sustainability

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Does a Logging Ban Policy Increase Socio-Ecological Resilience? A Case Study of Key State-Owned Forest Areas in Northeast China

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Abstract: The resilience of forests refers to the ability of a forest to withstand disturbance and maintain its function and control. After an early phase of historical logging to support economic development, changes in the socio-ecological resilience of key state-owned forest areas in Northeastern China (later collectively referred to as Northeastern state-owned forests) after implementing a total logging ban policy remain unknown. In this study, the Northeast state-owned forest area was selected as the study area, and based on the panel data from 2008 to 2021, the indicator system at both social and ecological levels was established, and the socio-ecological resilience of the Northeast state-owned forest area was assessed using comprehensive weights and set-pair analysis. The results show that (1) the logging ban policy effectively improves socio-ecological resilience, which reached the highest point of the whole measurement period in 2018. (2) The socio-ecological system has a certain self-adjustment and resilience but has shown a decreasing trend in recent years. By exploring the causes behind the results, we can provide guidance and suggestions for the further implementation of the logging ban policy and, at the same time, provide some lessons for other developing countries with similar problems.

Keywords: socio-ecological system; resilience; stated-owned forest; logging ban policy

Citation: Luo, S.; Qiao, D.; Han, X.; Song, B.; Wan, Z.; Li, H. Does a Logging Ban Policy Increase Socio-Ecological Resilience? A Case Study of Key State-Owned Forest Areas in Northeast China. *Sustainability* **2024**, *16*, 8368. https://doi.org/10.3390/su16198368

Academic Editor: Usama Al-Mulali

Received: 19 August 2024
Revised: 10 September 2024
Accepted: 12 September 2024
Published: 26 September 2024

1. Introduction

Forests are irreplaceable and essential in providing ecosystem services, sustaining populations' livelihoods, and enhancing well-being [1]. Each forest region has specific local problems, often with large-scale impacts [2]. This is because the combined forces of economic globalization and global environmental change have led to increased interdependence within resource use systems, but more so in the case of forest resource management, where the impacts are not local but global [3].

The large and small Xing'an Mountains and the Changbai Mountains in Northeast China, with their vast natural forests, are one of the mainland ecosystems in Northeast Asia, with a critical forestry industry base, a strategic timber reserve base, and a significant ecological barrier in the north [4]. In the mid-20th century, to promote national economic construction, the state-owned forest areas in the Northeast carried out a large number of forest development activities to meet the country's industrialization demand for timber, which provided a large number of labor positions by the basic policy of "production first, construction later". It was a proud job to work in the Northeast's state-owned forests. Still, this gradual and uncontrolled development process has led to a significant decline in the quantity and quality of forests in the Northeast. To reverse the imminent collapse of the ecosystem, in 2015, the Northeast state-owned forest areas completely stopped commercial logging activities in natural forests. The logging suspension mainly included state-owned forest areas in Inner Mongolia, Jilin, and other places, as well as state-owned forests in Inner Mongolia, Jilin, and Daxing'anling that were not included in the protection of natural forest resources project. Since then, the forest industry enterprises transformed into large-scale ecological public welfare enterprises. According to the requirements of the state-owned forest resources supervision methods announced by the state, the ban directly stopped all commercial logging of trees, all forest industry enterprises and employees from the demand for protection, and economic development from the dependence on timber to the development of the under-forest economy. Moreover, the government has become a strong policy maker and regulator, and has implemented a policy of being the economic supporter. Accompanied by the reform of state-owned enterprises, the implementation of policies such as a comprehensive logging ban, a large amount of surplus labor in the forest areas, a large number of people engaged in timber logging, timber processing, manufacturing, and other labor-intensive industries, the labor force is facing an unemployment crisis [5]. The Northeast state-owned forest area is a special zone with local characteristics, which is an ecological function area that is neither different from the countryside nor belongs to the towns and cities [6]. The total amount of natural forests in this area is 25.308 million hectares, accounting for 95.6% of this forest area and accounting for 15.63% of the national area of natural forests. The Northeastern state-owned forest area is China's most significant forest area, with the most concentrated distribution of natural forests and the richest biodiversity, and it undertakes the critical functions of promoting the sustainable development of the national ecological and economic society, safeguarding the country's environmental security, and enhancing the carrying capacity of national resources [7]. It has a critical strategic position in global ecological construction, climate change, forest resource cultivation, and carbon sink reserve [8]. To sum up, the state-owned forest areas in Northeast China are a particular regional system developed along with forestry resources and organized by specific social and production relations, and have a significant impact on China and the world at both the social and ecological levels [9].

The core terms of a complete cessation of commercial logging in natural forests include "natural forests" and "commercial". On the one hand, a complete ban on logging will strengthen ecological construction in state-owned forest areas, increase the total amount of forests, improve forest quality, and enhance the environmental functions of forests. At the same time, forest land protection faces ecological protection problems such as returning farmland to forests for reforestation, deforestation, and reclamation under the pretext of developing the forest economy and using forest land as agricultural land for production. On the other hand, the cessation of commercial logging has resulted in many job losses. Due to the low level of education and skill shortage of laid-off forest farmers, the majority of forest workers have difficulties in the transition, weak self-employment, and other social livelihood issues, which are primarily dependent on the government's introduction of various types of subsidies to alleviate the problems of economic development, the transformation of forest industries, and worker resettlement. The logging ban policy is undoubtedly an ecologically favorable policy that must be adopted in line with the development of the times. Still, it has also brought about many ecological and social synergistic development problems, which will undoubtedly threaten the stability of the forest areas if not adequately solved. By combing through previous research on logging ban policies, scholars have mainly analyzed and interpreted the impact and effectiveness of logging ban policies from a macro perspective [10,11], the impact of international trade in timber [12–14], economic compensation [15], and other dimensions; the implementation of logging ban policies undoubtedly improves the ecological environment, but at the same time, it is at the cost of a loss of economic value. Therefore, the majority of scholars have focused on the effectiveness of the logging ban policy and whether or not it is worthwhile to implement it. A micro-integrated perspective needs to be added here that takes a specific site as the study area and analyzes changes in its resilience.

In studies of state-owned forest areas in Northeast China, scholars have focused on such issues as employee livelihoods and public satisfaction [16–20], ecological products and restoration [21–23], employment of remaining employees [5,24,25], and the Tianbao project and government–enterprise reform [26,27]. In the stage of combing data, based on the statistical yearbooks published by the government, we found that the income level of employees in the state-owned forest areas of Northeast China is generally lower than the national average; coupled with the fact that the logging ban policy caused a decline in the economic income of the enterprises, the development of a large number of employees and enterprises in the region has become an ongoing concern. After the logging ban policy in the Northeast State Forestry Region, scholars have mainly focused on the value of ecosystem services [28], enterprise economic problems [29], government governance [30], employee income [31], and forestry equipment [32]. Combining the three aspects of research, we find that the Northeastern state-owned forest areas need an entirely new perspective from which to study the quantitative measurement of the logging ban policy and socio-ecological resilience.

