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Original Research

Effects of Increased Vegetation Cover and Green Economic Development Pathway: Evidence from China

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Abstract

Although studies on the driving factors of vegetation growth and restoration have been widely discussed, the influences and effects of vegetation growth on the ecological environment have not been clearly discussed. In recent years, China has made remarkable achievements in vegetation growth and restoration, so it is meaningful to discuss the effects of increased vegetation and ecological environment change in China. Through spatial analysis and curve estimation, we found that vegetation in China has increased rapidly in recent years, especially in northeast China, southwest China, and the Loess Plateau. The grassland ecosystem is the largest vegetation ecosystem in China. The distribution pattern of grassland was basically unchanged, distributed in alpine and arid regions, and the main changes were in Inner Mongolia Plateau, Loess Plateau, and Xinjiang. These changes are related to national policies and agricultural development. Vegetation growth is accompanied by the overall improvement of the ecological environment and economic development. Increased vegetation in China has both natural and human effects. Natural effects include the impact on the atmosphere, pedosphere, biosphere, and hydrosphere, while human impacts include the urban environment, national health, ecological economy, and ecological civilization system. However, the long-term effects of increased vegetation need to continue to be observed and studied.

Keywords: China, ecological environment improvement, economic development pathway, effects, increased vegetation cover

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Introduction

Monitoring changes in vegetation growth has been one of the most significant research topics in the field of ecology. This is because vegetation plays an important role in the current global environmental change [1, 2]. However, its role in the ecosystem and human society is unpredictable, due to the varied contribution of vegetation in different regions and times [3]. How does vegetation affect the natural and social environment? Meanwhile, grassland vegetation is an important component of the vegetation ecosystem. The ecological situation of the ecosystem reflects the quality of its management. There is also an urgent need to address how this impacts the natural and social systems in the system of vegetation.

The world is a greener place than it was 20 years ago. The data show that the areas with significant global vegetation growth trends are mainly located in equatorial savannas with dry winters, warm temperate climates with dry winters, and warm temperate climates with completely humid climatic zones [4]. Vegetation is increasing in Europe and East and South Asia as a whole. For example, the study using UA data found that the total amount of agricultural land, natural land, forests and vegetation in Turkey increased by 18.32% [5]. Data from NASA Earth satellites show that human activity in China and India dominates this greening of the planet. Furthermore, accounting for nearly 25% of that, China has the highest rate of vegetation growth, particularly in plantation areas ranking first in the world [6]. At the same time, China's ecological environment has been effectively and significantly improved, with fewer environmental emergencies, significantly improved air quality, and reduced areas of soil erosion. Therefore, the effects of vegetation restoration and growth in China should be considered seriously.

It is generally accepted that there is a link between economic development and the ecological environment: in the early stages of economic development, large-scale resource extraction and utilization can cause a certain degree of damage to the ecological environment; with economic development, the original development model may not be sustainable, while individuals' environmental awareness gradually increases, forcing the adoption of a more sustainable and greener development model. This view is summarized as the Environmental Kuznets Curve (EKC), which has been widely studied empirically. Scholars have mostly expressed environmental conditions and social well-being in terms of CO_2, SO_2, and other air pollutants and GDP per capita, respectively [7, 8], while some scholars have further validated the EKC curve from the perspective of ecological footprint [9]. Scholars are also concerned with the factors influencing the inflection point of the decoupling relationship between economic development and environmental degradation. Besides, some scholars have also proposed natural resource dependence (NRD), arguing that resource-based countries can hardly escape from the resource curse and the EKC curve can hardly explain the development of such countries [10]. In terms of forests, the EKC theory relates to a forest transition curve in which the rate of forest loss starts low and then accelerates [11]. This is before the total forest area reaches a trough and recovers, usually with a lower diversity of tree species than in the original forest. The restoration of China's vegetation has been accompanied by rapid economic development and the increased well-being of its people. When considering sustainable development, ecological civilization construction, and high-quality development, a major issue is whether vegetation growth and economic development have achieved coupling in China, as well as ecological restoration and economic development.

In some studies, there is an interaction between vegetation change and climate change [12, 13]. Vegetation influences the exchange of matter and energy in the atmosphere through physical, chemical, and biological processes [14]. Growing vegetation can reduce the concentration of carbon dioxide in the atmosphere and increase carbon sinks [15, 16]. However, the carbon sequestration potential of vegetation, such as forests, may have been overestimated, and unjustified vegetation growth may also damage local ecosystems [17]. Furthermore, vegetation, especially the grassland ecosystem, plays an important role in regional geological hazards such as soil and water conservation and ecosystem stability because of its root function [18]. Vegetation can also affect the water cycle and modify energy flow [19].

In addition to the potential natural environment and ecological effects, vegetation change can also have an impact on human social and economic activities. First of all, growth in forest areas affects the income of forest owners and the downstream timber industry [20]. Then, as vegetation cover increases, it promotes higher agricultural yields and reduces rural poverty [21]. With the development of human society, people are becoming more environmentally conscious and the demand for comfortable climatic conditions is increasing [22, 23]. Vegetation change is closely related to land use change generated by human activities [24]. In cities with active human activities, green space is an important carrier of vegetation, and green space provides a healthy environment and aesthetic value, among other things [25]. Additionally, the monetary valuation of ecological function makes people realize the economic value of vegetation change along with the valuation of the ecosystem [26]. The growth of vegetation promotes ecological improvement and to a certain extent increases the desire for ecotourism [27]. But this has received less attention.

In the existing studies on vegetation effect, most scholars pay more attention to the natural and ecological effects of vegetation than those of human and social economy. Due to China's remarkable achievements in vegetation restoration and growth in recent years, it is of critical significance to study the effects of vegetation growth in China. This is especially relevant to China's economic development and ecological protection. Utilizing NDVI data and the accompanying information on China's ecological environment and economic development over the past two decades, we investigated the following three issues: (1) temporal and spatial changes of vegetation change and the growth of vegetation in China, such as forests, arable land, and grasslands; (2) changes of ecological environment and economic development pathways in China, and (3) natural and human effects of forests, grasslands, and arable land growth.

Data Source and Methods

Data on Vegetation Change

The normalized difference vegetation index (NDVI) can indicate the change of vegetation cover in an area [28]. In this study, we used NDVI data during the growing season from Resource and Environment Science and Data Center (https://www.resdc.cn/Default.aspx). The spatial distribution dataset of NDVI in the growing season (from March to November) in China is derived from SPOT/VEGETATION NDVI satellite remote sensing data.

Additionally, we used forest coverage rate and stock volume of forest from the National Forestry Survey. China conducted five National Forestry Surveys between 1994 and 2018, once every five years. The data of the Fifth National Forestry Survey were from 1994 to 1998, and the data of the Ninth National Forestry Survey were from 2014 to 2018. Some of the data also came from the third National Land Survey.

Based on the 1:100000 land use/land cover data, the spatial distribution data set of China's terrestrial ecosystem types was formed by identifying each ecosystem type through classification and processing. China's terrestrial ecosystem is divided into farmland ecosystem, forest ecosystem, grassland ecosystem, water and wetland ecosystem, desert ecosystem, settlement ecosystem and other unused land. Spatial distribution data of terrestrial ecosystem types in China were obtained from Resource and Environment Science and Data Center (https://www.resdc.cn/Default.aspx).

The land use transfer matrix describes the conversion of land use types over a period of time [29]. $A_{i\times j}^{k}$ and $A_{i\times j}^{k+1}$ are maps of the same land use type within two different time periods. Based on the algebraic approach, the calculation formula is as follows [30].

$$C_{i\times j} = A_{i\times j}^{k} \times 10 + A_{i\times j}^{k+1}\ (land\ use\ type < 10) \quad (1)$$

Where $C_{i\times j}$ is land use map from k to $k + 1$. It represents land use change types and pattern. Based on $C_{i\times j}$, land use transfer matrix A_{ij} can be obtained.

$$A_{ij} = \begin{vmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{vmatrix} \quad (2)$$

Where A_{ij} is the area converted from land use type i to land use type j over a period of time.

China has eight forestry programs at the national level, respectively three-north shelterbelt program, afforestation program for Taihang Mountain, shelterbelt program for Liaohe River, shelterbelt program for middle reaches of Yellow River, shelterbelt program for Huaihe River and Taihu Lake, shelterbelt program for upper and middle reaches of Yangtze River, shelterbelt program for Pearl River, and coastal shelterbelt program. These forestry programs exhibit different ecological functions, and their location maps were derived from Resource and Environment Science and Data Center (https://www.resdc.cn/Default.aspx).

