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The Temporal and Spatial Evolution Characteristics of the Ecosystem Service Value and Conversion Rate in China's Key State-Owned Forest Regions

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Abstract: To achieve a sustainable development path that harmonizes ecological and economic considerations, China has advocated the "two mountains" concept: "lucid waters and lush mountains are invaluable assets". This idea posits that those who protect the environment can economically benefit by selling pristine landscapes and utilizing rich ecological resources. This paper use "the equivalence factor method" to calculate ecological benefits, introduces a technical measure—the conversion rate of ecosystem service value—and analyzes its temporal and spatial evolution from 2003 to 2020 in the operational areas of 87 state-owned forestry enterprises in Northeast China. The findings show: (1) a significant improvement in ecosystem-service quality, with its value increasing from 404.7 to 850.2 billion CNY between 2003 and 2020. The restoration of the ecological environment in China's KSFR provides a foundation for economic and social development. (2) A decrease in the economic gains derived by operators from developing protected ecosystems, with the most significant decline observed in economic benefits generated from the supply product, including timber harvesting. However, the industrial structure in KSFR shifted from being dominated by timber production to diversified development, with non-timber forest resources becoming an important part of regional economic growth. (3) Significant potential for realizing the value of ecosystem services, evidenced by an increasing trend in the conversion rates of cultural, regulatory, and supporting services. These findings underscore the effectiveness of China's natural forest protection and restoration policies in optimizing forest ecology and realizing the "two mountains" concept through appropriate market transactions and ecological compensation mechanisms.

Keywords: ecosystem service value (ESV); value conversion rate; China's key state-owned forest region (KSFR); spatiotemporal characteristics; the equivalence factor method

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1. Introduction

To reconcile the dichotomy between ecological preservation and economic expansion, China has advanced the scientific conclusion that "lucid waters and lush mountains are invaluable assets" [1–3] (the "two mountains" concept) while concurrently investigating methodologies for translating ecological worth into economic capital. This concept delineates a promising blueprint for sustainable development: in one sense, ecological conservation fosters the ongoing restoration of resources and functionalities within ecosystems, thereby establishing a cornerstone for the development and utilization of forest resources [4]. In another sense, the formulation of suitable market transactions and ecological compensation schemes is directed toward catalyzing the transformation of forest ecological worth into economic value [5]. Simultaneously, the sustained economic value derived from forest growth serves to incentivize operators in cherishing and safeguarding the ecological environment [6]. However, presently, the majority of forest conservationists and operators have not yet achieved sufficient economic remuneration, often finding themselves in a relatively impoverished state [7–9]. Consequently, avenues for converting ecological value into economic value remain ripe for exploration.

The paradox of ecological resources hindering economic growth affects not only China but also other countries globally. Many developing nations have found that despite having abundant ecological resources, economic growth is not accelerated; instead, it is impeded [10]. This phenomenon occurs even in regions with well-functioning institutions and markets [11–13]. Consequently, to achieve short-term economic growth, countries with rich ecological resources often overexploit them, leading to ecological and economic crises [14]. Therefore, the extent to which ecological resources can be converted into economic growth, as well as the mechanisms through which this conversion occurs, pose formidable challenges for economies worldwide.

In academic circles, discussions surrounding the conversion of ecological value into economic value have gained prominence. The discourse primarily centers on the following three aspects. First, the debate centers on whether ecological value should undergo conversion into economic worth. Radical viewpoints posit that ecosystem services' value serves merely as a utilitarian rhetorical construct and does not align with economic valuation [15,16]. Conversely, mainstream perspectives argue that, despite encountering diverse constraints, promoting the translation of ecological value into economic worth remains imperative [17]. Second, deliberations pivot on identifying which ecological values can be transmuted into economic value. Ethically, given individuals' direct or indirect benefits from ecological preservation, it is deemed essential to offer economic recompense for conservation endeavors [18–20]. From a feasibility standpoint, ecosystem services exhibiting both exclusivity and competitiveness hold the potential for monetization [21–23]. Third, there is debate over who should facilitate the conversion of ecological value into economic value. Some advocate for a balance between government intervention ("visible hand") and market forces ("invisible hand") to drive this transformation [24–26]. However, this overlooks a critical aspect: the extent of the gap between the economic and ecological values of ecosystem services, as well as which services contribute to this gap. This oversight leads to debates mired in ideological disputes.

This paper aims to clarify the process, extent, and components of converting ecological value into economic value by proposing a reasonable technical indicator. We focus on the key state-owned forest regions in Northeast China and Inner Mongolia (KSFR), collecting relevant data to quantify their ecological and economic values. Our study seeks to elucidate China's ecological civilization construction and the relationship between ecological and economic values in this context. We specifically examine three aspects: the ecological value of the KSFR, the extent of its conversion into economic value, and the stage-specific characteristics and reasons for this conversion. The significance of this work lies in its ability to measure the disparity between the expected and actual payments for ecosystem services and propose solutions to bridge this gap.

2. Theoretical Framework: The Conversion Process and Logic of Ecological Value

2.1. The Process of Ecological Value Conversion in China

In the course of China's social development, ecological and economic systems have gradually merged [27]. The reform and opening-up policy initiated in 1978 marked the onset of rapid economic growth. However, this growth, centered on economic development, has been accompanied by significant ecological degradation [28]. Major floods in 1998, affecting rivers like the Yangtze, Nenjiang, and Songhua, prompted a reevaluation of China's development model [29]. To balance ecological and economic considerations, the Chinese government implemented various environmental protection policies, including the well-known Natural Forest Protection Project (NFPP). This initiative, which began in 2016, halted commercial logging in all natural forests in Northeast China, representing a significant step toward nationwide natural-resource conservation [30–33].

Following over two decades of the Natural Forest Protection Project, China's forest resources, particularly natural forests, have seen significant restoration [34]. However, the logging-ban policy within the project has constrained operators' activities, leading to a search for alternative economic growth strategies [35]. Non-timber resources and forest recreation services, once overlooked, have become vital sources of income for residents and forestry enterprises in forest areas [36]. In addition, forestry communities and enterprises facing short-term transition challenges heavily rely on government ecological compensation for forest protection, significantly impacting residents' employment and livelihoods, along with forestry enterprises' production and revenue [37].

To address the complex interplay between economics and ecology, the Chinese government has championed the development principle that "lucid waters and lush mountains are invaluable assets". This so-called two mountains concept embodies three key ideas: first, ecological and economic values are not mutually exclusive and can coexist harmoniously [38]; second, ecological health forms the basis for economic prosperity, providing essential resources for growth [5]; third, ecological value and economic value are interconnected and can be mutually transformed, and under appropriate market and institutional designs, ecological value can be realized as economic value [4]. This vision of sustainable development has become a cornerstone of China's pursuit of an ecological economy.

China's forestry management reflects the logic and challenges of ecological-value conversion. First, there exists a profound interaction between ecosystems and economic systems: based on different stages of market and institutional designs, ecosystems can generate various products and services, thereby bringing economic value to operators through transactions and other means. Second, ecological value and economic value are not entirely equivalent, resulting in a conversion gap. Historically, a significant portion of forests' ecological value has not been fully realized as economic value, primarily owing to institutional deficiencies and market failures, particularly in the value of regulating services. Third, the extent to which ecological values estimated from various ecosystem services translate into actual economic benefits also reflects the level of sustainable economic and social development. In theory, the higher the degree of value realization, the more perfect the mechanisms and markets are for transforming ecological value into economic value. Building upon this, this paper further designs an analytical framework and empirical strategies to elucidate and validate the above stages of development more accurately.

2.2. Theoretical Analysis Framework

Drawing from the practical experiences of ecological value conversion in China, this paper presents a theoretical framework for analyzing the conversion of ecological value into economic value. This framework examines the interaction between ecosystem services and economic products/services within ecological economic systems (Figure 1). Ecosystems continuously provide various services, including provisioning, cultural, and regulating-and-supporting services. According to the Millennium Ecosystem Assessment (MA) [39], these services yield benefits for humanity. For instance, wood and non-wood forest products, as well as recreational services from forests, are consumed in the market. In addition, ecological conservation and restoration actions, under appropriate institutional designs or voluntary agreements, also yield economic returns [40,41]. Thus, the transition from ecosystem services to economic products/services is evident.

Although the transition of product types is intuitive, the transition of value forms is obscured. Ecological value is described as a normative state, implying the monetary amount that should be paid for ecosystem service utility [39]. By contrast, the economic value represents an actual state; that is, consumers, government agencies, and NGOs pay for a portion of ecosystem services and their derived products/services [42,43]. The disparity between the normative and actual states is often imperceptible. Since both ecological and economic values can be monetarily accounted for, this paper proposes a rational technical indicator—the conversion rate—from the perspective of value forms as a measure of the degree of ecological value conversion.

