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Research Article

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Assessment of the Forestry for Carbon Sequestration

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Abstract Forests play a critical role in mitigating climate change by carbon sequestration. We develop models of carbon sequestration to determine how much carbon dioxide forests and their products can store over time. Primarily, simulate the carbon cycling of forest ecosystem through the Biome-BGC model based on GIS emote sensing data, calculate the NEP of forests, and estimate the carbon sequestration of forest ecosystems. Then, introduce two variables, deforestation rate and supplementary planting rate, to estimate the impact of management plan on carbon sequestration. Finally, empirical data shows that the model is more feasible, and appropriate selective logging can improve carbon sequestration.

Keywords Forest, Carbon Sequestration; Biome-BGC; Logistic Regression

1. Introduction

With the development of agriculture and industry, the situation of global warming is becoming more and more serious. At present, carbon neutrality has become the consensus of mankind, and countries are gradually making carbon emission reduction a priority. The carbon cycle of the earth's ecology is a dynamic balance between terrestrial and aquatic plants that alternate between life and death to form emission and absorption.

According to the modeling of the earth's original ecological carbon cycle and the global data on carbon emissions and emission reduction, it is not difficult to find that forests have contributed greatly to reducing the harm of greenhouse gases to the earth. Scientific management of a forest may effectively improve the carbon sequestration capacity of the forest, including cutting down tall trees and turning them into wood products. It is especially critical to balance the benefits of wood products from harvesting with the preservation of forests that continue to sequester carbon.

At present, in large-scale research, the carbon accumulation of forest ecosystems is approximated as NEP, which characterizes the net carbon accumulation between terrestrial ecosystems and the atmosphere, and directly and quantitatively describes the regulating effect of forest ecosystems on climate. When NEP>0, the forest sequesters carbon; when NEP<0, the forest releases carbon, and when NEP=0, there is a balance between the carbon sequestration and carbon releasing.

For this quantitative description, relevant scholars have defined proper nouns: 1) ***GPP*** (Gross Primary Productivity): The amount of carbon fixed by photosynthesis per unit time on a unit surface area of a green plant (Chapin, Francis Stuart, et al., 2002); 2) ***NPP*** (Net Primary Productivity): GPP represents the net carbon uptake by vegetation (Watson R T, Noble I R, Bolin B, et al., 2000) after deducting autotrophic respiration (Chapin, Francis Stuart, et al., 2002); 3) ***NEP*** (Net Ecosystem Productivity): The difference value between the carbon sequestration by photosynthesis and the carbon release by respiration in an ecosystem (Chapin, Francis Stuart, et al., 2002). In a stable natural ecosystem, NEP is close to the rate of net carbon accumulation in the ecosystem (Wang X C, and Wang C K, 2015); 4) ***Re*** (Ecosystem Respiration, Re): Total respiration of all organisms in an ecosystem per unit land area per unit time, including autotrophic respiration and heterotrophic respiration. Autotrophic respiration is divided into maintenance respiration and growth respiration (Wang X C, and Wang C K, 2015).

2. Assumptions and Notations

The establishment of the carbon sequestration model and the decision-making model for forest ecosystem management is carried out under stable natural conditions, and does not consider unexpected factors such as fire and pests, but the treatment of unexpected factors should be on the highest priority in the management plan.

Spatially, each spatial unit element is homogeneous and a set of model parameters can be used to represent the properties of the unit. The model is run on each spatial unit throughout the target area, but each unit is an independent model run that does not interact with other units.

In terms of time, the dynamic succession of ecosystems is ignored throughout the simulation time period, and the competition between different vegetation functional types is ignored, and only user-set vegetation functional types are used for simulation.

Table 1: Abbreviations and Description

Abbreviations	Description
α	Deforestation Rate
β	Supplementary Planting Rate
NEP	Net Ecosystem Productivity
NEP_1	NEP for Trees that Are Cut and Replanted
NEP_2	NEP for Forests that Remains as They Are
CS	Carbon Sequestration
ΔCS	Net Carbon Sequestration

3. Carbon Cycling Model of the Forest Ecosystem

Carbon cycling model of the forest ecosystem is a mathematical method to quantitatively describe the carbon cycling of the forest ecosystem and its relationship with global change. From the perspective of model construction, the carbon cycling model of the forest ecosystem is divided into climate productivity model, light energy utilization model, physiological process model and ecological remote sensing coupling model (Cramer, Wolfgang, et al., 1999).