Environmental and Ecological Data

In environmental emergencies, pollutants or harmful substances such as radioactive substances enter the atmosphere, water, soil, and other environmental media, potentially endangering public health and safety, causing ecological damage, or causing significant social impact, requiring emergency measures to be taken to respond to. The number of environmental emergency events can be used to represent the changes in the ecological environment in China in the past 30 years. Environmental emergencies are events that can damage economic and social stability, even pose a significant threat to public safety. The data comes from the China Environmental Statistics Yearbook, which covers the period from 1991 to 2019.

In addition, ambient air quality is a basic measure of air pollution in a place, including the concentration of various types of air pollutants and the number of days of air quality equal to or above grade II. The data of ambient air quality of key cities, including Chinese municipalities and provincial capitals, come from the China Statistical Yearbook between 2003 and 2019. It is worth noting that China implemented a new ambient air quality standard in 2013, adjusting and revising the items and limits of air pollutants.

Although there are so few areas that are in pristine condition, Nature reserves reflect the natural background of an area and maintain biodiversity [31]. The area of nature reserves reflects the basic situation of nature conservation in each region. Most of the data between 2000 and 2018 are from the China Statistical Yearbook and some of them are from China's Ecological Environment Bulletin published by the Ministry of Ecology and Environment.

China is one of the countries with the most serious soil erosion and has a long history of soil and water conservation practices [32]. Early in the 1999, the Ministry of Water Resources organized the second national investigation of soil and water loss by using remote sensing. From then, China had developed a national monitoring network and information system for soil and water conservation, and continued to carry out dynamic monitoring of soil and water loss throughout the country. We used the data from national erosion surveys conducted in 1999 and 2019.

Vegetation plays an important role in the water cycle, such as soil evaporation, plant transpiration, and surface runoff, so vegetation can conserve water [33]. The function can be characterized by water and wetland ecosystem, including marshes, rivers, reservoirs, lakes, beaches, glaciers and permanent snow cover. Therefore, the above terrestrial ecosystem distribution data will be used to analyze water changes.

Economic Development Data

Environmental Kuznets curve (EKC) is an empirical curve based on actual data, which reflects the nonlinear relationship between environmental quality and economic growth [34-36]. We indicate the change of environmental quality by the number of environmental emergency events. Economic growth is expressed by per capita GDP because per capita GDP can more truly reflect the impact of economic growth on environmental quality compared with total GDP. The per capita GDP data comes from China Statistical Yearbook, covering the period from 1991 to 2019. This paper tests the EKC hypothesis using a polynomial regression model, which is shown in Equation (3):

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \cdots + \beta_d x^d + \varepsilon \qquad (3)$$

In Equation (3), y denotes the number of environmental emergency events, x denotes the per capita GDP, and β_0, β_1, β_2, β_d, are parameters. ε is the random perturbation the random perturbation term, d is the number of polynomial regression functions.

In order to estimate the land surface temperature (LST) and to investigate the areas affected by urban heat island (UHI), Landsat 8 OLI_TIRS products dated back to 2013 and 2019 in August were used. The data is from Geospatial Data Cloud (http://www.gscloud.cn/). After atmospheric and radiometric corrections, we get the radiation brightness temperature [37]. The earth is assumed to be a blackbody in calculating the radiation brightness temperature, however, most of the objects on earth are not blackbodies. Therefore, the radiation brightness temperature cannot characterize the LST accurately [38]. Using the surface emissivity of different objects, the radiation brightness temperature is converted to land surface temperature [39, 40].

GDP and value-added data reflect the development status of a certain industry. These data also come from the China Statistical Yearbook. In addition, some key data come from annual bulletins published on the official websites of the Ministry of Ecology and Environment (https://www.mee.gov.cn/) and the National Forestry and Grassland Administration (http://www.forestry.gov.cn/).

Results

Situation of Vegetation Cover and Change of Forest and Arable Land in China

China has experienced a significant increase in greenness over the past two decades, and the greening area has expanded obviously. Fig. 1 shows the difference in NDVI values in China between 2000 and 2019. We divided the difference into the areas where the NDVI value decreased (the difference<0), the areas where the NDVI slightly increased (0≤the difference<0.2), and the areas where the NDVI increased significantly (the difference≥0.2). Results show that most regions of China experienced a trend of increasing greening, while some areas with the harsh environment such as deserts and areas with better urban economic development such as the regions of Yangtze River Delta, Pearl River Delta, Bohai Rim show a trend of greening degradation. However, there are also some areas where green growth is evident, such as northeast China, Southwest China, the Loess Plateau, and the oases on the edge of the desert in northwest China. The greening area improved accounted for 70.2% of the total land area, among which 6.5% were significantly improved.

In the process of vegetation restoration and growth, the increase of forest area is an important source and reason for the greening of China in recent years. According to the National Forestry Survey, the forest coverage rate increased from 16.6% at the end of the last century to 23% in recent years (Fig. 2). Thanks to the continuous implementation of afforestation and forestry management policies, as well as the return of farmland to the forest, China's vegetation coverage rate has increased significantly. The forest coverage rate in Beijing, Guangxi, Yunnan, Guizhou, and Chongqing has increased by more than 20%, while that in Shaanxi, Ningxia, Henan, Hubei, Hunan, Jiangsu, and Shanghai has increased by more than 10%.

Arable land is also closely related to vegetation change. Data from the third National Land Survey show that China's arable land area has decreased by 7.5×10^6 hm^2 over the past decade. Although the area of the arable land decreased, it is mainly due to the adjustment of agricultural structure and land greening, rather than conversion into construction land. The arable land has been converted into 7.5×10^6 hm^2 of forest land and 4.2×10^6 hm^2 of garden land.

Distribution Pattern and Change of Grassland Ecosystem

Grassland is an important type of vegetation ecosystem, which is widely distributed in China, especially in the Qinghai-Tibet Plateau and the arid and

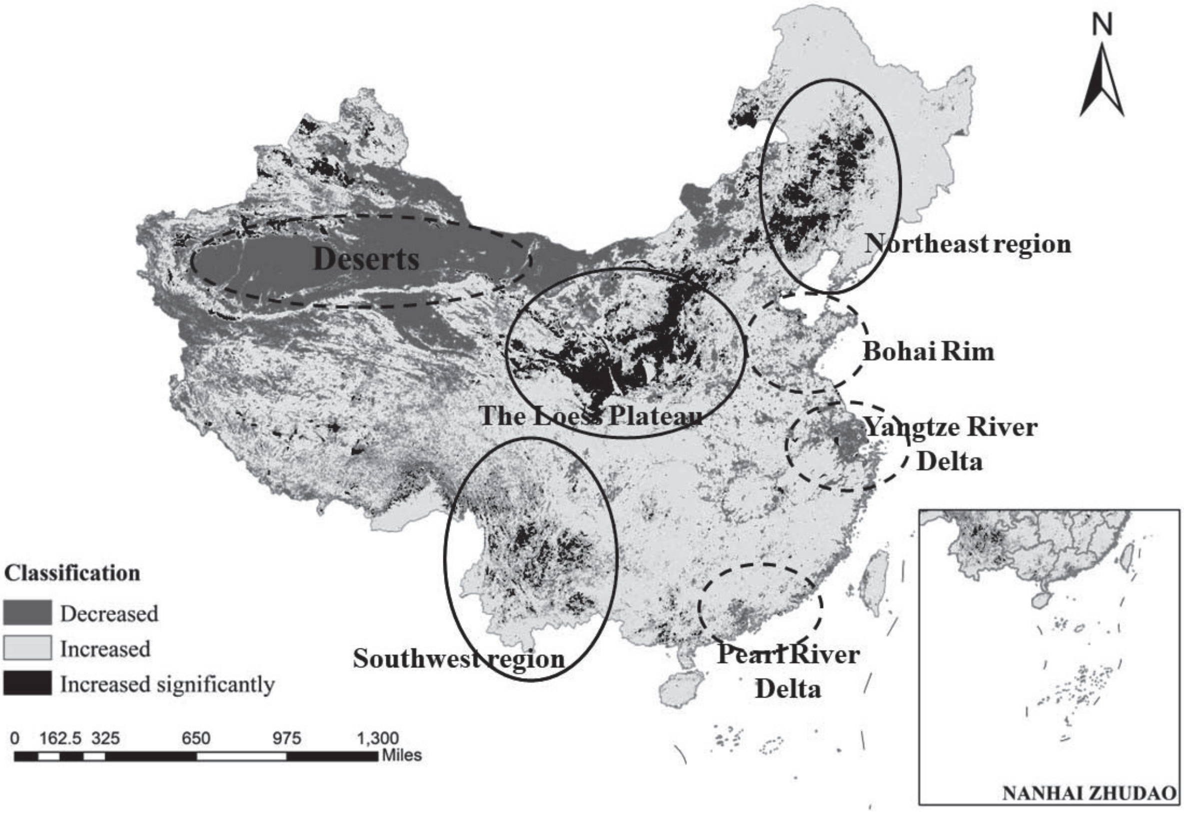

Fig. 1. The difference of NDVI value between 2000 and 2019.

