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Spatiotemporal Patterns and Interconnections of Forest Biomass and Economic Density in the Yellow River Basin, China

Yaopeng Hu [1,2], Jiahui Zhai [2,3], Qingjun Wu [2,4], Xuanqin Yang [2,5], Yaquan Dou [2] and Xiaodi Zhao [2,6,*]

[1] Research Institute of Forest Resource Information Techniques, Chinese Academy of Forestry, Beijing 100091, China; huyaopeng123@gmail.com
[2] Research Institute of Forestry Policy and Information, Chinese Academy of Forestry, Beijing 100091, China; 20221100374@csuft.edu.cn (J.Z.); wqj2020@cau.edu.cn (Q.W.); xuangin23@swfu.edu.cn (X.Y.); douyq@caf.ac.cn (Y.D.)
[3] College of Electronics and Physics, Central South University of Forestry and Technology, Changsha 410018, China
[4] College of Economics and Management, China Agricultural University, Beijing 100107, China
[5] College of Economics and Management, Southwest Forestry University, Kunming 650233, China
[6] Faculty of Forestry, The University of British Columbia, Vancouver, BC V6T 1Z4, Canada
* Correspondence: zhaoxiaodi@caf.ac.cn; Tel.: +86-136-7105-3260

Abstract: Forests are among the most diverse ecosystems on the planet, and their biomass serves as a key measure for assessing the biological productivity and carbon cycle of terrestrial forest ecosystems. Recognizing the factors that impact forest ecosystems is essential for assessing their health and developing effective conservation strategies to preserve species diversity and ecological equilibrium. This study considered forest biomass as the explained variable, economic density as the explanatory variable, and human activities, land use, and forestland protection as the control variables. Panel data encompassing 448 counties within the Yellow River Basin (YRB) for the years 2008, 2013, and 2018 were utilized as inputs for ArcGIS spatial analysis and two-way fixed-effects modeling. This approach aimed to evaluate the impact of socio-economic factors on forest biomass. The findings indicate that, (1) from both temporal and spatial viewpoints, the distribution of forest biomass in the upper reaches of the Yellow River demonstrated an improvement over the period from 2008 to 2018. Notably, in 2013, there was a significant reduction in the forest biomass distribution in the middle and lower sections, although the levels remained substantially above the average for those regions. Throughout the period from 2008 to 2018, the overall forest biomass within the YRB displayed a spatial distribution pattern, with elevated levels observed in the western areas and diminished levels in the eastern regions. (2) A one-unit increase in economic density led to a 1.002% increase in forest biomass. In the YRB, a positive correlation was observed between the economic density and forest biomass, especially in the middle and lower reaches of the river. (3) In the upstream region, forest biomass was strongly negatively correlated with cultivated land but significantly positively correlated with forest land protection. In the middle reaches, although population growth and arable land expansion led to a decrease in forest biomass, primary industry development and urbanization promoted forest biomass growth. The development of primary industries other than planting, such as the forestry industry, can contribute to the forest biomass. Moreover, in the downstream area, a strong negative correlation was observed between the number of permanent residents and forest biomass. We recommend modifications to human activities to enhance the forest biomass and the preserve forest ecosystem stability.

Keywords: forest biomass; socio-economic factors; the two-way fixed-effects model; Yellow River Basin

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1. Introduction

Forests represent the largest reservoir of organic carbon among the world's terrestrial ecosystems and, thus, are crucial for managing the global carbon balance. They help to mitigate increases in greenhouse gas levels in the atmosphere, improve the carbon absorption capabilities of living organisms, and contribute to the stability of the global climate [1,2]. Forest biomass plays a crucial role in forest ecosystems, serves as a significant climatic factor for assessing the exchange of carbon dioxide between the land and atmosphere, and is essential for preserving the ecological equilibrium and safeguarding soil and water resources [3]. However, in recent years, forest ecosystem deterioration has surpassed the threshold of acceptable change, resulting in a decline in forest cover and biomass that has had profound effects on both socio-economic and environmental systems [4]. Although ongoing increases in resource-intensive and energy-intensive development coupled with population growth and urbanization [5] have contributed to economic advancement, they have also exerted detrimental effects on forest vegetation. Quantitative and precise assessments of the magnitude and distribution patterns of forest biomass and analyses of the factors influencing these patterns can help mitigate climate change [6]. Moreover, comprehensive examinations of the intrinsic relationship between the economic density and forest biomass are essential for elucidating the true implications of economic development on the ecological environment.