Biome-BGC model is a typical eco-physiological process model of carbon cycle in terrestrial ecosystem, which was developed by Numerical Terra Dynamic Simulations Group of the University of Montana, USA. Biome-BGC model has been widely used in regional and even global scale, such as frigid zone, temperate zone, subtropical zone and tropical zone, carbon and water cycle simulation of forest, grassland, shrub and farmland and other ecosystems, forest management and its influence on climate change and human activities. The research results show that the BiomeBGC model is reasonable and widely applicable to the simulation of carbon accumulation in forest ecosystems at regional scale.

Model	Examples	Advantages	Disadvantages
Climate Productivity	Miami	Simple model with few parameters	Neglecting decomposition of soil microorganisms
Light Energy Utilization	CASA	Easy to convert regional scales	Lack of reliable physiological and ecological basis
Physiological Process	Biome-BGC	A physiological and ecological mechanism and an accurate estimation	Complex model with many parameters
Ecological Remote Sensing Coupling	BEPS	Sensitive information on vegetation change	Human factors have a great influence on parameters

Figure 1: Comparison of the advantages and disadvantages of different NEP estimation models

The Biome-BGC model simulates Carbon, Nitrogen and water ecological cycling processes as well as accumulation and states between atmosphere-plant-soil in terrestrial ecosystems on a daily time scale (White, Michael A., et al., 2000).

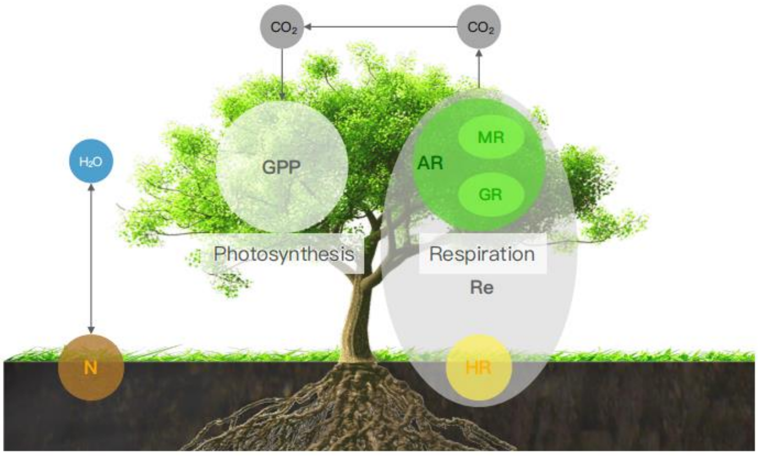

Figure 2: Main processes of the carbon cycle simulated by Biome-BGC Model

The main processes related to the carbon accumulation simulated by the Biome-BGC model include: canopy radiative transfer, photosynthesis, canopy evapotranspiration, respiration, decomposition and distribution, carbon accumulation calculation.

The calculation formulas of the main carbon accumulation variables simulated by the model are as follows:

$$\begin{cases} AR = MR + GR \\ \mathrm{Re} = AR + HR \Rightarrow NEP = GPP - MR - GR - HR \\ NEP = GPP - \mathrm{Re} \end{cases}$$

4. Logistic Regression Model of Net Carbon Accumulation

In a stable natural ecosystem, NEP is close to the rate of net carbon accumulation in the ecosystem (Wang X C, and Wang C K, 2015). Therefore, for forest ecosystems without any external disturbance, it is important to consider changes in forest carbon sequestration capacity over time.

After a certain period of high growth rate due to the interaction of internal and external factors, the growth rate starts to decrease gradually with the end of the exponential growth law, and the whole growth process curve is "***S***" shaped. Scholars in related fields have gradually deepened their research on species and tree growth process

based on the previous growth model establishment of individual trees, tree micro-description quantity and the combination of spatial structure of tree species and
tree distribution (Ritchie, Martin W., and Jeff D. Hamann, 2006).
Net carbon accumulation was positively correlated with its growth rate. At present, Richards equation, Logistic equation and Schumacher equation are the most widely used growth equations to describe the growth relationship of different tree species.

