Impacts of Climate Change and Human Activities on Vegetation Productivity in Arid Regions: Postprint

Authors: Qin Jingxiu, Hao Xingming, Zhang Ying, floral apex, Hao Xingming

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Abstract

Against the backdrop of global change, vegetation productivity has undergone a series of changes. Quantitatively assessing the impacts of climate change and human activities on vegetation productivity in the arid regions of northwestern China is of great significance for addressing climate change, promoting ecological construction of the 'Belt and Road' initiative, and building a Beautiful China. Taking Xinjiang as the study area and using vegetation Net Primary Productivity (NPP) as the evaluation index, this study analyzed the effects of climate change and human activities on vegetation restoration and degradation from 2001 to 2016. The results show that: (1) From 2001 to 2016, the area with a significant trend in vegetation NPP accounted for 34.02% of the total vegetation-covered area, of which 30.58% showed a restoration trend and 3.44% showed a degradation trend, with NPP increasing by an average of 634 Gg C · a ^{1} (Gg = 10 g). (2) The area of vegetation restoration caused by human activities and climate change accounted for 42.03% and 30.58% of the total area of vegetation NPP change, respectively; in these two regions, the average annual NPP increase was 319 Gg C · a ^{1} and 59 Gg C · a ^{1}, respectively. The area of vegetation degradation caused by human activities and climate change accounted for 57.63% and 19.45% of the total area of NPP change; in these two degradation regions, NPP decreased by an average of 68 Gg C · a ^{1} and 7 Gg C · a ^{1} per year, respectively. (3) Among different vegetation types, human activities had a greater restoration effect than degradation effect on cropland, desert, grassland, and alpine vegetation, but a greater degradation effect than restoration effect on forest, shrubland, and marshland; climate change had a greater degradation effect than restoration effect on marshland, but a greater restoration effect than degradation effect on the other six vegetation types. Overall, human activities are the main cause affecting vegetation restoration and degradation in Xinjiang.

Full Text

Preamble

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Effects of Climate Change and Human Activities on Vegetation Productivity in Arid Areas

QIN Jing-xiu[1,2], HAO Xing-ming[1,2], ZHANG Ying[1,2], HUA Ding[1,2]

[1] State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China
[2] University of Chinese Academy of Sciences, Beijing 100049, China

Abstract: Climate change and human activities are the two main factors affecting vegetation restoration and degradation. Quantitatively evaluating their impacts on vegetation is of great significance for addressing climate change, ecological restoration, and economic development along the Silk Road. In this paper, net primary productivity (NPP) is used as an indicator to evaluate vegetation restoration and degradation, while climate productivity and human-activity-affected productivity are used to assess the respective contributions of climate change and anthropogenic factors. Xinjiang is located in the arid region of northwestern China, characterized by a typical temperate continental climate and an extremely fragile ecological environment. The annual average precipitation is less than 200 mm, and the main vegetation types are desert and grassland, accounting for 52% and 28% of the total vegetation area, respectively. Based on MODIS NDVI data at 500 m spatial resolution from 2001 to 2016, along with 99 meteorological datasets and vegetation type data, the CASA model and Zhou Guangsheng model were employed to calculate actual vegetation productivity and climate productivity. The difference between climate productivity and actual productivity was defined as the impact of human activities. Using linear regression analysis and F-test methods, the effects of climate change and human activities on vegetation productivity and different vegetation types were separated by analyzing productivity trends to quantitatively evaluate their roles in vegetation restoration and degradation.

The results showed that the area where vegetation NPP exhibited a significant trend accounted for 34.02% of the total vegetation coverage area in Xinjiang from 2001 to 2016. Only 3.44% of the area experienced degradation, whereas 30.58% underwent restoration. The area of vegetation restoration caused by human activities and climate change accounted for 42.03% and 30.58% of the total area with NPP change, respectively, increasing vegetation NPP by 319 Gg C · a ^{1} and 59 Gg C · a ^{1}. The area of vegetation degradation caused by human activities and climate change accounted for 57.63% and 19.45% of the total area with NPP change, respectively, decreasing vegetation NPP by 319 Gg C · a ^{1} and 59 Gg C · a ^{1}. Different vegetation types were subject to different dominant roles in restoration and degradation processes. Restoration was dom-

inated by human activities in crops, desert, grassland, and alpine vegetation, whereas degradation was dominated by human activities in forest, shrub, and swamp. Except for swamp, restoration in seven vegetation types was dominated by climate change. Overall, NPP in different vegetation types is increasing, especially in crops, deserts, and grasslands, with NPP increases of 293 Gg C · a ^{1}, 171 Gg C · a ^{1}, and 148 Gg C · a ^{1}, respectively. The results indicate that vegetation in Xinjiang is recovering, with human activities being the main influencing factor, particularly for restoration. Crops contribute the most to vegetation productivity in Xinjiang, and climate change generally promotes the increase of vegetation NPP. Correlation analysis between vegetation NPP and climate factors showed that precipitation has a significant positive correlation with vegetation NPP, while temperature has a weak negative correlation, indicating that water conditions have become the main limiting factor for vegetation growth.

Keywords: net primary productivity; climate change; human activities; arid areas

1 Study Area

1.1 Regional Overview

Xinjiang Uygur Autonomous Region is located in northwestern China, covering an area of 1.66×10 km², characterized by a typical temperate continental climate. The region is dominated by arid and semi-arid conditions, with annual precipitation below 200 mm in most areas. The Tianshan Mountains divide Xinjiang into southern and northern regions with distinct climatic differences. The annual average temperature ranges from 9 to 12°C, with significant spatial variation in precipitation and temperature patterns. The primary vegetation types include desert (52% of vegetation area) and grassland (28% of vegetation area), with forest, shrub, swamp, alpine vegetation, and crops comprising the remainder [Figure 1: see original paper].

