forests

Article

Economic Loss Assessment and Spatial–Temporal Distribution Characteristics of Forest Fires: Empirical Evidence from China

Zhixuan Han [1], Guangjie Geng [2,3,*], Zhen Yan [1,4,5,*] and Xi Chen [6]

[1] School of Mathematics and Statistics, Guangxi Normal University, Guilin 541006, China
[2] School of Banking and Finance, University of International Business and Economics, Beijing 100029, China
[3] School of Finance, Xuzhou University of Technology, Xuzhou 221018, China
[4] Center for Applied Mathematics of Guangxi, Guangxi Normal University, Guilin 541006, China
[5] Guangxi Key Lab of Multi-Source Information Mining & Security, Guangxi Normal University, Guilin 541004, China
[6] Finance and Investment, Guangdong University of Finance, Guangzhou 510521, China
* Correspondence: ggfjack@163.com (G.G.); zhenyan@gxnu.edu.cn (Z.Y.)

Abstract: Forest fires are a type of disaster with both human and natural factors; they differ from other forest disasters, in that they can cause significant damage not only to the ecological environments but also to the economy and society in many irreversible ways. While the risk factor of forest fires has been large, systematic studies on economic losses caused by forest fires have been lacking in recent years, and there is also a lack of analysis on forest fire economic losses in both spatial and temporal dimensions. Therefore, based on the forest fire data from 2006 to 2018, this paper establishes a forest fire economic loss evaluation system to calculate the economic losses in China and analyzes the spatial distribution characteristics and change trends of the forest fire economic losses in each province through thermal mapping. The results show the following. (1) The economic loss from forest fires in China is generally characterized by a fluctuating decline, but anomalous values due to human factors may occur. (2) The spatial heterogeneity of economic loss in China's provinces is limited by many factors, such as the differences in resource endowments, showing the characteristics of "low in the eastern and western regions and high in the central region". (3) Forest fires in China cause the most serious losses to forest ecological benefits. (4) Forest resources and fires are not independent of each other between regions, and areas with similar economic losses related to forest fires are often found in blocks. (5) Although the overall economic losses caused by forest fires in China are fluctuating and decreasing, some provinces are showing signs of increasing economic losses, most notably in Inner Mongolia. Therefore, this paper suggests targeted recommendations based on forest fires in different regions and with reference to the changing trends of economic loss caused by forest fires. For low-loss areas, we can further reduce the economic loss per unit area while ensuring that the losses do not increase any further. For high-loss areas, the main focus should be to find the weak points in the adaptation to forest fires. The right way to permanently reduce the damage caused by forest fires is to improve the adaptive and symbiotic capacity of the ecosystems and residential communities in relation to fires in a targeted manner and to improve the capacity for quick economic recovery after a fire.

Keywords: forest fire; economic damage assessment; loss of forest ecological benefits; loss of forest social benefits; spatial and temporal distribution characteristics

check for updates

Citation: Han, Z.; Geng, G.; Yan, Z.; Chen, X. Economic Loss Assessment and Spatial–Temporal Distribution Characteristics of Forest Fires: Empirical Evidence from China. *Forests* **2022**, *13*, 1988. https://doi.org/10.3390/f13121988

Academic Editor: Peter Elsasser

Received: 20 October 2022
Accepted: 22 November 2022
Published: 24 November 2022

1. Introduction

Forest fires are characterized by suddenness, great destructiveness, and problems of disposal, which can cause direct economic losses in forestry products, economic property, etc. [1]. At the same time, forest fires will endanger human life and health and have an impact on cultural education and economic development in surrounding communities, that is, on the social benefit level of regional forests [2,3]. In terms of the greenhouse effects, carbon emissions, and ecological security, which are currently of major concern to the world, forest fires will increase the emissions of particulate matter [4], carbon dioxide [5], and other greenhouse gases [6,7], resulting in carbon loss [8]. In addition to this, forest fires will also damage forests and soils, reduce the carbon sequestration capacity of forests and soils [9,10], and increase surface runoff and erosion [11,12]. These hazards will cause significant losses to the ecological benefits of forests, and in China and other countries in the world, they limit the capacity to protect the economic benefits of their own forests and achieve the targets of "carbon peaking and carbon neutralization".

After China's reformation and opening up, rapid industrialization processes and the tropical and subtropical climate characteristics have exacerbated the frequent occurrence of forest fires. According to the data of the "China Forestry Yearbook" from 1992 to 2018, the annual average frequency of forest fires in China is 6220.8 times, and the annual average fire area is 190018.6 hectares. In 1987, the forest fire in Greater Khingan Range became the most serious forest fire since the founding of the new China, causing direct economic losses of about CNY 500 million and indirect losses of about CNY 6.913 billion. The total loss was about 42.4% of the 1987 GDP in Heilongjiang and 0.61% of the total GDP of China. In order to reduce the frequency of man-made forest fires and improve the benefits of forests, the Chinese government pays special attention to forest fire prevention legislation and forest fire safety education [13], and it implements ecological projects, such as nature protection projects, the conversion of farmland to forests, and key shelterbelt construction projects in the three northern regions [14]. Considering the heavy losses caused by forest fires in economic property, life safety, and the ecological environment, it is of great significance to scientifically and effectively measure forest fire losses and analyze their spatial and temporal distribution characteristics. The aim is to prevent forest fires, improve the level of forest resource management, and promote the realization of China's targets of "carbon peaking and carbon neutralization".

The assessment of forest fire economic losses can be traced back to the 1950s [15,16], and it has since become the focus of research by scholars at home and abroad. While scholars generally agree on the importance of forest fire economic loss measurement, the evaluation index system of forest fires [17,18], classification methods [19], and assessment methods [20,21] have not been agreed upon. On the whole, the current forest fire damage assessment objectives and research scopes are relatively narrow and more limited to a certain geographical area or experimental observation point [22] or to the evaluation of the loss of a certain type of forest asset and direct economic factors [19,23]. The assessment and dynamic spatiotemporal comparative analysis of forest fire economic losses struggle to accurately describe the spatiotemporal distribution characteristics of forest fire economic losses among the various provinces in China, and it is also impossible to clarify the external factors of forest fires' occurrence. In addition, the forest fire economic loss assessment systems currently used by scholars usually lack integrity, universality of assessment methods, and a process for the scientific selection of measurement indicators [16,24,25]. In particular, price indicators usually operate on fixed prices, without considering the loss changes in different regions from the perspective of regional development differences and lack dynamic thinking. In addition, none of the above studies break away from the logic of the fire suppression approach. It has been shown that while fire suppression measures are important, it is even more undesirable to ignore the potential for larger scale damage caused by forest fire suppression because fire suppression leads to fuel accumulation, which can set the stage for larger scale forest fires [26,27].

Therefore, based on the existing research and the analysis of the shortcomings of current research, the main contributions of this paper are as follows. Firstly, it is the first attempt to effectively measure the economic losses of forest fires in each province of China. Secondly, considering the direct economic losses, ecological benefit losses, and social benefit losses caused by forest fires, 12 loss index factors are established to expand the range of forest fire economic loss estimations and reduce the errors in the said estimations. Thirdly, we scientifically screen the measurement indicators, expand the range of measurements, and adjust the measurement indicators according to the different conditions in the provinces of China. The purpose of doing so is to narrow the gap between the assessment results and the real values that arises due to the inconsistency in research approaches when using results from other studies, so as to make the measurement results adhere more closely to reality. Fourthly, for price data, this paper moves away from using fixed prices and discounts price data that cannot be directly obtained, such that the forest fire economic loss assessment results can be made more accurate. Finally, we dynamically analyze the inter-temporal characteristics of forest fire economic losses in China as a whole. In each province, the changing trend and the spatial distribution are both taken into account to analyze the forest fire economic losses in China. Lastly, we offer targeted recommendations according to the special circumstances and unique forest fire economic losses in different provinces. Then, we give valuable suggestions from the perspective of increasing fire adaptability according to the situation in each different province.

2. Materials and Methods

The data in this paper are mainly derived from the China statistical yearbook, China forestry statistical yearbook, China health statistical yearbook, China forest resources report, China database of soil fertility, China soil resources survey database, provincial environmental statistical yearbooks, provincial statistical yearbooks, and existing research results [25,28–37].

2.1. Study Scope

This paper mainly studied the trends and distributions of forest fire economic losses in 31 provinces in mainland China from 2006 to 2018.

2.2. Introduction of Soil Conditions in Provinces of China

This part statistically describes the soil conditions of forestland in each province of China and obtains the distribution of land types and soil nutrients. The results are shown in Table 1.