The social-ecological system is chosen because from the development history of the Northeast State Forestry Region, the region is a typical area where nature and human society are closely dependent, and it is necessary to seek some organically linked theoretical frameworks to be introduced into the study of the region. Introducing the socio-ecological system into the forest resilience index can reflect the recovery ability of the forest social-ecological system when it is disturbed by the outside, and it is a crucial index system for observing the self-regulation ability of the forest. From the viewpoint of foreign research, taking the socio-ecological system (SES) as the primary research object and studying the resilience and adaptability of the system to external disturbances from multiple perspectives is an essential trend in recent years in the research on sustainability and global change [33]. However, fewer perspectives combine the logging ban policy and socio-ecological resilience, and specific quantitative statistical results still need to be included.

The research content of this paper is to construct a framework of SES indicators for the Northeastern stated-owned forest area based on existing studies, measure the changes in the socio-ecological resilience of the area before and after the logging ban policy using set-pair analysis, and further analyze the changes and the causes. The marginal contributions of this paper are as follows: first, based on the existing literature, we try to construct a social-ecological system of SES indicators for the Northeastern state-owned forest area with a total of 18 indicators from the social and ecological levels, in order to fill the gaps in this section of research on the Northeastern state-owned forest area. Second, based on the fact that existing scholars have conducted fewer studies on the social-ecological resilience of the Northeastern state-owned forest area—there is a certain lack of relevant studies in China, and the methodology is not common in the international arena—this study quantitatively measured the social-ecological resilience index of Northeastern state-owned forest areas by using a set-pair analysis commonly used in relevant studies, in order to further clarify the relationship between the logging ban policy and social-ecological resilience and the factors affecting it. In view of this, this paper constructs a social-ecological system for state-owned forest areas in Northeast China and empirically examines the changes in social-ecological resilience before and after the logging ban policy, in order to further analyze the causes behind the policy, to make policy recommendations for the further transformation and development of state-owned forest areas in Northeast China, as well as to provide references and lessons for different regions in similar situations.

2. Materials and Methods

2.1. Study Areas

The Northeast China State Forestry Region is located in the Heilongjiang, Jilin, and Inner Mongolia provinces of China, from the edge of the Hulunbeier grassland in the west to the northernmost tip of Mohe in the north, from Wanda Mountain on the Ussuri River in the east to the banks of the Yalu River in the south. It lies on the east longitude of 119°36′26″~134°05′00″ and the north latitude of 41°37′00″~53°33′25″. It is a significant ecological security barrier and backup. It is an essential environmental security barrier and a strategic base for the cultivation of forest resources in China. It comprises six forest industry (forestry) groups, 87 forest industry enterprises (forestry bureaus), and several experimental forest farms and protected areas under their jurisdiction. The operating area of the forest area is 32,741,200 hectares, accounting for 3.41 per cent of the country's total land area; the forest area is 27,274,800 hectares, accounting for 12.64 per cent of the country's forest area; and the forest stockpile stands at 3,007,000,000 cubic meters, accounting for 17.55 per cent of the country's forest stockpile.

2.2. Datasets

Considering the existing research frameworks of various scholars and the availability of data from the state-owned forest areas in Northeast China, a total of 18 indicators were selected for this research framework, including nine indicators at the ecological level and nine indicators at the social level, and the data years were 2008–2021, with multiple interpolations of missing data. The selection of indicators was based on the current research status of domestic scholars, as well as the accessibility and openness of the data, and was not randomly selected; the selection criteria will be explained later.

Due to the vastness of the Northeast state-owned forest area, China does not measure forest resources on an annual basis but conducts forest resource inventories regularly, and it takes about three years for each stage of the inventory, with a significant period for data collation after the inventory until the release of the data. Based on the accessibility of data from the Northeast State Forestry Region at the current stage and the research of existing scholars, the relevant social-ecological system indicator data from 2008–2021 were selected. The data were obtained from China Forestry Statistical Yearbook, China Forestry and Grassland Statistical Yearbook, Seventh Forest Inventory, Eighth Forest Inventory, Ninth Forest Inventory, and the National Bureau of Statistics (NBS), which are all available on public websites.

2.3. Theoretical Framework for the Resilience of Social-Ecological Systems

As one of the most important ways to implement sustainable development, resilience has become a familiar and highly valued focus of many environmental disciplines, including ecology, environmental hazards, and climate change [34]. Ecologist Holling (1973) initially proposed the resilience theory and first defined what ecological resilience means, arguing that the expressive behavior of ecosystems can be determined by two attributes, resilience and stability, and applying it to explain how forests and other ecosystems can persist over time despite being threatened [35]. In the 1980s, Pimm put forward a different idea: resilience is the rate at which a system can return to its original equilibrium state after being subjected to a perturbation [36]. The common point is that both are concerned with the maintenance of the structure and function of the system. Still, the difference is that Holling emphasizes the amount of perturbation the system can withstand, i.e., stability. In contrast, Pimm, based on the equilibrium state, is concerned with the combined ability of the system to recover, resist, persist, and change after being perturbed. Later, Holling (1996) further proposed Engineering Resilience, in which the definition of resilience is based on the assumption of a single stable state and the assumption that the system has only one "optimal" equilibrium state. When the system appears to be in other unstable states [37], measures should be taken to restore the system to its optimal state. In this definition, resilience is based on the assumption of a single stable state, that the system has only one "optimal" equilibrium state, and that measures should be taken to return the system to equilibrium when other unstable states occur. The difference between these two approaches stems from their different perspectives on system stability, which have a certain degree of validity and applicability. Figure 1 gives a clear picture of the theoretical framework of the socio-ecological system resilience.

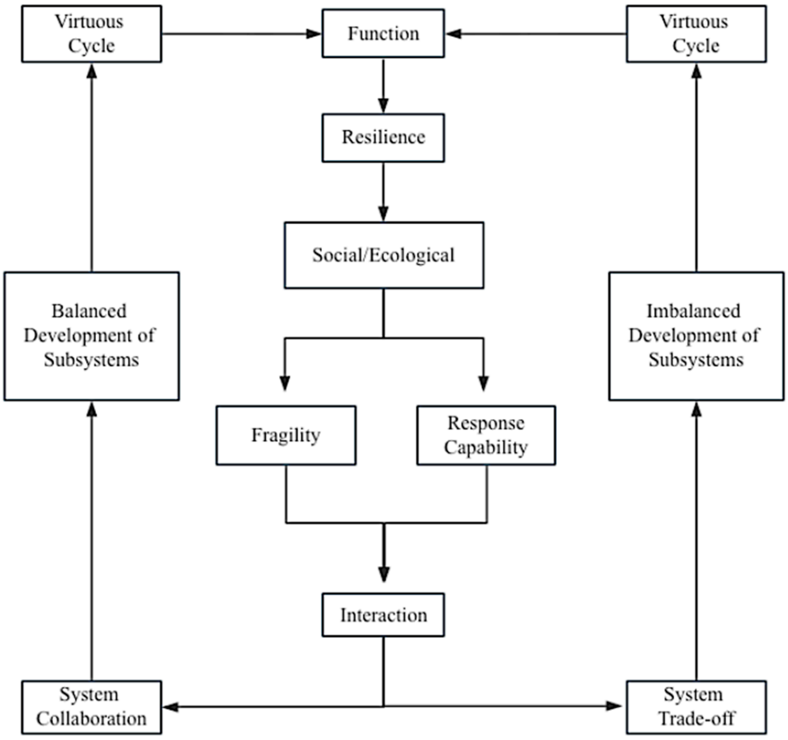


Figure 1. The theoretical framework of the socio-ecological system resilience.