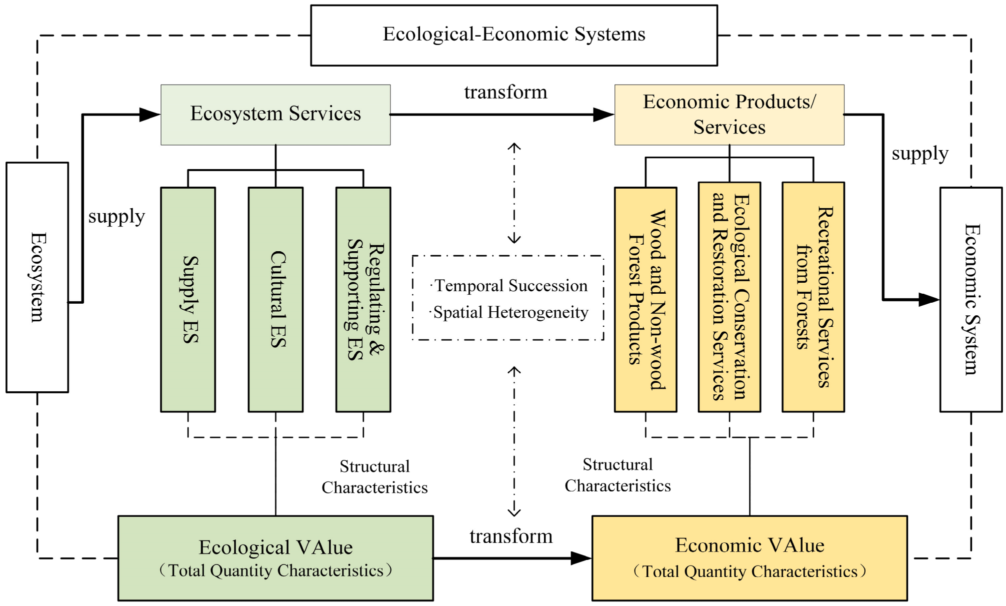


Figure 1. Theoretical analysis framework.

The conversion rate of ecosystem service value (K) can be applied to observe both the total quantity and structural characteristics of value. From the perspective of the total quantity, K explains to what extent ecological value is transformed into economic value by comparing the value of ecosystem services with the GDP generated by these services. From the perspective of structural characteristics, the conversion rate of ecosystem service value further deconstructs the economic value created by different types of ecosystem services and identifies which type of ecosystem service serves as the foundation for the continuous operation of the ecological economic system. Using panel data, this study examines the conversion rate of ecosystem service value in the KSFR from two perspectives: temporal and spatial. Over the past two decades, these areas have transitioned from timber harvesting to conservation, with non-timber forest products, forest tourism, and ecological services replacing timber as primary income sources [44]. Meanwhile, the 87 state-owned forestry-industry enterprises in the KSFR exhibit spatial variations in factors like geographical location, resource endowment, and capital investment, influencing the degree and structure of ecosystem service value conversion [45,46]. Assessing the conversion rate of ecosystem service value (K) from these two dimensions provides insights into the temporal evolution and spatial heterogeneity of ecosystem-service-value conversion in KSFR.

By applying the theoretical analysis framework mentioned above, this paper attempts to observe the experiences of ecological value conversion in KSFA from two perspectives: total quantity characteristics and structural characteristics, as well as temporal succession and spatial heterogeneity. Specifically, the research questions of this study are divided into three levels. First, what is the value of ecosystem services in the KSFR? Second, how much economic value do ecosystem services in the KSFR generate, and to what extent is ecological value converted? Third, what temporal succession experiences and spatial heterogeneity characteristics are exhibited by the cases of ecological value conversion in state-owned forest areas in Northeast China?

3. Materials and Methods

3.1. Study Area

The key state-owned forest region in Northeast China and Inner Mongolia (KSFR) is located roughly 120° E–135° E longitude and 38° N–56° N latitude. The forest area is 27.2748 million hectares, accounting for 12.64% of China's total forest area. The forest stock is 3.007 billion cubic meters, accounting for 17.55% of China's total forest stock [7]. The KSFR mainly consists of state-owned forest areas in three provinces of China: Heilongjiang, Jilin, and Inner Mongolia. They mainly include six state-owned forestry-industry groups. From the spatial distribution on the map, the northern part of the study area includes the Inner Mongolia Forest Industry Group and the Daxinganling Forest Industry Group. The central part comprises the Yichun Forest Industry Group and the Longjiang Forest Industry Group, while the southern part encompasses the Jilin Forest Industry Group and the Changbaishan Forest Industry Group. These groups are specifically divided into 87 state-owned forestry-industry enterprises for operation and management [47] (Figure 2).

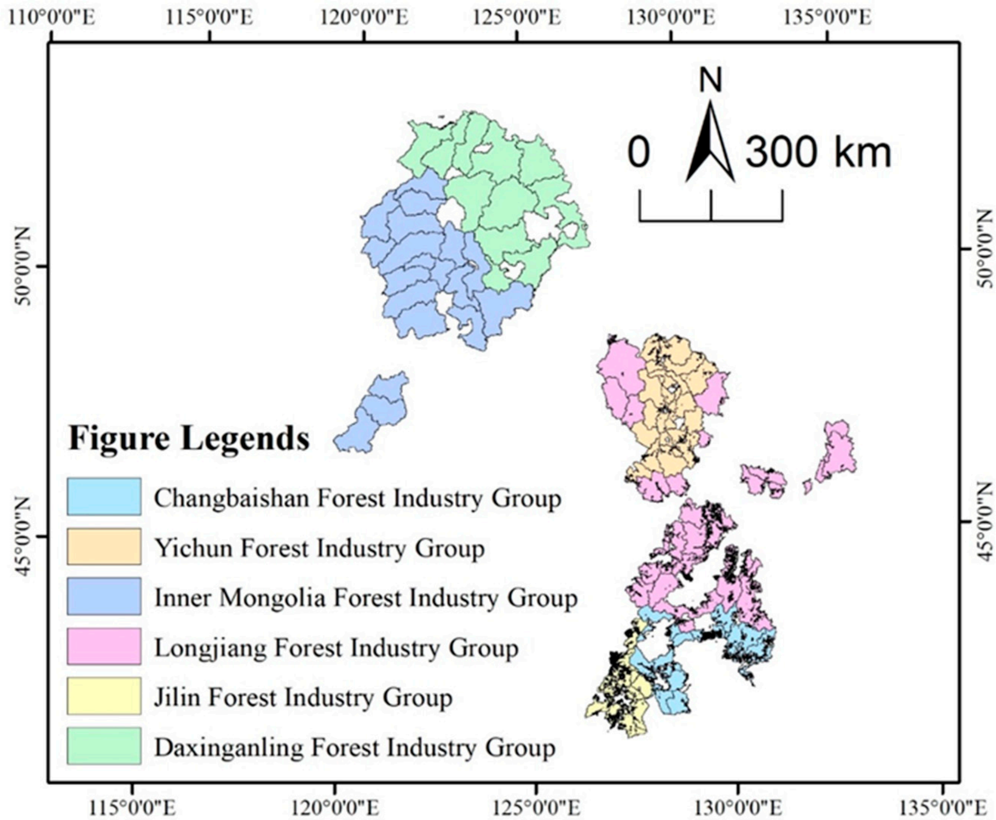


Figure 2. Spatial distribution map of NSFR.

The KSFR has long faced the dilemma of economic development versus ecological conservation. Its developmental trajectory has mainly passed through three stages: (1) there was a phase of timber-based economic growth marked by extensive forest resource consumption. Initially vital for China's timber production, these areas accounted for two-thirds of the country's output before 2000. However, rampant logging led to a dramatic decline in natural forest resources, shrinking by 71.50% from 1949 to 1990. (2) Strict limitations on resource exploitation were imposed during an ecological protection-and-restoration phase. Facing severe resource and environmental crises owing to extensive logging, the KSFR experienced significant challenges. In 1998, the Songhua River Basin in Northeast China witnessed severe flooding, threatening people's survival and regional food security. To strictly protect natural forest resources and mitigate local environmental degradation, the Chinese government initiated natural forest conservation projects in the region, gradually implementing strict measures such as logging restrictions and bans. However, for KSFR, heavily reliant on the timber economy, stringent resource constraints inevitably resulted in adverse effects on regional economic development. The timber industry faced extinction, residents struggled to sustain their livelihoods, and state-owned forestry enterprises grappled with transformation dilemmas. (3) Finally, there was the stage of exploring sustainable economic development under strict adherence to ecological protection policies. In this phase, the KSFR took on the responsibility of conserving vital ecological functions such as water conservation and biodiversity maintenance. State-owned forestry enterprises in the region transformed into nonprofit organizations, focusing on the realization of forest ecological product values while concurrently undertaking the public welfare tasks of protecting and restoring natural forests.