Table 1. Name of main soil species and average nutrient content (%) in each province of China.

Province	Main Soil Species	Organic Matter	N	P	K
Beijing	Mountain Meadow Soils, Brown Earths	17.17	0.40	0.06	3.00
Tianjin	Brown Earths	10.15	0.525	0.06	1.88
Hebei	Coastal Solonchak, Gray Forest Soils, Brown Earths	3.13	0.64	0.08	1.66
Shanxi	Castano-Cinnamon Soils, Brown Earths	3.21	0.17	0.06	1.73
Inner Mongolia	Dark-Brown Earths, Gray Forest Soils	6.33	0.29	0.06	1.80
Liaoning	Dark-Brown Earths, Meadow Soils, Skeletol Soils, Aeolian Sandy Soil, Cinnamon Soils, Brown Earths	2.62	0.15	0.05	1.66
Jilin	Dark-Brown Earths, Brown Earths, Albic Soils	4.09	0.19	0.06	1.91
Heilongjiang	Dark-Brown Earths, Meadow Soils, Litho Soils, Alluvial Soils, Brown Coniferous Forest Soils	6.34	0.33	0.09	1.93
Shanghai	Purplish Soils	2.37	0.15	0.08	2.17
Jiangsu	Purplish Soils, Limestone Soils, Fluvo-Aquic Soils, Volcanic Soils	1.85	0.12	0.19	2.11
Zhejiang	Skeletol Soils, Red Earths, Red Clay Soils, Yellow Earths, Limestone Soils, Purplish Soils	3.85	0.17	0.05	1.87
Anhui	Skeletol Soils, Red Earths, Yellow Earths, Yellow-Brown Earths, Purplish Soils, Limestone Soils, Brown Earths	3.71	0.22	0.09	1.91

Table 1. *Cont.*

Province	Main Soil Species	Organic Matter	N	P	K
Fujian	Yellow Earths, Red Earths, Purplish Soils	4.58	0.18	0.04	1.5
Jiangxi	Skeletol Soils, Red Earths, Yellow Earths, Limestone Soils, Purplish Soils	3.22	0.14	0.03	1.32
Shandong	Fluvo-Aquic Soils	0.92	0.01	0.08	2.11
Henan	Fluvo-Aquic Soils, Solonetzs, Litho Soils, Brown Earths	1.93	0.09	0.11	1.71
Hubei	Red Earths, Skeletol Soils, Yellow Earths, Limestone Soils, Purplish Soils	1.29	0.06	0.18	1.3
Hunan	Red Earths, Skeletol Soils, Yellow Earths, Limestone Soils, Purplish Soils, Yellow-Brown Earths	3.52	0.16	0.04	1.77
Guangdong	Lateritic Red Earths, Aeolian Soils, Red Earths, Yellow Earths, Limestone Soils, Purplish Soils, Acid Sulfate Soils, Humid-Thermo Ferralitic	3.15	0.14	0.03	1.32
Guangxi	Humid-Thermo Ferralitic, Lateritic Red Earths, Red Earths, Skeletol Soils, Yellow Earths	3.65	0.12	0.04	1.35
Hainan	Humid-Thermo Ferralitic, Lateritic Red Earths, Acid Sulfate Soils, Torrid Red Soils	2.10	0.11	0.02	1.25
Chongqing	Yellow Earths, Yellow-Brown Earths	6.08	0.20	0.09	1.62
Sichuan	Yellow Earths, Red Earths, Yellow-Brown Earths, Brown Coniferous Forest Soils	6.88	0.53	0.07	1.69
Guizhou	Limestone Soils, Yellow Earths, Skeletol Soils, Yellow-Brown Earths, Mountain Meadow Soils	6.51	0.30	0.05	0.94
Yunnan	Lateritic Red Earths, Yellow-Brown Earths, Purplish Soils, Brown Earths, Brown Coniferous Forest Soils	12.02	0.43	0.05	1.32
Tibet	Yellow-Brown Earths, Dark-Brown Earths, Gray-Cinnamon Soils, Brown Earths	16.99	0.54	0.09	1.95
Shaanxi	Aeolian Soils, Cinnamon Soils, Red Clay Soils, Cultivated Loessial Soils, Brown Earths	2.76	0.13	0.06	1.72
Gansu	Dark-Brown Earths, Cinnamon Soils, Red Clay Soils, Cultivated Loessial Soils, Gray-Cinnamon Soils	5.70	0.27	0.06	1.51
Qinghai	Gray-Cinnamon Soils, Aeolian Soils, Gray Forest Soils	5.03	0.22	0.08	2.04
Ningxia	Aeolian Soils, Sierozems, Red Clay Soils	0.64	0.04	0.06	1.73
Xinjiang	Aeolian Soils, Gray-Cinnamon Soils, Takyr, Gray Forest Soils, Solonetzs, Brown Coniferous Forest Soils	5.09	0.19	0.11	2.12

As can be seen from Table 1, the forest soils in China show a certain spatial continuity, and the soil species in regions with similar climates show similar overall fertility. Taking Zhejiang, Fujian, and Jiangxi as examples, the soil types in these provinces are mainly Yellow Earths and Red Earths, and the differences in soil composition are small due to their adjacent geographical locations and similar climatic characteristics. Specifically, the difference between soil organic matter contents in Zhejiang, Fujian, and Jiangxi is less than 1%; the difference in soil N contents is less than 3%; the difference in soil P content is less than 0.02%; and the difference in soil K content is less than 0.5%. The above comparison shows that the distribution and physical and chemical properties of China's forests are spatially continuous, and this further highlights the significance of this paper in studying the forest fire economic losses in China's provinces from the perspective of spatial distribution.

2.3. Brief Introduction of Different Dominant Forest Stands in Chinese Provinces

According to the results of China's seventh forest resources census (2004–2008), eighth forest resources census (2009–2013), and ninth forest resources census (2014–2018), there are 22 dominant tree species in the 31 provinces of China. In northern China, such as Beijing, Inner Mongolia, and other provinces, deciduous coniferous forests, such as Chinese Pine and Larch, dominate, supplemented by deciduous broad-leaved forests, such as Oak and Poplar. In southern China, such as Hubei and Hunan, evergreen coniferous forests, such as *Pinus Massoniana*, *Pinus Yunnanensis,* and Slash Pine, are predominant, supplemented by evergreen broad-leaved trees, such as Oak and Camphor. Please refer to Table 2 for the basic information of different stand species and proportions in each province in China.

Table 2. Dominant tree species and area proportion (%) in each region of China.

Province	Dominant Tree Species 1	Dominant Tree Species 2	Dominant Tree Species 3	Dominant Tree Species 4
Beijing	Oak (19.74)	Cypress (10.89)	Chinese Pine (10.60)	
Tianjin	Alamo (40.55)	Black Locust (12.09)	Willow (8.58)	
Hebei	Oak (23.76)	Alamo (14.40)	Chinese Pine (10.03)	
Shanxi	Chinese Pine (23.19)	Oak (16.92)	Alamo (10.33)	
Inner Mongolia	Birch (31.23)	Larch (20.52)	Oak (11.82)	
Liaoning	Oak (22.04)	Chinese Pine (11.07)	Larch (10.47)	
Jilin	Oak (11.09)	Larch (8.22)	Alamo (7.22)	
Heilongjiang	Larch (16.50)	Birch (15.19)	Oak (9.13)	
Shanghai	Camphor (38.31)	Metasequoia (6.92)	Alamo (4.43)	
Jiangsu	Alamo (42.52)	Camphor (5.97)	Slippery Elm (3.23)	
Zhejiang	Cedar (15.71)	Pinus Massoniana (12.96)	Oak (4.25)	
Anhui	Cedar (13.9)	Alamo (11.46)	Pinus Massoniana (11.35)	
Fujian	Cedar (21.83)	Pinus Massoniana (11.03)	Eucalyptus (3.36)	
Jiangxi	Cedar (23.99)	Pinus Massoniana (9.98)	Slash Pine (5.86)	
Shandong	Alamo (45.98)	Cypress (9.00)	Black Locust (8.16)	
Henan	Oak (24.56)	Alamo (17.91)	Cypress (3.07)	
Hubei	Pinus Massoniana (15.24)	Oak (9.49)	Alamo (4.96)	
Hunan	Cedar (26.14)	Pinus Massoniana (11.62)	Slash Pine (2.89)	
Guangdong	Eucalyptus (23.90)	Cedar (10.32)	Pinus Massoniana (5.04)	
Guangxi	Eucalyptus (24.38)	Cedar (16.22)	Pinus Massoniana (10.16)	
Hainan	Rubber (39.07)	Areca (13.01)	Eucalyptus (7.46)	Broadleaf Mixed Plantations (31.19)
Chongqing	Pinus Massoniana (34.88)	Cypress (6.57)	Cedar (6.12)	
Sichuan	Fir (13.56)	Cypress (12.68)	Oak (11.66)	
Guizhou	Cedar (18.11)	Pinus Massoniana (15.1)	Oak (3.28)	
Yunnan	Pinus Yunnanensis (15.20)	Oak (10.74)	Spruce (3.50)	
Tibet	Spruce (19.93)	Fir (13.70)	Alpine Pine (9.63)	
Shaanxi	Oak (25.65)	Black Locust (6.74)	Chinese Pine (6.29)	
Gansu	Black Locust (12.75)	Oak (11.48)	Spruce (8.72)	
Qinghai	Cypress (35.22)	Spruce (28.43)	Birch (13.24)	
Ningxia	Alamo (16.41)	Larch (12.54)	Slippery Elm (9.47)	
Xinjiang	Spruce (37.77)	Alamo (15.62)	Larch (15.24)	