A social-ecological system is a coupled system formed based on the mutual influence and interaction between social system and ecosystem, which is characterized by both system wholeness, internal hierarchy, complexity, uncertainty, etc. [38,39]. Resilience, as a key attribute of a social-ecological system [40], is defined as the system's ability to withstand disturbances and to be able to maintain its own structure, function, characteristics, and feedback [41]. Taking social-ecological systems as research objects to study the system's resilience and adaptability to external disturbances has been a significant trend in research on sustainable development and global change in recent years. Scholars at home and abroad have conducted extensive research on measuring and assessing the resilience of social-ecological systems involving different levels of geography [42], agronomy [43–46], economics [47], sociology [48,49], etc. With the gradual deepening of the research, scholars have found that humans and nature are inseparable aggregates. The state-owned forest areas in Northeastern China are the typical areas where human and nature, society and ecology, are combined; for example, the local adoption of the logging ban policy, ecological compensation, and other means and other factors will affect the change in social-ecological resilience in the area. Most research on social-ecological resilience is qualitative, without a unified quantitative research framework and indicators, because the factors affecting resilience in different regions are very complex. However, some research cases are available at the practical level of small and medium scales. Huang T. et al. (2024) used set-pair analysis to measure the social-ecological system resilience of rural tourism in the core and fringe areas of the Yangtze River Delta region in China. Further, they explained the resilience-influencing factor mechanisms and curve patterns [50]. Bunting W S. et al. (2017) used the DPSIR to construct a framework to evaluate the impacts of the coastal areas of Bangladesh and West Bangladesh, India on the contribution of diversified shrimp rice agroecosystems to socio-ecological resilience [51]. Hou Caixia et al. (2018) used a system dynamics approach to measure socio-ecological system resilience to examine the impact of ecological policies on grassland socio-ecological resilience [52]. There is also the entropy weight TOPSIS method [53], comprehensive index method [54], variable fuzzy identification model [55], and other methods used to research social-ecological system resilience. Taken together, there are two main quantitative research methods; the first is to construct a resilience assessment system model [56], and the second is a resilience evaluation index system [57]. The social-ecological system of Northeastern state-owned forest areas has multiple attributes, including fragility, response capacity, and resilience. The lower the fragility, and the less damage suffered by the forest area system, the higher the resilience. Response capacity refers to the ability to maintain the basic structure and function of the forest social-ecological system when it suffers damage; the stronger the response capacity, the stronger the adaptability and resilience of the forest social-ecological system.

2.4. Methods

In general, due to the existence of regional variability, the choice of the indicator system for socio-ecological system resilience varies among academics and there is no consistent indicator framework. However, most of them include social, economic, and ecological systems in order to comprehensively assess socio-ecological system resilience from the perspective of socio-economic and ecological interactions. In this paper, we will follow the three principles of comprehensiveness, dominance, and quantifiability in the selection of indicators. In addition, in terms of research scale, this paper evaluates social-ecological system resilience at the scale of Northeastern state-owned forest areas, and is able to put forward targeted recommendations for their socio-economic development and ecological environmental protection.

With the continuous promotion of the logging ban policy, the social-ecological system of the Northeastern state-owned forest area has been subject to many changes, which have a great impact on the system's structure and function. Although the Northeastern state-owned forest areas have made some achievements in socio-economic development and ecological environmental protection since the implementation of the logging ban policy, the phenomenon of high input and low efficiency still exists in some areas, which highlights the imbalance of regional development.

Combining the scope of use and specific implementation requirements of each research method, this indicator framework establishes two subsystems, ecological and social, and each subsystem is further divided into fragility and response capacity. At the level of calculation method, given that most scholars in China use a single weight calculation method, this paper adopts the comprehensive weight method combined with the set-pair algorithm, which avoids the error caused by a single assignment. This paper adopts the entropy value method, CRITIC method, and coefficient of variation method, respectively, to calculate the indicator weights, then constructs the objective function according to the principle of minimum information entropy, and then adopts the genetic algorithm to search for the optimal combination of weights. After determining the indicator weights, the set-pair analysis method is used to calculate the comprehensive score of the social and ecological resilience of the Northeastern state-owned forest areas after implementing the logging ban policy. The entropy value method is a method to determine the weight of indicators through the size of the information utility value of each indicator; the CRITIC method is a comprehensive measure of the objective weight of the indicators based on the comparative strength and conflict of the evaluation indicators; and the coefficient of variation method is an objective weight calculated through the degree of variation of each indicator.

This indicator system establishes two subsystems at the ecological and social levels, with each sub-level divided into fragility and response capacity.

2.4.1. Combined Weights

By normalizing the data of each index, the weights of the indices were calculated according to the entropy value method, CRITIC method, and coefficient of variation method, respectively. Finally, the objective function was constructed according to the principle of minimum information entropy, and the optimal weights were calculated by using a genetic algorithm; this result is shown in Table 1. The direction means the attributes of the indicator, + is positive, − is negative.

Table 1. The state forest area in Northeast China of SES's indicators.

Subcriterion Level	Form	Index Layer	Direction	Implications	Variable Name	Combined Weights
ecological level	fragility	Afforestation area (million hectares)	+	Support of ecosystems by forest volume	x_1	7.52%
		Forest conservation area (ha)	+	Securing ecosystems by forest management	x_2	2.58%
		Forestation area (ha)	+	Strength of artificial regeneration to restore forest ecology	x_3	6.61%
		Forest park area (ha)	−	Pressure on the ecosystem caused by forest tourism development	x_4	3.35%
		Forest management area (ha)	+	Support of forest ecological construction of the ecosystem	x_5	3.11%
	responsecapability	Investment in forest management (RMB 10,000)	+	Strength of financial support for systematic and orderly	x_6	7.42%
		Investment in environmental protection for forest tourism (RMB 10,000)	+	Strength of financial support for ecosystem disturbance	x_7	5.35%
		Investment in forest fire prevention (RMB 10,000)	+	Strength of financial support for the prevention of fire disturbance	x_8	3.97%
		Fixed investment in forestry actually completed at the end of the year (RMB 10,000)	+	Strength of financial support for forestry development	x_9	6.65%
social level	fragility	Number of actual retirees at the end of the year (persons)	−	Changes in the structure of labor force	x_{10}	7.42%
		Number of persons who have left the organization and are still in labor relations (persons)	−	Additional stresses on the system	x_{11}	7.62%
		Share of secondary forestry industry in total forestry output value (%)	−	Dependence of the system on forest products processing	x_{12}	6.47%
		Share of secondary forestry industry in total forestry output value (%)	−	Dependence of the system on forest resources	x_{13}	5.05%
		Average number of employees on board at the end of the year (persons)	+	Employment absorption status of the system	x_{14}	5.06%
	responsecapability	Gross output value of forestry (RMB 10,000)	+	Total economic volume in the system	x_{15}	5.83%
		Output value of forestry tertiary industry (RMB 10,000)	+	Trend of industrial development and evolution in the system	x_{16}	5.71%
		Average annual salary of state-owned forest employees on the job (RMB 10,000)	+	Social benefits within the system	x_{17}	5.39%
		Per capita gross forestry output value (RMB 10,000)	+	Industrial efficiency within the system	x_{18}	4.89%

The sources of data have been described in the previous section. The + means positive, − means negative.