At present, the KSFR is exploring ways to achieve synergistic ecological and economic development through the conversion of ecosystem service value. By scientifically assessing the ecological and economic value of these services and value conversion rates and analyzing their spatiotemporal evolution patterns, the KSFR can optimize strategies. This effort aims to provide valuable insights and experiences for developing countries and regions worldwide that rely on forest resources.

3.2. Methods

3.2.1. Methods for Measuring the Conversion Rate of Ecosystem Service Value (K) of the KSFR

This study utilizes the conversion rate of ecosystem service value (K) to gauge the extent to which ecological values in the KSFR are translated into economic benefits. Essentially, it examines the conversion process from ESV to GDP. A higher rate indicates a more effective conversion of ecological benefits into economic gains, signifying a higher level of sustainable development in regions. Equations (1)–(4)are employed to compute the ecosystem service value conversion rates (K_T) for the operational areas of 87 state-owned forestry enterprises in the KSFR from 2003 to 2020. This calculation includes the conversion rates for supply-service value (K_S), regulating-and-support-service values (K_RP), and cultural-service value (K_C). Spatial-distribution maps illustrating the magnitude of the values for each sample within the study area are created using ArcGIS 10.7 software, and it is divided into five groups according to values, from small to large, and displayed in different colors.

The calculation formula is as follows:

$$K\_T = GDP\_T/ESV\_T \times 100\% \quad (1)$$

$$K\_S = GDP\_S/ESV\_S \times 100\% \quad (2)$$

$$K\_RP = GDP\_RP/ESV\_RP \times 100\% \quad (3)$$

$$K\_C = GDP\_C/ESV\_C \times 100\% \quad (4)$$

In the formula, K_T is the total ecosystem service value conversion rate (%), K_S is the supply-service-value conversion rate (%), K_RP is the regulating-and-support-service-value conversion rate (%), and K_C is the cultural-system-service-value conversion rate (%).

3.2.2. Methods for Measuring the Ecological Value of the KSFR

1. Types of Ecosystem Service Value Accounting

This study uses ecosystem service value (ESV) as a measure of the ecological value of the KSFR. ESV refers to the value of products and services provided by an ecosystem to society. It is assessed by quantifying various ecological functions and services of forest ecosystems in monetary terms. These services are categorized into supply, regulating, supporting, and cultural services, as outlined in the Millennium Ecosystem Assessment (MA). Referring to Costanza's research [48], Chinese scholars like Xie Gaodi et al. further categorized the four types of ecosystem services into eleven subtypes. These include three subtypes of supply services: food production, raw material production, and water supply; four subtypes of regulating services: gas regulation, climate regulation, environmental purification, and hydrological regulation; three subtypes of supporting services: soil conservation, nutrient cycling maintenance, and biodiversity maintenance; and one subtype of cultural services, mainly providing aesthetic landscape services (Table 1) [49].

Table 1. Categories of ecosystem services value.

Categories		Sub-Categories	Explanation
Ecosystem Services Value (ESV_T)	Supply service (ESV_S)	(1) Food production, (2) raw material production, (3) water supply	Obtain material outputs from the ecosystem, such as wood, fresh water
	Regulating service (ESV_R)	(4) Gas regulation, (5) climate regulation, (6) environmental purification, (7) hydrologic regulation	Ecosystems act as regulators of services provided
	Support service (ESV_P)	(8) Soil conservation, (9) nutrient cycling maintenance, (10) biodiversity maintenance	To provide living space for organisms on the earth and to provide prerequisites for the existence of all ecological resources
	Cultural service (ESV_C)	(11) Providing aesthetic landscape services	Offers opportunities in recreation and health, tourism, aesthetics, art

2. Accounting methods and formulas for ecosystem service value

The assessment of ecological value, namely ecosystem service value (ESV), primarily involves evaluating physical quantity, value quantity, and energy value. The assessment of value quantity entails pricing the demand for the physical quantity of various ecosystem functions' corresponding indicators, allowing the physical quantities of ecosystem services from multiple functions to be standardized into a common unit of measurement and facilitating the summation to measure the value magnitude of ecosystem services provided by entire ecosystems with multiple functions simultaneously. The assessment methods for value quantity mainly consist of two approaches: the method based on unit ecological service product prices (ecological function pricing method) and the method based on unit area value equivalent factors (the equivalence-factor method) [49]. The equivalence-factor method involves categorizing various types of ecosystems based on land use types, setting a standard functional unit of the ecosystem providing ecological services as the unit ecosystem, establishing an ecosystem service value equivalent factor table, and using it together with known land use areas for evaluation. This approach, characterized by its intuitive nature, ease of use, and minimal data requirements, is particularly suitable for macro-region and continuous-time ESV assessments [50–52]. In 1997, Costanza and other American scholars assigned global value coefficients to diverse ecosystems worldwide [53,54]. Subsequently, the Chinese scholar Xie Gaodi revised these coefficients to suit China's specific circumstances, creating a unit area ecological system service value equivalent table for the country [49].

In this study, we adopted the Chinese ecosystem service valuation model established by Xie Gaodi et al. [49] and made necessary adjustments to the value coefficient equivalents by considering the specific conditions of the study area. This regionalized refinement enables a more accurate reflection of local realities, ensuring the precision of parameters within the ecosystem service value equivalency table [55,56]. We use the equivalent factor method with revised coefficients to evaluate ESV within the operational areas of 87 state-owned forestry-industry enterprises in the KSFR from 2003 to 2020. According to the classification of ESV, the total ESV value is equal to the sum of all types of ESVs. We calculate the total value of ecosystem services (ESV_T) using Equations (5)–(8). This includes provisioning services (ESV_S), regulating-and-supporting services (ESV_RP), and cultural services (ESV_C). We use ArcGIS 10.7 software to draw the spatial-distribution map of the ESV of each sample in the study area.

Firstly, according to the classification of ecosystem service functions, the total value of ecosystem services can be obtained by summing the values of several categories of service functions. The calculation formulas are as follows:

$$ESV\_T = ESV\_S + ESV\_R + ESV\_P + ESV\_C \quad (5)$$

$$ESV\_RP = ESV\_R + ESV\_P \quad (6)$$

In the equation, ESV_T represents the total value of ecosystem services in the KSFR, where ESV_S denotes the value of supply services, ESV_R represents the value of regulating services, ESV_P stands for the value of supporting services, ESV_C indicates the value of cultural services, and ESV_RP is the sum of the values of regulating and supporting services.

Secondly, we determine the economic value of the standard ecosystem ecological service value equivalent factor. Based on Chinese ecological experts' scoring and field surveys, the revised value coefficients estimate that natural ecosystems contribute one-seventh of the economic value of major grain crops within the study area [49]. Using this modification method focused on grain yield, we computed the economic value per unit area of grain crops using basic data including planting area, yield, and prices from three provinces within the study area spanning from 2003 to 2020, ultimately comprising one standard ecosystem ecological service value equivalent factor in the study area.

The specific calculation steps of ESV consist of the following formula:

$$C = 1/7 \times P \times Q \quad (7)$$

In the formula, C is the value of one standard unit of ESV equivalent factor (yuan/hm^2); P is the average price of grain in each province (yuan/kg); and Q is the grain output per unit area of each province (kg/hm^2).

Finally, based on the actual distribution characteristics of land use types in the study area and the improved 'China Land Ecosystem Unit Area Service Value Equivalent Table' (see Appendix A), the unit area ecosystem service value (ESV) of different types is calculated.

The formula for calculating the ESV value coefficient per unit area is as follows:

$$Ci = Eci \times C, i = 1, 2, \ldots, 11 \quad (8)$$

In the formula, Ci is the value of type i ecosystem services for all land use types per unit area. (yuan/hm^2); C is the value of one standard unit ESV equivalent factor (yuan/hm^2); ECi is the equivalent factor coefficient table; and i is the type of ESV, including eleven indicators. The land-use type includes cultivated land, forest land, grassland, water area, desert, and urban land [57].

3.2.3. Methods for Measuring the Economic Value of the KSFR

This paper uses the gross-output value of ecosystem services/products (GDP_T) operated by state-owned forestry enterprises in KSFR as a proxy for measuring the economic value derived from ecosystem exploitation. GDP_T is the total economic value obtained through market transactions or ecological compensation by state-owned forestry enterprises in the KSFR, including the collection and processing of timber, water resources, and other products, as well as ecological restoration work such as afforestation [58]. It is categorized into three types: provisioning-product output value, regulating-and-supporting-service output value, and cultural-service output value. In addition, we employ the GDP deflator index to adjust for price fluctuations and maintain clarity in economic-value changes. Equations (9)–(12) are employed to compute the gross output value of ecosystem services/products (GDP_T) in the KSFR from 2003 to 2020. Spatial-distribution maps illustrating the magnitude of values for each sample within the study area are then generated using ArcGIS 10.7 software.