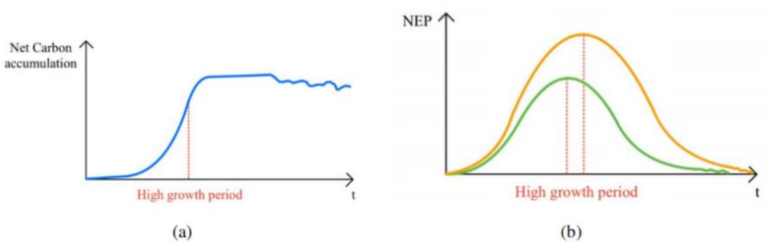

Figure 3: Net Carbon Accumulation and NEP of Forest over Time

Figure 3 above shows the relationship of net carbon accumulation in forests over time under natural ecosystems (The yellow curve represents forests with high growth capacity while the green one represents forests with low growth capacity). Under these conditions, NEP is approximately the rate of net carbon accumulation, that is, the derivative of net carbon accumulation as a function of time, calculated as follows:

$$NCA(t) = \frac{e^{\theta_0 + \theta_1 t}}{1 + e^{\theta_0 + \theta_1 t}}$$

$$NEP(t) = \frac{d}{dt} NCA(t) = \frac{\theta_1 e^{\theta_0 + \theta_1 t}}{\left(1 + e^{\theta_0 + \theta_1 t}\right)^2}$$

Where, ***NCA (t)*** is the function of net carbon accumulation on time. ***NEA (t)*** is a function of NEP with respect to time; θ1is the regression coefficient; θ_0 is a constant term.

5. Assessment of the Carbon Sequestration

The variables deforestation rate ***α*** and supplementary planting rate ***β*** are introduced under the consideration of anthropogenic disturbance to forest ecosystem. At time t0, trees are cut down and seedling are supplemented. After the Δ***t*** time period, the Carbon Sequestration formula is as follows (Jia-hua, Zhang, and Yao Feng-mei, 2001):

$$Fell\_CS = \alpha \times 0.565 \times NEP(t_0) \times S \times \delta$$

$$NotFell\_CS = (1-\alpha) \times 0.565 \times S \times \delta \times [NEP(t_0) + NEP(t_0 + \Delta t)]$$

$$NewPlanting\_CS = \beta \times 0.565 \times NEP(t_0 + \Delta t) \times S \times \delta$$

Therefore, carbon sequestration after ***t*** **+** Δ***t*** for a forest is:

$$\begin{aligned} CS &= Fell\_CS + NotFell\_CS + NewPlanting\_CS \\ &= 0.565 \times S \times \delta \times [NEP(t_0) + NEP(t_0 + \Delta t) \times (1 - \alpha + \beta)] \end{aligned}$$

Where: ***Fell_CS*** is the carbon sequestration of felled trees; ***NotFell_CS*** is the carbon sequestration of not cut down trees; ***NewPlanting_CS*** is the carbon sequestration of supplementary planted trees; $NEP(t_0)$ is the NEP of the forest at time point t_0; $NEP(t_0 + \Delta t)$ is the NEP of the forest at time point $t_0 + \Delta t$; ***S*** is the forest area; $\boldsymbol{\delta}$ is the conversion of biomass to the coefficient of conversion of biomass to carbon is taken as 0.5 according to the relevant study of IPCC.