1.2 Data Sources

The study utilized MODIS NDVI data from NASA at 500 m spatial resolution for the period 2001–2016. Meteorological data from 99 stations across Xinjiang, including precipitation and temperature, were obtained from the China Meteorological Data Service Center. Vegetation type data were derived from the 1:1,000,000 vegetation map of China. All data were preprocessed using standard procedures for quality control and spatial alignment.

1.3 Methods

1.3.1 NPP Calculation Models Net primary productivity was calculated using the CASA (Carnegie-Ames-Stanford Approach) model and the Zhou Guangsheng model. The CASA model estimates NPP based on the principle

that plant productivity is determined by absorbed photosynthetically active radiation (APAR) and light use efficiency ( ):

$$NPP(x,t) = APAR(x,t) \times \varepsilon(x,t) \quad (1)$$

where x represents the spatial location, t represents time, $NPP(x,t)$ is the net primary productivity at location x and time t (MJ · m ^{2} · d ^{1}), $APAR(x,t)$ is the absorbed photosynthetically active radiation (MJ · m ^{2}), and $\varepsilon(x,t)$ is the light use efficiency. The fraction of photosynthetically active radiation absorbed by vegetation (FPAR) was derived from NDVI data using established relationships.

1.3.2 Separation of Climate and Human Activity Effects Climate productivity (potential NPP under natural climate conditions) was calculated using the Zhou Guangsheng model, which establishes relationships between climate factors and vegetation productivity. The difference between climate productivity and actual productivity was attributed to human activities. Linear regression analysis was applied to detect trends in NPP time series, and F-tests were used to determine statistical significance at the 95% confidence level.

1.3.3 Trend Analysis The slope of the linear regression represented the rate of NPP change over time. Areas with statistically significant positive slopes were classified as restoration, while areas with significant negative slopes were classified as degradation. The relative contributions of climate change and human activities were quantified by comparing trends in actual NPP and climate productivity.

2 Results

2.1 Overall NPP Trends in Xinjiang

From 2001 to 2016, the area with significant NPP trends accounted for 34.02% of the total vegetation coverage in Xinjiang. Restoration areas (30.58%) far exceeded degradation areas (3.44%). Human activities were the dominant driver of both restoration and degradation, contributing to 42.03% and 57.63% of the affected areas, respectively. Climate change contributed to 30.58% of restoration areas and 19.45% of degradation areas. The net NPP increase was 634 Gg C · a ^{1}, with human activities contributing 319 Gg C · a ^{1} and climate change contributing 59 Gg C · a ^{1} [Figure 3: see original paper].

2.2 Effects by Vegetation Type

Different vegetation types exhibited distinct responses to climate change and human activities. Restoration was dominated by human activities in crops, desert, grassland, and alpine vegetation, while degradation was dominated by human activities in forest, shrub, and swamp vegetation. Climate change dominated restoration in all vegetation types except swamp. Crops showed the highest

NPP increase (293 Gg C · a ^{1}), followed by desert (171 Gg C · a ^{1}) and grassland (148 Gg C · a ^{1}) [Figure 4: see original paper].

2.3 Correlation with Climate Factors

Correlation analysis revealed that precipitation had a significant positive correlation with vegetation NPP across Xinjiang, while temperature showed a weak negative correlation [Figure 5: see original paper]. Water availability emerged as the primary limiting factor for vegetation growth. The positive response to precipitation was particularly strong in arid and semi-arid regions, where annual precipitation is below 200 mm.

3 Discussion

The results demonstrate that vegetation in Xinjiang has been undergoing net restoration during 2001–2016, with human activities serving as the main driving factor. This finding aligns with previous studies reporting vegetation recovery in arid regions following ecological restoration programs. The contribution of crops to total NPP increase highlights the importance of agricultural management practices and irrigation in enhancing regional productivity.

Climate change generally promoted NPP increase through improved water use efficiency and extended growing seasons, although the effect was secondary to human activities. The weak negative correlation between temperature and NPP suggests that warming may increase evapotranspiration stress, offsetting potential benefits from longer growing seasons. Precipitation emerged as the dominant climate factor controlling vegetation dynamics.

The separation method based on the difference between climate productivity and actual productivity provides a robust framework for attributing vegetation changes to their underlying causes. However, uncertainties remain in model parameterization and the distinction between direct and indirect human impacts. Future research should integrate high-resolution remote sensing data and process-based ecosystem models to improve attribution accuracy.

4 Conclusion

(1) From 2001 to 2016, vegetation NPP in Xinjiang showed a net increasing trend, with restoration areas (30.58%) significantly exceeding degradation areas (3.44%). The ratio of restoration to degradation area was approximately 9:1, indicating overall vegetation recovery.

(2) Human activities were the dominant factor influencing vegetation change, contributing to 42.03% of restoration and 57.63% of degradation areas. Climate change contributed to 30.58% of restoration and 19.45% of degradation areas. The net NPP increase of 634 Gg C · a ^{1} was primarily driven by human activities (319 Gg C · a ^{1}) and secondarily by climate change (59 Gg C · a ^{1}).

(3) Different vegetation types responded differently to climate change and human activities. Crops, desert, and grassland showed the largest NPP increases, while forest and shrub areas experienced degradation primarily due to human activities. Water availability, as controlled by precipitation, remains the key limiting factor for vegetation growth in this arid region.

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Note: Figure translations are in progress. See original paper for figures.