Quantitative Assessment of NPP Changes in the Yellow River Source Area from 2001 to 2017

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Abstract - It is of great significance to quantitatively evaluate the ecological degradation and restoration of the Yellow River source area from 2001 to 2017. Net primary productivity (NPP) is the core indicator used to indicate the health of terrestrial ecosystems. Based on the improved CASA (Carnegie-Ames-Stanford Approach) model and MOD17A3 NPP products, 174 measured sample sites were used to validate the NPP simulation results, select the model with higher accuracy as the actual NPP simulation, and using Theil-Sen median trend analysis and Mann-Kendall test to investigate the dynamics of NPP changes. The results are as follows: (1) the accuracy of the CASA model is higher than that of the MOD17A3 NPP product, and it is more suitable for the simulation of the actual NPP in the source area of the Yellow River; (2) the Yellow River Source region has shown a fluctuating upward trend in net primary productivity over the past 17 years, with 50% of the region showing a slight improvement, 36% showing a significant improvement, 13% showing a slight decline, and only 1% showing a significant decline, the average annual growth rate of NPP is 2.6 g C/yr-1. Compared with 2001, the net primary productivity in 2017 increased by $5.24 \times 10^{12}$ g C.

1. Introduction
The source area of the Yellow River is located in the northeastern part of the Qinghai-Tibet Plateau, and is an important source of freshwater resources in China, with a source runoff close to 38.15% of the total flow of the Yellow River basin, which play an important role in guaranteeing ecological security in the north of China and is known as the "Yellow River water tank". Due to the intensification of human activities and the obvious rise of temperature, the evapotranspiration of the source area of the Yellow River has increased and the runoff has decreased significantly, causing a series of problems such as ecological degradation, pasture degradation and soil erosion. The ecological environment of the source area of the Yellow River has attracted much attention from the state and scholars at home and abroad. Net primary productivity of vegetation refers to the amount of organic matter accumulated by green plants through photosynthesis per unit area and per unit time, and is the core indicator used to indicate the health of terrestrial ecosystems.

Common simulation models of net primary productivity can be divided into four categories. 1) Climate-related statistical models, which mainly introduce climate factors such as temperature and precipitation into the model, establish a simple statistical regression model between NPP and climate factors, and are widely used. The climate-related statistical models include Miami model, Thornthwaite Memorial model, Chikugo model, classification index model, and comprehensive model. 2) Light
The most common light energy utilization model with the highest accuracy is the CASA model. The CASA model has been widely used in various regions, such as Central Asia\textsuperscript{11} and the Qinghai-Tibet Plateau\textsuperscript{2-3} after a series of improvements. 3) Ecosystem process model. Commonly used models are BIOME-BGC model and CENTURY model. The NPP data of MOD17A3 product is calculated based on the BIOME-BGC model. 4) The ecological remote sensing coupling model is mainly connected to the process model through the leaf area index (LAI) from the light energy utilization model, which simplifies the physiological and ecological process to a certain extent. Such as PEM model and BEPS model.

Traditional methods of monitoring grassland dynamics have relied excessively on manual field surveys. Field surveys are both time-consuming and costly, which makes them impractical, especially for large-scale grassland surveys. In this study, remote sensing data and meteorological data were used as input parameters, and actual measured grassland biomass was used as validation, based on the improved CASA model and MOD17A3 NPP products compared with actual measured grassland above-ground biomass data. The objectives of the study were to: (1) select the result with higher accuracy between CASA model and MOD17A3 as the actual measured NPP in the Yellow River source area; (2) to reveal the spatial and temporal changes of grassland NPP changes in the Yellow River source area during 2001-2017, and to explore the dynamics of grassland degradation and recovery in the Yellow River source area.

2. Materials and Methods

2.1 Study Area Overview

The source of the Yellow River is usually defined as the upstream catchment above the Tangnaihai hydropower station\textsuperscript{4}, located between 32.16N-35.72N and 95.89E-103.41E (Figure 1), the total area is about $12.2 \times 10^4km^2$, the average altitude exceeds 4000m, with extreme seasonal precipitation, strong evaporation and strong solar radiation. The ecological environment in the region is fragile and sensitive to climate change. There are about 5300 lakes in the region, the largest lake is Zaling Lake, Eling Lake, which is influenced by the southwest monsoon, the average multi-year rainfall range is concentrated between 281.8mm-1058.6mm, with rainfall gradually decreasing from southeast to northwest, the average multi-year rainfall is 576.7mm, mainly concentrated in the summer months of June-September. The multi-year average temperature is concentrated between -12.7\degree C -5.6\degree C, and the multi-year average temperature is -1.3\degree C. Located in the hinterland of Qinghai-Tibet Plateau, which is known as the third pole of the earth, the Yellow River source area has long been a concern for many scholars at home and abroad.