Previous studies have investigated the spatiotemporal distribution of forests by analyzing biomass measurements and monitoring data. To estimate forest biomass, statistical methods such as the Tau Omega model [7], stepwise regression [8], Richards growth equation fitting method [9], and multiple linear regression model [10] are frequently applied. Furthermore, the mean biomass density method (MBM), mean ratio method (MRM), and continuous biomass expansion coefficient (BEF) method utilize forest inventory data to estimate forest biomass [11]. The application of remote sensing technology to examine the spatiotemporal distribution characteristics of forest biomass holds considerable importance for comprehending the structural and functional dynamics of forests alongside the carbon sequestration potential of various ecosystems [12]. Remote sensing data, such as MODIS, the Landsat series, and SPOT, are widely used because of their high spatial and temporal resolutions [13–15]. Previous research on forest biomass can be classified into aboveground biomass and underground biomass studies. For instance, research has examined the spatial variability of aboveground forest biomass and the factors influencing it [16], which serve as indicators of energy flow and material cycling within forest ecosystems [17,18].

The majority of research examining the determinants of forest biomass has concentrated on natural variables. The influence of temperature and precipitation on forest biomass represents a significant area of inquiry within ecological studies [19] because these variables are instrumental in influencing the distribution patterns of forest biomass [20,21]. For example, increases in precipitation augment the biological growth capacity of organisms [22–25]. The allocation of forest biomass reflects the direct response of plants to environmental changes [26]. Compared to aboveground biomass, root biomass (underground biomass) is less limited by precipitation owing to changes in biomass allocation [27]. Continuous economic development impacts the climate, soil, and forest type, thereby affecting forest biomass [28]. Researchers have identified a significant correlation between urbanization and the ecological functions of forests in the warm and humid regions of the YRB, employing coupling coordination and cross-sectional threshold regression models in their analysis [29]. Analyses have also indicated that the impact of human socio-economic activities on variations in forest biomass are not well-understood [30]. Thus, research efforts to identify the factors underlying the effects of human activities on forest biomass must be increased to promote the restoration and enhancement of forest biomass [31].

Although the research on forest biomass is relatively mature, previous studies were primarily performed at the macro level, with only a few studies applying multiple regression models to analyze the factors that influence forest biomass. In addition, more comprehensive research is needed on how human socio-economic activities affect forest biomass. Therefore, this study takes the YRB as a typical forested study area and explores the impact of economic development on forest biomass by characterizing the spatial and temporal evolution of county-level forest biomass and economic density. This study helps to formulate more targeted and practical policies to balance the relationship between forest biomass and socio-economic development, and, ultimately, achieve the coordinated development between forest ecology and social economy.

2. Materials and Methods

2.1. Study Area

The Yellow River Basin is located between 96–119° E and 32–42° N, encompassing a total area of 795,000 km^2. Positioned in a mid-latitude zone, the Yellow River Basin is impacted by atmospheric and monsoon circulation patterns and exhibits significant climatic differences in different sections of the basin. The source of the Yellow River is found in the northern base of the Bayan Kara Mountains on the Qinghai Plateau. The river flows eastward, traversing the Loess Plateau and Huang-Huai-Hai Plain before discharging into the Bohai Sea. The main stream has a total length of 5464 km and experiences a water surface drop of 4480 m. The YRB has a vast territory, numerous mountain ranges, and significant differences in elevation characterized by a high western region and a low eastern region, resulting in a three-tiered topographical staircase that transitions from west to east.

In accordance with the division plan established by the Yellow River Water Conservancy Commission, the Yellow River is segmented into upper, middle, and lower reaches, with Hekou town separating the upper and middle reaches and Taohuayu separating the middle and lower reaches. The area situated above Hekou Town in Toktuo County, Inner Mongolia Autonomous Region, constitutes the upper reaches of the YR, which extends for 3472 km and presents a drainage area of 428,000 km^2. The Taohuayu, which flows from Hekou Town in Toktuo County to Guangwu Town in Xingyang City, Zhengzhou City, Henan Province, represents the middle reaches of the YR, which extends for 1206 km and covers a drainage area of 344,000 km^2. The area below Taohuayu represents the downstream area, which extends for 786 km and covers a drainage area of only 23,000 km^2 (Figure 1). The Yellow River traverses various provinces and municipalities, including Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong. Notably, economic development differs greatly across regions, which significantly influences the establishment and sustainability of forest ecological engineering and resource management.