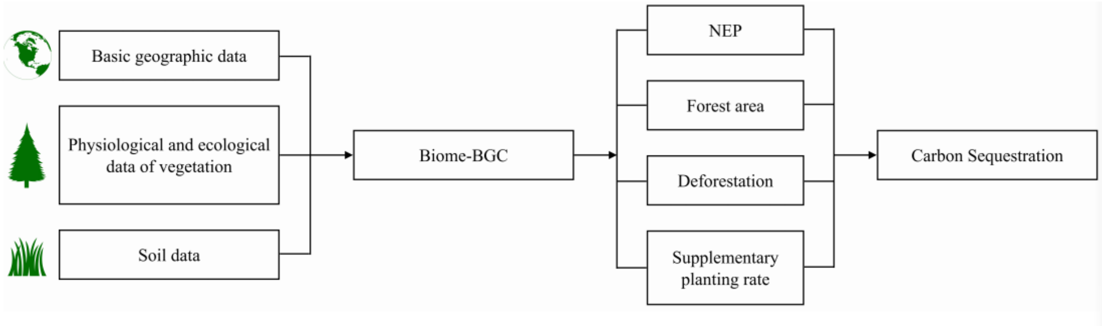

Figure 4: Estimation process of Carbon Sequestration

6. Feasibility of Models of the Carbon Sequestration

If the deforestation rate α and the supplementary planting rate β are introduced, it can be found by theoretically calculating the difference between the carbon sequestration of uncut and deforestation: cutting after the high growth period of trees is the most effective way to store carbon. The relevant theoretical calculations are as follows.

$$CS_{notfell} = 0.565 \times S \times \delta \times \left[NEP(t_0) + NEP_2(t_0 + \Delta t)\right]$$

$$CS_{fell} = 0.565 \times S \times \delta \times \left[NEP(t_0) + (1 - \alpha + \beta)NEP_1(t_0 + \Delta t) - NEP_2(t_0 + \Delta t)\right]$$

$$\Delta CS = CS_{fell} + CS_{notfell}$$

$$= 0.565 \times S \times \delta \times \left[(1 - \alpha + \beta)NEP_1(t_0 + \Delta t) - NEP_2(t_0 + \Delta t)\right]$$

As can be seen from the formula, $\boldsymbol{NEP_1}$ (**NEP** for trees that are cut and replanted) is much larger than $\boldsymbol{NEP_2}$ (**NEP** for forests that remain as they are). If $\boldsymbol{\alpha} = \boldsymbol{\beta}$, then $\Delta CS = 0.565 \times S \times \delta \times \left[NEP_1(t_0 + \Delta t) - NEP_2(t_0 + \Delta t)\right]$.

At this time, $\Delta \boldsymbol{CS} > \boldsymbol{0}$, indicating that there are more carbon sequestrations in forests supplemented by planting after harvested. If $\boldsymbol{\alpha} > \boldsymbol{\beta}$, $\Delta \boldsymbol{CS}$ depends on whether $\frac{(1 - \alpha + \beta)NEP_1(t_0 + \Delta t)}{NEP_2(t_0 + \Delta t)}$ is greater than ***1***.

Due to the limitation of actual data, the data of deforestation rate $\boldsymbol{\alpha}$ and supplementary planting rate $\boldsymbol{\beta}$ are seldom counted. Therefore, assuming that the deforestation rate $\boldsymbol{\alpha}$ and the supplementary planting rate $\boldsymbol{\beta}$ are both ***0***, the carbon sequestration of the forest can be estimated. And collect the actual carbon sequestration of 11 groups of forests for correlation analysis. The correlation coefficients are $\boldsymbol{R^2 = 0.987}$ and $\boldsymbol{p - value < 0.05}$, and the results show that the model is feasible. Draw a scatter plot as shown in Figure 5.

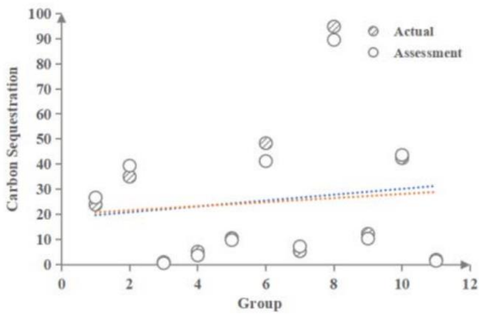

Figure 5: Comparison between Actual and Assessment Value of Forest Carbon Sequestration

7. Conclusions

At present, it has become the consensus of mankind to achieve "carbon neutrality" to deal with climate change. Governments around the world are prioritizing the drive to reduce emissions from industry. After studying the carbon cycle model of the earth's "original ecology", we found that the forest carbon sink has a more prominent contribution to reducing the global greenhouse effect than the intentional reduction of carbon emissions by humans.