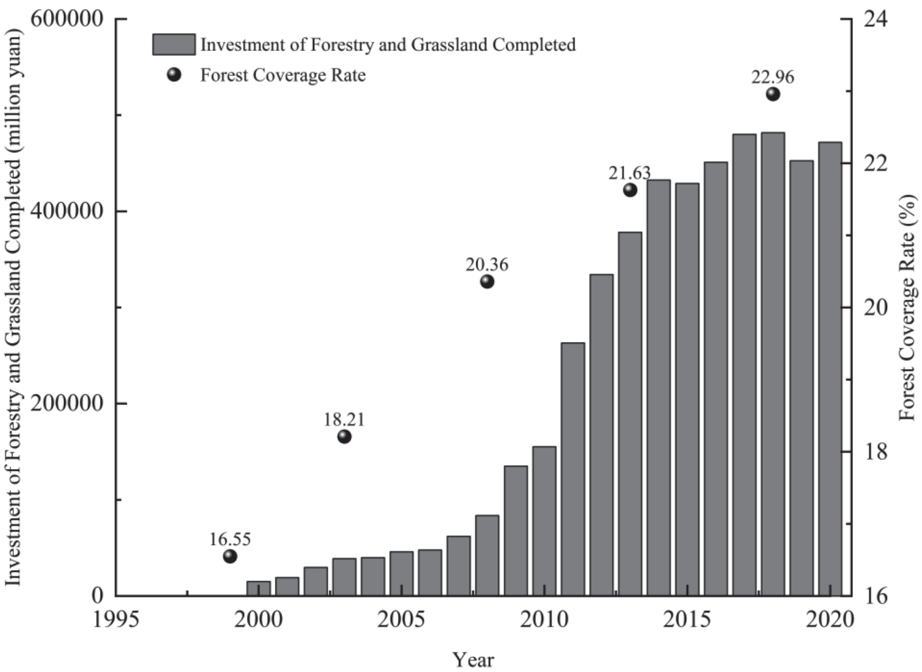

Fig. 2. The change of investment of forestry and grassland completed and forest coverage rate according to the National Forestry Survey.

semi-arid areas of northwest China (Fig. 3). In recent years, the change of grassland ecosystem area in China is not obvious, and the increase is mainly in Inner Mongolia Plateau, oasis around Xinjiang desert and Qinghai Province.

The changes of grassland ecosystem types in China since 2000 mainly show the following characteristics (Table 1). Grassland ecosystem was still the largest vegetation ecosystem, accounting for 42.7% of the total vegetation ecosystem in 2015. The unchanging area

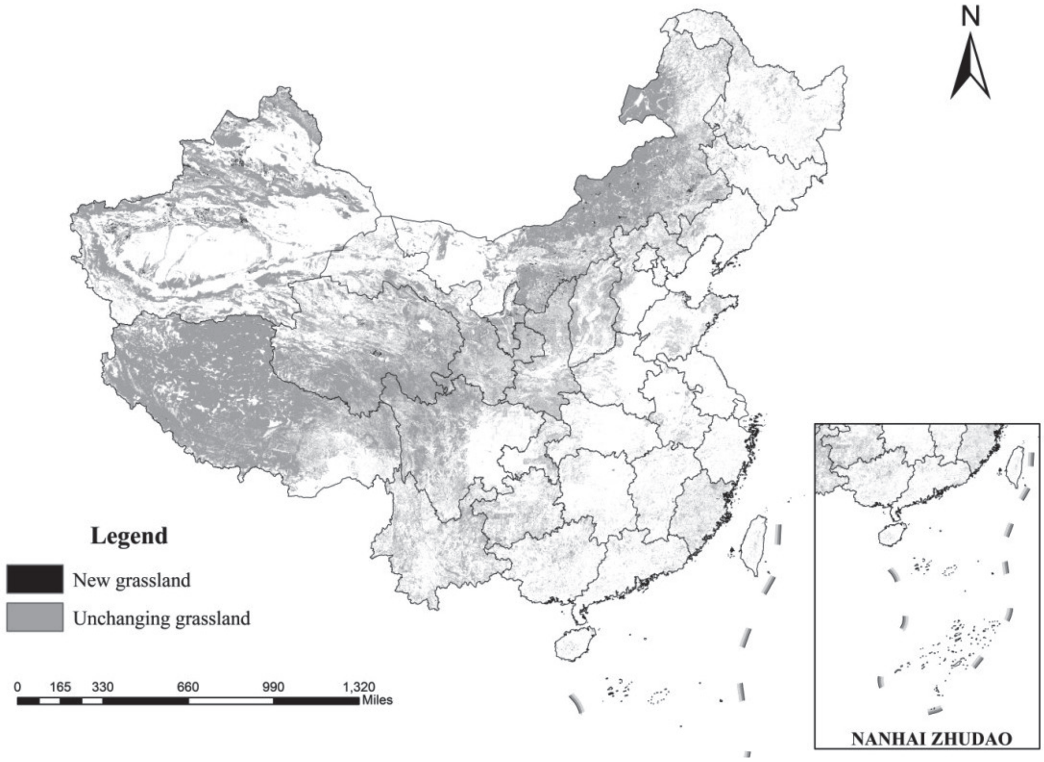

Fig. 3. Distribution pattern and change of grassland ecosystem.

reached 2,970,407 km², and the grassland ecosystem transferred to other ecosystems reached 40,670 km². 65.1% of grassland ecosystem was mainly transferred to farmland ecosystem and forest ecosystem, which was related to China's increasing food demand, farmland protection and grassland returning to forest policy. The area of other ecosystems transferred to grassland ecosystem reached 20,063 km², of which 32.8% were transferred from farmland ecosystem, which was related to the policy of farmland returning to grassland in some areas. 28.0% and 25.1% were transferred from settlement ecosystem and forest ecosystem respectively. The National programs like "Returning grazing land to grassland" help increase the grassland ecosystem, which restores grassland vegetation, improves grassland ecology, and increases grassland productivity through artificial grass planting, replanting and improvement, grassland pest control and fence construction, grazing ban, grazing rest and zoning rotation.

The changes of grassland ecosystem are mainly concentrated in the arid and semi-arid areas of northwest China, and the changes in and out of grassland ecosystem are similar in space (Fig. 4). From the perspective of turning-out, most oases around deserts in Xinjiang have grassland ecosystem turning into farmland ecosystem, which is related to the increase of food demand and agricultural development after population growth. In Shaanxi and Gansu, grassland ecosystem was transformed into forest ecosystem. In Inner Mongolia, Ningxia and Qinghai-

Table 1. Transition matrix of the ecosystem types in China from 2000 to 2015.

2000 (km^2) / 2015 (km^2)	Farmland ecosystem	Forest ecosystem	Grassland ecosystem	Water and wetland ecosystem	Desert ecosystem	Settlement ecosystem	Unused land
Farmland ecosystem	1749033	5001	18390	4980	550	7307	692
Forest ecosystem	6171	2224847	8067	331	92	578	52
Grassland ecosystem	6586	5025	2970407	2407	129	5612	304
Water and wetland ecosystem	5382	1382	3794	344133	275	2693	150
Desert ecosystem	32702	6231	5307	2548	171352	2569	191
Settlement ecosystem	190	102	4546	1652	20	1268406	31
Unused land	485	178	566	278	5	218	629460

Tibet Plateau, grassland ecosystem transfer is diverse. From the perspective of turning-in, Inner Mongolia has obvious settlement transfer to grassland, which is related to the regulation of industrial and mining land. In Shaanxi, Ningxia and Gansu, the policy of farmland returning to forest has transformed farmland ecosystem into grassland ecosystem.