2.4. China's Forest Fire Economic Loss Assessment Index System and Calculation Method

Various types of disasters can occur through two main modes, direct and indirect, and cause economic losses of different degrees [38]. In forest disasters, direct economic loss refers to the loss of timber resources and the loss of forest cash crops, which has an impact on the current benefits. Indirect economic loss, on the other hand, refers to the negative impacts of disasters on the ecosystem and environment, which thus reduce the economic benefits of forests and can cause reductions in the long-term economic and social development [39]. Especially in recent years, with the rapid development of China, soil erosion, soil desertification, soil consolidation, water pollution, biodiversity reduction, and other problems are becoming ever more serious, and the issue of ecological benefits is receiving ever more attention from all sides [40]. Some studies have shown that over- or underestimation of the losses caused by forest fires can have a bad influence on the final decision and is not conducive to the targeted control of forest fires in order to ultimately reduce forest fire economic loss [27,41,42]. Therefore, based on the characteristics of soil and forest stand in each province of China, this paper constructs a forests fire economic loss evaluation system at the provincial level and comprehensively assesses the economic losses of forest fires in China from 2006 to 2018 using seven methods, including the market price method and the alternative market price method. At the same time, this paper further analyzes the spatial and temporal distribution characteristics and changing trends of forest fire economic losses in China. The specific contents of the evaluation system and calculation method of forest fire economic losses are shown in Table 3.

Table 3. Evaluation index system and calculation method for forest economic losses caused by fire.

Economic Loss	Loss Indicator Category		Loss Index Factor	Loss Calculation Method
Direct economic loss	Loss of stumpage resources	Loss of standing stock	Loss of reduced standing stock	Market Value Method
		Loss of standing tree growth	Loss of growth reduction in standing trees	Market Value Method
	Loss of non-wood products	Loss of economic forest output	Loss of reduced crop output from economic forests	Market Value Method
Indirect economic loss	Loss of forest ecological benefits	Loss of carbon fixation and oxygen release	Loss of carbon fixation	Surrogate Market Approach
			Loss of oxygen release	Surrogate Market Approach
			Loss of carbon from combustion	Surrogate Market Approach
		Loss of water conservation	Loss of water storage	Shadow Project
			Loss of purifying water	Surrogate Market Approach
		Loss of soil fixation and fertilizer conservation	Loss of soil fixation	Shadow Project
			Loss of fertilizer conservation	Surrogate Market Approach
			Loss of litter nutrient return	Surrogate Market Approach
		Loss of air purification benefits	Loss of dust retention	Surrogate Market Approach
			Loss of SO_2 absorption	Surrogate Market Approach
			Loss of noise reduction	Shadow Project
		Loss of nutrient accumulation	Loss of nutrient accumulation	Surrogate Market Approach
		Loss of biodiversity	Loss of conservation species diversity	Opportunity Cost Approach
	Loss of forest social benefits	Loss of invalidation of investment	Loss of ineffectual use of forestry investment	Market Value Method
		Loss of casualty	Loss of life and injury	Human Capital Approach/Willingness to Pay Approach
		Other losses	Loss of something else	Market Value Method

3. Evaluation Method of Forest Fire Economic Loss in China

In this paper, the direct and indirect economic losses caused by forest fires in China from 2006 to 2018 are evaluated by reference to the relevant contents of the "Statistical investigation system for loss caused by particularly serious natural disasters" and the EMA-DLA disaster loss evaluation system [43]. In order to more clearly and accurately assess the indirect economic losses caused by forest fires in China, we further divided the indirect losses from forest fires into two parts: the loss of forest ecological benefits and the loss of forest social benefits. At the same time, we considered that the constant price method [37,44] will lead to large errors in the assessment results. Therefore, this paper uses the price discount method [45] to conduct a dynamic study on the economic losses caused by forest fires in China, so as to provide targeted theoretical support for forest fire prevention in China's provinces.

3.1. Loss of Standing Stock

The existing assessments of the loss of standing wood resources caused by forest fires mainly focus on the value of burnt trees. However, for those burned trees that do not completely lose their value, the damage caused by forest fires is difficult to quantify [19]. Therefore, few studies have included burned trees in the loss assessment system, which will lead to deviations in the loss assessments of forest resources. In order to deal with this problem, this paper refers to the relevant research of Zhang [22] and divides trees of different forest ages into burnt wood and burned wood for evaluation via the death coefficient parameter. The specific expressions are as follows:

Loss of Mature Forest

The specific economic loss calculation formula is:

$$P_1 = \sum_{i=1}^{n} f_i Z_i \tag{1}$$

where P_1 represents the total loss of burnt wood in mature and overmature forests, f_i represents the average transaction price of the volume of standing timber in the ith forest stand over the years, and Z_i is the volume of burnt wood of the ith forest stand.

$$P_2 = \sum_{i=1}^{n} \alpha f_i Z_i \tag{2}$$

where P_2 represents the total loss of burned wood, and α represents the death coefficient, which represents the proportion of burned forest stand i that cannot recover its growth in the near future. Referring to the research of Zhang [22], we determine the probability of occurrence of mild, moderate, and severe burns according to the proportions of the numbers of general fires, disastrous fires, and extraordinary fires to the total number of forest fires. Thus, the death coefficients of mild, moderate, and severe burns are set to 0.15, 0.45, and 0.8.

$$P_3 = \sum_{i=1}^{n} F_i N_i \tag{3}$$

where P_3 represents the total loss of burned young trees in young forests, F_i represents the price of young trees in the ith forest stand, and N_i represents the price of burned young trees in the ith forest stand.

$$P_4 = \sum_{i=1}^{n} \beta F_i N_i \tag{4}$$

where P_4 represents the total quantity of burned wood loss in young forests, and β represents the death coefficient of young forests, which is consistent with the death coefficient of burned wood loss in specific species in mature and overmature forests.

3.2. Loss of Standing Tree Growth

The loss of standing tree growth refers to the lower accumulated value generated during the period from the end of the fire to the time at which the trees should return to normal growth and the lower accumulated value generated by the average growth of trees in the area affected by reforestation [36]:

$$P_5 = \sum_{i=i}^{n} G_i T(F_i - C) \quad (5)$$

where P_5 represents the annual net growth of the ith forest stand; T represents the average timber yield of all tree species in China, which is set as 65%; F_i represents the average transaction prices of the standing timber volumes of the ith forest stands in different regions; and C represents the average production cost of China's timber market.

3.3. Loss of Economic Forest Output

Non-wood resources are any renewable products produced in the forest or on any land of similar use, including tea, dried fruits, fruits, flowers, medicinal herbs, etc., and their by-products. Considering the issue of indicator representativeness and data availability, this paper uses economic forest output to define non-wood resources of forests. The economic output loss of forests refers to the direct economic losses [46] caused by the burning of output and the decline in the quality of economic forest crops due to forest fires:

$$P_6 = \sum_{i=1}^{n} H_i \eta_i \quad (6)$$

where P_6 represents the loss of economic forest output, H_i represents the loss of the ith economic forest crop, and η_i represents the average transaction price of the ith economic forest crop in each province over the years.