2.4.2. Entropy Weight Method

Taking n evaluation years, each with m evaluation indicators, constituting an initialization matrix $x = \left(x_{ij}\right)_{n\times m}$, the negative indicators were first positively normalized, and then all indicators were standardized to eliminate errors caused by different statistical units. The formulas are shown in Equations (1)–(4):

$$Z_{ij} = \frac{X_{ij} - \min\{X_{1j}, X_{2j}, \ldots, X_{nj}\}}{\max\{X_{1j}, X_{2j}, \ldots, X_{nj}\} - \min\{X_{1j}, X_{2j}, \ldots, X_{nj}\}} \tag{1}$$

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} P_{ij} \ln(P_{ij}) (j = 1, 2, 3, \ldots, m) \tag{2}$$

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{n} z_{ij}} \tag{3}$$

$$w_{1j} = \frac{1 - e_j}{\sum_{i=1}^{\infty} 1 - e_j} \tag{4}$$

2.4.3. The Method of CRITIC

Firstly, the standard deviation of the indicator is calculated as S_j to indicate the variability of the indicator. Secondly, the conflicting nature of the indicators is calculated, where the correlation coefficient is R_j. The informativeness of the indicator is C_j, and the indicator's objective weight is w_{2j}. The formulas are shown in Equations (5)–(7):

$$R_j = \sum_{i=1}^{m} (1 - r_{ij}) \tag{5}$$

$$C_j = S_j \cdot R_j \tag{6}$$

$$w_{2j} = \frac{C_j}{\sum_{j=1}^{m} C_j} \tag{7}$$

2.4.4. The Coefficient of Variation Method

$$v_j = \frac{\sigma_j}{\overline{x_j}} \tag{8}$$

$$w_{3j} = \frac{v_j}{\sum_{j=1}^{m} v_j} \tag{9}$$

where σ_j denotes the standard deviation of the j indicator, $\overline{x_j}$ is the mean of the j indicator, v_i is the coefficient of variation of the j item, and the weight is w_{3j}.

2.4.5. Combined Weights Method

The final objective function is constructed based on the principle of minimum information entropy to find the optimal combination of the weights calculated from Equations (4), (7) and (9), respectively. Weight w_j:

$$\mathrm{minF} = \sum_{j=1}^{m} \mathrm{w_j}(\mathrm{lnw_j} - \mathrm{lnw_{1j}}) + \sum_{j=1}^{m} \mathrm{w_j}(\mathrm{lnw_j} - \mathrm{lnw_{2j}}) + \sum_{j=1}^{m} \mathrm{rw_j}(\ln \mathrm{w_j} - \ln \mathrm{w_{3j}}) \tag{10}$$

$$\mathrm{Ps}:\ \sum_{j=1}^{m} w_j = 1, w_j > 0, min\{w_{1j}, w_{2j}, \ldots, w_{nj}\} < w_j < max\{w_{1j}, w_{2j}, \ldots, w_{nj}\}.$$

By the genetic algorithm, the above optimization problem can be solved to obtain the one that satisfies the objective function. The entropy, CRITIC, and coefficient of variation methods have their own advantages and disadvantages, and the combination of weights can try to avoid the error of the results and make them more informative.

2.4.6. Set-Pair Analysis

Set-pair analysis is to consider two sets with some connection as a set pair, and in the context of a specific problem, classify the sets into certainty and uncertainty according to a certain characteristic of the set pair. Among them, the explicit "same" and "opposite" are certainty, while "difference" is uncertainty, and the connection degree is established from the same, different, and opposite aspects to analyze things and their systems. If the set-pair analysis under the specific problem Q is to analyze the characteristics of the set H, and there is a total of N characteristics, of which there are S for the set A and the set U in common, and P opposites, then the remaining $F = N - S - P$ characteristics are neither different from one another nor opposites, the relationship is uncertain, and the degree of connection between the two A, U μ is as follows:

$$\mu(\mathrm{Q}) = \frac{\mathrm{S}}{\mathrm{N}} + \frac{\mathrm{F}}{\mathrm{N}}\mathrm{i} + \frac{\mathrm{P}}{\mathrm{N}}\mathrm{j} = \mathrm{a} + \mathrm{bi} + \mathrm{cj} \tag{11}$$

where a, b, and c are categorized as becoming the degree of congruence, degree of difference, and degree of opposition of the sets A, U under the problem Q, and $a + b + c = 1$, where a and c are relatively deterministic while b is relatively indeterministic; and i and j are the markers of both the degree of difference and the degree of opposition, and the coefficients of the two, with $i \in [1, -1]$, j = −1.

The multi-attribute evaluation problem can be denoted as $Q = F, D, E, W$. The valuation program is set as $F = f_1, f_2, \ldots, f_m$, evaluation indicator is set as $D = d_1, d_2, \ldots, d_m$, evaluation object is set as $E = e_1, e_2, \ldots, e_k$, e_k is the k evaluated object, and the evaluation indicator weight is set as $W = w_1, w_2, \ldots, w_n$. Comparing the same space to determine the optimal evaluation set in each evaluation program for $U = u_1, u_2, \ldots u_n$, the worst evaluation indicator in each evaluation indicator constitutes the worst evaluation set for $V = v_1, v_2, \ldots, v_n$, where u_r, v_r are the optimal and worst values of the indicator, respectively. For the set pair $\{F_m, U\}$ on $[U, V]$, the degree of connection is

$$\begin{cases} u(f_m, u) = a_m + b_m i + c_m j \\ a_m = \sum w_p a_{pk} \\ c_m = \sum w_p c_{pk} \end{cases} \tag{12}$$

where a_{pk} and c_{pk} are the degree of congruence and the degree of opposition between the evaluation indicator d_{pk} and the set $[U_n, V_n]$, respectively; w_p is the weight of the p indicator. The formulas for when d_{pk} acts positively and negatively on the evaluation indicators are in order:

$$\begin{cases} a_{pk} = \frac{d_{pk}}{u_p + v_p} \\ c_{pk} = \frac{u_p \cdot v_p}{d_{pk}(u_p + v_p)} \end{cases} \tag{13}$$

$$\begin{cases} a_{pk} = \frac{u_p \cdot v_p}{d_{pk}(u_p + v_p)} \\ c_{pk} = \frac{d_{pk}}{u_p + v_p} \end{cases} \tag{14}$$

The relative closeness of r_m scheme f_m to the set of optimal schemes U can be defined as follows:

$$r_m = \frac{a_m}{a_m + c_m} \tag{15}$$

where r_m reflects the degree of connection between the evaluated program $\mathrm{f_m}$ and the optimal program set U. The larger the value of r_m, the closer the evaluated object is to the optimal program, i.e., the status quo of the system is close to the optimal state, so as to assess the magnitude of the resilience.

3. Results

3.1. Weights

According to Formulas (1)–(15), the raw data of the critical state-owned forest areas in Northeast China are processed and calculated, and the results of the entropy weight method, the CRITIC method, the coefficient of variation method, and the combined weights are shown in Table 2.

Table 2. Weights in SES indicators of state-owned forest area in Northeast China.

