of SC is 0.12, which means that after balancing the economic benefits of the forest with the value of carbon sequestration, the deviation level of woody forest products from the original demand is 12%. This indicates that forest managers in Cariboo Forest Region have some consideration for balancing the social impact of the forest with the value of carbon sequestration, but there is still room for improvement.

In terms of specific categories: Cariboo Forest Region has a large deviation from the optimal proportion of paper products manufacturing, with a deviation of 18%. It recommend that forest managers adjust their forest management plans to increase the proportion of trees harvested for paper-based manufacturing and to reduce the proportion of furniture and construction wood products, depending on the actual situation.

The five regions were scored according to the weights of the indicators, and the results obtained are shown in Figure 6 below.



	Hystadmarkjo Nature Reserve	Amazon forest	Northeast shelterbelt	African grasslands	Egypt
25℃	54.73	98.69	44.48	57.6	57.31
15℃	59.08	87.34	49.92	51.38	51
5℃	70.4	82.45	57.63	47.43	45.3

Figure 6: Rating of 5 forest areas

The results in the figure show that the Amazon Forest always scores above 70, which indicates that it has a good environment for the trees to grow. This coincides with the results of the model.

After considering the treatment of forest products, it can obtain the dynamic carbon stock results of Cariboo Forest between 100 years as shown in the Figure 7 below.

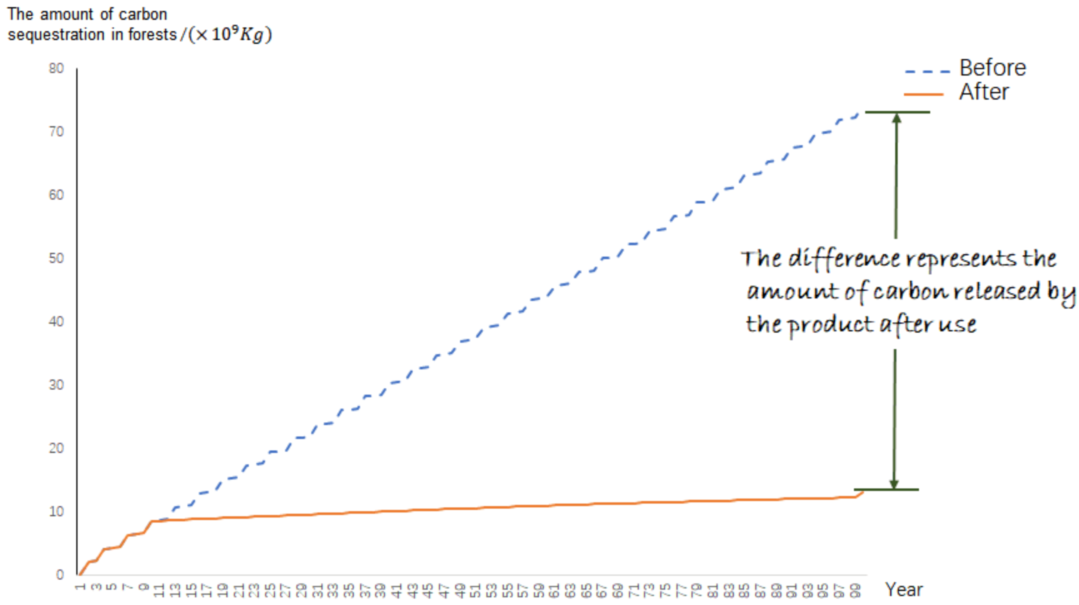


Figure 7: Dynamic carbon stock projection results

It can be seen that forest carbon stock is positively proportional to time when forest product depletion is not considered. When considering forest product carbon stock depletion, forest carbon stock decreases significantly after 10 years and then increases slowly with time to reach 1.2 million tons per 100 ha after 100 years. The disposal of paper by burning and landfilling has a huge impact on carbon stocks, and the adoption of only burning and landfilling policies without recycling can cause great harm to the environment.

5. Conclusion

With a total area of 80.7 million hectares, the Cariboo Forest is able to absorb a large amount of carbon dioxide each year, which is of high value in mitigating the global greenhouse effect. The Cariboo Forest is also an important source of timber for Canada. In order to construct a sustainable management plan, both ecological and economic aspects of the forest need to be considered. It analyse this in terms of forest carbon stocks as a measure and forest product allocation, respectively. It is important to ensure both sufficient carbon stocks and sufficient economic benefits to support forest managers. It need to determine the management plan for Cabrillo Forest in three ways. First, forest products allocation: 25% for paper, 26% for furniture, 49% for construction. Secondly, the felling cycle should be 15 years, and selective felling is preferred. Last, choose to cut down trees that are 20 years old or older. The benefits of forest areas do not pertain only to forest managers, and the best management plans are not the best for everyone. That is why transitions in the plan need to be considered before the forest management plan is implemented.

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