3.4. Loss of Carbon Fixation and Oxygen Release

Forests absorb carbon dioxide and release oxygen through photosynthesis and respiration, playing an irreplaceable role in maintaining the dynamic balance of carbon and oxygen in the atmosphere. Especially given the current drastic context of the greenhouse effect and global carbon emissions increasing year by year, the function of forest carbon fixation and oxygen release is becoming increasingly important. In the case of the loss of carbon fixation and oxygen release due to natural disasters, this paper assesses the carbon dioxide released by the burning of forests in relation to the loss of carbon fixation by forests according to the actual situation of forest fires [47]. In view of the fact that China does not have a perfect carbon tax system at present, in order to reduce the errors [48] caused by the use of carbon tax prices for evaluation in other countries, this paper uses the transaction data of carbon emission trading markets over the years to evaluate the value of forest carbon sequestration.

3.4.1. Loss of Carbon Fixation

The specific economic loss calculation formula is:

$$U_1 = U_c + U_0 = \sum_{i=1}^{n} A_i C_c (1.63 R_c B_i + F_i) \quad (7)$$

where U_1 represents the total value of carbon sequestration losses in different forest regions caused by fire; U_c represents the total value of carbon sequestration losses in forests; U_0 represents the total value of carbon sequestration losses in soils of different forests; A_i represents the area of a forest fire in the ith forest stand; C_c represents the carbon sequestration price (that is, the average transaction price of carbon emission rights in Beijing over the years); R_c represents the carbon content in carbon dioxide (set as 27.27%;

that is, the weight of a carbon atom in a carbon dioxide molecule); B_i represents the annual net primary productivity of the ith forest stand; and F_i represents the annual carbon sequestration of soil in the ith forest stand.

3.4.2. Loss of Oxygen Release

The specific economic loss calculation formula is:

$$U_2 = \sum_{i=1}^{n} 1.19 A_i C_o B_i \tag{8}$$

where U_2 represents the value of the total reduction in oxygen emitted by different forest stands caused by fire (that is, the loss value of released oxygen); and C_o represents the selling price of industrial oxygen in China.

3.4.3. Loss of Carbon from Combustion

The specific economic loss calculation formula is:

$$U_3 = \sum_{i=1}^{n} A_i P C_c \tag{9}$$

where U_3 represents the carbon emission loss caused by the carbon dioxide emitted when forests are burned, and P represents the carbon dioxide released per unit area of forest fire in each province.

3.5. Loss of Water Conservation

Forest fires can damage soil structure, cause the compaction of forest soil, and reduce the water storage capacity of forest soil, exacerbating soil erosion in the region [49]. This will not only affect the water cycle of the forest's ecosystem [50], but it will also increase the surface runoff of the forest and reduce the ability of the forest to weaken the flood peak flow [51], resulting in significant losses. In addition, Wang et al.'s [52] research shows that the water quality of rainwater stored through forest interception can be significantly improved after multi-layer filtration. Therefore, this paper evaluates the benefit losses of water conservation related to forest fires from two aspects: water storage and flood control, and water quality purification. The current studies on forest soil water storage capacity mainly use indices such as non-capillary porosity and soil thickness to study forest static water storage capacity [53,54]. However, forest water storage is often a dynamic process, which means it is difficult to accurately calculate forest water storage per unit area using indices such as non-capillary porosity and soil thickness [55]. Therefore, based on the principle of water balance, we start from the perspective of the dynamic balance of precipitation, evapotranspiration, and runoff, and develop a new loss assessment index.

3.5.1. Loss of Water Storage

The specific economic loss calculation formula is:

$$W_1 = \sum_{i=1}^{n} 10 C_w A_i (P - E_i - C) \tag{10}$$

where W_1 represents the loss in the total value of water regulated annually as a result of forest fires in each province; C_w represents the investment per unit of storage capacity of reservoirs in each province; A_i represents the ith forest stand area; P represents the annual precipitation of each province; E_i represents the evapotranspiration of the ith forest stand; and C represents the annual surface runoff of each province.

3.5.2. Loss of Purifying Water

The specific economic loss calculation formula is:

$$W_2 = \sum_{i=1}^{n} 10K_w A_i (P - E_i - C) \tag{11}$$

where W_2 represents the total value of annual purified water quality of forest stands in each province, and K_w represents the average purification cost of industrial wastewater in each province.

3.6. Loss of Soil Fixation and Fertilizer Conservation

For a long time, with the continuous development of research on the ecological benefits of forests, the function of forests in greatly reducing soil erosion has been gradually revealed [37,56]. However, the burning and even death of trees caused by forest fires will weaken the soil fixation ability of forests and accelerate soil erosion [57]. Moreover, as an important nutrient source of the forest ecosystem, the nutrient return of forest litter plays a crucial role in maintaining the material cycle and nutrient balance of the forest ecosystem, and even the stability of the ecosystem [58]. Therefore, this paper assesses the loss in soil fixation and fertilizer conservation benefits caused by forest fires from three points of view: loss of soil fixation benefits, loss of fertilizer conservation benefits, and the loss of nutrient return of forest litter.

3.6.1. Loss of Soil Fixation

The specific economic loss calculation formula is:

$$V_1 = \sum_{i=1}^{n} A_i C (X_2 - X_{1i}) / \rho_i \tag{12}$$

where V_1 represents the loss of soil fixation benefits; A_i represents the area of fire loss in the ith forest stand; C represents the cost of dredging and transporting sediment in China; X_2 represents the modulus of soil erosion in non-forest land; X_{1i} represents the modulus of soil erosion of the ith forest stand; and ρ_i represents the soil density of the ith forest stand.

3.6.2. Loss of Fertilizer Conservation

The specific economic loss calculation formula is:

$$V_2 = \sum_{i=1}^{n} A_i (X_2 - X_{1i})(N_i C_1 / R_1 + P_i C_1 / R_2 + K_i C_2 / R_3 + M_i C_3) \tag{13}$$

where V_2 represents the loss of fertilizer conservation benefit; N_i represents the average N content of soil in the ith forest stand; P_i represents the average P content of soil in the ith forest stand; K_i represents the average K content of soil in the ith forest stand; C_1 represents the average price of diammonium phosphate; C_2 represents the average price of potassium chloride; C_3 represents the average price of organic matter; R_1 represents the nitrogen content of diammonium phosphate fertilizer (set to 0.144); R_2 represents the phosphorus content of diammonium phosphate fertilizer (set to 0.123); R_3 represents the potassium content of potassium chloride fertilizer (set to 0.448); and M_i represents the content of organic matter of the soil in the ith forest stand.

3.6.3. Loss of Litter Nutrient Return

The specific economic loss calculation formula is:

$$V_3 = \sum_{i=1}^{n} A_i (D_{Ni} C_1 / R_1 + D_{Pi} C_1 / R_2 + D_{Ki} C_2 / R_3) \tag{14}$$

where V_3 represents the loss of nutrient return benefits of litter; D_{Ni} represents the total amount of N elements returned to all litters of the *i*th forest stand; D_{Pi} represents the total amount of P elements returned to all litters of the *i*th forest stand; and D_{Ki} represents the total amount of *K* elements returned to all litters of the *i*th forest stand.

3.7. Loss of Air Purification Benefits

With the accelerating process of industrialization, global atmospheric pollution is becoming ever more serious. Toxic and harmful gases, such as sulfur dioxide, and inhalable particles, such as dust, are important factors affecting the forest ecosystem and economic and social development [59–61]. However, forest fires will not only cause harmful gases to be released from forests [62], but they will also cause indirect losses due to the reduction in trees and the consequential loss of forests' capacity for noise reduction, purification, and the absorption of harmful gases. Therefore, this paper studies the effects of forest fires on the purification capacity of the forest's atmospheric environment in relation to the loss of sulfur dioxide absorption, dust retention, and noise reduction abilities.

3.7.1. Loss of Dust Retention

The specific economic loss calculation formula is:

$$A_1 = \sum_{i=1}^{n} K_s Q_{si} A_i \tag{15}$$

where A_1 represents the damage caused by the lower sulfur dioxide absorption capacity of forests as a result of fires in each province over the years; K_s represents the cost of sulfur dioxide treatment in each province; Q_{si} represents the amount of sulfur dioxide absorbed by the *i*th forest stand per unit area; and A_i represents the disaster area of the *i*th forest stand.

3.7.2. Loss of SO_2 Absorption

The specific economic loss calculation formula is:

$$A_2 = \sum_{i=1}^{n} K_d Q_{di} A_i \tag{16}$$

where A_2 represents the damage caused by the lower dust retention capacity of forests as a result of fires in various provinces over the years; K_d represents the cost of dust removal in various provinces; and Q_{di} represents the amount of dust retention in the *i*th forest stand per unit area.

