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Research Advances in Net Primary Productivity of Terrestrial Ecosystem

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Abstract

The net primary productivity of vegetation reflects the total amount of carbon fixed by plants through photosynthesis each year. The study of vegetation net primary productivity is one of the core contents of global change and terrestrial ecosystems. This article reviews the current research status of net primary productivity of terrestrial vegetation, and comprehensively analyzes the advantages and disadvantages of three types of productivity estimation models, climate relative models, biogeochemical models, and light energy utilization models. The light energy utilization models have become the mainstream method for estimating vegetation net primary productivity because they can directly use remote sensing data. However, there are still many deficiencies in the estimation of vegetation net primary productivity, which need to be further improved and tested.

Keywords

Net Primary Productivity, Productivity Model, Terrestrial Vegetation, Global Change

1. Introduction

Vegetation is the main body of the biosphere, which plays an important role in regulating global carbon balance, maintaining the concentration of greenhouse gases in the atmosphere, especially in the global material and energy cycle. Net primary productivity refers to the amount of organic matter accumulated by green plants per unit area and unit time (Liu et al., 1999), that is, the part of the organic carbon fixed by photosynthesis deducting plant respiration consumption, also known as net primary productivity. Vegetation net primary productivity is a key variable that represents vegetation activity and is also the main reason for seasonal changes in atmospheric CO_2 concentration. Net ecosystem productivity determines whether there is an accumulation of excess atmospheric CO_2 in the biosphere, so accurate estimation of NPP helps to understand the global carbon cycle (Sun & Zhu, 1999). Therefore, net primary productivity is not only an important factor reflecting the activities of plants, but also a major factor for assessing the effects of carbon sources and carbon sinks in ecosystems (Field et al., 1998). The study of vegetation net primary productivity is of great significance for analyzing the response of the carbon cycle process to global change. The International Geosphere-Biosphere Project (IGBP), Global Change and Terrestrial Ecosystem (GCTE), and Kyoto Protocol have identified vegetation net primary productivity research as one of the core contents (IGBP, 1998). There are many research methods for net primary productivity. According to the model's focus on various regulatory factors and the interpretation of the regulatory mechanism, the existing models can be divided into climate relative models, biogeochemical models, and light energy utilization models (Gang et al., 2015).

2. Estimation Models of Vegetation Net Primary Productivity

2.1. Climate Relative Models

In the natural environment, the productivity of vegetation community is mainly affected by climatic factors besides the biological and soil characteristics of plants. Therefore, the net primary productivity of vegetation can be estimated by analyzing the correlation between climate factors (such as temperature, precipitation, light, etc.) and plant dry matter production. According to the correlation principle between plant growth and environmental factors, the statistical regression models were established on the basis of a large number of measured data, and the vegetation net primary productivity was estimated by the established models. This type of model is represented by Miami model, Thornthwaite Memorial model, and Chikugo model.

Miami model was first established by Lieth & Whittaker (1975) according to the measured net primary productivity values of 50 stations around the world, annual average temperature and annual average precipitation. In fact, the net primary productivity of vegetation is also affected by other climatic factors, and the reliability of the results estimated by this model is only 66% - 75% (Sun et al., 2012). Therefore, in order to further improve the reliability of the model, Lieth et al. proposed the Thornthwaite Memorial model, which links net primary productivity with the average annual evapotranspiration. Since evapotranspiration is affected by various climatic factors and has a certain relationship with photosynthesis, the estimation of net primary productivity is more reasonable. Uchijima & Seino (1985) established Chikugo model of net primary productivity related to net radiation and radiation dryness based on 682 sets of forest vegetation data, physiological ecology theory and mathematical statistical methods. This model takes into account the influence of many factors and is relatively a good semi theoretical and semi empirical method for estimating vegetation net primary productivity. However, this model is based on the premise of sufficient soil water supply, so the estimated net primary productivity is actually the potential or maximum net primary productivity, which is different from the actual situation. In order to estimate NPP of vegetation better, many models have been developed. Zhu (1993) improved the poor applicability of Chikugo model in grassland and desert areas. Zhou & Zhang (1995) improved the Chikugo model based on the physiological and ecological characteristics of plants, combined with the energy balance equation and the water balance equation, so that the estimated value in arid and semi-arid areas is closer to the actual value. The climate relative models consider fewer climate factors and lack the theoretical basis of physiology and ecology, and the statistical laws obtained under different regions and conditions lack broad universality.

2.2. Biogeochemical Models

The biogeochemical models have a relatively complete plant physiological and ecological basis. It takes climate, soil conditions and vegetation types as input variables to simulate the process of ecosystem, including photosynthesis, respiration, soil microbial decomposition process, and ecosystem material circulation process, and calculates the carbon and nutrient cycle and greenhouse gas exchange flux between plant, soil and atmosphere. The most commonly used biogeochemical models are TEM model, CENTURY model, BIOME-BGC model, etc.