2.2. Variable Selection and Data Sources

Explained variable: Forest biomass pertains to the total accumulation of dry matter generated by forest plant communities throughout their life cycles. This accumulation is a consequence of the prolonged production and metabolic activities within the forest ecosystem. Furthermore, forest biomass serves as a significant metric for assessing the stability and biodiversity of these ecosystems [32]. The forest biomass for each county within the YRB was determined utilizing forest resource inventory data from the seventh to ninth assessment periods (2008, 2013, and 2018) through the application of the weighted average method. Additionally, linear interpolation was employed to address the limited number of missing values.

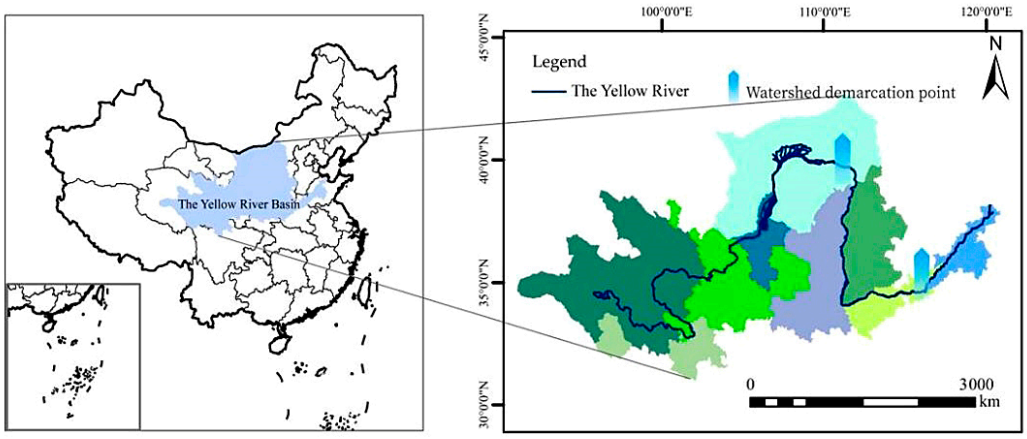


Figure 1. Map of the study area. The demarcation point separating the middle and upper sections of the Yellow River Basin (YRB) is identified as Hekou Town, located in Toktuo County within the Inner Mongolia Autonomous Region. The boundary distinguishing the middle and lower sections of the YRB is designated as Taohuayu, situated in Xingyang County, Zhengzhou City, Henan Province.

Core explanatory variable: Economic density is expressed as the ratio of regional GDP to regional area; economic density is used to reflect the level of economic benefits per unit area. It was used to investigate the impact of economic development level on forest biomass [33]. In addition to assessing the efficiency of economic activities and the intensity of land use within an urban area, economic density serves as an indicator of the concentration of economic activity within a specific region [34–36]. Relevant data were sourced from the main data bulletins of the 2008, 2013, and 2018 National Economic Census of the National Bureau of Statistics of China (https://www.stats.gov.cn/ (accessed on 3 November 2024)).

Control variables: The selected variables, which include the proportion of the primary industry, the proportion of the secondary industry, population density, the rate of urbanization, the proportion of cultivated land area, the proportion of construction land, and the degree of forest land protection, were identified based on the findings of prior research [37]. Among them, socio-economic data such as proportion of primary and secondary industries, population density, and urbanization rate were sourced from the National Bureau of Statistics of China (https://www.stats.gov.cn/ (accessed on 3 November 2024)). The land use data, characterized by a spatial resolution of 10 m, were obtained from datasets released in the years 2008, 2013, and 2018 by the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/ (accessed on 5 November 2024)). The pertinent information regarding the levels of forest land protection was sourced from the National Forestry and Grassland Administration of China (https://www.forestry.gov.cn/ (accessed on 3 November 2024)). The forest conservation classification system utilized in the forest resource inventory categorizes forests into four distinct grades, designated as I through IV. It is observed that, as the grade ascends, the degree of protection afforded to the forest decreases. Detailed descriptions of each variable are shown in Table 1.

Table 1. Description of control variables.

Variables	Abbreviation	Description
Explained variable		
Forest biomass	bm	Mass of accumulated dry matter per unit area (t/hm^2)
Core explanatory variable		
Economic density	eco	Gross regional product/area of administrative region (billion yuan/km^2)
Control Variables		
Proportion of the primary industry	agri	Ratio of the value added of the primary industry in the county to the county's GDP (%)
Proportion of the secondary industry	indus	Ratio of the value added of the secondary sector in the county to the county's GDP (%)
Population density	ps	Ratio of permanent population to county area (thousands of people/km^2)
Urbanization rate	urbi	Percentage of permanent urban residents (%)
Proportion of the cultivated land area	farmland	Ratio of cultivated land area to county area (%)
Proportion of the construction land	constru	Ratio of construction area to county area (%)
Forest protection level	protect	Weighted average of "forest land protection level" in the sample land attribute table