3.7.3. Loss of Noise Reduction

The specific economic loss calculation formula is:

$$A_3 = K_n A_n \tag{17}$$

where A_3 represents the damage caused by the reduction in noise absorption capacity in the forest as a result of fires in various provinces over the years, and K_n represents the expenditure required to reduce the noise. In this paper, the engineering substitution method is used (that is, the construction cost involved in building a sound insulation wall, assuming a height of 4 m and a length of 1 km), and A_n represents the required kilometers of sound insulation wall converted from the areas of forest fires in various provinces over the years.

3.8. Loss of Nutrient Accumulation

Tree nutrient accumulation is a very important part of the geochemical cycle and plays an important role in maintaining the balance of material exchange between biological and abiotic environments [63]. The forest ecosystem can not only store N, P, K, and other nutrient elements in the soil, but it can also seal these in plants and release them into various environments in different forms. The flow of these nutrient elements plays an important role in reducing water pollution and eutrophication [64]. Therefore, this paper estimates the loss of nutrient accumulation caused by forest fires based on the net primary productivity of different forests in different environments:

$$NA = \sum_{i=1}^{n} A_i B_i (N_{Yi} C_1 / R_1 + P_{Yi} C_1 / R_2 + K_{Yi} C_2 / R_3) \quad (18)$$

where NA represents the total reduction in nutrient accumulation by trees caused by forest fires; A_i represents the area of fire loss in the ith forest stand; B_i represents the net primary productivity of different forests; N_{Yi} represents the average N content of trees in the ith forest stand; P_{Yi} represents the average P content of trees in the ith forest stand; K_{Yi} represents the average K content of trees in the ith forest stand; C_1 represents the average price of diammonium phosphate; C_2 represents the average price of potassium chloride; R_1 represents the nitrogen content of diammonium phosphate fertilizer (set to 0.144); R_2 represents the phosphorus content of diammonium phosphate fertilizer (set to 0.123); and R_3 represents the potassium content of potassium chloride fertilizer (set to 0.448).

3.9. Loss of Conservation Species Diversity

Biodiversity is the basis for human survival and development. The loss of any link in a stable biological chain formed over a long time will have an unimaginable impact on human society [65]. Although the conservation value of species diversity belongs in the non-use value category of biodiversity [66,67], which is difficult to calculate, it can better reflect the value of forest ecosystems to species diversity protection. The previous studies have mainly evaluated the conservation value of species diversity by means of willingness to pay [68]. However, given that the willingness to pay method is limited by the respondent's living area, living standard, education level, and understanding of forest conservation in the visited area [69], the results of biodiversity conservation loss assessed via the willingness to pay method show large deviation and poor feasibility. Therefore, this paper uses relevant research on the Specifications for Assessment of Forest Ecosystem Services, with Wang's research [70] as reference, and we then adopt the Shannon–Wiener index method to evaluate the conservation value of different forests in various provinces in China.

$$B = \sum_{i=1}^{n} S_{bi} A_i \quad (19)$$

where B represents the annual species conservation value of the forest; S_{bi} represents the annual opportunity cost of species loss per unit area; and A_i represents the area of fire loss in different forests. Table 4 shows the indicator ranges and their corresponding values.

Table 4. Shannon–Wiener index classification and values.

Level	Shannon–Wiener Index	Unit/(CNY·hm^{-2}·a^{-1})
I	≥ 6	50,000
II	$5 \leq$ index < 6	40,000
III	$4 \leq$ index < 5	30,000
IV	$3 \leq$ index < 4	20,000
V	$2 \leq$ index < 3	10,000
VI	$1 \leq$ index < 2	5000
VII	index ≤ 1	3000

3.10. Loss of Life and Injury

Among all the kinds of losses caused by forest fires, the most difficult one to assess is the economic value of human losses. Although the value of human life can be calculated scientifically in economic, legal, and other fields, it involves many other aspects, such as morality and human rights. Therefore, a scientific life loss assessment method is very important [71], and so, this paper combines the human capital method [15] with the willingness to pay method [72] and uses the discount method to predict future income changes resulting from deaths, so as to evaluate the value of life. For the injured, we use medical expenses and hospitalization expenses to measure the loss related to injuries caused by forest fires [63]:

$$L_1 = \sum_{t=T}^{\infty} y_t P_T^t (1+r) - (t-T) \tag{20}$$

where L_1 represents the value of the people who died in the forest fire; y_t represents the total income obtained by deducting any non-human capital income and basic living costs from personal income in year t; P_T^t represents the probability of a person living from year T to year t; and r represents the expected social discount rate applied to year t.

$$L_2 = 2P_1M + P_2H \tag{21}$$

where L_2 is the total economic loss suffered by people injured by forest fires; P_1 represents the number of people with minor injuries caused by fires in each province; M represents the average medical expenses of outpatients in each province over the years; P_2 represents the number of people with serious injuries caused by fires in each province; and H represents the number of people hospitalized in each province.

3.11. Loss of Ineffectual Use of Forestry Investment

The ineffective use of investment refers to a situation in which investments in forestry fixed assets, afforestation costs, and forest protection costs are directly destroyed by forest fires, without any losses in due value, which can be understood as the loss value of wasted resources [46]:

$$I = (F_a/15) \cdot (S_d/S_f) \tag{22}$$

where I represents the size of the indirect loss caused by the ineffective use of an investment; F_a represents the forestry investment over the years; S_d represents the forest fire disaster area over the years in each province; and S_f represents the forest area over the years in each province.

3.12. Loss of Something Else

Other losses mainly include the financial losses suffered by surrounding residents caused by forest fires, such as losses of cash, houses, etc., and the value of materials consumed in the rescue process. The data source is the China forestry statistical yearbook.

3.13. Price Discount Method

The discount method is an interest-bearing method in which the bank issues a loan to an enterprise by first deducting the interest portion from the principal, while the borrowing enterprise has to repay the entire principal of the loan at maturity. The price discount method is based on a discount method that uses bank deposit and loan rates to replicate price data in order to prevent excessive underestimations of various losses due to discontinuous price data. The specific calculation formulae are shown in Equations (23) and (24).

$$Y_n = (1 + d_{m+1})(1 + d_{m+2}) \cdots (1 + d_n) Y_m \tag{23}$$

$$d_i = (D_i + L_i)/2 \tag{24}$$

where Y_n represents the price of the commodity in year n; Y_m represents the price of the commodity in year m (where $m < n$); d_i represents the commodity price parameter in year i (where $m < i \leq n$); D_i represents the average deposit rate of the People's Bank of China in year i; and L_i represents the average loan rate of the People's Bank of China in year i.

4. Results

This section first describes the changes in the total loss caused by forest fires in China from 2006 to 2018 and the proportions of direct economic losses, ecological benefit losses, and social benefit losses out of the total loss, analyzing the reasons for each. Secondly, the loss caused by forest fires in China's provinces is discussed in the two dimensions of time and space, and the distributions of and changes in forest fire losses in China are studied. Finally, we perform a targeted analysis of forest fire loss in provinces with abnormal forest fire occurrences in China.

4.1. Economic Loss and Change Trend of Forest Fire in China

The sample data show that there were 56,281 forest fires in 31 provinces in China from 2006 to 2018, with a total area of 1,282,972.6 hectares, including 590,454 hectares of damaged forests, 16.4508 million cubic meters of mature and overmature forest stand resources lost, and 838.883 million young forests lost, causing serious economic losses. Based on the loss assessment method, Figure 1 shows the changes in China's forest fire economic losses from 2006 to 2018. The losses caused by forest fires in China in 2006 were much higher than those in any year from 2007 to 2018, mainly because of the catastrophic fire in Heilongjiang Province in 2006. The forest fire area reached 325,972.8 hectares, accounting for 79.8% of China's fire area in 2006. After excluding the outliers, it can be seen that the economic loss caused by forest fires in China is characterized by fluctuation and decline, which fully conforms to the theories and understandings of economic and social development, as well as of scientific and technological progress in reducing natural disaster losses [73].