Here we need to introduce a concept: carbon sequestration, which is to store excess carbon dioxide and not emit it into the atmosphere. The carbon sequestration capacity of the earth's surface depends on the ecological volume. Abundant vegetation, soil and water systems make forests the main force for surface carbon sequestration. In 2015, the world's forests were about 4 billion hectares (data source: FAO). If the goal is to maximize the ecological function of forests, the carbon accumulation of the world's forests can reach 73 billion tons of carbon dioxide equivalent, which is more than double the carbon dioxide emitted by the world's industry in 2018.

However, studies have shown that the ability of forests to absorb carbon dioxide is "S" shaped. When the tree reaches the highest growth ability, the carbon sequestration ability is the strongest, and then the growth ability fluctuates and the carbon sequestration ability also fluctuates.

To sum up, we established an estimation model for forest carbon sequestration based on Biome-BGC and tree growth curves. After introducing the deforestation rate and supplementary planting rate, we verified the accuracy of the model with data to obtain a model with strong feasibility and the forest ecosystem. Proper harvesting is required to sequester more carbon dioxide.

With the increase of tree age, the forest productivity begins to decline after reaching the maximum value. When it reaches the mature stage, the amount of carbon dioxide absorbed and emitted is equal to that of the mature forest, which means that the mature forest loses the ability to continuously sequester carbon. At the same time, when trees and vegetation die, the litter will be converted into methane and carbon dioxide through an oxidation reaction and released into the atmosphere. We know that

methane is far more harmful to the earth than carbon dioxide is to the greenhouse effect. For every 1 ton of biomass formed in the process of plant growth, 1.83 tons of carbon dioxide will be absorbed, but the methane emission produced by the natural degradation of 1 ton of biomass is equivalent to 16.8 tons of carbon dioxide.

Consider a situation: when the carbon sequestration capacity of trees gradually declines, cutting them down and replanting a tree seedling can maximize the benefits of forest carbon sequestration? The fact is that humans are already doing this.

The tall and majestic trees take away the young trees that surrender to their shadows, and let the seedlings that yearn for sunshine grow silently in the only remaining sunlight. When we cut down that tall tree, the sunlight spreads more evenly across the land. Humans see light as hope, and trees see sunlight as growth. And the tree that was cut down, after fully releasing its carbon sequestration ability, fixed carbon in itself in another way - wood products. The sum of the carbon sequestered by these wood products and the replanted young trees would be far greater than the sum of the carbon sequestered by the forest left alone. Through "ecological nourishment and resource increase - wood resources are transformed into energy resources - green energy income, increasing conservation funds", relying on the sound development of reliable industries, to solve the lack of funds in the maintenance of forests.

Of course, we can't just cut it down indiscriminately. In order to ensure the health, stability and continuous productivity of the forest ecology, priority is given to selecting trees with poor health and infested by pests. In order to ensure that the forest ecology can better live in harmony with the human society, the trees that are still growing are preserved. For some trees that are windbreak and sand fixation, and whose landscape human value far exceeds the economic value of carbon sequestration, we must use modern knowledge to protect them.

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References

[1]. Chapin, Francis Stuart, et al. "Principles of terrestrial ecosystem ecology." (2002).

[2]. Watson R T, Noble I R, Bolin B, et al. "Land use, land-use change and forestry: a special report of the I ntergovernmental Panel on Climate Change." (2000).

[3]. Wang X C, and Wang C K. "Fundamental concepts and field measurement methods of carbon cycling in forest ecosystems: a review." Acta Ecologica Sinica 35.13 (2015).

[4]. Cramer, Wolfgang, et al. "Comparing global models of terrestrial net primary productivity (NPP): over view and key results." Global change biology 5.S1 (1999): 1-15.

[5]. White, Michael A., et al. "Parameterization and sensitivity analysis of the BIOMEBGC terrestrial ecos ystem model: Net primary production controls." Earth interactions 4.3 (2000): 1-85.

[6]. Ritchie, Martin W., and Jeff D. Hamann. "Modeling dynamics of competing vegetation in young conife r plantations of northern California and southern Oregon, USA." Canadian journal of forest research 36 .10 (2006): 2523-2532.

[7]. Jia-Hua, Zhang, and Y. Feng-Mei . "Simulating leaf net CO 2 assimilation rate of C3 & C4 plants and i ts response to environmental factors." Journal of Forestry Research 12.1(2001):9-12.