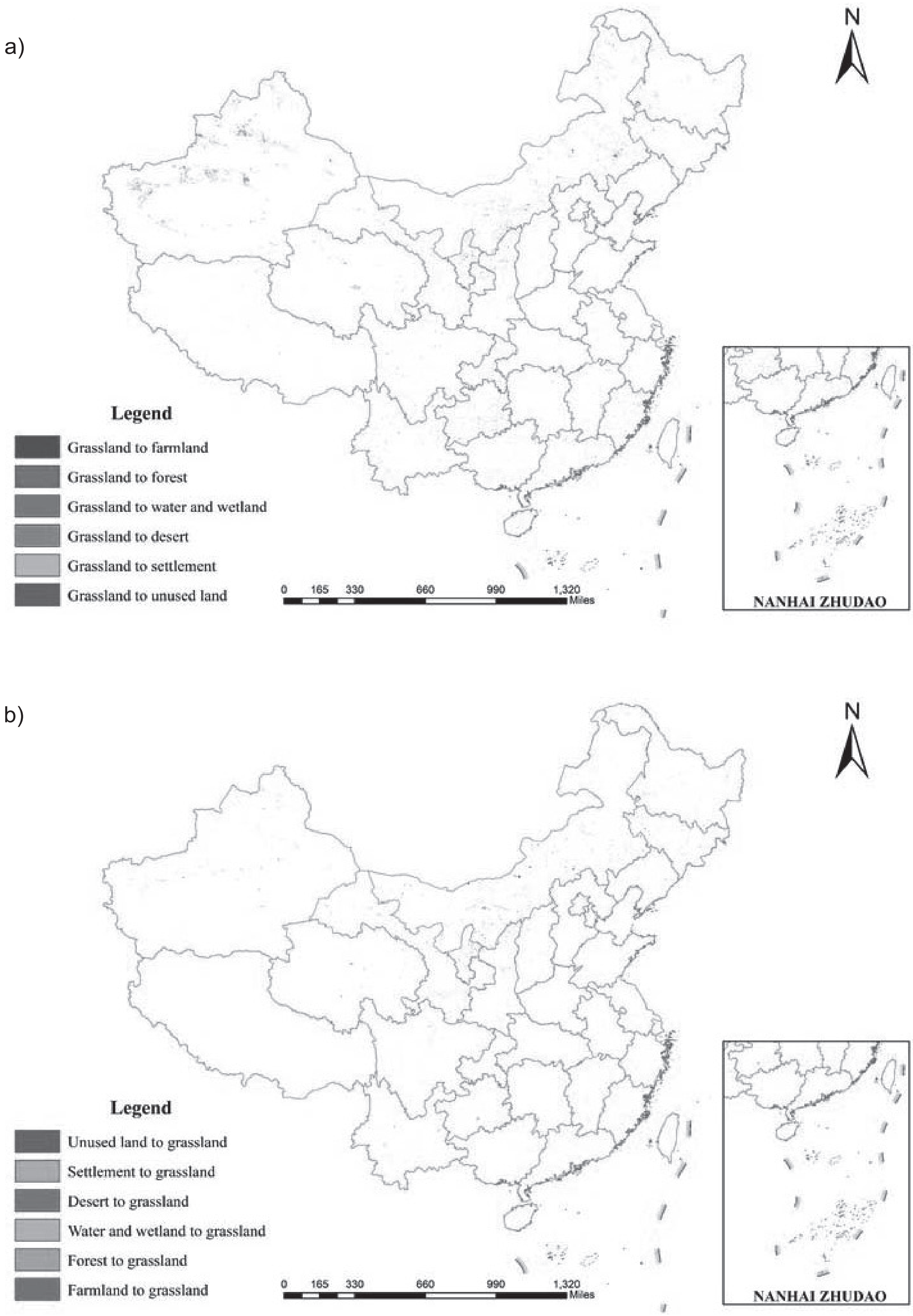

Fig. 4. The distribution of ecosystem land transition in China. a) Grassland ecosystem to other ecosystems; b) Other ecosystems to grassland ecosystem.

Table 2. Model summary and parameter estimates of per capita GDP and environmental emergency events.

Equation	Model summary					Parameter estimates			
	R^2	F	df1	df2	Sig.	Constant	b1	b2	b3
Cubic	0.889[2]	66.912	3	25	0.000[1]*	3898.033	-1.234	0.000[1]**	0.000[1]***

[1] * 4.409×10^{-12}; ** 0.00014^9; *** -6.201×10^{-9}.

[2] This model's $R^2 = 0.889$, which proves that the curve can represent 88.9% of the true data. And this model's sig.<0.01, which proves that this model could fit well with the real data.

China's Economic Development Pathway and Ecological Environment Improvement

China's economy has developed rapidly since the reform and opening-up in 1978. The per capita GDP increased from 1912 yuan in 1991 to 70892 yuan in 2019. At the same time, China's ecological environment has also been effectively improved to some extent. The number of environmental emergency events decreased from 3038 times in 1991 to 261 times in 2019.

EKC curve shows the relationship between environmental quality and economic development, taking per capita GDP at a constant price according to the 1978 standard as an indicator of economic development, and environmental emergency events as an indicator of environmental quality. SPSS software was used for curve estimation, and the results were shown in Table 2 and Fig. 5. The relationship between per capita GDP and environmental emergency events is well fitted with cubic curves. Fig. 5 shows that China's environmental quality is gradually improving with the economic development, which proves that China's economic development has been more concerned with the improvement of environmental quality, unlike the traditional EKC hypothesis which is an inverted U-shaped relationship between environmental degradation and economic growth [41]. China's economic development pathway is different from that of developed countries. China pays more attention to the development model of "environmental governance while promoting economic development".

In particular, China put forward the construction of ecological civilization on a nationwide scale in 2012, changing the idea of economic development model from economic-oriented to economic- and ecological-oriented. Since 2013, the number of environmental emergencies has decreased significantly and entered a relatively stable period and China's investment in environmental protection also increased year by year (Fig. 6). According to the latest National Land Survey, the area of forest land, grass-land, wetlands, rivers, and lakes which have strong ecological functions has increased by a total of 1.7×10^7 hm^2 in the past 10 years, making positive progress in ecological construction.

The Effects of Increased Vegetation Cover

The ecological environment is gradually improving along with China's economic development, which is closely related to the restoration and growth of

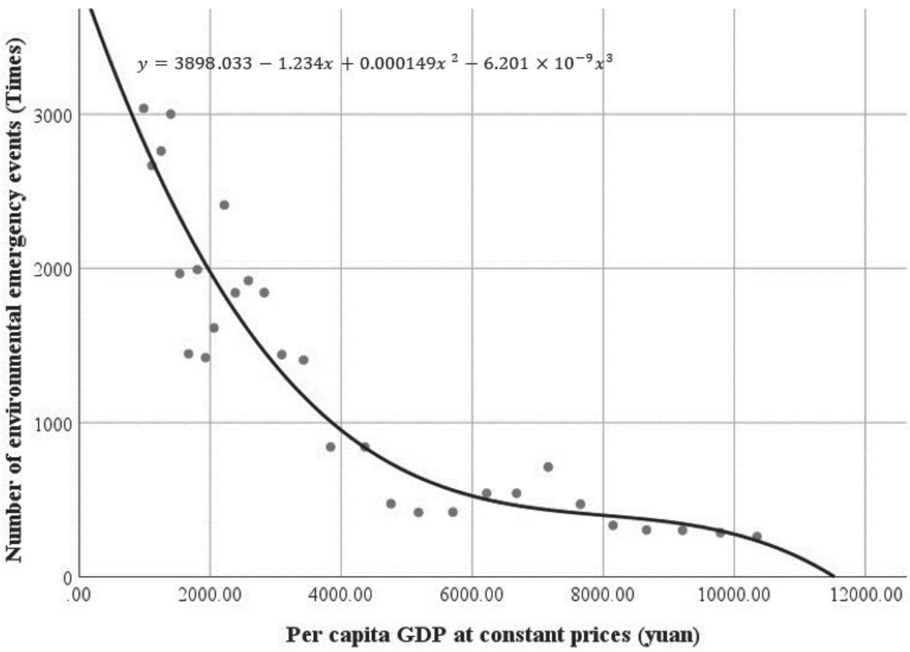

Fig. 5. Plot model of per capita GDP and environmental emergency events.