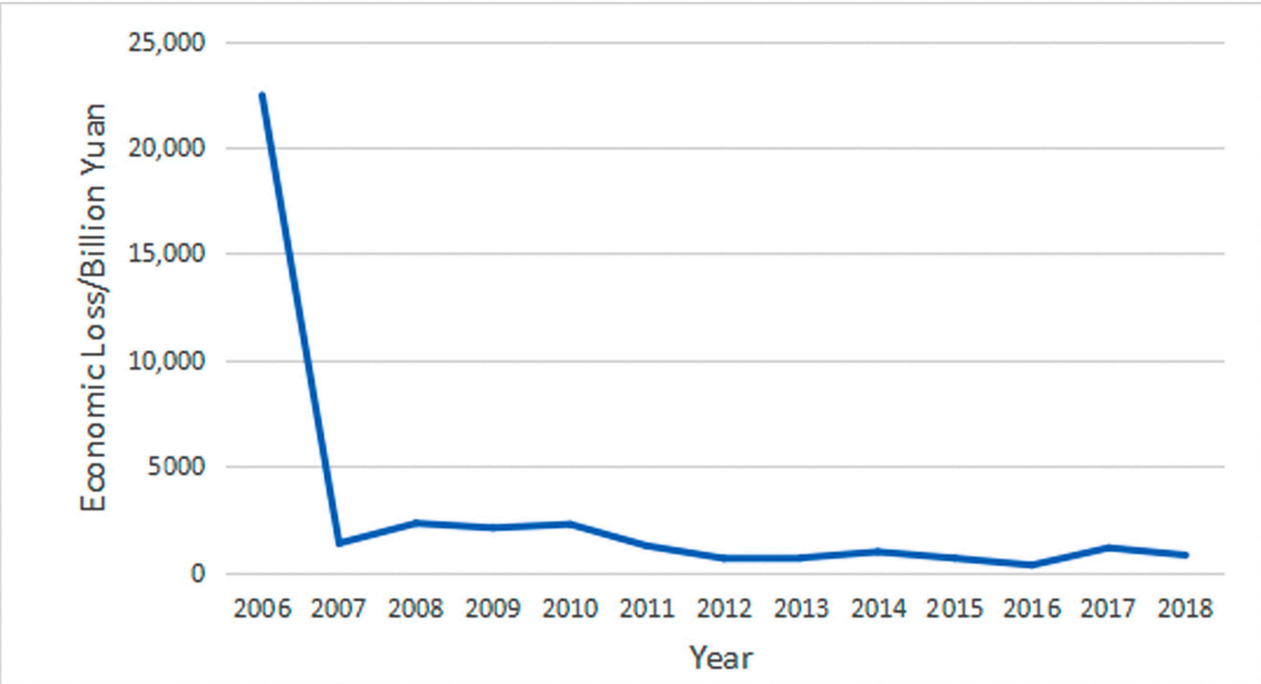

Figure 1. Changes in economic loss caused by forest fires in China from 2006 to 2018.

The data in Table 5 show that the proportion of ecological benefit loss in China from 2006 to 2018 remained high. Although Sheng et al. [74] found that the losses in ecological service benefits and forest protection function caused by forest fires accounted for 60% to

90%, and the direct economic losses accounted for about 10% of the total loss, the evaluation results of this paper show that the loss of forest ecological benefit was more serious. The economic loss calculated by the indirect assessment method itself will be lower than the actual loss caused by forest fires, which shows that the losses of forest ecological benefits caused by forest fires in China are quite serious, and their severity is far greater than that caused by other forest disasters.

Table 5. The proportion of each type of loss caused by forest fires in China.

Year	Proportion of Stumpage Resources Loss (%)	Proportion of Non-Wood Products Loss (%)	Proportion of Forest Ecological Benefits Loss (%)	Proportion of Forest Social Benefits (%)
2006	0.088376	0.004603	99.906531	0.000490
2007	0.886162	0.094662	99.009252	0.009924
2008	0.713713	0.108908	99.171094	0.006285
2009	0.405837	0.095220	99.490948	0.007995
2010	1.064032	0.051289	98.878240	0.006439
2011	0.446626	0.107163	99.425259	0.020951
2012	1.006623	0.097823	98.875269	0.020285
2013	0.167614	0.093187	99.725874	0.013325
2014	0.196013	0.075264	99.679597	0.049125
2015	0.721528	0.073617	99.190303	0.014552
2016	3.506376	0.068692	96.406011	0.018920
2017	0.466350	0.020208	99.498730	0.014712
2018	0.385131	0.032398	99.552918	0.029553

4.2. Time Variation of Forest Fire Economic Loss in Different Regions of China

According to the regulations of the National Development and Reform Commission, the study area was divided into three regions: eastern, central, and western. Based on the assessment results of forest fire economic losses in China from 2006 to 2018, this paper excludes the outliers of forest fire economic losses in 2006 from the analysis and describes the loss changes of all provinces in the three regions from 2007 to 2018. The data trend in Figure 2a shows that the economic losses caused by forest fires in central China were higher than those in eastern and western China, and they were higher than the total losses in eastern and western China from 2007 to 2010. From the change trend of forest fire economic loss data, it can be seen that the changes in forest fire economic losses in the central region show repeated fluctuations, while in the eastern and western regions, the fluctuations are mainly declining and tend to be stable.

The economic loss caused by forest fires in eastern China showed uncertainty from 2007 to 2012, reaching its two maximum values in 2009 and 2011, and stabilizing after 2012. The change trends of forest fire economic loss in Fujian, Zhejiang, and Guangdong are consistent with the overall change trend in the eastern region, while the change range of forest fire economic loss in other provinces is small. Further observation shows that Fujian, Zhejiang, and Guangdong are geographically adjacent, which indicates that forest fires among provinces are not independent of each other and often show a certain spatial diffusion. Therefore, in order to effectively reduce the economic losses caused by forest fires, the relevant departments of all provinces in China need to strengthen their cross-provincial exchanges and cooperation. The overall reduction in economic loss caused by forest fires in Fujian, Zhejiang, and Guangdong indicates a significant improvement in forest fire warning and mitigation mechanisms in the eastern region and a significant improvement in the construction of fire symbiosis. We take the number of forest fires in the eastern region and the assessment results of economic loss as an example. In 2016, there were 389 forest fires in the eastern region, and the economic loss caused by forest fires was CNY 10.734 billion. In 2017, there were 570 forest fires—46.53% higher than in 2016. However, the economic loss caused by forest fires was CNY 10.4 billion, showing a reduction of 3.11% year on year, indicating that the economic loss per unit area of forest fires was decreasing.