The calculation formula is as follows:

$$GDP\_T = GDP\_S + GDP\_RP + GDP\_C \tag{9}$$

In the formula, GDP_T is the total output value of ecosystem services/products, GDP_S is the output value of supply products, GDP_RP is the output value of the regulating-and-supporting-service industry, and GDP_C is the output value of the cultural-service industry. The specific accounting formula is as follows:

(1) GDP_S

According to the definition of the GDP_T, the value of supply services in ecosystems represents the economic value realized through market transactions after state-owned forestry enterprises in KSFR engage in activities such as timber harvesting, forest-product collection, and the processing of wood and non-wood forest products. Therefore, the GDP_S equals the sum of the values of these material products produced by enterprises. The calculation formula is as follows:

$$GDP\_S = GDP_1 + GDP_2 + GDP_3 + GDP_4 + GDP_5 \tag{10}$$

In the formula, GDP_S represents the output value of supplied products, broken down as follows: GDP_1 for timber mining and transportation, GDP_2 for planting and collecting non-wood forest products (e.g., medicinal materials), GDP_3 for processing and manufacturing of wood forest products (e.g., artificial panels), GDP_4 for the processing and manufacturing of non-wood forest products (e.g., traditional Chinese medicine), and GDP_5 for livestock products (e.g., Rana).

(2) GDP_RP

GDP_RP is primarily generated by state-owned forestry enterprises in the KSFR through activities such as afforestation, nurturing, and forest-management practices like pest and disease control. These activities, partly converted into economic value through governmental ecological compensation, contribute to regulating and supporting ecosystem services. Therefore, the GDP_RP equals the sum of the output values of the aforementioned industries operated by enterprises:

$$GDP\_RP = GDP_6 + GDP_7 + GDP_8 + GDP_9 \tag{11}$$

In the formula, GDP_RP represents the output value of regulating-and-supporting services. GDP_6 refers to forestry services, covering forest-fire prevention and pest and disease control. GDP_7 denotes the tree-breeding-and-seedling-cultivation output value. GDP_8 indicates the afforestation-and-reforestation output value. GDP_9 represents the forest-management output value.

(3) GDP_C

GDP_C comes from activities conducted by state-owned forestry enterprises through the development of forest ecotourism and wellness industries. These activities generate economic value through market transactions. Therefore, the GDP_C equals the output value of forest ecotourism operated by enterprises:

$$GDP\_C = GDP_{10} \tag{12}$$

In the formula, GDP_C is the output value of the cultural-service industry, and GDP_{10} is the output value of the eco-tourism industry.

3.3. Data Sources

The panel data utilized in this study, spanning from 2003 to 2020, originate from two distinct sources, encompassing (1) economic and sociological data disseminated by official websites such as the National Bureau of Statistics of China and (2) natural resource data, including maps and other relevant data extracted through geographic information system software, ArcGIS 10.7 software.

Among them, the natural resource data mainly include administrative-boundary data and land-use data of key state-owned forest areas. The administrative-boundary data come from public data applied to the Ministry of Natural Resources of China (https://www.mnr.gov.cn/, accessed on 29 May 2023). The land-use data come from ESA's CCI-LC project (http://maps.elie.ucl.ac.be/CCI/viewer/index.php, accessed on 18 January 2022). Owing to the long-term sequential nature of the samples, the CCI-LC used the dataset consisting of two versions: the land-use data atlas from 2003 to 2015 uses version 2.0.7, and the land-use data atlas from 2016 to 2020 uses version 2.1.1. Both versions are produced with the same processing chain with a spatial resolution of 300 m × 300 m and a temporal resolution of 1 year.

The economic and social data come from the "China Forestry and Grassland Statistical Yearbook", "China Statistical Yearbook", and "National Agricultural Products Cost and Benefits Data Collection", as well as provincial statistical yearbooks and the official website of the National Bureau of Statistics. Among them, the output value of forestry-related industries in key state-owned forestry areas is obtained through the "China Forestry and Grassland Statistical Yearbook" (2003–2020); the main grain output, area, and price indicators in the unit area equivalent factor coefficient index formula for calculating ESV are obtained from the "China Statistics Yearbook" (2004–2021) and from the "Compilation of Costs and Benefits of National Agricultural Products" (2004–2021).

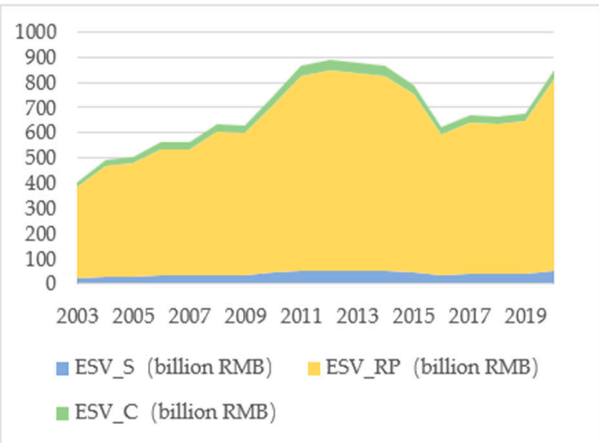
4. Results

4.1. Spatiotemporal Changes in ESV

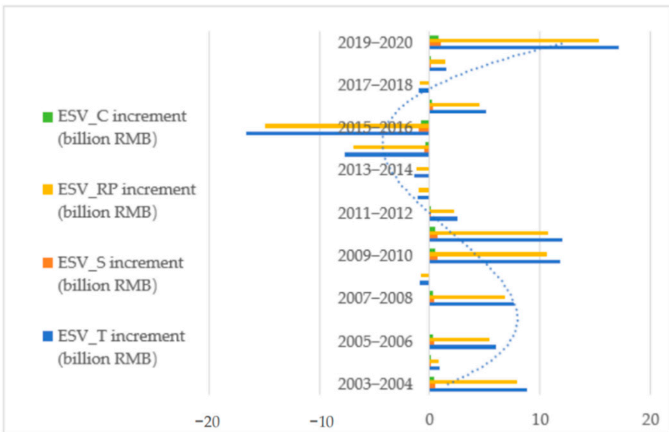
4.1.1. Timing Variation Characteristics of ESV

1. ESV_T shows a fluctuating upward trend

The ESV_T calculated using Equations (1)–(5) yields results, as depicted in Figure 3. From 2003 to 2020, the ESV_T of key state-owned forest areas exhibits a fluctuating upward trend, increasing from 404.7 billion CNY in 2003 to 850.2 billion CNY in 2020, a growth of 110%. This indicates a favorable trend of ecological-value growth within the study area. The fluctuation in ESV_T growth is evident from the incremental changes in ESV_T. Particularly notable is the significant decrease in ESV_T observed during 2014–2016, with ESV_T decreasing by −770.29 billion CNY from 2014 to 2015 and by −1663.83 billion CNY from 2015 to 2016. The years 2019–2020 show the largest increase in ESV_T, with a growth of 1715.94 billion CNY.



(**a**)



(**b**)

Figure 3. Changes in value and growth of various types of ESV in KSFR: (**a**) changes in value of various types of ESV; (**b**) changes in growth of various types of ESV.

2. Different types of ESV show clear disparities among categories and remain stable over time

Based on the functions and types of ecosystem services (ES) (see Figure 3), ESV_T comprises ESV_S, ESV_RP, and ESV_C. Regulating services exhibit the highest value in key state-owned forest areas from 2003 to 2020, followed by provisioning services, while cultural services show the lowest value. The relative proportions of these services remain relatively stable over time. Specifically, ESV_S increases from 239.45 billion CNY (5.919% of ESV_T) in 2003 to 502.87 billion CNY (5.917%) in 2020. ESV_RP increases from 3621.46 billion CNY (89.513% of ESV_T) in 2003 to 7607.62 billion CNY (89.516%) in 2020. ESV_C increases from 184.82 billion CNY (4.568% of ESV_T) in 2003 to 388.11 billion CNY (4.567%) in 2020.

4.1.2. Spatial Distribution Characteristics of ESV

Using ArcGIS software for visualization (see Figure 4), we find that ESV demonstrates a clear spatial differentiation in KSFR from 2003 to 2020. Overall, ESV in these areas maintains a consistent “higher in the north, lower in the south” pattern over time, with no significant spatial changes despite increasing ESV across the region. In addition, owing to consistent accounting methods, ESV_S, ESV_RP, and ESV_C show similar spatial distributions to ESV_T (see Table 2).