2.3. Methods

2.3.1. ArcGIS Spatial Analysis

ArcGIS geographic information system (GIS) software was developed by the American Institute for Environmental Systems (ESRI), and it has powerful map-making, spatial analysis, and spatial-data-database-building functions. The most important application of ArcMap is that it provides data and layout views in two ways. ArcGIS spatial analysis technology facilitates the extraction and transmission of spatial information by utilizing the spatial data associated with specific locations and the characteristics of geographical entities [38]. In this study, ArcGIS (version 10.8) software was used to process forest resource inventory data from periods 7 to 9 and extract vector data. Subsequently, forest biomass vector data in the YRB were analyzed as follows: (1) GIS spatial analysis function was used to perform biomass spatial interpolation and modeling and generate a forest biomass distribution map; (2) GIS technology was used to analyze data related to economic density to understand the economic environment around forest resources; and (3) forest biomass and economic density index data were integrated into the GIS platform for spatial analysis and visualization. We then applied the natural breakpoint classification method to divide forest biomass and economic density in the YRB into different grades. Each grade represents a collection of counties or regions with similar forest biomass or economic density.

2.3.2. Two-Way Fixed-Effects Model

In this study, a two-way fixed-effects model was used to assess the impact of economic development on forest biomass in the YRB. The model is calculated as follows:

$$Y_{it} = \beta_0 + \beta_1 eco_{it} + \beta_2 X_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (1)$$

where i represents county (district) and t is time; Y_{it} represents the forest biomass of each county (district) in the YRB, and eco_{it} represents economic density; X represents the set of control variables that may affect forest biomass besides economic density; β_0 represents

the intercept term; β_1 and β_2 represent the regression coefficients, which reflect the degree of influence of each variable on the dependent variable; μ_i represents individual effects that remain unchanged over time; σ_t indicates the time fixed effect; and ε_{it} is the random interference term.

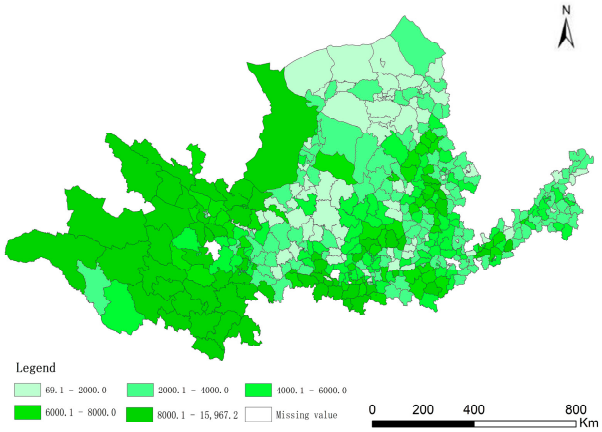
3. Results and Analysis

3.1. Spatial and Temporal Distribution Patterns of Forest Biomass and Economic Density

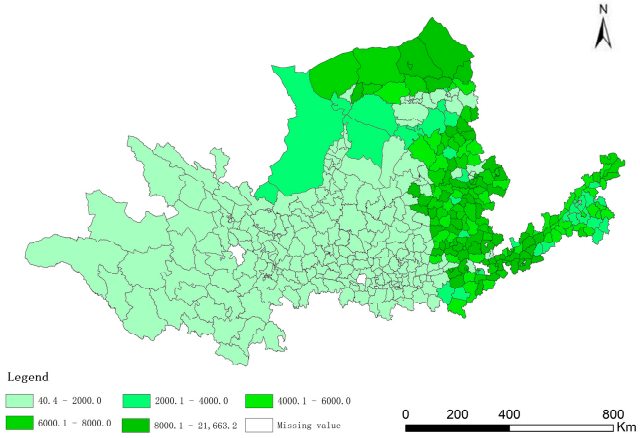
To visually reflect the spatial differences and temporal evolution characteristics, this study uses ArcGIS 10.8 software to visualize the forest biomass of the counties within the YRB in 2008, 2013 and 2018, respectively (Figure 2). The forest biomass within the county of the YRB was subsequently categorized into five distinct grades utilizing the natural break classification methodology. An analysis of the distribution patterns of forest biomass in the three phases reveals significant improvements in forest biomass in the YRB that were characterized by considerable fluctuations from 2008 to 2018. In 2013, a substantial decline in forest biomass was observed in the upper reaches, while a marked increase was observed in the middle and lower reaches. In 2018, however, a significant increase in forest biomass was observed in the upper reaches while a considerable decrease was observed in the middle and lower reaches. The significant decline in forest biomass may be related to anthropogenic-activity-induced forest degradation.