![Fig. 1 Location map of study area](image-url)
2.2 Data acquisition and pre-processing

2.2.1 Remote sensing data acquisition and processing
The NDVI data were obtained from the MOD13A2 data product with a temporal resolution of 16 days and a spatial resolution of 1 km, downloaded through Google Earth Engine, and the monthly values were synthesized using the maximum synthesis method and batch reprojected through python. BESS (Breathing Earth System Simulator) model. BESS is a simplified process-based model that combines atmospheric and canopy radiative transfer, canopy photosynthesis, transpiration, and energy balance. (http://environment.snu.ac.kr/bess_rad/). The PAR data have a temporal resolution of 4 days and a spatial resolution of 5 km. The PAR data obtained from the download were synthesized into monthly values and then converted from NC format data to TIF format using Python software, and then defined using ArcGIS 10.2.2. The MOD17A3 product NPP was developed by NASA based on the BIOME-BGC model (https://ladsweb.modaps.eosdis.nasa.gov/search/), which has a temporal resolution of 1 year and a spatial resolution of 1 km. All raster data projections in this paper are projected as Krasovsky_1940_Albers.

2.2.2 Meteorological data acquisition and processing
The meteorological data were obtained from the daily values of 832 meteorological stations nationwide from 2001-2017 provided by the China Meteorological Science Data Sharing Service. The meteorological raster data with the same size and projection as NDVI data image elements were obtained by interpolation process. In this study, the special meteorological data interpolation software ANUSPLIN was used to interpolate the climate data and was widely used in the study of the Tibetan Plateau region[5]. The obtained national meteorological data interpolation results were then cropped with images of the Yellow River source area.

2.2.3 Measured data acquisition
The NPP data converted from above-ground biomass was used to replace the measured data of NPP for model verification. The root-shoot ratio of different grassland types provided by Piao Shilong was used to convert the root-shoot ratio by 0.45 to g C/m2. The classification of grassland types is based on the 10 grasslands classified by the comprehensive sequential classification method proposed by Ren Jizhou. Under this classification system, there are a total of 51 measured sample points for tundra alpine grassland and 123 measured sample points for temperate forest grassland. The root-to-shoot ratio of the alpine grassland in the tundra was 7.92. The root to shoot ratio of temperate humid grassland to temperate forest grassland is 4.25.

2.3 Research Methodology

2.3.1 CASA Model
In this paper, Zhu Wenquan's improved CASA model is used to estimate the NPP in the Yellow River source area. The improved CASA model has been used in numerous applications, and the estimation accuracy is higher compared with the traditional CASA model. Its estimation equation is as follows.

\[ NPP(x, t) = \text{APAR}(x, t) \times \varepsilon(x, t) \]

Where APAR(x,t) denotes the photosynthetically active radiation absorbed by the image element x in month t (unit: MJ/m2/month), and \( \varepsilon(x, t) \) denotes the actual light energy utilization of the image element x in month t (unit: g C/MJ). The results of the CASA model simulations were recorded as ANPP (actual NPP).

2.3.2 Theil-Sen median trend analysis and Mann-Kendall test
The combination of Theil-Sen median trend analysis and Mann-Kendall test is used to determine the trend of long time series and has been gradually applied to vegetation long time series analysis. The advantage of this method is that it does not require the data to obey a certain distribution and has a more
solid basis for the significance level test, making the results more scientific and credible. Among them, the Theil-Sen median trend analysis is a robust nonparametric statistical method for trend calculation, and the calculation formula is found in the literature.

In this paper, the significance of the trend of NPP change is judged at the confidence level $\alpha=0.05$. When $Z>|1.96|$ means time series confidence level $\alpha<0.05$, $Z<|1.96|$ means confidence level $\alpha>0.05$. The formula of Mann-Kendall mutation test can be found in the literature. In this paper, Theil-Sen median trend analysis and Mann-Kendall test and Mann-Kendall mutability test were run in Matlab in this paper.

3. Result

3.1 Model validation

In this paper, the $R^2=0.47$ (Fig. 2a) is based on 174 measured points and CASA simulated values. $R^2=0.36$ (Fig. 2b) is based on MOD17A3 product and measured points, and according to MOD17A3 product data is significantly smaller compared with measured data, CASA model is more accurate compared with MOD17A3 NPP product and more suitable for simulation of actual NPP in the Yellow River source area. Therefore, the improved CASA model is selected as the measured NPP value for subsequent analysis in this paper.