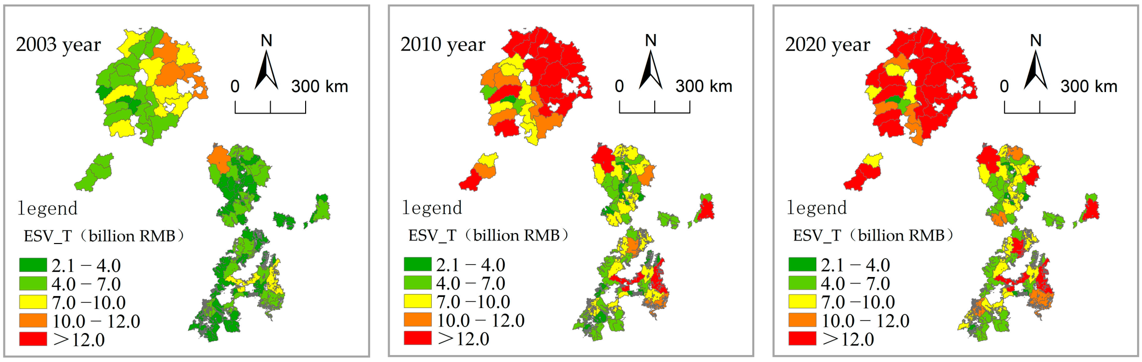


Figure 4. Spatial distribution of ESV in KSFR.

Table 2. The ESV mean values of six forest industry groups from 2003 to 2020.

Name	Year	ESV_T: Billion CNY	ESV_S: Billion CNY	ESV_RP: Billion CNY	ESV_C: Billion CNY
Daxinganling Forest Industry Group	2003	9.19	0.54	8.24	0.42
	2010	16.95	0.99	15.18	0.77
	2020	19.36	1.13	17.35	0.89
Inner Mongolia Forest Industry Group	2003	5.27	0.31	4.71	0.24
	2010	9.72	0.57	8.69	0.45
	2020	11.10	0.66	9.92	0.51
Longjiang Forest Industry Group	2003	4.40	0.27	3.93	0.20
	2010	8.13	0.49	7.26	0.37
	2020	9.25	0.56	8.26	0.42
Yichun Forest Industry Group	2003	3.22	0.19	2.89	0.15
	2010	5.94	0.35	5.32	0.27
	2020	6.76	0.39	6.05	0.31
Changbaishan Forest Industry Group	2003	3.47	0.20	3.11	0.16
	2010	6.37	0.37	5.71	0.29
	2020	7.24	0.42	6.49	0.33
Jilin Forest Industry Group	2003	2.74	0.16	2.45	0.12
	2010	5.02	0.29	4.50	0.22
	2020	5.71	0.33	5.12	0.25

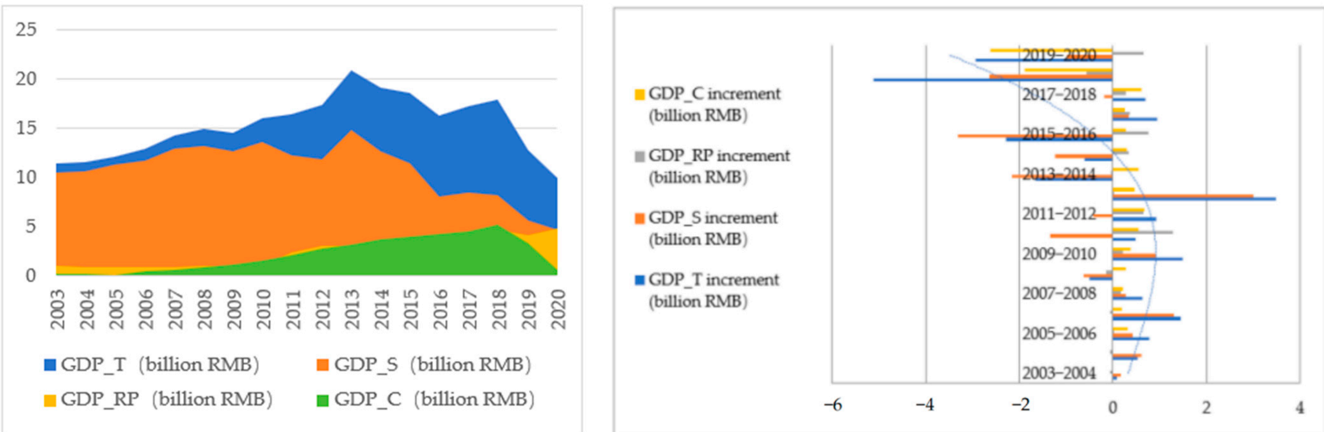
From the perspective of spatial distribution, comparing the six major forestry-industry groups in these areas, the ESV_T mean values as of 2003–2020 rank as follows (Table 2): The ESV_T mean values of the Daxinganling Forest Industry Group located in the northern spatial region were 9.19 billion CNY in 2003, 16.95 billion CNY in 2010, and 19.37 billion CNY in 2020. The ESV_T mean values of the Inner Mongolia Forest Industry Group Group were 5.27 billion CNY in 2003, 9.72 billion CNY in 2010, and 11.10 billion CNY in 2020. The Longjiang Forest Industry Group located in the central spatial region had ESV_T mean values of 4.40 billion CNY in 2003, 8.13 billion CNY in 2010, and 9.25 billion CNY in 2020. The Yichun Forest Industry Group had ESV_T mean values of 3.22 billion CNY in 2003, 5.94 billion CNY in 2010, and 6.76 billion CNY in 2020. In the southern spatial region, the Changbaishan Forest Industry Group had mean ESV_T values of 3.47 billion CNY in 2003, 6.37 billion CNY in 2010, and 7.24 billion CNY in 2020. The Jilin Forest Industry had ESV_T mean values of 2.74 billion CNY in 2003, 5.02 billion CNY in 2010, and 5.72 billion CNY in 2020.

4.2. Spatiotemporal Changes in GDP

4.2.1. Timing Variation Characteristics of GDP

1. GDP_T exhibits a trend of initial increase followed by a decline

The results of GDP_T, calculated using Equations (6)–(9), are depicted in Figure 5. Within the KSFR from 2003 to 2020, GDP_T shows a trend of an initial increase followed by a decrease. GDP_T initially increases, peaking at 208.16 billion CNY in 2013, with a growth rate of 81.88%, before declining to 98.71 billion CNY in 2020, marking a −13.75% growth rate. Although minor increases are observed in 2016–2018, with GDP_T reaching 179.17 billion CNY in 2018, a sharp decline follows after that.



(**a**) (**b**)

Figure 5. Changes in value and growth of various types of GDP in KSFR: (**a**) changes in the value of various types of GDP; (**b**) changes in the growth of various types of GDP.

2. The disparities in GDP values are progressively diminishing over time

Considering the composition of GDP_T (see Figure 5), it comprises GDP_S, GDP_RP, and GDP_C. Over the period from 2003 to 2019, GDP_S holds the highest position relative to GDP_RP and GDP_C, but in 2020, GDP_RP surpasses GDP_S. Moreover, examining the trend over time unveils a decreasing proportion of GDP_S within GDP_T, while GDP_RP and GDP_C exhibit growth trends. Consequently, the disparities in sizes among various GDPs are progressively diminishing. Specifically, in the calculation of each ecosystem service value realization, GDP_S shows a trend of first increasing and then decreasing, rising from 104.00 billion CNY in 2003 to 147.41 billion CNY in 2013, then declining to 45.59 billion CNY in 2020, with its proportion within GDP_T dropping from 90.87% to 46.18%. By contrast, GDP_RP demonstrates an upward trend, increasing by 37.86 billion

CNY by 2020, with an average annual growth rate of 10.01%. GDP_C increases from 1.13 billion CNY in 2003 to 50.93 billion CNY in 2018, but it experiences declines in 2019 and 2020.

4.2.2. Spatial Distribution Characteristics of GDP

ArcGIS 10.7 software is used to visualize the realization of ecosystem service value in key state-owned forest areas, with the spatial distribution results depicted in Figure 6. Spatially, significant heterogeneity in the values of GDP is observed among the six major forest industry groups in the KSFR. The specific distribution characteristics are as follows.