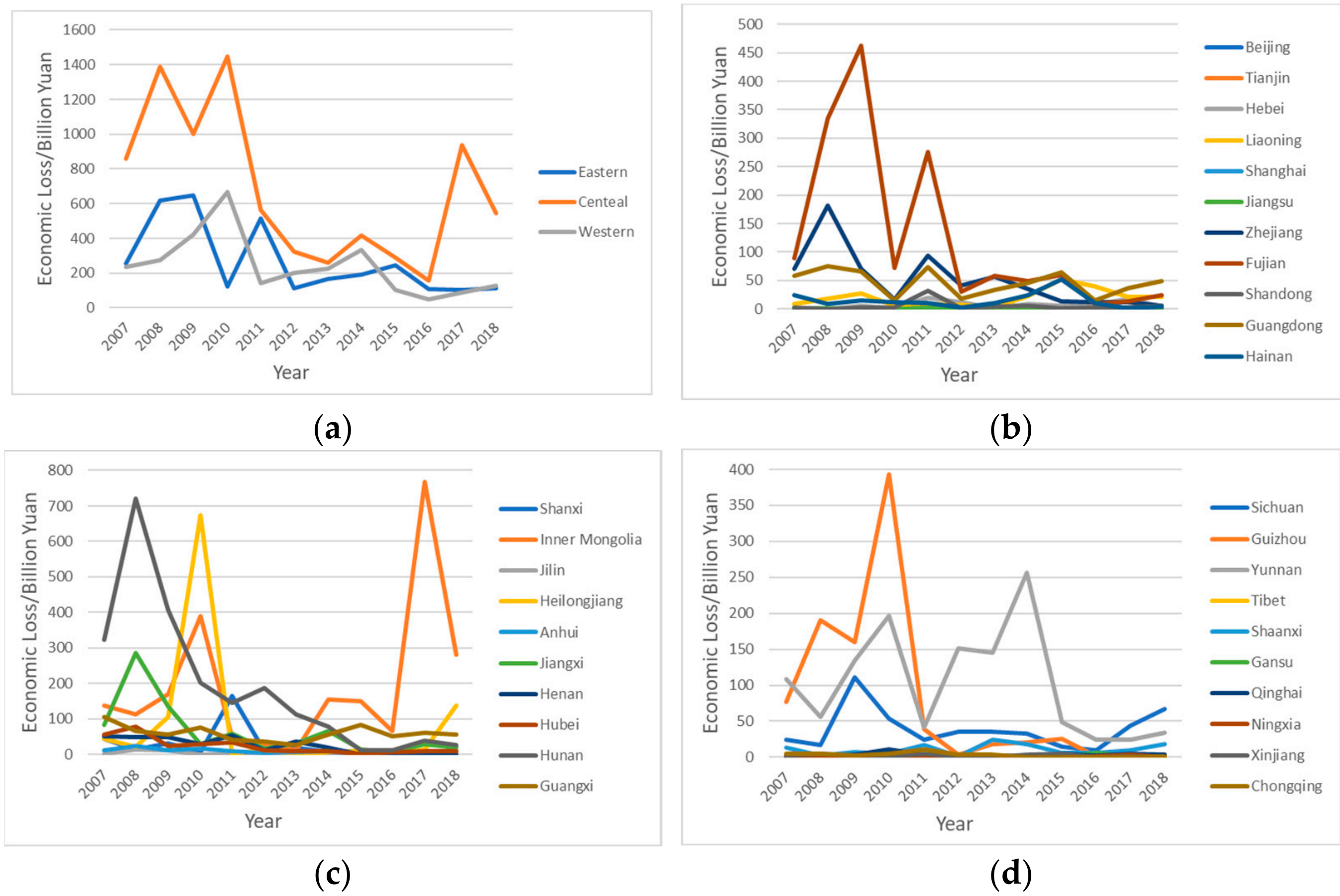

Figure 2. Trend of economic losses caused by forest fires in China. (**a**) Overall changes in economic losses caused by forest fires in three regions of China. (**b**) Changes in economic loss caused by forest fires in eastern provinces of China. (**c**) Changes in central loss caused by forest fires in eastern provinces of China. (**d**) Changes in economic loss caused by forest fires in western provinces of China.

The economic loss caused by forest fires in central China is characterized by "high loss and great fluctuation", and Inner Mongolia is the most typical. Although the huge fire in Hunan Province in 2008 caused the economic losses suffered in Hunan to be far higher than in other provinces in the same year, in the long run, the economic losses caused by forest fires in other provinces in the central region, except Inner Mongolia, remained stable as a whole, showing a declining volatility. In addition to the sudden increase in the economic losses caused by two unique forest fires in 2006 and 2010, the economic losses caused by forest fires in Heilongjiang after 2015 showed a steady growth trend year by year and reached the second highest level in the central region in 2018. This change is thought provoking.

The economic loss caused by forest fires in western China also shows the characteristic of "fluctuating decline", indicating that the forest fire protection and disaster relief capacity in western China has enhanced year on year. The economic loss in Guizhou remained high until 2010 and fell to the lowest position among all provinces in the western region after 2011. The economic loss caused by forest fires in Yunnan showed a similar trend. Specifically, after reaching a high level, the economic loss caused by forest fires in Yunnan was controlled and stabilized at a low level in 2015. Sichuan is also a province showing strong volatility in forest fire loss within the central region. The economic losses it has suffered from forest fires have been effectively controlled and showed a decreasing trend year on year after 2011, but they have been increasing again since 2016. The reason for this phenomenon may be that Sichuan and Yunnan are richer in forest resources and are unable to restructure their forests in the short term to increase fire resistance and improve the adaptability of the forest ecosystem to fires.

4.3. Spatial Variation of Forest Fire Loss at Provincial Level in China

In view of the randomness and inconsistency of forest fires, this paper does not use the data of a single year, with equal intervals selected via econometrics, for analysis [75] but instead measures the degree of forest-fire-related loss suffered in each province for three consecutive years and describes this in the form of spatial distribution maps—see Figure 3 for details.

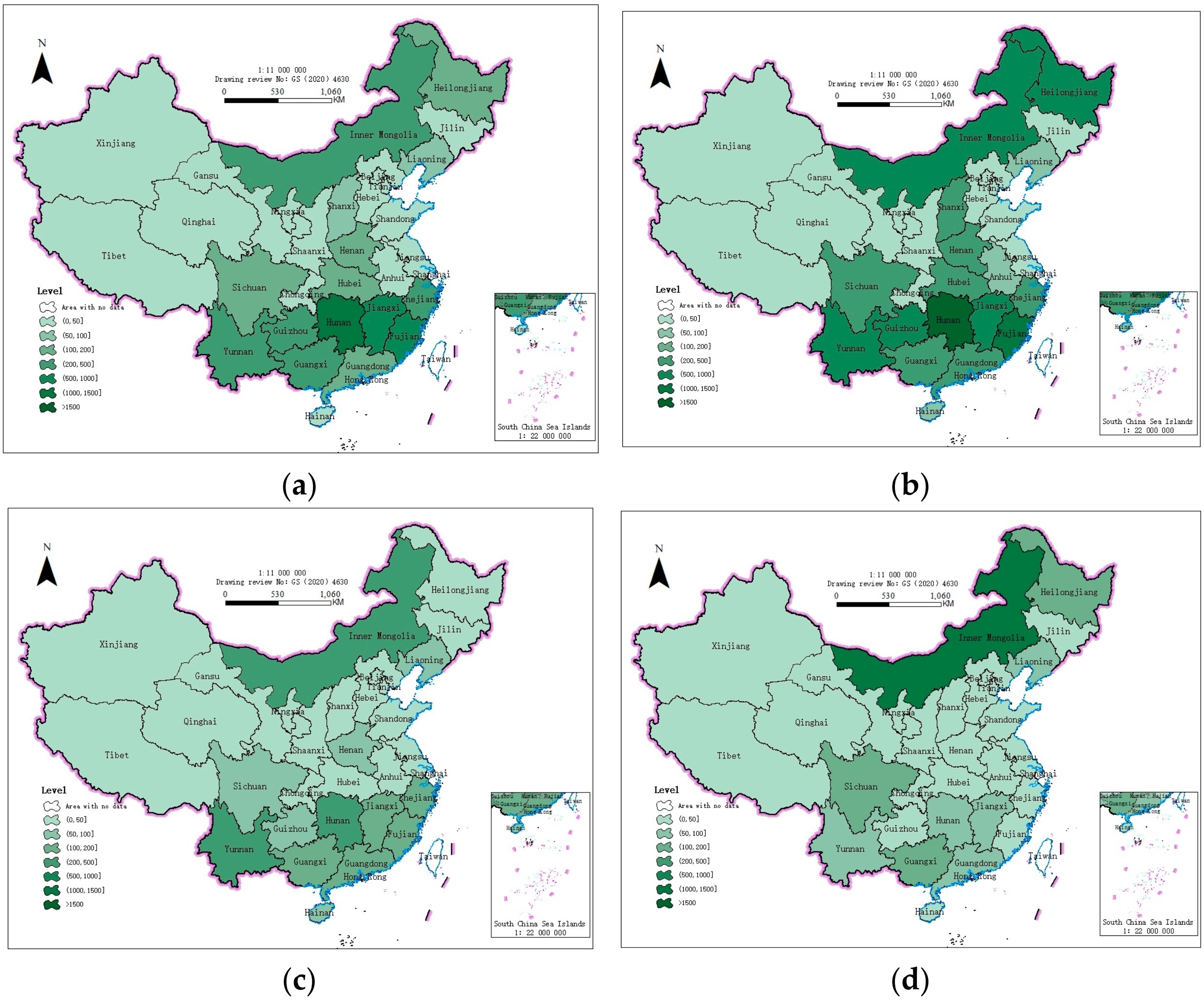

Figure 3. Spatial distribution of forest fire economic loss in China. (**a**) Total economic loss caused by forest fires in China's provinces from 2007 to 2009. (**b**) Total economic loss caused by forest fires in China's provinces from 2010 to 2012. (**c**) Total economic loss caused by forest fires in China's provinces from 2013 to 2015. (**d**) Total economic loss caused by forest fires in China's provinces from 2016 to 2018.

It can be seen from Figure 3 that the economic loss caused by forest fires in China is high in central China and low in eastern and western China. The economic losses caused by forest fires in the central region accounted for 56.92%, 56.98%, 43.11%, and 73.56% of the total loss, respectively, and the average loss here exceeded the sum of the loss in the eastern and western regions. In particular, in 2016–2018, the economic losses in the central region were close to three times the sum of the loss in the eastern and western regions. From 2007 to 2009, the economic loss caused by forest fires was mainly concentrated in the southwest (Inner Mongolia, Yunnan, Guizhou, Guangxi) and central regions (Hunan, Jiangxi), among which the central and southern coastal areas and those adjacent were the most seriously affected. The provinces with smaller losses and less fluctuation were mainly distributed in the northwest, north–central, and eastern parts of China. From 2010 to 2012, the losses in some central (Inner Mongolia, Heilongjiang, Hunan, Shaanxi) and eastern regions (Fujian, Guangdong) increased significantly, while the economic losses in western regions remained at a low level. However, since 2013, the economic losses caused by forest fires in China have begun to decline steadily. In the three years of 2013–2015 alone, the economic losses decreased by CNY 756.233 billion compared with 2009–2012, showing an increasing trend in the number of low-loss areas and a decreasing trend in the number of high-loss areas moving from coastal areas to inland areas.