Subcriterion Name	From	Variable Name	w_{1j}	w_{2j}	w_{3j}	w_j
ecological level	fragility	x_1	7.19%	6.85%	6.27%	7.52%
		x_2	2.36%	4.76%	3.22%	2.58%
		x_3	6.56%	5.27%	6.90%	6.61%
		x_4	2.54%	7.28%	3.32%	3.35%
		x_5	3.23%	4.10%	3.98%	3.11%
	response capability	x_6	9.10%	4.37%	7.56%	7.42%
		x_7	6.06%	4.43%	5.82%	5.35%
		x_8	4.31%	4.09%	4.87%	3.97%
		x_9	5.94%	7.21%	5.64%	6.65%
Social level	fragility	x_{10}	7.28%	5.42%	7.61%	7.42%
		x_{11}	6.81%	7.28%	6.39%	7.62%
		x_{12}	6.36%	6.04%	5.95%	6.47%
		x_{13}	5.06%	5.31%	5.18%	5.05%
		x_{14}	3.87%	8.11%	4.45%	5.06%
	response capability	x_{15}	6.12%	5.15%	5.88%	5.83%
		x_{16}	6.31%	4.81%	5.85%	5.71%
		x_{17}	5.61%	4.86%	5.81%	5.39%
		x_{18}	5.29%	4.66%	5.30%	4.89%

The sources of data have been described in the previous section.

Regarding the average weight of the 18 indicators, the weights of indicators X_1, X_3, X_6, and X_9 in the ecological subsystem are all greater than 5.5%, accounting for a more significant proportion. In terms of the content of the indicators, they are afforestation area (10,000 he), forestation area (he), forest management investment (RMB 10,000), and the actual amount of forestry fixed investment at the end of the year (RMB 10,000), which accounted for 7.52%, 6.61%, 7.42%, and 6.65%, respectively. The afforestation area (10,000 he) and forestation area (he) belong to ecosystem fragility indicators, the investment in forest management (RMB 10,000) and actual completion of fixed forestry investment at the end of the year (RMB 10,000) belong to indicators of the response capacity of the social system, and the four are in a balanced state from the perspective of weighting values.

In the social subsystem, the weights of $X_{10,}$ X_{11}, X_{12}, X_{15}, and X_{16} are more significant than 5.5 percent, and are the actual number of retired persons at the end of the year (persons), the number of persons who left the unit and still retained the labor relationship (persons), the proportion of the secondary industry in forestry in the total output value of forestry (percent), the total output value of forestry (RMB 10,000), and the output value of the tertiary industry in forestry (RMB 10,000). Their proportions are 7.42%, 7.62%, 6.47%, 5.83%, and 5.71%; the first three are fragility indicators, and the last two are response capacity indicators. Numerically, the weighting of the fragility indicators in the social subsystem is generally more significant than that of the response capacity indicators.

Figure 2 shows the different weights calculated by the four methods, from which we can clearly see the difference in each metric under different algorithms. The weights in the innermost circle represent the entropy weighting method weights, followed in order by the CRITIC method weights, the coefficient of variation method weights, and the combined weights. It can be clearly seen that the combined weighting method effectively circumvents the differences in weights under different methods.

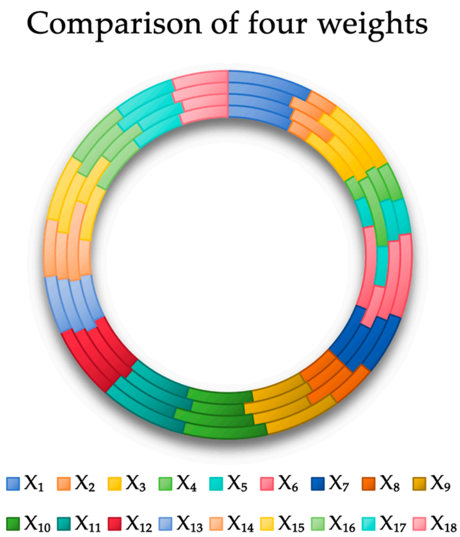


Figure 2. Comparison of four weights.

3.2. Northeast State-Owned Forestry Area Socio-Ecological System Resilience Index

Based on the social-ecological resilience index system of the Northeast State Forest Region established in this paper, the fragility, response capacity, and resilience of the two social and ecological subsystems will be measured and analyzed from 2008 to 2021. According to the research results of scholars nowadays, the recognized method is selected to classify the system resilience into Low, Middle, and High, relatively within the range. The specific values are shown in Table 3.

Table 3. The level of r_m.

$\mathbf{r_m}$	$\mathbf{0 < r_m \leq 0.33}$	$\mathbf{0.33 < r_m \leq 0.67}$	$\mathbf{0.67 < r_m \leq 1}$
Level	low	middle	high

3.2.1. Time-Series Changes in Total Fragility, Response Capacity, and Resilience

During the period of 2008–2021, the total social-ecological system fragility of the state-owned forest areas in Northeast China shows a fluctuating increase, and the level is located in the Middle, which shows a fluctuating downward trend before 2015 and a fluctuating upward trend after 2015, and reaches a maximum value of 0.67 in 2019. The total response capacity is High for most of the time and is at the Middle level after falling back, increasing steadily after 2015 and decreasing from 2019 on. Under the interaction of the two, the total system resilience also shows a fluctuating increase. Still, from 2015 to the present, resilience was not significantly enhanced, and it only reached a maximum value of 0.671 in 2018, which is at the High level, and then was at the Middle level in the following nearly three years. The annual change in total fragility, response capital, resilience are shown in the Table 4 and Figure 3.

Comparing the three, from 2008 to 2010, the total fragility is greater than the total response capacity, and at this time, the resilience is located in the middle of the two. From 2010 to 2018, the total fragility was less than the total response capacity. During this time, the total resilience rose significantly, especially after 2015. The total resilience increased to the maximum of the whole observation period of 0.671 in 2018 and then began to fall back somewhat. At this time, the specific relationship between the three was total fragility < total response capacity < total resilience. From 2018 to 2020, the total fragility, response capacity, and resilience index were be in equilibrium. From the table, it can be concluded that the resilience index of the critical state-owned forest areas in Northeast China experienced a development and evolution process of Middle (2008–2017)–High (2018–2019)–Middle (2020–2021).

Table 4. The annual change in total fragility, response capital, resilience.

Year	Fragility	Response Capital	Resilience
2008	0.531	0.217	0.384
2009	0.538	0.272	0.415
2010	0.474	0.384	0.434
2011	0.528	0.567	0.545
2012	0.521	0.629	0.567
2013	0.444	0.679	0.545
2014	0.412	0.678	0.522
2015	0.448	0.674	0.543
2016	0.514	0.706	0.594
2017	0.522	0.770	0.632
2018	0.588	0.773	0.671
2019	0.670	0.661	0.666
2020	0.606	0.576	0.593
2021	0.603	0.574	0.591

The sources of data have been described in the previous section.