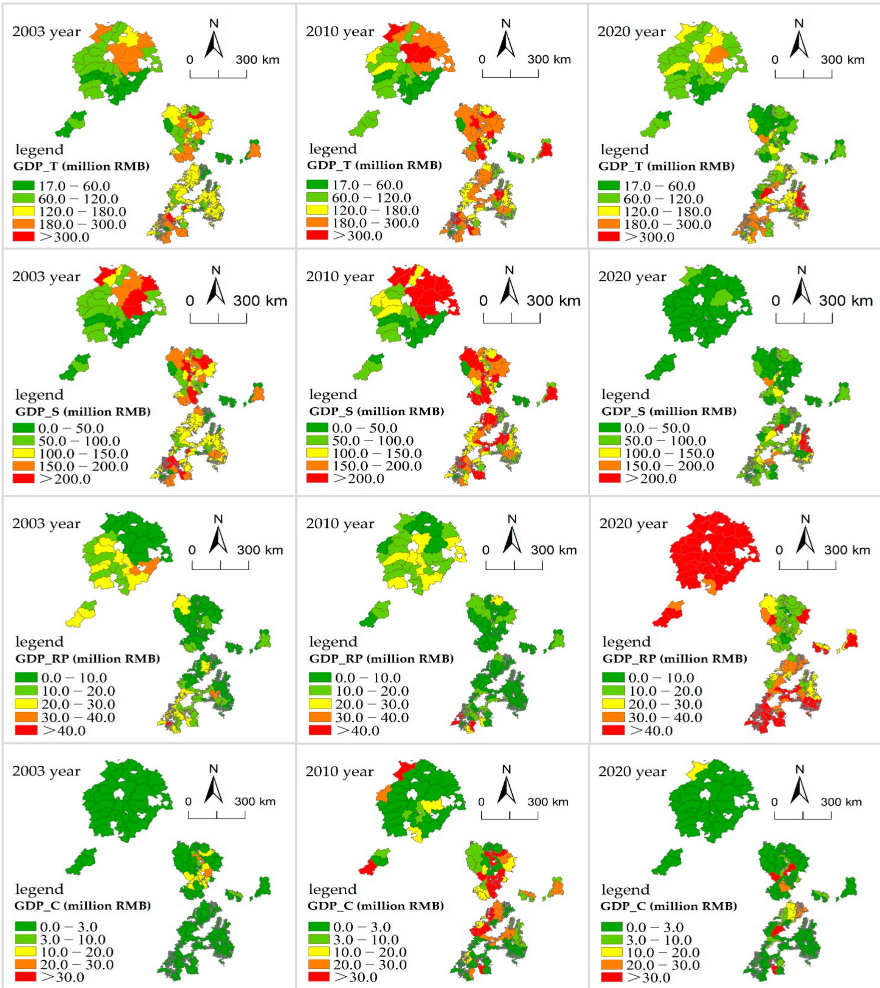


Figure 6. Spatial distribution of GDP in KSFR.

The spatial distribution of GDP_T shows a "high in the southeast, low in the northwest" pattern overall, with the northern and central regions exhibiting an initial increase followed by a decrease over time. In 2020, the Jilin Forest Industry Group in the south had an average GDP_T of 178.86 million CNY, while the Changbaishan Forest Industry Group averaged 135.39 million CNY. In the north, the Inner Mongolia Forest Industry Group had a lower average GDP_T of 75.6 million CNY, compared to the Daxinganling Forest Industry Group's average of 129.95 million CNY.

The spatial distribution characteristics of GDP_S generally align with those of GDP_T. In 2003, the average GDP_S of the Jilin Forest Industry Group in the south was 136.99 million CNY, while the Changbaishan Forest Industry Group averaged 147.28 million CNY. In the central region, the Longjiang Forest Industry Group averaged 108.19 million CNY, and the Yichun Forest Industry Group averaged 157.87 million CNY. In the northern region, the Inner Mongolia Forest Industry Group averaged only 55.62 million CNY, whereas the Daxinganling Forest Industry Group averaged 160.21 million CNY. By 2020, despite a downward trend in the southern and central regions, the northern region experienced a greater decline in GDP_S. In the south, the Jilin Forest Industry Group averaged 55.67 million CNY, while the Changbaishan Forest Industry Group averaged 73.39 million CNY. In the central region, the Longjiang Forest Industry Group averaged 86.64 million CNY, and the Yichun Forest Industry Group averaged 52.95 million CNY. In the northern region, the Inner Mongolia Forest Industry Group averaged only 8.94 million CNY, whereas the Daxinganling Forest Industry Group averaged 31.69 million CNY.

Regarding GDP_RP's spatial distribution, it follows a "high on the periphery, low in the middle" pattern overall, while GDP_C's spatial distribution presents the opposite pattern: "high in the middle, low on the periphery". In 2003, the average GDP_RP of the Longjiang Forest Industry Group and the Yichun Forest Industry Group in the central region was 6.21 million CNY and 4.29 million CNY, respectively, half of the averages in other regions. By 2020, the Longjiang Forest Industry Group's GDP_RP average increased to 32.51 billion CNY, while the Daxinganling Forest Industry Group in the north averaged 96.90 million CNY, and the Jilin Forest Industry Group in the south averaged 122.13 million CNY, four times that of the Longjiang Forest Industry Group. In contrast, the spatial distribution of GDP_C presents a different pattern. For example, in 2020, the Longjiang Forest Industry Group and the Yichun Forest Industry Group in the central region averaged 12.42 million CNY and 9.87 million CNY, respectively, while the Inner Mongolia Forest Industry Group in the north averaged only 0.30 million CNY.

4.3. Spatiotemporal Changes in K

4.3.1. Timing Variation Characteristics of K

1. The K_T is low and shows a fluctuating declining trend

The K_T, computed using Equation (11), is illustrated in Figure 7. From 2003 to 2020, K_T in key state-owned forest areas remains at a low level and exhibits a declining trend, indicating that the improvement in ecological benefits has not been fully translated into economic value. It peaks at 2.83% in 2003, declines to 1.89% in 2011, and increases to 2.70% in 2018 but sharply drops to 1.16% by 2020.

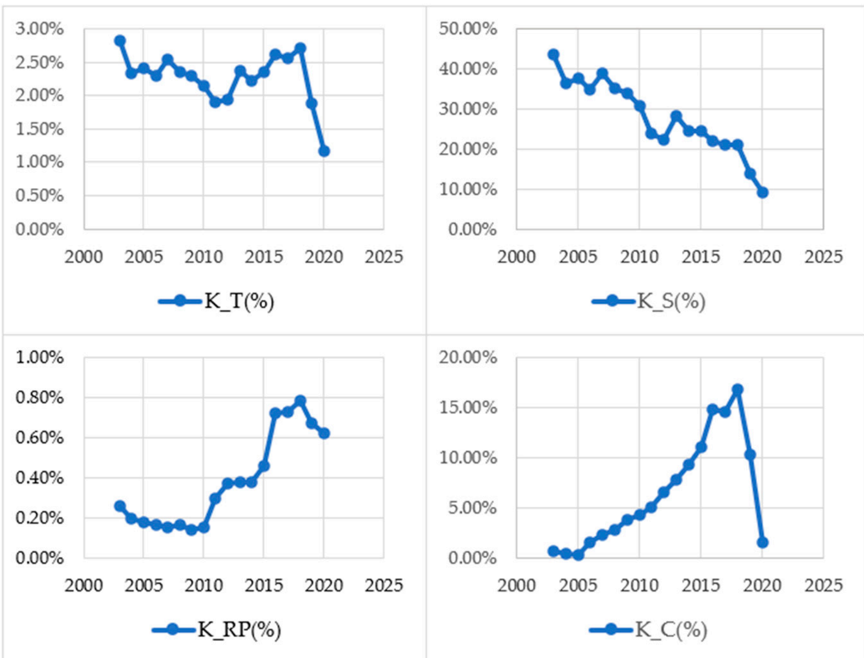


Figure 7. Changes in ecosystem service value conversion rate (K) from 2003 to 2020.

2. Different K values show opposite trends over time

Figure 7 further illustrates the magnitude and trends of ecosystem product value conversion rates. When sorted by the mean value of conversion rates, we find that K_S > K_C > K_RP. However, their trends over time are the opposite. Specifically, K_S shows a significant declining trend from 43.43% in 2003 to 9.07% in 2020. By contrast, K_C, with a mean value of 6.31%, exhibits a noticeable increasing trend, except for 2019–2020, rising from 0.61% in 2003 to 16.82% in 2018 but dropping to 1.35% in 2020 owing to the pandemic. Finally, K_RP, with a mean value of 0.38%, shows an overall upward trend, increasing from 0.26% in 2003 to 0.62% in 2020. This suggests that KSFR is gradually shifting away from traditional supply-oriented product realization focused on timber production to relying more on providing environmental regulation and cultural services. However, this transition has yet to be fully translated into higher economic benefits.

4.3.2. Spatial Distribution Characteristics of K

Utilizing ArcGIS software, we visualize the spatial distribution of K within the study area, shown in Figure 8. Observing K from 2003 to 2020 reveals pronounced heterogeneity in both spatial patterns and temporal trends across various samples within the key state-owned forest areas, mirroring the patterns observed in GDP.