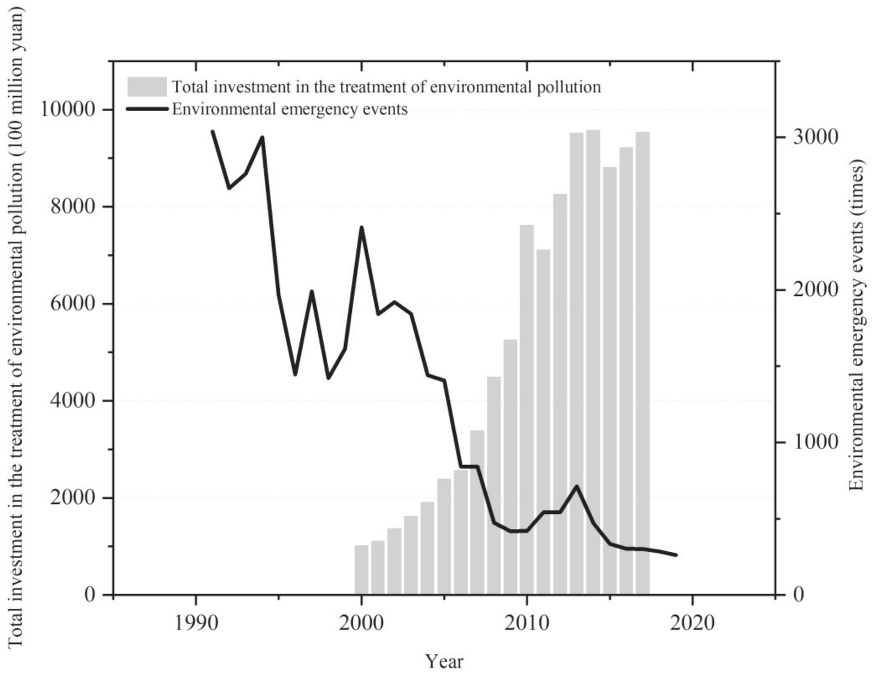

Fig. 6. The number of environmental emergency events from 1991 to 2019 and the total investment in the treatment of environmental pollution from 2000 to 2017.

vegetation in China. Increased vegetation has a positive effect on both the natural environment and human society [42]. The natural and human effects of vegetation should be recognized.

Natural Environment and Ecological Effects

As a part of the terrestrial ecosystem, vegetation is an important part of the biosphere, which is related to the hydrosphere, pedosphere, and atmosphere. Thus, the natural environment and ecological effects of vegetation act on the spheres of the earth's surface, such as the atmosphere, lithosphere, biosphere, and hydrosphere [43, 44].

The Effects on the Atmosphere

Vegetation exerts influence on the atmospheric environment by participating in the atmospheric cycle and carbon cycle. Its possible impacts include improving air quality, increasing the capacity of carbon sink, and becoming windbreaks to stabilize the sand.

The air quality in China continued to improve from 2003 to 2019, especially in recent years. In 2020, the proportion of days with good air quality in 337 Chinese cities was 87%, up 5% year-on-year. A total of 202 cities met the standards, accounting for 59.9%, an increase of 45 cities year-on-year. The average annual $PM_{2.5}$ concentration was 33 μg/m^3, which decreased 8.3% year-on-year. The average annual concentration of PM_{10} was 56 μg/m^3, which decreased 11.1% year-on-year. The average concentration of PM_{10} was 118 μg/m^3 in 2003 and it decreased to 68 μg/m^3 in 2019. As China revised its ambient air quality standards in 2012, the items and limits of pollutants were adjusted, including limits for average $PM_{2.5}$ concentration and eight-hour average O_3, and limits for PM_{10}, NO_2, and other pollutants were tightened. Therefore, there's a clear shift in 2013. However, the trend from 2003 to 2012 and from 2013 to 2019 was the same: PM_{10} decreased year by year, and the number of days of air quality equal to or above grade II increased year by year (Fig. 7).

Since the beginning of the new century, the sand and dust storm events and associated disasters over China have decreased in a fluctuating manner (Fig. 8). According to the National Ecological meteorological Bulletin released in 2019, with the improvement of the ecological quality of vegetation in northern China since 2000, the proportion of the land susceptible to dust and sand in northern China decreased from 48.1% in 2000 to 41.9% in 2019, with an average annual decrease of 0.4%, showing a slow downward trend. The proportion of the area with not easy to dust and sand increased from 30.3% in 2000 to 39.6% in 2019, indicating that the ecological function of vegetation for wind prevention and sand fixation has significantly improved.

Thanks to afforestation projects, China's standing forest stock has increased significantly in recent years, from 9.5 billion m^3 in 1998 to 19 billion m^3 in 2018, nearly doubled. The national vegetation biomass showed an increasing trend from 2000 to 2020, with an average annual increase of 12 gC/m^2. The biomass of vegetation increased from 909 gC/m^2 in 2000 to 1159 gC/m^2 in 2020, representing a 27.5% increase in vegetation carbon sink. In terms of spatial distribution, forest biomass increased significantly in the central

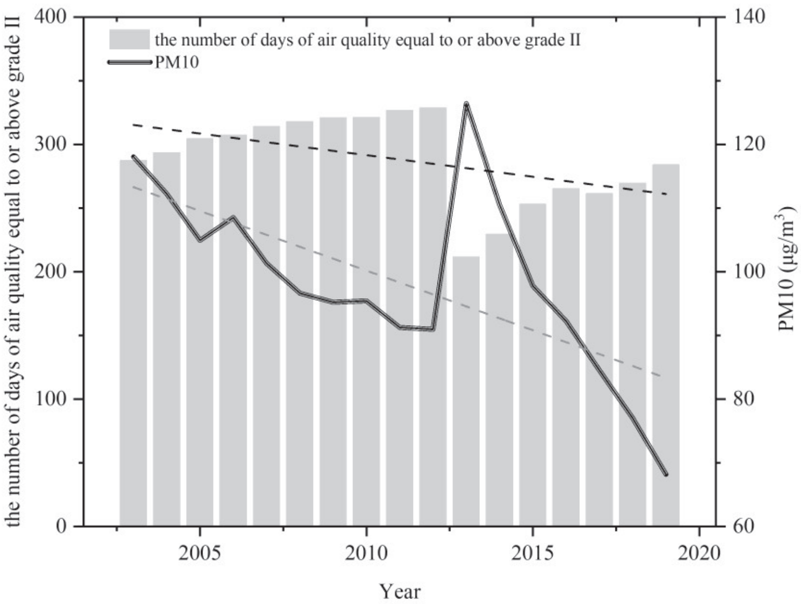

Fig. 7. The average air quality of key cities in China from 2003 to 2019.

and eastern regions of China with an average annual increase of 20-60 gC/m^2. The continuous and nationwide increase of vegetation biomass from 2000 indicates that the vegetation plays a significant role in offsetting carbon emissions from human beings and reducing atmospheric carbon dioxide levels.

The Effects on the Pedosphere

Vegetation cover can play an important role in determining the stability of the pedosphere through its stabilizing effects on the land surface. With the increase of vegetation area, the area of sandy land in China is decreasing, and it decreased by 1.85 million hectares. Over the past two decades, the area of soil erosion has decreased in most regions of the country. By the end of the 1990s, soil erosion had reached 3.56 million km^2, including 1.63 million km^2 of erosion by water and 1.91 million km^2 of erosion by wind. By 2019, the area of soil erosion in China was reduced by 2.71 million km^2, including 1.13 million km^2 of erosion by water were eroded by water and 1.58 million km2 of erosion by water. A total of 836,901 km^2 of soil erosion was reduced nationwide, a decrease of 23.59%.

From the spatial perspective, the decrease of soil erosion area in the north is more obvious than that in the south. Xinjiang and Inner Mongolia, in particular, saw the biggest reduction in the area by 196,314 km^2 and 167,743 km^2, respectively. Gansu, Shaanxi, Sichuan, and Yunnan decreased 76,489 km^2, 64,056 km^2, 45,481 km^2, and 40,426 km^2 respectively. And the proportion of reduced soil erosion in Ningxia is 56.88%, ranking first among all provinces and regions in China. This is largely due to China's construction of the Three-North shelterbelt and the control of soil erosion in the Loess Plateau and Yellow River basins (Fig. 9).