Between 2008 and 2018, the spatial distribution of forest biomass in the YRB exhibited a pattern characterized by lower biomass levels in the eastern region and higher levels in the western region. Moreover, the distribution of forest biomass in different sections showed significantly uneven characteristics. An annual analysis revealed that the forest biomass distribution in the YRB in 2008 was low in the east and high in the west. Furthermore, the forest biomass in the upper reaches of the Yellow River was significantly greater than that recorded in the middle and lower reaches, with the middle reaches demonstrating the lowest distribution of forest biomass. Affected by various factors, the 2013 YRB forest biomass pattern was high in the west due to serious damage to the vegetation of the YRB, soil erosion on the Loess Plateau, low forest coverage rates, and slow recovery speeds. In 2018, the distribution of forest biomass in the YRB presented a gradient characterized by lower levels in the eastern region and higher levels in the western region. Notably, the forest biomass in the upper reaches was substantially higher than that in the middle and lower reaches.

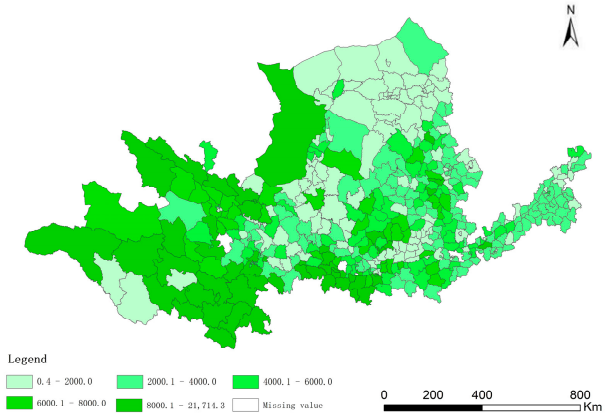
The natural break classification method was used to divide the economic density of 448 counties in the YRB into five levels [39], and the results are shown in Figure 3. The alterations in economic density within the YRB from 2008 to 2018 demonstrated a notable imbalance. The economic density of the upstream region has been developing slowly over a long time, while that in the middle and lower reaches has significantly increased, indicating that the speed of economic development in the upstream region lags behind that in the middle and lower reaches. Moreover, the economic density distribution showed a trend of low density in the west and high density in the east in 2008, 2013, and 2018. The economic density in the upper reaches of the Yellow River has consistently been characterized by a relatively low level, while that in the middle reaches shows obvious development momentum, with the development in only a few central urban areas matching that in downstream areas. The downstream has always presented the highest level of economic development in the YRB.



(**a**)

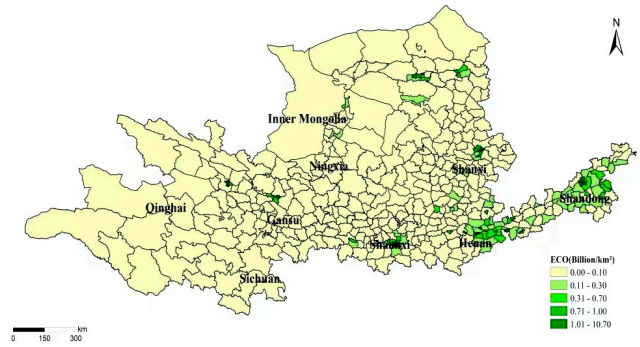


(**b**)