The terrestrial ecosystem model (TEM) proposed by Melillo et al. (1993) is the first mechanistic model for estimating the net primary productivity of global terrestrial ecosystem. TEM model divides terrestrial ecosystems into 18 different types. After collecting and investigating a large number of data, the specific physiological and ecological parameters corresponding to different ecosystem types are determined. On this basis, the carbon and nitrogen cycle and productivity of the ecosystem are further calculated. Although TEM model is a mechanistic model, it is based on a large number of empirical parameters and empirical formulas, and does not describe the biological and physiological processes, so there are many defects in the estimation of vegetation net primary productivity (Sun et al., 2012). Running & Hunt (1993) proposed BIOME-BGC model to simulate and estimate the cycling process of carbon, water and nutrients among vegetation, soil and atmosphere in terrestrial ecosystem. At present, this model has the complete physiological and ecological parameters of seven biological communities, including evergreen broad-leaved forest, evergreen coniferous forest, deciduous broad-leaved forest, deciduous coniferous forest, shrub, C3 and C4 grassland. However, the application of this model in areas with non-single vegetation types, such as mixed forests, still has limitations. CENTURY model is based on the relationships among climate, human activities (such as grazing, felling, burning, etc.), soil properties, plant productivity, litter and soil organic matter decomposition. It is mainly used to simulate the long-term dynamics of C, N, P, S and water in different vegetation soil systems, It is one of the representative biogeochemical models in the world

(Parton et al., 1993). However, this model only describes the physiological and ecological processes of plants based on experience, which is still far from the actual situation. The biogeochemical models have clear physiological and ecological mechanism, and can reveal the ecosystem process and its interaction with the environment. Moreover, it can be coupled with the atmospheric circulation model (GCM), which is beneficial to study the impact of global change on the net primary productivity of vegetation. However, the model relies on a large number of parameters, and many parameters are difficult to obtain accurately, so the application of the model is greatly restricted.

2.3. Light Energy Utilization Models

The light energy utilization models mainly consider the light energy utilization rate and the photosynthetically effective radiation absorbed by the vegetation, which affect the net primary productivity of vegetation. This type of model is based on the theory of resource balance. It is assumed that the ecological process is the process of plants constantly adjusting their own characteristics to respond to the surrounding environmental conditions. When the growth of plants cannot fully adapt to the surrounding environment, the net primary productivity is limited by the most scarce resources. With the rapid development of remote sensing technology and the wide application of various spatial and temporal remote sensing data, light energy utilization models based on remote sensing data have gradually become the mainstream method for estimating vegetation net primary productivity (Yuan et al., 2014).

Monteith (1972) first proposed to use the photosynthetically active radiation absorbed by vegetation and the conversion efficiency of light energy to calculate crop net primary productivity, and believed that the small range of light energy conversion efficiency can be regarded as a constant, and photosynthetically active radiation can be obtained from incident photosynthetically active radiation monitored by remote sensing. Heimann & Keeling (1989) calculated the global vegetation net primary productivity by using photosynthetic active radiation and light energy conversion efficiency, and found that the light energy conversion efficiency as a constant in the global range would cause great error. Ruimy & Saugier (1994) considered the difference of light energy conversion efficiency in different ecosystems, but did not consider the change of light energy conversion efficiency over time, nor did it consider the change of light energy conversion efficiency within the community. Potter et al. (1993) proposed CASA (Carnegie-Ames-Stanford Approach) model, which effectively realized the estimation of global vegetation net primary productivity. The data of this model is mainly derived from large-space and long-term remote sensing satellite data. In addition, it takes full account of photosynthesis stress factors such as water and temperature, and is more suitable for monitoring the dynamic change of vegetation net primary productivity in a large-scale range (Li et al., 2018; Liu et al., 2020). At the regional scale, some scholars used CASA model to quantitatively estimate the vegetation NPP in Northwest China (Pan & Li, 2015), Southwest China (Rong et al., 2017) and Three-River Headwater Region of China (Sun et al., 2016), and explored their spatial and temporal patterns and influencing factors. Wang et al. (2016) used CASA simulated grassland NPP to explore the relative impact of climate change and human activities on grassland degradation on the Tibetan Plateau. However, in research on the regional scale, the sensitivity and response characteristics of different vegetation types to environmental factors such as climate, topography and soil type are quite different. Therefore, it is difficult to determine the driving mechanism of spatial and temporal changes of NPP on regional scale (Li et al., 2014; Huston, 2012; Zhang & Zhou, 2011). Prince & Goward (1995) developed the GLO-PEM (Global Production Efficiency Model) model, which considered plant respiration and other physiological stresses, and combined all net primary productivity regulatory factors in a relatively simple way. The use of remote sensing data-driven models has greatly enhanced the ability to conduct global scale assessments. The development of new satellite platforms and sensors provides more abundant data sources for net primary productivity research. Due to the high time resolution and high spectral resolution of MODIS data from the medium-resolution imaging spectrometer, it has important application value in vegetation net primary productivity research. The MODIS-GPP model is currently one of the most widely used vegetation net primary productivity models (Yuan et al., 2014; Gulbeyaz et al., 2018).

3. Conclusion

The vegetation productivity is the foundation for the existence and development of human society, and it is also the beginning of the global carbon cycle. It plays an important role in maintaining the global atmospheric greenhouse gas concentration and regulating the global climate pattern. There are three types of main models to estimate vegetation net primary productivity: climate relative productivity models, biogeochemical models and light energy utilization models. Climate relative models are simple in form, but estimate potential vegetation net primary productivity. The biogeochemical models have a strong theoretical basis, but they are more complicated, and the parameters are difficult to obtain. The light energy utilization models have become the mainstream method for estimating vegetation net primary productivity because they can directly use remote sensing data. Remote sensing data reflects continuous land surface information in time and space, and provides a relatively reliable method and data basis for estimating vegetation net primary productivity of terrestrial ecosystems. However, due to the influence of human disturbance in remote sensing data observation or sampling, there are some errors; secondly, due to the complexity of ecosystem processes, the uncertainty of remote sensing model depends on people's understanding of ecosystem process. Therefore, there are still many deficiencies in the estimation of vegetation net primary productivity, which need to be further improved and tested.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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