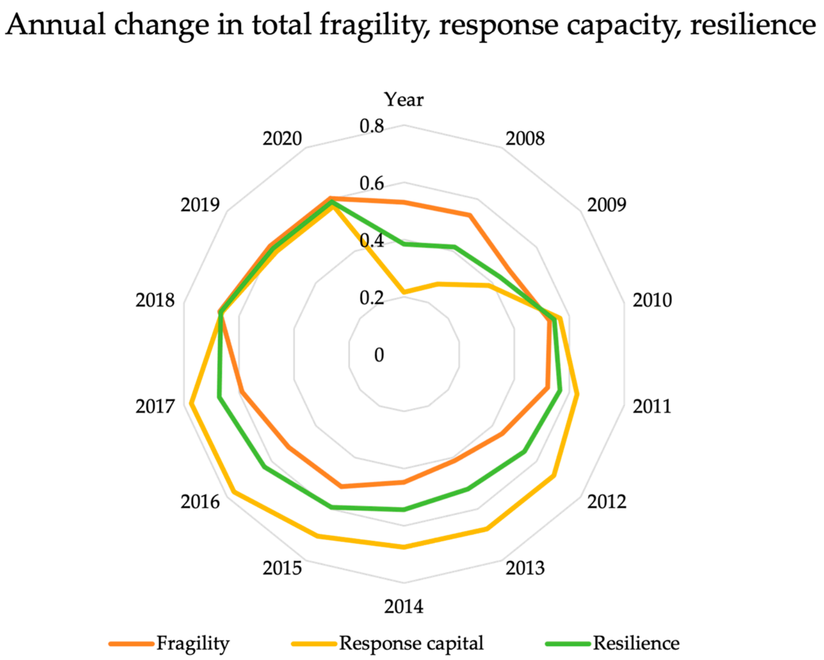


Figure 3. Annual change in total fragility, response capital, resilience.

3.2.2. Time-Series Changes in Ecological, Social, and Total Resilience Indices

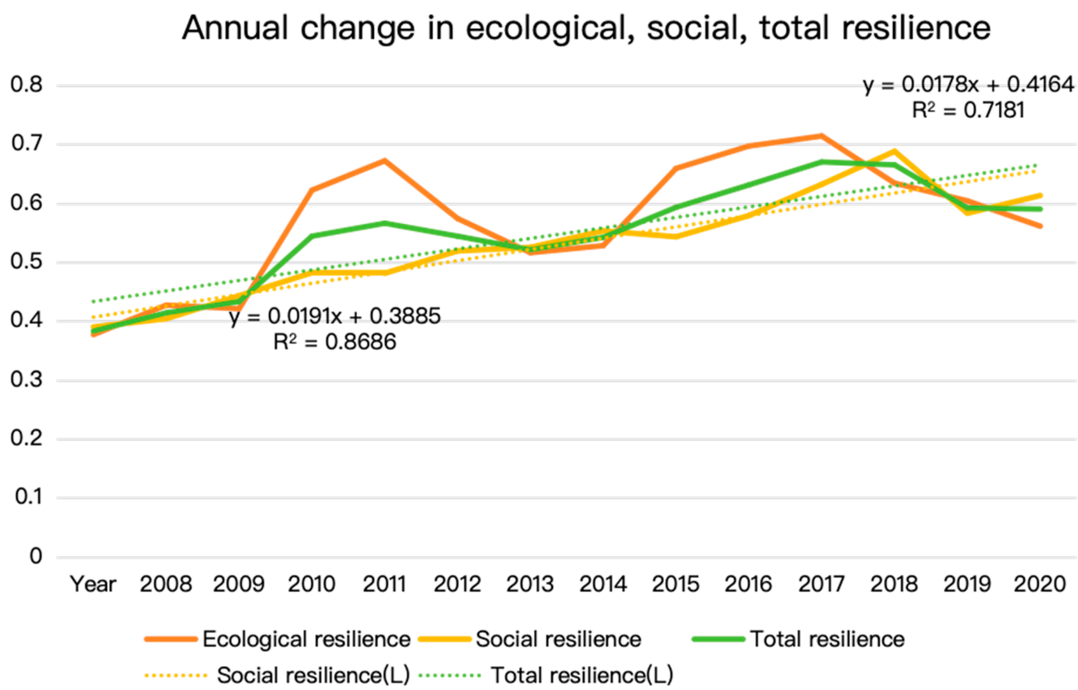
Between 2008 and 2020, the ecological, social, and total resilience indices were all in a fluctuating upward trend, in which the level of the ecological resilience index fluctuated between Middle and High, and ushered in a second increase after 2015, but fell back in the last two years. The social resilience index fluctuated less yearly, and its level was mainly located in the Middle. It only reached a high in 2019, as calculated by Excel 2021, resulting in a trend line fitting equation of Y = 0.0178x + 0.4164, R^2 = 0.7181, whose coupling coordination was positively related to resilience. The indices of ecological resilience, social resilience, total resilience are shown in the Table 5.

Table 5. The index of ecological resilience, social resilience, total resilience.

Year	Ecological Resilience	Social Resilience	Total Resilience
2008	0.378	0.391	0.384
2009	0.428	0.405	0.415
2010	0.422	0.444	0.434
2011	0.623	0.483	0.545
2012	0.673	0.482	0.567
2013	0.575	0.520	0.545
2014	0.517	0.526	0.522
2015	0.529	0.554	0.543
2016	0.660	0.544	0.594
2017	0.698	0.580	0.632
2018	0.715	0.633	0.671
2019	0.635	0.689	0.666
2020	0.605	0.584	0.593
2021	0.562	0.614	0.591

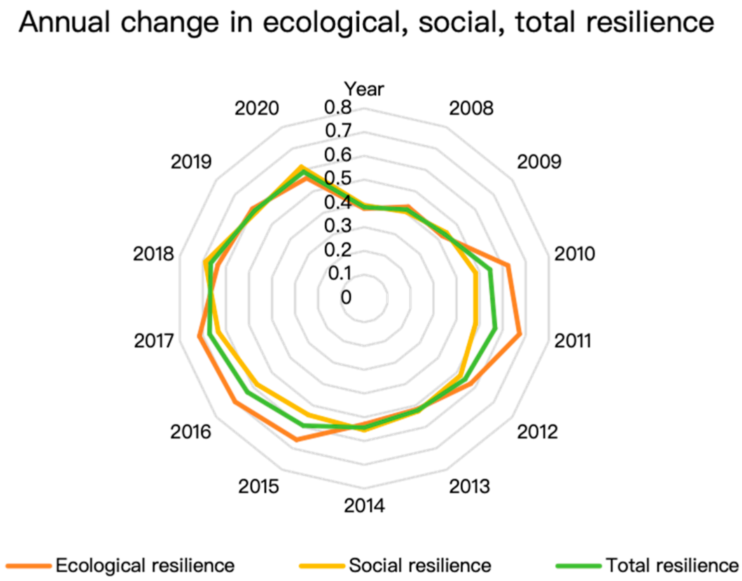
The sources of data have been described in the previous section.

Comparing the three, the ecological, social, and total resilience indices were more compatible and in balance from 2008 to 2010; from 2010 to 2012, the ecological resilience index was more significant than the social resilience index; from 2012 to 2014, the three tended to be compatible again; from 2015 to 2017, the ecological resilience index was more significant than the social resilience index, but the gap between them was smaller than that between 2010 and 2012. From 2017 to 2020, the three converged again. Overall, except for 2008–2010, when the three indices were significantly lower, there were no significant fluctuations in social resilience and total resilience in the remaining years, and the overall situation was very stable, but the ecological resilience index fluctuated considerably twice, in 2010–2012 and 2015–2017, respectively. The annual changes in ecological resilience, social resilience, total resilience are shown in the Figure 4.