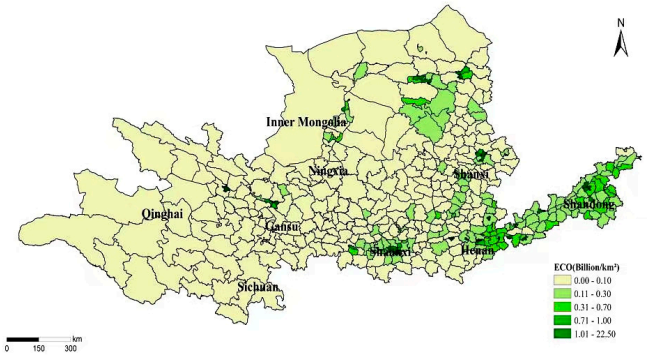


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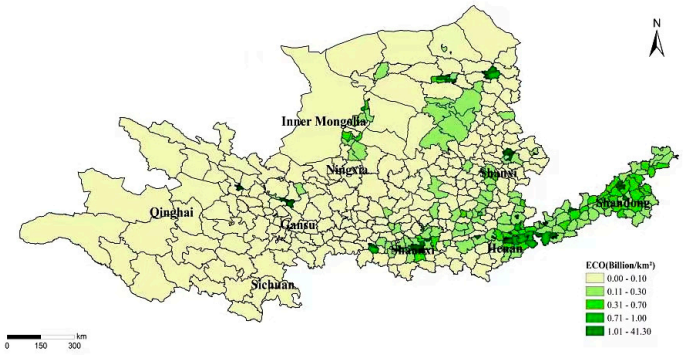
Figure 2. Spatial distribution pattern of forest biomass (t/hm^2) in the YRB in 2008, 2013, and 2018. (**a**) represents the spatial distribution pattern of forest biomass in the YRB in 2008, (**b**) represents the spatial distribution pattern of forest biomass in the YRB in 2013 (**c**) represents the spatial distribution pattern of forest biomass in the YRB in 2018.



(**a**)



(**b**)



(**c**)

Figure 3. Spatial distribution pattern of economic density in the YRB in 2008, 2013, and 2018. (**a**) represents the spatial distribution pattern of economic density in the YRB in 2008, (**b**) represents the spatial distribution pattern of economic density in the YRB in 2013 (**c**) represents the spatial distribution pattern of economic density in the YRB in 2018.

3.2. Regression Results

Due to the substantial disparities in economic development across counties within the YRB, economic density had varying impacts on forest biomass. As shown in Table 2, the fixed-effects regression indicated that, from 2008 to 2018, the economic density in the YRB significantly positively impacted the county-level forest biomass across the entire basin. For every 1 unit increase in economic density (i.e., 100 million yuan increase in economic output per square kilometer of land), the forest biomass will increase by 1.002%. From a watershed perspective, economic density exhibited a positive yet statistically insignificant influence on forest biomass in the upper reaches of the Yellow River. Conversely, it demonstrated a significant positive impact in the middle and lower reaches of the river. These findings

indicate that a certain balance has been reached between economic development and forest ecological protection in these regions.

Table 2. Estimated results for the fixed-effects regression coefficients.

Variable	Entire Basin		Upper Reaches		Middle Reaches		Lower Reaches	
	Coefficient	t	Coefficient	t	Coefficient	t	Coefficient	t
eco	1.002 ***	96.07	0.066	0.61	0.281 ***	3.82	0.462 ***	2.94
agri	0.001	0.12	0.084	1.02	0.188 ***	3.84	0.083	0.77
indus	−0.011	−0.72	−0.051	−0.43	0.087	1.03	0.134	0.61
ps	−0.553 ***	−34.75	−0.016	−0.17	−0.224 ***	−2.99	−0.535 ***	−3.51
urbi	−0.046 ***	−2.20	−0.109	−0.61	0.01 **	0.08	−0.400	−1.45
farmland	0.002 *	0.24	−0.113 ***	−2.66	−0.104 **	−2.38	−0.002	−0.02
constru	−0.008	−1.03	−0.132 **	−2.14	−0.100	−1.33	0.270	1.04
protect	−0.057 ***	−2.22	−0.691 **	−1.96	0.808 ***	3.93	0.091	0.35

Note: ***, **, and * represent significance at the 10%, 5%, and 1% levels, respectively.

Among other variables, population density, urbanization rate, and forest land protection had significant impacts on forest biomass throughout the entire basin. Specifically, for every 1% increase in population density, 1% increase in urbanization rate, and 1 unit increase in forest protection, the forest biomass decreased by 0.553%, 0.046%, and 0.057%, respectively.

A significant negative correlation was observed between forest biomass and the proportions of arable and construction land and level of forest protection in the upper reaches of the YR, which reflects the negative effects of land expansion for production and living on forest biomass and the positive effect of forest conservation on forest biomass. In the middle reaches of the YR, the factors that influenced the forest biomass were more complex, with a significant positive correlation observed between economic development, especially primary industry development, and forest biomass. Population growth and arable land area expansion were significantly negatively correlated with forest biomass, while population urbanization promoted the growth of forest biomass. This indicates that vigorously developing primary industries other than planting, such as the forestry industry, represents an effective path to increasing forest biomass in this region. This also explains why counties with higher forest protection levels had a higher forest biomass. The general scarcity of natural forest resources and abundance of artificial forests may be an important reason for this phenomenon. At present, the lower reaches of the Yellow River represent the most densely populated area in the entire basin, and further increases in population density are not conducive to the accumulation of forest biomass. This result reveals that excessive population agglomeration has an unavoidable influence on forest ecology.