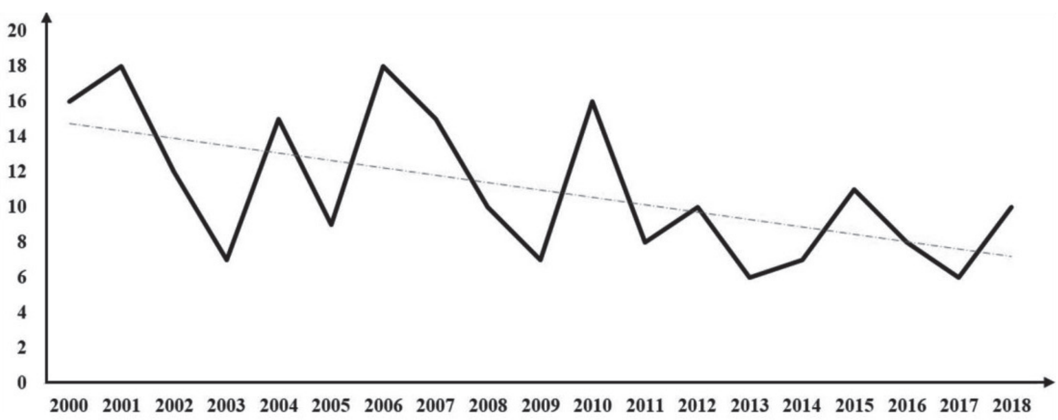

Fig. 8. The number of the sand and dust storm events and associated disasters over China from 2000 to 2018.

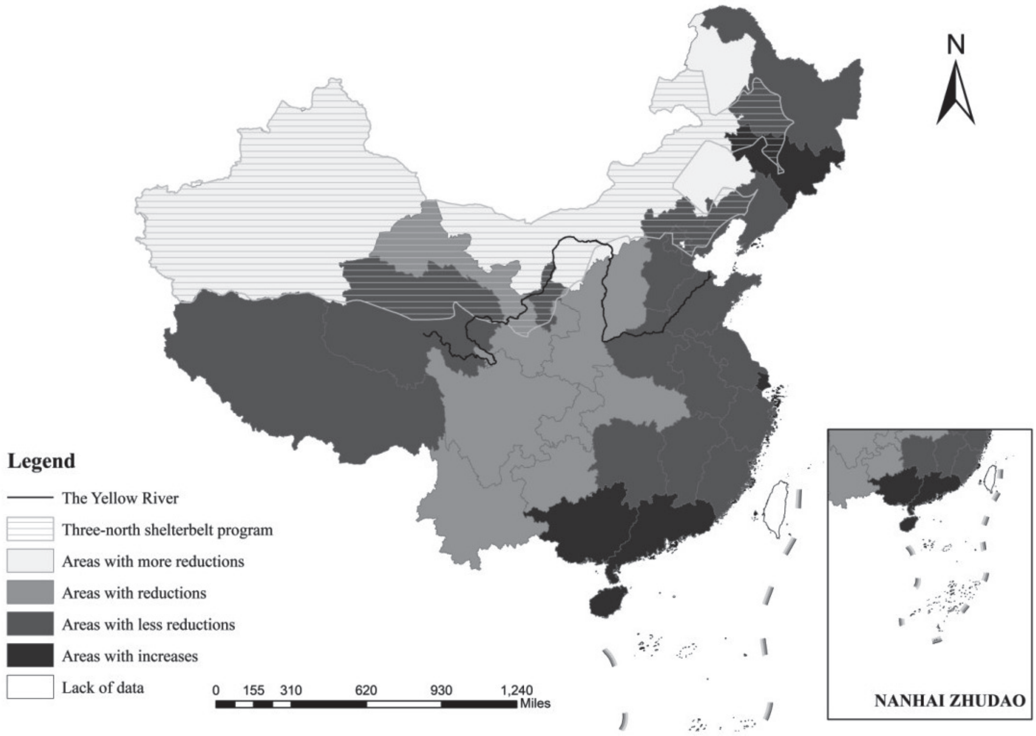

Fig. 9. The area of soil erosion reduced in 20 years.

The Effect on the Biosphere

The restoration and growth of vegetation are often the growth of forest and grassland ecosystems, which are often closely related to biodiversity as an important part of the biosphere.

The area of China's nature reserves increased from 98.21 million hectares in 2000 to 147.17 million hectares in 2018, an increase of 48.96 million hectares. The proportion of increased nature reserves area has increased by nearly 50% over the past two decades. Qinghai, Inner Mongolia, Heilongjiang, Gansu, and Xinjiang saw the largest increase in the area of nature reserves, with an increase of 16.42 million hectares, 6.06 million hectares, 4.73 million hectares, 3.83 million hectares, and 3.64 million hectares, respectively. In addition, the proportion of increased nature reserves area in Shanxi, Hebei, Jiangxi, Qinghai, Henan, Shaanxi, and Shanghai saw the biggest increases, an increase of more than two times.

The Effect on the Hydrosphere

Vegetation interacts with water through its unique structure to infiltrate and accumulate precipitation, which has the function of water conservation. In recent years, China's water and wetland ecosystems have significantly increased with the growth and restoration of vegetation from 2000 to 2015. The improvement of vegetation cover has also contributed to the improvement of water quality and the protection of China's water environment.

China currently has eight forestry programs, and the increase in water and wetland areas is mainly concentrated in these areas (Fig. 10). Among them, the construction area of the Three-north shelterbelt program increased by 4,258 km^2 and the increase of the water and wetland area in the coastal shelterbelt program accounted for 1.41% of the program's area.

Human Environment and Economic Effects

The restoration and increase of vegetation not only promote the improvement of the natural environment but also have an important impact on human society. In recent years, the improvement of the urban environment and the health of urban residents are closely related to the construction of urban greening. In addition, China's economic development is heading towards a new trend with the integration of green and ecological concepts into China's economic development. As the world increasingly focuses on environmental and ecological issues such as climate change, China is also moving towards green development.

Improvement of Urban Environment

In the past two decades, both the green land area and the green coverage rate of Chinese cities have increased significantly. China's urban green land increased from 865,295 hectares in 2000 to 3,152,889 hectares in 2019, a total increase of 2,287,694 hectares, an increase of more than 2.5 times. Especially in the economically developed areas, the increase in green land area was the

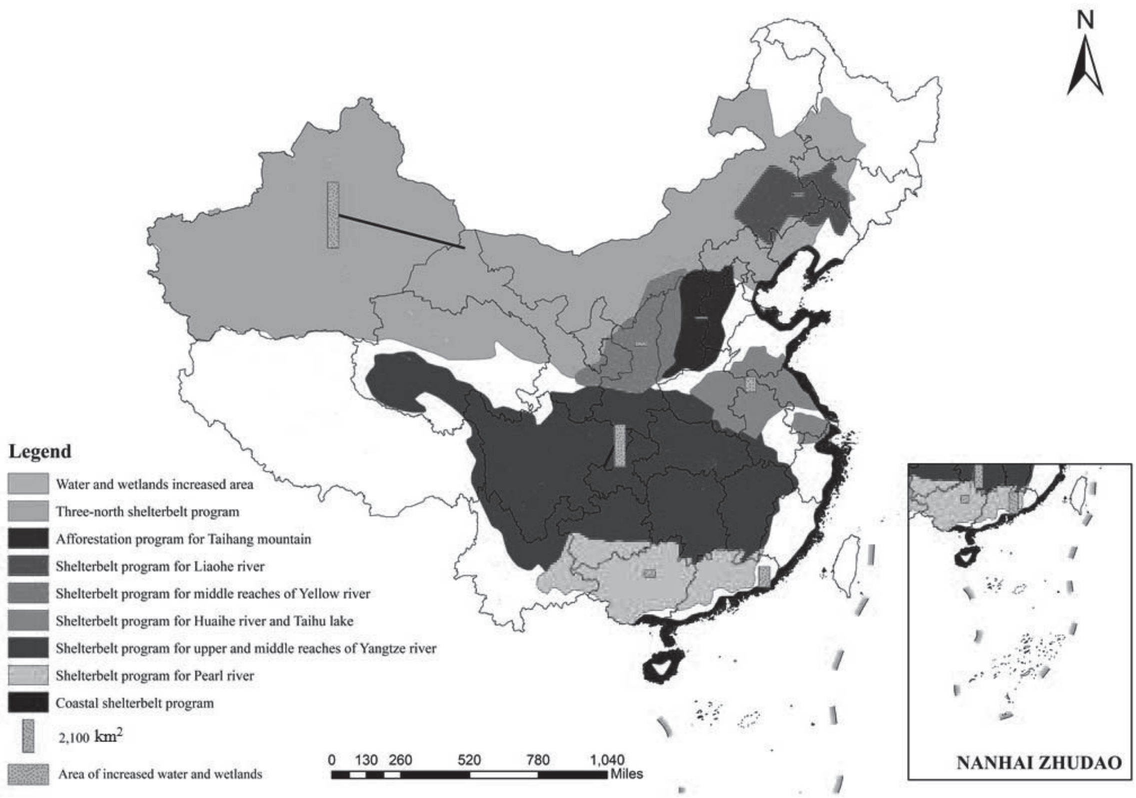

Fig. 10. China's eight major forestry programs and water and wetland increased areas from 2000 to 2015.