![Fig. 2 Model Accuracy Verification](image)

3.2 Spatial distribution pattern of the annual average ANPP of the Yellow River source in 2001-2017

The average NPP value of the Yellow River source area from 2001 to 2017 is 301.6 g C/m2, 71% of the area is less than 400 g C/m2 (Figure 3), NPP decreases from southeast to northwest, NPP greater than 500 g C/m2 (16%) is mainly distributed in Hongyuan County, Aba County, Ruoergai County in Sichuan Province, NPP less than 200 g C/m2 of low value area is mainly located in the northwest of the Yellow River source near Zaling Lake and Eling Lake, located in the inland hinterland, weaker influence by the Pacific warm and humid airflow, resulting in less regional precipitation, and water resources become one of the key factors affecting the growth and development of vegetation, and there are perennial permafrost and glaciers, rainfall is relatively low, and vegetation growth is poorer compared to the southeast.
Fig. 3 ANPP spatial distribution

3.3 Trend analysis of the annual average ANPP of the Yellow River source from 2001-2017

As shown by the Theil-Sen trend analysis and MK test (Figure 4), the grassland ANPP in the Yellow River source area showed an overall increasing trend in the past 17 years. The percentage of places where ANPP showed an increasing trend reached 86%. The percentage of ANPP with decreasing trend was 14%. 2017 grassland NPP increased by $5.24 \times 10^{12} g C$ compared with 2001. Based on the assessment method in Table 1, it can be obtained that the places with decreasing grassland NPP were mainly distributed in the border of Dari and Gand County in Goluo Tibetan Autonomous Prefecture, Qinghai Province. The distribution was fragmented, with only 1% of the areas in obvious degradation. The percentage of areas with significant improvement in grassland NPP was 30%, mainly in the northern and southeastern parts of the Yellow River source area, while the rest of the areas were mostly in a slightly improved state, accounting for 50%.

Fig. 4 ANPP trends

4. Discussion and Conclusion

4.1 Model and Method Deterministic Analysis

The accuracy of the CASA model was verified using the measured points, which indicates that the CASA model is suitable for the simulation of NPP in the Yellow River source region, in addition to the fact that
the improved CASA model has been reliably demonstrated in numerous studies for the application on the Tibetan Plateau[6-8], and the CIM model based on the wetness index K compared to the Thornthwaite, which only uses precipitation and temperature as input parameters memorial model may reduce the uncertainty in the NPP simulation process compared to the Thornthwaite model, which only uses precipitation and temperature as input parameters.

4.2 Impact of climate change on ANPP changes
The overall warming and wetting trend in the Yellow River source area from 2001-2017, with annual precipitation increasing by 4.43 mm per year and mean annual temperature increasing by 0.07°C per year approximately twice the warming rate of the past 50 years. The increasing trend of both temperature and rainfall may be the main climatic reason for the overall increase of NPP in the whole Yellow River source region since 2001. The reason for the lower NPP values in the northwestern Yellow River source region is that the region is located in the inland hinterland and is weakly influenced by the warm and humid Pacific air currents, resulting in less regional precipitation, while water resources become one of the key factors affecting vegetation growth and development in the region, precipitation determines the maximum amount of water available for vegetation growth, and reduced precipitation will reduce photosynthetic efficiency of grasslands, inhibit overall plant activity, suppress organic matter production, and ultimately reduce grassland productivity. Conversely, increased rainfall can increase soil moisture content in semi-arid and arid ecosystems, thereby increasing grassland productivity in these areas. The main reason for the higher NPP in the southern region is the relatively low elevation, the rapid increase in photosynthesis of vegetation with the increase in temperature, and the large daily difference in temperature in the region, which facilitates the accumulation of plant dry matter and thus the recovery of vegetation ecosystems. Climatic factors such as temperature and precipitation are considered to be the main factors regulating the growth of grasslands. Climate change achieves its effects on vegetation biomass by changing the structure and composition of vegetation communities in the region, and is also an important factor leading to changes in the net primary productivity of vegetation[9].

4.3 Impact of human activities on ANPP changes
In addition to the warming and humidification of the climate, there is also the influence of human activities. This may be closely related to the national policies of "returning farmland to grass" and "returning grazing to grass" and "grassland subsidies" in the region, where overgrazing is the main driver of grassland degradation. Overgrazing is the main driver of grassland degradation, and the implementation of these policies has led to a reduction in the number of grazing animals, thus curbing the degradation of grassland and putting it in a recovery position. In addition to the reduction in the number of livestock, the ecological awareness of the herders to protect the grassland is being strengthened. In the household research, we learned that the village rules and regulations of each village in the Yellow River source area involve the concept of protecting the grassland ecology and protecting the grassland ecology like one's own eyes.

4.4 Conclusion
CASA model is more suitable for the simulation of NPP in the Yellow River source area with higher simulation accuracy compared with MOD17A3 NPP product. In the past 17 years, the ecological environment of the Yellow River source area is gradually recovering, and the grassland productivity shows a fluctuating upward trend, with 86% of the regions showing an increasing trend of ANPP, 50% of the slight improvement, 36% of the obvious improvement, 14% of the regions with a decreasing trend, but only 1% of the regions with an obvious decrease, and an increase of $5.24 \times 10^{12} \text{gC}$ in 2017 compared with 2001. The degradation of grassland in the Yellow River source area has been improved. Admittedly, the interpolated meteorological data may reduce the accuracy of NPP simulations due to the large elevation drop and complex topographic conditions in the Yellow River source area. Nevertheless, this study provides new insights into the ecological restoration dynamics and causes of changes in the Yellow River source area in recent years, and the results of this study will help
government agencies to achieve effective management of grasslands in the Yellow River source area.

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