Specifically, (1) Figure 8 clearly illustrates that in most regions of the KSFR, both K_T and K_S exhibit a significant downward trend, especially in the northern regions, such as the Daxinganling, Changbaishan, and the Yichun forest industry groups in the central region. From 2003 to 2020, the average K_T of the Daxing'anling Forestry Industry Group in the north decreased from 1.85% to 1.68%, while that of the Yichun Forestry Industry Group in the central region decreased from 5.81% to 1.22%, and that of the Changbai Mountain Forestry Industry Group in the south decreased from 4.77% to 2.01%. Simultaneously, the average K_S of the Daxing'anling Forestry Industry Group in the north decreased from 46.76% to 16.43%, that of the Inner Mongolia Forestry Industry Group decreased from 30.36% to 2.88%, and that of the Yichun Forestry Industry Group in the central region decreased from 93.74% to 14.28%. (2) Concerning K_RP, it is evident that in most regions of the KSFR, there is a marked upward trend, with notably higher levels observed for the Jilin Forest Industry Group in the southern region, the Longjiang Forest Industry Group in the middle of the region, and the Daxinganling in the north. Among them, the K_RP of the Daxinganling Forest Industry Group has the highest growth rate, and its average value increased from 0.09% in 2003 to 0.57%. (3) K_C is notably higher in the central Longjiang forestry industry group, and its spatial changes demonstrate a diffusion pattern from the central point outward. However, there was a significant increase in K_C for the Jilin and Changbaishan Forest industry groups in the southern region. During the period from 2003 to 2020, the mean K_C of the Longjiang Forest Industry Group increased from 0.27% to 3.24%. The mean K_C of the Jilin Forest Industry Group increased from 0.01% to 0.45%, while the mean K_C of the Changbaishan Forestry Industry Group increased from 0.09% to 3.96%.

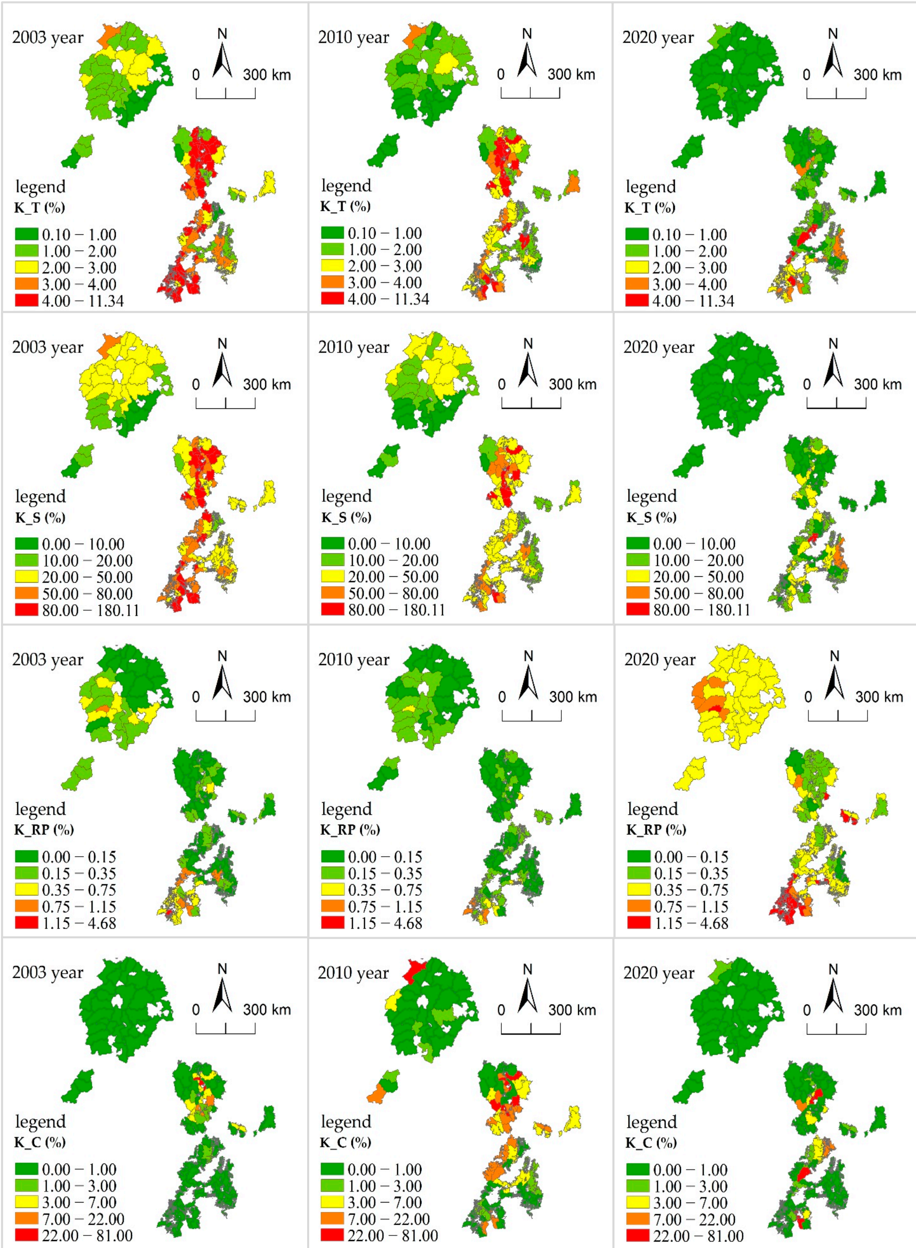


Figure 8. Spatial distribution of K in KSFR.

5. Discussion

This paper quantifies the physical value of ecosystem services (ESV), the economic value of ecosystem service realization (GDP), and the ESV conversion rate (K) to address three predetermined questions. Based on the research findings, it proposes the feasibility and development potential of realizing ESV in the KSFR, as well as policy measures to enhance ESV. The aim is to showcase China's research achievements and contributions in converting forest ESV into economic value for the world.

5.1. The Ecological Benefits of the KSFR in China Have Increased Significantly

The present study reveals that the ESV within the study area shows an increase from 404.7 billion CNY in 2003 to 850.2 billion CNY in 2020. This significant growth in ecosystem service value in key state-owned forest areas reflects effective restoration and improvement of the regional ecosystem, resulting in substantial enhancements in ecological benefits.

The conclusions align closely with the assessments of the changing trends in ecosystem regulation service value in this region by Chinese scholars such as Huang Longsheng [59].

According to our assessment method, land-use change is often one of the primary driving factors influencing changes in ecosystem service value [60]. The enhancement of ESV is attributed, in part, to the strict ecological conservation policies formulated and implemented by the Chinese government [61]. Since the initiation of the Natural Forest Protection Project in key state-owned forest areas in 2000, the Chinese government has gradually implemented logging restrictions and even bans on natural forests. As a result, forest-area depletion has ceased, and significant financial investments have been made to assist state-owned forestry enterprises in afforestation and forest-management activities, leading to effective growth in forest areas within key state-owned forest regions [47,62,63].

5.2. The Conversion Level of Ecosystem Service Value in the KSFR Is Low, but the Potential Is Huge

The mean value of the ecosystem service value conversion rate (K_T) in key state-owned forest areas is only 2.27. This finding suggests a considerable enhancement in ecological benefits within the region; however, the improved ecological benefits have not been fully translated into economic benefits. Nevertheless, the specific analysis of different types of ecosystem service value conversion rates reveals significant spatiotemporal heterogeneity in their evolution. This heterogeneity is manifested in three specific aspects.

The types of ecosystem service value conversion in KSFR are evolving toward regulation and cultural-services conversion. Combining the analysis of the changing trends in various types of ecosystem-product-value conversion rates, it is observed that K_S in KSFR exhibits a declining trend, while both K_RP and K_C show an increasing trend. This observation aligns with the views of Li Chaohong et al. [64], indicating that the significant strengthening trend in ecological construction in KSFR has played a beneficial role in promoting economic transformation and development.

The realization mode of ESV is overly singular, necessitating active exploration of diverse implementation modes. Currently, the realization of ESV mainly relies on market transactions, predominantly driven by market forces and consumers, with payment entities including the government and residents (both collective and individual) [65]. Although market transactions represent the most efficient mode of value realization for ecosystem products at present, the disproportionate proportion of regulation-and-support service values still heavily relies on vertical ecological compensation from the state [66]. Products that can enter the market (e.g., carbon sequestration products and green financial products) have yet to achieve effective value realization owing to the incomplete development of transaction mechanisms such as property rights and market platforms.

Although the conversion rate of cultural-service value continues to increase with environmental improvement, it is also susceptible to policy intervention. In one sense, China's territorial spatial-planning policy encourages the construction of an integrated spatial system for the overall protection of cultural, natural, and landscape resources while strictly controlling the size of land use types and limiting development [67]. In another sense, the realization of cultural-service value is vulnerable to the impact of unforeseen events. In 2019, the realization rate of ecological cultural services broke the trend of continuous growth owing to the outbreak of the COVID-19 pandemic. The control measures implemented by China to restrict population movement harmed the development of the regional ecotourism industry.