largest, with Guangdong, Jiangsu, Shandong, Shanghai, and Zhejiang increasing by more than 140,000 hectares. In ecologically fragile areas, green land increased the most, with Ningxia, Chongqing, Shaanxi, Gansu, and Shanxi increasing by more than four times. The green coverage rate in built-up areas increased from 35.1% in 2006 to 41.5% in 2019, an increase of 6.4%. The green coverage rate increased by more than 15% in Chongqing and Tibet, and by more than 10% in Yunnan, Inner Mongolia, Ningxia, Jiangxi, Shanxi, Anhui, and Guizhou.

Vegetation mitigates the urban heat island effect. Taking Shanghai in August 2013 and August 2018 as an example, the green land area in Shanghai increased from 124,295 hectares to 157,785 hectares in two years, a total increase of 33490 hectares, a growth rate of nearly 27%. Meanwhile, the summer land surface temperature of Shanghai has dropped significantly from 2013 to 2019, with the average temperature dropping from 30.39ºC to 26.09ºC, and the maximum temperature dropping from 48.24ºC to 41.63ºC. The area below 25ºC in the central urban area increased significantly, and the surface temperature of the new development zone in Shanghai increased obviously due to land development for construction (Fig. 11). The urban heat island intensity decreased significantly.

The increased area covered by vegetation contributes to changes in the urban ecological environment, especially the reduction of urban air pollution, and also benefits the health of the population. From 2000 to 2015, China's average life expectancy increased from 71.40 years old to 76.34 years old. In the 14th Five-year Plan, China proposes to build green cities, improve urban ecological conservation capacity, scientifically plan the layout of urban green rings, green corridors, and green roads, and promote ecological restoration projects. For example, the construction of urban parks increases the activity places for the residents around the city and provides them with leisure and entertainment venues. Urban residents can improve the physical quality and mental health in these parks through walking, running, and other ways.

Ecological Economy Development

Vegetation not only has an ecological effect but also has rich economic value. Firstly, the increase in forest and farmland areas promotes the increase in the output of forest and agricultural products and increases the economic income of forestry and crop industry. The GDP of agriculture, forestry, animal husbandry, and fishery increased from 1.494 trillion yuan in 2000 to 7.357 trillion yuan in 2019. And the value-added by agriculture, forestry, animal husbandry, and fishery grew from 2.141 trillion yuan in 2004 to 6.756 trillion yuan in 2018 (Fig. 12).

Secondly, with the improvement of people's awareness of environmental protection and the orientation of national policies, industries related to vegetation and green have been developed. For example,

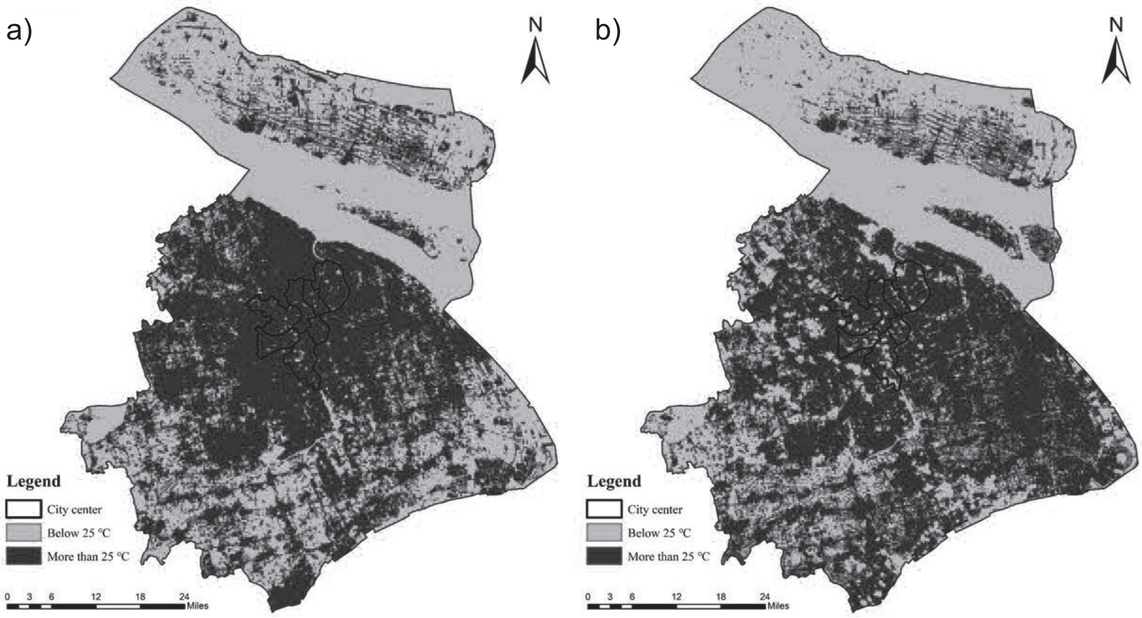

Fig. 11. Land surface temperature of Shanghai. a) 2013; b) 2019.

enterprises have begun to join in planting trees, and the construction of green infrastructure has been widely agreed upon, and green building materials have been applied in production and life. In addition, management of water conservancy, environment, and public facilities have seen their value-added grow from 76.86 billion yuan in 2004 to 509.61 billion yuan in 2018, an increase of more than 5.5 times (Fig. 12).

Thirdly, the establishment and improvement of scenic spots related to the growth of forests and other vegetation increases the income of ecotourism and promotes the development of tourism. China has established national forest parks nationwide since the last century. And the construction of national forest parks has been accelerated since 2000. There were 897 national forest parks in China by 2019. National forest

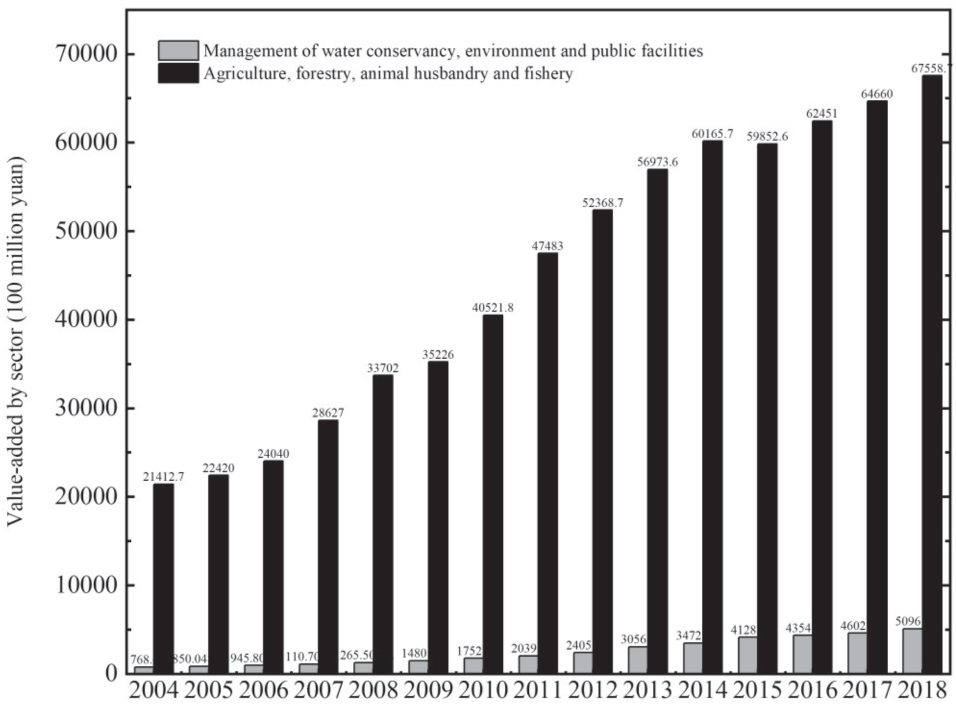

Fig. 12. The value-added by agriculture, forestry, animal husbandry, and fishery and management of water conservancy, environment, and public facilities.

park refers to the forest park with abundant forest landscape and concentrated humanistic scenery, which has high ornamental and cultural value and is one of the important tourist destinations. In addition, protected areas including nature reserves, scenic areas, national forest park, national geological park and so on is the important foundation of vegetation restoration. In order to the management and development of the system integration of these protected areas, China put forward carrying out the national park system in 2015. And China has 10 national parks by 2021, which lays the foundation for the development of ecological tourism in China.