(**a**)

Figure 4. *Cont.*



(**b**)

Figure 4. Annual change in ecological resilience, social resilience, total resilience. (**a**) The line graph of the annual change in ecological resilience, social resilience, total resilience. (**b**) The radar graph of the annual change in ecological resilience, social resilience, total resilience.

4. Discussion

4.1. Logging Ban Policies as an Effective Way to Increase Socio-Ecological Resilience

The results of this study show that the socio-ecological resilience of Northeastern state-owned forest areas has been improved to a certain extent since the implementation of the comprehensive logging ban policy in 2015, and its resilience index shows a fluctuating growth trend. According to the specific values, the socio-ecological resilience developed from 0.384 in 2008 to reach a maximum value of 0.671 in 2018 for the whole observation period. This indicates that implementing the logging ban policy was an effective way to strengthen the ecological construction of Northeastern state-owned forest areas, enhance the ecological function of forests, and promote the sustainable management of forest areas.

To investigate the reasons, we in turn targeted a collection of state-owned forest areas currently doing specific work, from the social level. For example, we found that the forest enterprises in the Northeastern state-owned forest areas generally carried out extensive and in-depth publicity after the implementation of the logging ban policy so that the majority of forest workers would recognize the necessity of the logging ban policy, and gradually change from the initial resistance and worry to the relationship and supportive attitude, which firmly guaranteed the smooth implementation of the subsequent logging ban areas, and maintained the social harmony and stability of the forest areas. The initiative firmly guaranteed the smooth implementation of the subsequent logging ban area and maintained the social harmony and stability of the forest area. For the laid-off forest workers, relevant measures such as vocational education, job transfer, social insurance subsidies, etc., were carried out. This series of measures effectively stabilized the social unrest caused by the logging ban policy. On an ecological level, the logging ban policy stopped commercial logging of trees in the Northeastern forest areas, which is the most compulsory and strict measure in China at present, and this allowed the forests to recuperate to a certain extent. In the Yichun forest area of Heilongjiang, for example, as of 2024, the forest cover in Yichun will reach 83.8%. The forest stock will increase to 3.75×10^8 m^3, with an average annual net increase of more than 10^7 m^3, and the results of the total logging ban in the forest area will continue to expand.

4.2. Social-Ecological Systems Have Some Capacity for Self-Adjustment and Resilience but Have Shown a Declining Trend in Recent Years

Combined with the results section of this paper, the socio-ecological resilience shows a fluctuating upward trend from 2008 to 2018. In terms of specific values, its resilience index increased from 0.384 in 2008 to 0.671 in 2018, but began to have a yearly decreasing trend after 2018; in terms of specific values, the resilience index decreased year by year from 0.671 in 2018 to 0.591 in 2021. To analyze the reasons for the decline in the resilience index, we consider the establishment of the Longjiang Forestry Group in 2018 to implement the separation of government and enterprises, the 18 lightning fires in the Daxinganling forest area in 2019, which increased the vulnerability of the social-ecological system in the area, as well as a certain amount of disruption in coping capacity, which suggests that resilience enters into certain bottlenecks and challenges when coping with complex or large-scale problems. However, considering that it did not cause a more significant decline and the change was less than before 2015, this indicates that the Northeastern state-owned forest area has a certain stability through a period of restoration and reform, and at the same time, it shows that the socio-ecological system has the ability to self-adjust and recover.

In terms of specific ecological, social, and total resilience, the ecological, social, and the total resilience indices all show a fluctuating upward trend, but the changes in these three indices do not have synchronization. It can be clearly seen that before the implementation of the logging ban policy in 2015, the ecological resilience index showed a rising and then falling trend, while the social resilience index had a fluctuating upward trend. The magnitude of the change was relatively small compared with the ecological resilience, and we consider that this is mainly related to China's annual state financial forestry industry subsidies such as forest conservation subsidies; the strong governmental subsidized policies compensate for the logging ban policy.

During the period 2008–2021, the comparison among these three indices shows that the trend of social resilience and total resilience change was more consistent, but all three indices began to have a fallback phenomenon during the period 2018–2019. In terms of specific values, the change in the value of social resilience was more stable, while the change in the value of ecological resilience was relatively large. Here, we consider that due to the unique climate of the Northeast, which leads to the long growth cycle of local tree species, the growth of forest stands and the increase in the coverage rate need a longer cycle to be realized, so its stability will be slower to improve and realize. In terms of key time points, all three had a clear upward trend after 2015, mainly due to the release of two important guiding opinions in 2015, one to completely stop the commercial logging of natural forests, and the other to carry out the separation of the government and enterprises; however, all three declined to a certain extent during the period of 2018–2019. We conclude that, in the context of state intervention, social and ecological resilience has shown a more stable trend over the long term, although there has been some fluctuation, in contrast to a certain decline in social and ecological resilience in recent years. Therefore, although social-ecological resilience has a certain self-adjustment and resilience, to improve the social-ecological resilience of Northeastern state-owned forest areas in a long-term and stable manner, it is necessary to increase social and ecological inputs, so that the state-owned forest areas can have better ecological protection, restoration, and management, which is mainly based on forest management, afforestation, and nurseries.

4.3. Reflections on the Logging Ban Policy

Globally, ecological protection, a reduction in forest land loss, and the mitigation of the climate change crisis have become the core issues of concern for all countries. In this context, China's logging ban policy not only reflects the country's sense of responsibility to deal with the environmental crisis but also provides a policy framework and implementation program for other countries and regions to follow. According to the results of this study, the logging ban policy is effective. Still, due to the national system, the forest industry enterprises are under the robust protection of the state, and the development of the Northeastern state-owned forest areas is in a passive state. However, from the perspective of sustainable development, when the Northeastern state-owned forest enterprises in the forest industry leave the large government policy subsidies, how much risk-coping ability will they have? How much potential do these enterprises have for transferring surplus labor from various sectors? These questions need to be studied and evaluated in depth. From a rational person's point of view, under the subsidies, there will be a certain degree of slackness in the forest industry enterprises, which is not conducive to the sustainable development of the regional industry. And in the process of research, we found that in 2008, the average annual salary of state-owned forest workers on the job was RMB 0.996 million, which rose to RMB 50,000 in 2021; however, in 2021, the national average annual salary of urban non-private sector employees was RMB 107,000, although the income of the employees in the Northeastern state-owned forest areas is still lower than the national average level. But at present, there are still a large number of non-employed people on the books, a phenomenon that actually occurs in order to maintain the stability of the regional society, and the government has ensured the basic functioning of the local economy and society by maintaining the treatment of these redundant laborers. However, this solution has, to a certain extent, increased the pressure on local governments and social systems, making resource allocation inefficient and further affecting long-term economic development.

Against this complicated background, how to raise the effectiveness of the logging ban policy to a new stage has become an important issue that we must face. Relying only on the state's subsidy policy is far from enough, and ensuring the direction of sustainable development requires the joint efforts of more parties. Improving the internal management of enterprises, increasing the efficiency of resource utilization, and promoting the transformation of the local economy are all measures that must be considered to enhance the effectiveness of the logging ban policy.