5.3. The Conversion Rate Situation Informs the Economic and Social Development of China's KSFR

The restoration of the ecological environment in China's KSFR provides a foundation for economic and social development. From 2003 to 2020, there was significant ecological environment restoration in these regions, with ESV increasing by 110.08%. During this period, the economic and social development in China's KSFR became more pronounced, with GDP growth reaching 849.13%, surpassing the respective regions' (Heilongjiang Province, Jilin Province, Inner Mongolia Autonomous Region) growth of 424.82%. Converting ecological advantages into economic advantages through ecological industrialization can achieve economic and social development beyond the average level. Additionally, accompanying the ecological environment restoration, the industrial structure in China's KSFR shifted from being dominated by timber production to diversified development, with non-timber forest resources becoming an important part of regional economic growth. These regions have not only achieved economic and social growth but also industrial structure upgrading.

The significant conversion potential provides confidence for further socio-economic development in China's KSFR. As of 2020, the highest conversion rate in these regions was approximately 2.7%, indicating vast untapped ESV development potential. Particularly, the conversion potential of provisioning ESV and cultural ESV has not been fully realized. These types of ESV conversion are the main focus of enterprises or households in China's KSFR. Their conversion potential is gradually being unleashed, forming a virtuous reinforcement chain of "ecology-economy-society-ecology". The current conversion rate situation not only demonstrates the conditions and space for further development in China's KSFR but also provides direction for enterprise and household management.

5.4. The Enhancement of the ESV Conversion Rate in China within a Global Context

The improvement in the ecological value of China's key state-owned forest regions is closely tied to the implementation of strict forest-conservation policies by the Chinese government. These policies involve activities such as halting logging, afforestation, and forest management. However, some experts suggest that a key factor enabling the sustainability of China's long-term forest-conservation policies is the ability to obtain large quantities of timber from the global market [68]. The import of timber has compensated for the timber shortage caused by China's logging ban and has consistently supported China's eco-friendly forest policies [29]. This has allowed China to shift away from primarily timber extraction in the northeastern region of China, enabling the realization of regulating services value from forest conservation efforts. Our empirical results verify that ecosystem service value conversion has spatial differences, which are usually caused by differences in attributes, characteristics, qualifications, and other conditions of the location itself [69]. In comparison to economically developed regions in China, the KSFR has long been ecologically rich but economically underdeveloped. Historical deforestation has led to a dual crisis in resources and the economy. Conclusions drawn from the conversation of ecological product value in this region can provide valuable insights for other developing countries facing similar challenges. Therefore, China should enhance research on mechanisms for converting ESV and explore diverse models for realizing ecological product value in these forest areas.

5.5. Limitations and Research Prospects

This study acknowledges several limitations. Our primary research objective is to enhance awareness of the significant ecological and economic value inherent in ecosystem services, aiming to incentivize individuals, communities, and governments to effectively conserve the ecological environment and efficiently utilize and transform ecological assets. Accurate quantification of the value of ecosystem services is a prerequisite for their effective payment and monetization. While our current choice of the equivalent factor assessment method provides a comprehensive and intuitive reflection of the changes in the ecological value of ecosystem services in the study area, we believe there is still considerable room for improvement in precision measurement. Designing a more robust and unified accounting system for ecosystem service valuation, enhancing the transparency and accessibility of data, and coordinating government efforts and data platform construction are essential steps in this regard. Therefore, in future research, the ecosystem value accounting system should continue to evolve, with different regions in China adapting their approaches to ecosystem service valuation accordingly. Additionally, our future research endeavors aim to employ standardized techniques, such as Gross Ecosystem Product (GEP) accounting, to conduct more precise assessments of ecosystem service values. Furthermore, our analysis of the evolutionary patterns and underlying mechanisms affecting the conversion rate of ESV remains largely qualitative. In the future, it will be necessary to strengthen our empirical research methods by establishing appropriate modeling frameworks and combining empirical validation and analytical verification.

6. Conclusions

This study introduces a novel indicator system for measuring the conversion rate of ecosystem service value, which assesses the ability of ecosystem services to generate economic value. Using the KSFR as a case study, we analyze the evolution of ecosystem services from 2003 to 2020 through three indicators: the physical value of ecosystem services, the economic value of ecosystem service monetization, and the conversion rate. This dual-dimensional analysis considers both temporal and spatial aspects.

To begin with, this study addresses three crucial questions. First, the ecological value of the KSFR is substantial, exhibiting a noticeable increase over time and a spatial distribution pattern of "higher in the north and lower in the south". According to our calculations, the ecosystem service value in this region reached 850.2 billion CNY in 2020, marking a 110% growth compared with 2003. This value is primarily composed of regulating-and-supporting services. Second, the economic value derived from monetizing ecosystem services in KSFR is relatively low, indicating a challenge in effectively converting the increasing ecological value into economic value. While the overall conversion rate of ecosystem service value is low, there exists significant potential for value conversion. In addition, our empirical results confirm that there are spatial differences in ecosystem service value conversion, which are usually caused by differences in the attributes, characteristics, qualifications, and other conditions of the location itself. Our research results will shed light on the forest "resource curse" that this region once faced, as the trap other developing countries facing similar challenges of "synergistic development between ecological protection and economic development" provide valuable insights.

Third, a qualitative analysis reveals that the notable rise in ecosystem service value in the KSFR is closely tied to the Chinese government's Natural Forest Protection Project launched in 2000. This initiative, employing measures like logging restrictions, afforestation, management, and investment, has effectively sustained the growth of ecosystem service value.

Finally, this study proposes policy recommendations and future research directions. The KSFR is transitioning from traditional logging economies to industries such as green food production, forest medicine, eco-tourism, and health-care services. However, hindered by policy, funding, and technological limitations, industry development has been slow. To facilitate green transformation, the government should increase support, improve protection policies, and boost investment in green industries. In addition, exploring diverse value-realization models like regional ecological banks and green finance, as well as enhancing the ecological compensation system, are crucial steps.

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Data Availability Statement: Publicly available datasets were analyzed in this study. The border data were obtained through the official website of China's Ministry of Natural Resources (https://www.mnr.gov.cn/sj/sjfw/, accessed on 12 May 2023). The land use/cover data (2000–2020) were obtained from the European Space Agency's (ESA) CCI-LC project (http://maps.elie.ucl.ac.be/CCI/viewer/index.php, accessed on 10 June 2021).

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Ecosystem service equivalent value per unit area.

Ecosystem Classification		Supply Service			Regulating Service				Support Service			Cultural Service
First Level Classification	**Secondary Classification**	**Food Production**	**Raw Material Production**	**Water Supply**	**Gas Regulation**	**Climate Regulation,**	**Environmental Purification**	**Hydrologic Regulation**	**Soil Conservation,**	**Nutrient Cycling Maintenance**	**Biodiversity Maintenance**	**Providing Aesthetic Landscape Services**
Cultivated land	Non-irrigated farmland	0.85	0.40	0.02	0.67	0.36	0.10	0.27	1.03	0.12	0.13	0.06
	Paddy fields	1.36	0.09	−2.63	1.11	0.57	0.17	2.72	0.01	0.19	0.21	0.09
Forest land	Coniferous forest	0.22	0.52	0.27	1.70	5.07	1.49	3.34	2.06	0.16	1.88	0.82
	Mixed conifer and Broadleaf forest	0.31	0.71	0.37	2.35	7.03	1.99	3.51	2.86	0.22	2.60	1.14
	Broadleaf forest	0.29	0.66	0.34	2.17	6.50	1.93	4.74	2.65	0.20	2.41	1.06
	Shrubland	0.19	0.43	0.22	1.41	4.23	1.28	3.35	1.72	0.13	1.57	0.69
Grassland	Grassland	0.10	0.14	0.08	0.51	1.34	0.44	0.98	0.62	0.05	0.56	0.25
	Bushes	0.38	0.56	0.31	1.97	5.21	1.72	3.82	2.40	0.18	2.18	0.96
	Meadow	0.22	0.33	0.18	1.14	3.02	1.00	2.21	1.39	0.11	1.27	0.56
Wetland	Wetland	0.51	0.50	2.59	1.90	3.60	3.60	24.23	2.31	0.18	7.87	4.73
Desert	Desert	0.01	0.03	0.02	0.11	0.10	0.31	0.21	0.13	0.01	0.12	0.05
	Bare ground	0.00	0.00	0.00	0.02	0.00	0.10	0.03	0.02	0.00	0.02	0.01
Water land	Water	0.80	0.23	8.29	0.77	2.29	5.55	102.24	0.93	0.07	2.55	1.89
	Glacier snow	0.00	0.00	2.16	0.18	0.54	0.16	7.13	0.00	0.00	0.01	0.09

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