3.3. Robustness Test

The variable substitution method assesses the stability of the original base regression model by replacing the main variable economic density with GDP. The results of the regression analysis are shown in Table 3. The correlation coefficient for the substituted core variable, GDP, was found to be positive and exhibited a significant impact on the dependent variable, forest biomass. Consequently, the degree of economic development within the entire watershed and central region aligns with the fundamental regression findings regarding both directionality and significance.

Table 3. Robustness check with alternative core explanatory variable.

Variable	Entire Basin		Midstream	
	Coefficient	t	Coefficient	t
GDP	0.119 ***	3.08	0.150 ***	2.83
agri	0.145 ***	3.86	0.154 ***	3.20
indus	0.079	1.21	0.101	1.17
ps	0.057	−1.310	−0.058	−0.92
urbi	−0.025	1.41	0.127	0.98
farmland	−0.126 ***	−4.71	−0.112 **	−2.56
constru	−0.093 **	−2.19	−0.047	−0.65
protect	0.216	1.42	0.782 ***	3.77

Note: ***, ** represent significance at the 10%, 5% levels, respectively.

4. Discussion

4.1. Driving Forces on the Spatial and Temporal Variation of Forest Biomass

A significant variation in the levels of economic development has been identified across the provinces and regions within the YRB [40], which is closely related to differences in the reform and opening-up processes in different regions [41]. Over time, the economic development of these regions has produced great changes. To solve the problem of coordinated economic and ecological development, the government and local enterprises have taken measures such as strengthening water conservancy construction, promoting environmental protection and ecological restoration, and increasing support for scientific and technological innovation, talent training, entrepreneurship, and innovation. The YRB exemplifies a region in China characterized by ecological vulnerability, which is associated with its inadequate ecological foundation, limited water resources, significant soil erosion, and diminished capacity to support both resources and the environment. The growth and regeneration of forested areas have been improved by enacting ecological protection policies, promoting initiatives such as the conversion of agricultural land to forested areas, enhancing the public awareness of ecological and environmental conservation, and implementing other beneficial factors. Such policies led to a higher forest biomass in 2018 relative to the levels recorded in 2008. Increases in ecological protection work, strengthening of forest pest prevention and control, and improvements in forest management levels all led to increases in forest biomass in the YRB. However, the forest biomass declined slowly in 2018, which was associated with multiple factors. The results revealed that human activities can change forest ecological environments and directly impact forest biomass. Simultaneously, the human demand for forest resources increases with economic development and population growth, thereby increasing the pressure on forest ecosystems.

4.2. Relationship Between Forest Biomass and Economic Density

Changes in forest biomass are closely related to natural factors and human activities [42]. The rapid economic advancement, anthropogenic construction activities, and increased urbanization and industrialization in the YRB resulted in the degradation of forest biomass over a considerable period of time. Nevertheless, with the development of the region and focus on economic transformation, the economy has improved, which has also contributed to enhancing the forest biomass.

Overall, increases in economic density are associated with intensified economic activity and population expansion, which lead to a higher demand for forest resources and, thus, have a negative impact on forest biomass to some extent. In recent years, the awareness of ecological protection and sustainable development has continuously increased among the population, and strict forest protection policies have been introduced. The increasing investments in forest protection partially offset the negative impact of economic growth on

forest biomass. Economic development also indirectly affects forest biomass by promoting scientific and technological progress and industrial upgrades. For example, by promoting advanced forest management technologies and methods, the growth rate and biomass accumulation capacity of forests can be improved. Simultaneously, industrial upgrades have reduced the direct dependence on forest resources, thereby reducing the pressure on forest biomass [43]. Previous studies have shown that economic development has promoted improvements in forest biomass and forest quality in the YRB [44–46]. In addition, interactions among various factors lead to fluctuations in forest biomass, with the main influencing factors being population density, urbanization rate, and forest land protection. Population expansion and urbanization may encroach on the area of forest land, leading to the excessive development and utilization of forest resources. The significant negative correlation between the forest conservation grade and forest biomass indicates a greater emphasis on forest protection in a given region leads to increases in forest biomass. This fully highlights the importance of forest land protection. Of course, high levels of forest conservation also require strict management and protection measures, which may also have adverse effects on fragile ecosystems, leading to a decrease in forest biomass. Therefore, human activities should be prohibited or restricted when necessary to protect the forest biomass and ecosystem integrity.