4.4. The Policy Recommendations

4.4.1. Achieving Transformation of Sectors

The roles here can be specifically categorized into workers, enterprises, and the government. First, the government, being the regulator and supporter, should be excessive. The development task of state-owned forest areas has undergone a qualitative shift from pursuing economic benefits and rapid expansion to realizing the value of public welfare ecological forest products. In terms of policy orientation, protection policies such as the total logging moratorium have cut off at the root the possibility of forest areas centered on the pursuit of commercial interests, but this has also had a great impact on the livelihoods of forest workers. At this point, the government must move from the regulatory role of issuing policies, investments, and approvals to the supportive role of facilitating the emergence and development of new businesses in forest areas. The government needs to note that the ecological restoration of the Northeastern state-owned forest areas cannot rely excessively on financial subsidies. Although subsidies are in the early development of a very important decision, from the perspective of long-term development, it is necessary to grant the forest industry enterprises alone the ability to make a profit, such as the development of ecological products to realize the value of the path, and the modeling of forest economy development, combined with the local culture and tradition to develop attractive study routes and so on.

Secondly, the enterprise should be transformed from a market-oriented enterprise pursuing income to a public welfare enterprise undertaking forest care and nurturing. After the Chinese government put forward a series of requirements such as "separation of government and enterprises" and "public welfare forest industry enterprises", forest industry enterprises should have immediately realized the change in their own identity and actively undertaken the responsibility of forest conservation and nurturing. As purely public welfare forest industry enterprises, they need to do the following: (1) Nurture the forests, increase the forest stock, cultivate good trees and select seeds, etc., and continuously improve the quantity and quality of forests in state-owned forest areas. (2) In the development of the forest economy, focus on developing forest products with ecological product labeling to create their own brand and promote it nationwide. (3) While developing tertiary industries such as forest recreation, forest study, forest tourism, etc., focus on telling the story of Northeast China, further revitalize the local cultural resources, and create a fusion of special culture, tourism, services, and forest resources.

Finally, employees should change from relying on demands to paying for protection. At the same time the development of planning changes will inevitably be accompanied by the elimination of personnel and the lack of talent, there will be a need to reasonably guide the flow of personnel between different departments through the transfer of placement, departmental information sharing, and the flexible mobilization of existing human resources, so that the qualifications of personnel and the needs of the position match. This is specifically divided into three aspects: (1) proper placement of old employees. The old employees have been accustomed to the traditional way of operation, have a low learning ability, and are mainly engaged in labor-intensive work to make reasonable arrangements for the operation, such as forest care, forest nourishment, and so on. (2) For the new generation of forest personnel, encourage them to learn the relevant knowledge of the new industry through job training, qualification assessment, and other forms so that they can be integrated into the work of the new industry. For example, these personnel included forest recreation escorts, forest study supervisors, and so on. (3) Focus on introducing high-precision talents with forestry knowledge and skills into the forest area to participate in constructing the forest area on the ground, such as government–enterprise cooperation, school–enterprise cooperation, internship operations, etc.

4.4.2. Improvement of Industrial Layout

Reviewing the Traditional Industrial Model

Under the policy of a total ban on logging, it is necessary to abandon the past forest activities that were mainly based on single logging or low-level processing, and to retain the understory economic products derived from the protection of forest resources. Forest food has become the third-largest agricultural product in China. Scientific seeding and conservation of forest products in line with regional characteristics will be carried out to create high-quality, pollution-free, green ecological products. According to the local advantageous industries, we will create ecological product brands and actively play the brand effect to boost the development of forest food, forest farming, and other forest economies.

Learning from Excellent Cases at Home and Abroad

For example, by integrating forest recreation and forest study, which are widely recognized lifestyles in China in recent years, forest tourism is integrated with culture, service, health, and other industries to create a high-value-added tertiary forest industry. At the same time, it focuses on using the development history of the Northeast region to create a unique slogan belonging to the Northeast region, integrates this slogan into the process of research and study, and constantly enriches the connotation of the industry.

Development of Ecological Product Value Realization

As a public good with public attributes, forests have a strong externality, which requires us to focus on the value of intangible products provided by forests to make up for the lack of regional income. For example, the ecological functions provided by forests, such as water conservation, soil conservation, maintenance of biodiversity, and provision of carbon emissions, can be realized by the government in the form of compensation for the value of ecological products as well as carbon sinks trading of forest tickets and forest rights.

5. Conclusions

5.1. Main Contributions and Implications

In this study, we synthesized the current research related to China's logging ban policy and selected a new perspective for research on social-ecological resilience. We constructed an index of social-ecological system resilience in state-owned forest areas of Northeastern China. The time-domain changes in social-ecological resilience in the Northeastern state-owned forest area from 2008 to 2021 were measured based on the genetic algorithm and set-pair algorithm. This paper fills the gaps in the domestic research on state-owned forest areas in Northeast China, provides a new perspective and theoretical framework, and enables scholars to visualize the changes in the social-ecological resilience of state-owned forest areas in Northeast China before and after the logging ban policy, so that the government and related enterprises can make better decisions for the next step. At the same time, it can make foreign scholars understand the current situation of state-owned forest areas in Northeast China and the impacts and problems of the logging ban policy, which can provide certain references for relevant scholars' next research.

5.2. Limitations

The results of this study show that the total logging ban can effectively improve socio-ecological resilience and the Northeastern state-owned forest areas have a certain degree of stability through restoration and reform. However, from the sustainable development perspective, there are still some problems. For example, will government subsidies hinder the motivation of enterprises and employees? How effective is the transformation of enterprises? Can the caliber of statistical data in forest areas be consistent? All these questions need the cooperation of related departments to obtain answers with authenticity. Since this study is based on the analysis of official government statistics, there are some limitations; the government's statistical caliber is inconsistent in a particular year, so the selection of indicators is limited, and we hope to obtain more authentic and effective data through research in the future for the continuous improvement of the indicator framework.

5.3. Future Research Direction

The implementation of the logging ban policy has undoubtedly ensured the restoration of the ecosystem in the area, but at the same time, it has also affected the livelihood of the enterprises and employees who are mainly dependent on these resources. However, the forest area has not yet realized the transformation from resources to assets and then to capital. Therefore, the next step of the research should take into account the role change, industrial layout, and staff development, and make full use of the existing studies in similar contexts at home and abroad to explore how to break the deadlock in the reality of the Northeastern state-owned forest areas in order to seek the next step of transformation and development, which will enable the forest enterprises and their staff to take the initiative in the development.

Author Contributions: Conceptualization, S.L.; methodology, S.L.; software, S.L.; Validation, S.L.; formal analysis, S.L.; investigation, S.L.; resources, S.L., D.Q., X.H., and B.S.; data curation, S.L., X.H., and Z.W.; writing—original draft preparation, S.L., D.Q., X.H., B.S., and Z.W.; writing—review and editing, S.L., X.H., B.S., and Z.W.; visualization, S.L.; supervision, X.H., B.S., and Z.W.; project administration, H.L.; funding acquisition, H.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Beijing Forest University, Platform Highland Construction Project: Research on the Realization Mode of Ecological Product Value and its Policy System, grant number 2021SPZ03.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data will be made available upon request.

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

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