Ecological Civilization Construction and New Development Philosophy

China has integrated ecological civilization construction into economic development with the greening of the land, and at the same time, it has focused on solving the problem of harmony between man and nature in order to alleviate the contradiction between man and nature, thus promoting high-quality economic development.

For example, China has continuously improved its support capacities in order to strengthen the management of ecological projects for land greening and actively promoted the drafting of the Law on National Parks and the Law on Protected Natural Areas, and the revision of the Grassland Law and Regulations for the Implementation of Forestry Law. At the same time, the reform of state-owned forest farms was accelerated, with 4297 in total, 95.5% of them designated as public welfare institutions, and the transfer of collective forest rights was promoted steadily, with 283900 new business entities.

Discussion

China has experienced a remarkable period of vegetation growth over the past two decades, thanks to a variety of factors, including nature, human activity, and regulation [45-47]. Moreover, the increase in forest area dominates the greening area in China, which is mainly from forests (42%) and farmland (32%) compared to India, but India's greening is mainly from farmland (82%) and forests (4.4%) contribute less [6]. China has experienced a process of land greening which is different from that of other developing countries. Although there have been some studies on the factors and driving forces causing vegetation increase and restoration, there are no systematic results on the effects of vegetation increase and restoration.

In the past two decades, China's vegetation has increased significantly. Although its vegetation coverage rate is not the highest in the world, its increase rate is the highest in the world [48], especially in northeast China, the Loess Plateau, and southwest China. The vegetation growth in these areas is very significant, in addition to the key ecological areas of the Qinghai-Tibet Plateau and oasis in northwest China is also significant. The areas with significant vegetation growth were concentrated in the ecologically sensitive and key areas in China, while the areas with reduced vegetation were concentrated in the ecologically fragile and socio-economic development areas.

Grassland ecosystem is one of the important vegetation ecosystems, and grassland ecosystem occupies the largest area and the highest proportion in China. Changes in grassland ecosystems are beneficial to biodiversity, increased carbon sequestration, decreased soil erosion, land productivity and local human well-being [49], while climate change continues to reduce grassland ecosystem productivity [50]. This development of grassland ecosystems has a huge connection with livestock farming and ecological conservation. In recent years, studies have shown a negative correlation between the net profit of livestock and the environmental footprint achieved through the spatial combination of crop farms and livestock farms in northwest China, indicating a win-win situation for both ecology and economy [51].

Generally speaking, the current development path of developed countries deteriorates and then improves the environment and ecology with economic development [52, 53]. However, China's development path is different from that of developed countries. With economic development, environmental and ecological conditions are constantly improving, especially in the past two decades since the beginning of the new century. With economic growth, China's economy has become more dynamic, resulting in scale effects. Coupled with the structural effects of changes in economic structure and the technological effects of environmentally friendly technologies in recent years, China's economy has been developing along the pathway of sustainable development. Continuous land greening is an important embodiment of China's green economic development pathway.

The increased vegetation has produced abundant effects on the ecological environment, which can be divided into the natural environment and ecological effect and human environment and economic effect. From the perspective of natural effects, vegetation is an important part of the biosphere, which interacts with the atmosphere, pedosphere, and hydrosphere through its biological structure. For example, the water stress of vegetation largely regulates land carbon uptake [54]. The effect of vegetation increase on the atmosphere is mainly reflected in the reduction of air pollution prevention, carbon sink, and sand storms reduction. With the increase of vegetation, China's air quality is improving day by day, sand storms are gradually reduced, and the effect of carbon sink is increasingly obvious. In addition, increased vegetation can also slow soil erosion, especially in northwest China and the Loess Plateau. Different vegetation types have different effects on soil erosion, so suitable vegetation types should be used to control soil erosion [55]. What's more, increased vegetation is beneficial to the restoration of biodiversity and water conservation. From the perspective of human effects, the urban heat island effect is mitigated by the increase of urban vegetation, which is beneficial to the health of urban residents [56, 57]. Moreover, urban vegetation often appears in the form of parks and greenways, which increase the places for leisure and exercise for urban residents and help to improve residents' physical and mental health. In the process of vegetation restoration and growth, green is also gradually transformed into a driving force for economic development. Agriculture, forestry, animal husbandry, and fishery and environment-related industries are also developing rapidly in China, and the income from ecological tourism is also increasing. In addition, China's structural reform and ecological progress are also deepening with the greening of the country. Green has become an important concept of China's development philosophy. We have talked about the general effect of more vegetation, but since greening and afforestation projects in China have only been carried out on a large scale in the last two decades, some of the vegetation may still be in the growth stage and not yet mature, so the effect of more vegetation still needs observation and discussion, especially the sustainable management and development of mature vegetation. How much of these positive effects are due to increased vegetation and not to other ecological policies still needs more quantitative measurement. Currently, scholars have begun to question whether the carbon sequestration capacity of forests has been exaggerated by academia and governments [58]. At the same time, natural forests can better support biodiversity conservation and achieve ecosystem services such as surface carbon storage, soil conservation, and water harvesting than simple structural plantations [52]. Some scholars also argue that China's large-scale expansion on the Loess Plateau has actually damaged the local ecology and is not sustainable [59].

Conclusions

A large number of pieces of literature have discussed the driving factors of vegetation increase, but the influences and effects of vegetation increase on the ecological environment and human society are not discussed enough. Only a small number of kinds of literature have discussed the natural effects of vegetation growth separately, and such discussions are not systematic. Given the current situation of increased vegetation in China, based on the understanding of the basic path of China's economy and green development, this study analyzed some of the effects of increased vegetation and attempted to classify the effects into natural effects and human effects.

Our study found that vegetation in China has generally increased over the past two decades, except for ecologically fragile areas such as deserts and key socio-economic development areas such as the Yangtze River Delta, Pearl River Delta, and Bohai Rim. Especially in northeast China, southwest China, and the Loess Plateau, vegetation growth and restoration are very significant. Grassland ecosystems are the largest and most widely distributed vegetation ecosystems in China. The basic pattern of grassland ecosystem in China remains unchanged, and it is mainly distributed in the arid and semi-arid areas of northwest China and the Qinghai-Tibet Plateau, which are the arid and alpine regions in China. The changes of grassland ecosystem mainly occurred in Inner Mongolia Plateau, Loess Plateau and Xinjiang. Grassland ecosystem in these areas has changed due to the increase of food demand after population growth and the implementation of a series of national policies.

In this process, China's ecological environment has improved significantly and environmental emergency events have decreased significantly. Compared with the development path of developed countries, we find that the improvement of China's ecological environment along with economic development is different from the development idea of "treatment after pollution". China's environmental management model is "pollute as you treat". This finding demonstrates the uniqueness of China's ecological civilization construction and can serve as a reference for other developing countries.

The effects of vegetation can be discussed from natural effect and human effect. The natural effect is mainly reflected in the connection between the increased vegetation and the different layers of the earth. As the connection between the vegetation of the biosphere and the atmosphere, pedosphere and hydrosphere, vegetation has the functions of air purification, carbon fixation, wind prevention and sand fixation, water conservation, and so on. The human effect is mainly reflected in the impact on the urban environment and ecological economy. In addition, the increase of vegetation also strengthens the concept of ecological civilization construction and green development.

However, instead of bringing positive effects, blind and unreasonable greening of the country may cause more extensive ecological damage. Although China's land greening projects have yielded remarkable results, man-made green spaces such as planted forests and meadows may have fragile ecosystems of their own, posing great challenges for the management of these green spaces. Moreover, as these artificial green spaces tend to mature over time, their resulting effects are still unknown. Therefore, the long-term effect of increased vegetation in China is still uncertain and remains to be observed in the long term, and scientific management of vegetation is likely to make the vegetation effect most sustainable.

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Conflict of Interest

The authors declare no conflict of interest.

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