Due to the ecological sensitivity and the strategically important geographical location of the upper reaches of the Yellow River, this region has been classified as a critical national zone for restricted development. Although this area has experienced relatively slow economic growth, it possesses substantial potential for extensive forest cultivation. Our findings revealed that economic density had a minimal influence on the forest biomass in this region, whereas land use factors, such as the ratio of cultivated and constructed land and degree of forest land protection, exerted a considerable effect on forest biomass. While it is essential that we prioritize the preservation of forest biomass, the economic development of this region also remains a paramount concern. The implementation of western development strategies is, therefore, vital [47]. Such strategies were designed to build a synergistic relationship between ecological integrity and economic advancement, which can facilitate conservation efforts while increasing the income level and well-being of residents in upstream counties.

From 2008 to 2018, the economy of the middle reaches of the Yellow River underwent substantial growth; however, concomitantly, environmental issues emerged as a significant concern. This region is abundant in coal resources; thus, extensive coal mining operations have been undertaken to facilitate economic growth. However, due to rapid development and inadequate technological infrastructure, a series of ecological challenges have arisen, thereby accelerating local ecological environment degradation and decreasing the forest biomass. The rapid urbanization of densely populated areas has led to urban sprawl and alterations in land use. This urban expansion has encroached upon extensive areas previously designated as biological habitats, which has altered land use patterns and caused significant biological migrations. Additionally, the pollution and noise associated with urbanization have further adverse effects on forest biomass. Almost all regions in the middle reaches of the Yellow River have acknowledged that economic activities have led to ecological degradation and proactively undertaken initiatives to address these environmental issues. These initiatives encompass the thorough execution of ecological conservation strategies and policies, including the restoration of agricultural land to forest and grassland ecosystems. These measures aim to alleviate the negative impact of economic activities on forest biomass and restore the ecological balance of the region. Thus, increases in primary production and forest protection are positively associated with forest biomass.

In the lower reaches of the Yellow River, the areas surrounding Beijing and coastal cities, which present advantageous geographical attributes, have provided a robust foundation for economic advancement. In contrast to the middle and upper reaches of the Yellow River, the lower reaches demonstrate a greater degree of economic development, a more advantageous ecological environment, and a more significant alignment between ecological and economic considerations, although they remain below the national average. The swift pace of economic growth has led to the increased utilization and consumption of forest resources, thereby undermining the sustainable enhancement of biomass.

4.3. Limitations

This study delineates a viable trajectory for forest biomass conservation along with social and economic advancement in the upper, middle, and lower reaches of the YRB. Furthermore, it offers significant insights for other nations and regions seeking to achieve a harmonious balance between ecological sustainability and economic growth. Although our analysis was comprehensive, certain important factors that affect forest biomass may have been overlooked. The complexity of forest ecosystems is influenced by many factors, including climate change, policy adjustments, and human activity pattern changes. Therefore, to fully consider the interaction between climate change and economic development, follow-up studies should explore the specific mechanisms underlying the effects of these factors on forest biomass to obtain more comprehensive and in-depth research results. Moreover, only seven indicators, including economic density, human activity, land use, and woodland protection, were selected as the explanatory and control variables. However, other factors, such as climate change and land degradation, may have also influenced forest biomass. Therefore, the results may have been influenced by factors not considered in this study.

5. Conclusions

In this study, the relationship between economic density and forest biomass in counties in the YRB from 2008 to 2018 was analyzed at multiple levels and dimensions using ArcGIS spatial analysis and a two-way fixed-effects regression analysis. The following key conclusions were obtained:

First, according to temporal trends, the county-level forest biomass in the YRB showed a fluctuating increase from 2008 to 2018, and this overall improvement indicates that the forest ecosystems in the YRB were restored and protected to a certain extent during the study period. According to spatial distribution trends, the county-level forest biomass in the YRB showed a higher concentration in the western region and a lower concentration in the eastern region.

Second, economic density was significantly and positively correlated with forest biomass throughout the YRB, especially in the midstream and downstream counties, during the study period. This implies that the counties in the YRB have not sacrificed forest ecology at the expense of economic development but rather have achieved a win–win situation with forest land protection.

Third, additional factors such as population growth, urbanization, and forest conservation have significant impacts on forest biomass. In the upper reaches of the YRB, the increase in the proportion of arable land and construction land had a significant negative impact on forest biomass. However, policies to protect forest land can significantly increase forest biomass. In the middle reaches, population growth and arable land expansion were significantly negatively correlated with forest biomass, whereas the primary industry development and urbanization promoted the growth of forest biomass. The vigorous development of primary industries other than planting, such as the forestry industry, can

contribute to forest biomass. In regions downstream of high population areas, excessive population growth causes unavoidable interference on forest ecology.

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