At different observation stages, the economic losses caused by forest fires in some provinces were always at a low level, and most of them appeared in blocks. For example, seven western provinces, including Xinjiang and Tibet, and five eastern provinces, including Jiangsu and Shandong, constituted the two main sets of areas suffering low economic loss in China, and these areas showed the lowest economic losses caused by forest fires in each observation phase. In northwestern China, Xinjiang, Qinghai, Xizang, Gansu, and Ningxia had relatively fewer forest resources per unit forest area and ranked 31st, 30th, 27th, 29th, and 26th in the country in terms of forest coverage, respectively. Therefore, the low forest coverage rate and the scattered spatial distribution of forest resources were the most important reasons for the low economic losses caused by forest fires in these provinces. In contrast, although the forest coverage of Shaanxi and Chongqing in the west was relatively high, and the difficulty of fire prevention was slightly higher here than in Xinjiang and other regions, their economic levels were much higher than those of other western provinces. In addition, the science and technology level, the disaster prevention level, and the disaster bearing level were often significantly positively correlated with the level of economic development in these areas [76,77], and so, it could be concluded that the lower level of forest fire loss in Chongqing and Shaanxi might be due to the higher economic level. Jiangsu, Shandong, Hebei, Tianjin, and Beijing showed the characteristics of small forest area, low forest resource reserves, and high economic development levels, and they also showed strengthened regional communication, enabling them to ensure low levels of forest fire economic loss.

Although the number of areas suffering high forest fire losses in China was gradually decreasing, and the economic losses in all provinces also showed a downward trend, there were areas that did not conform to these laws of change. By comprehensively comparing Figure 3a–d, it can be found that the period with the lowest economic loss in Inner Mongolia was from 2007 to 2009. If the economic loss caused by forest fires was calculated in a period of three years, its level in Inner Mongolia was not reduced but was actually gradually increasing. This phenomenon, which is contrary to the overall trend of change in China, indicates a lack of awareness in Inner Mongolia about reducing economic losses related to forest fires and a lack of awareness about preventing man-made fires and the conditions that can be created to inhibit their spread. Perhaps the most pressing issue is the complex structure of the forests and the amount of work involved, along with the lack of fire-specific adaptations to forests and their surrounding communities in Inner Mongolia. At the same time, the dry, cold-temperate climate makes the need for forest fire prevention and control in Inner Mongolia severe, and the reduced moisture in forest combustibles is an important factor leading to fires, which reminds us of the need to adapt forests to the specific climatic factors of different regions. Similarly, the change trends of forest fire economic losses in Sichuan and Heilongjiang indicate that both Sichuan and Heilongjiang have been able to quickly and effectively suppress forest fires against the background of high losses in the early stages. However, after a certain period of time, the scale of and economic losses caused by forest fires in Sichuan and Heilongjiang gradually showed a trend of "rising". Unlike in Inner Mongolia, the areas of fires in Sichuan and Heilongjiang increased slowly. This indicates that Sichuan and Heilongjiang were able to address the root cause of forest fire loss generation in time; the small increase in loss was caused only by the accumulation of fuel, which differentiates these regions from Inner Mongolia with regard to reducing economic losses caused by forest fires.

4.4. Special Case Analysis

Based on the assessment of the economic losses caused by forest fires in various regions of China and the analysis of the temporal and spatial changes, this paper finds some deficiencies in forest fire protection in Inner Mongolia. Therefore, this section takes Inner Mongolia as its research object to closely study the basic conditions of forest fire loss in Inner Mongolia. Table 6 lists the forest fire area and the proportion of each type of loss in Inner Mongolia over the years.

From the changes in forest fire area shown in Table 6, it can be inferred that the change in forest fire area in Inner Mongolia also followed the periodic law of "first increasing, then decreasing, and then increasing". From this, we can consider the possible reasons for the abnormal changes in the forest fire situation in Inner Mongolia. When forest fires suddenly become serious, and the related losses increase sharply in a year, Inner Mongolia focuses on forest fire prevention and takes emergency measures to reduce forest fire loss, meaning that the extent of forest fires and the associated economic losses are effectively controlled in the following years. However, with the shift of attention and the accumulation of forest fuels, coupled with climatic and human factors, the areas of forest fires and the economic losses could suddenly increase in one year, and so on. Evidence of this variation can be found in the turning points of 2006, 2009, 2014, and 2017 and the scale of forest fire occurrence in the subsequent years. The continuous occurrence of this phenomenon further supports the views of Moreira et al., Calkin et al., and Bento-Gonçalves et al. [26,27,42].

The proportion of forest fire loss in Inner Mongolia shows that the loss of soil fixation and fertilizer conservation accounts for the highest proportion of forest fire loss, which can be stabilized at more than 95%. This indicates that within a certain disaster area, forest fires have the greatest impact on the loss of soil and nutrients in the forest ecosystem. This is because forest development needs soil, while the growth of soil fixation and fertility depends on trees. Soil that has been subjected to forest fires may show fertility reductions and hardening and may not play a positive role in possible reforestation; it may even inhibit subsequent forest restoration or even lead to permanent soil degradation. In addition to directly observed economic losses, the decline in soil quality caused by forest fires will produce a series of chain reactions, further intensifying soil erosion and expanding the flow of new sediment. In this case, the impact of the loss in forest soil fixation and fertilizer conservation is not only limited to forest soil but also affects the forest water environment. More seriously, it will cause river blockages, increasing the probability of flood disasters [78].

On the other hand, in terms of personnel loss, Inner Mongolia has shown relative security for personnel and has established a "life first" system. The proportions of carbon fixation and oxygen release loss, water conservation loss, air purification loss, nutrient accumulation loss, and biodiversity loss in 2006–2018 were relatively stable and basically remained at the same level. This shows that the regional forest property differences involved in forest fires in Inner Mongolia are not large, and the average forest ages are relatively similar. The changes in investment ineffectiveness losses show that the proportion of forest-fire-related ineffectiveness investment losses is increasing, which shows that the wasteful investments in forestry construction in Inner Mongolia are becoming more and more serious, and ineffective investment is increasing, that is, some forestry areas are overfunded, while the areas that need more investment are neglected. The change trend of other losses is not obvious, but the overall proportion is increasing. There is also a similar trend in direct economic losses. This may be because the increase in the overall price level of the market and the scarcity of forest output resources lead to a greater increase in forest prices compared to other types of losses, such as the price of dam construction, the price of purified water, the price of carbon emissions trading, etc.

Table 6. Proportion of forest fire loss types in Inner Mongolia over the years.

Year	Fire Area (Hm^2)	Loss of Forest Output (%)	Loss of Carbon Fixation And Oxygen Release (%)	Loss of Carbon Fixation And Oxygen Release (%)	Loss of Water Conservation (%)	Loss of Air Purification Benefits (%)	Loss of Nutrient Accumulation (%)	Loss of Biodiversity (%)	Loss of Invalidation of Investment (%)	Loss of Casualty (%)	Other Loss (%)
2006	60,245	0.0043	0.0254	99.5693	0.0028	0.0087	0.3664	0.0225	0.0004	0.0000	0.0001
2007	3023	0.0093	0.0265	99.5441	0.0031	0.0100	0.3839	0.0225	0.0005	0.0000	0.0000
2008	2439	3.0323	0.0239	96.5595	0.0037	0.0098	0.3444	0.0219	0.0005	0.0001	0.0040
2009	33,734	0.7913	0.0242	98.7995	0.0034	0.0097	0.3488	0.0224	0.0006	0.0000	0.0000
2010	8559	0.0006	0.0238	99.5967	0.0046	0.0093	0.3417	0.0225	0.0008	0.0000	0.0000
2011	1089	0.0230	0.0256	99.5429	0.0039	0.0110	0.3692	0.0225	0.0011	0.0000	0.0008
2012	650	0.0613	0.0236	99.5325	0.0057	0.0118	0.3394	0.0225	0.0000	0.0000	0.0031
2013	287	0.2618	0.0230	99.3237	0.0055	0.0135	0.3295	0.0225	0.0013	0.0000	0.0191
2014	3426	0.0264	0.0235	99.5700	0.0054	0.0099	0.3382	0.0225	0.0013	0.0000	0.0027
2015	3254	1.1550	0.0236	98.4205	0.0057	0.0098	0.3392	0.0223	0.0014	0.0000	0.0226
2016	1478	0.0724	0.0242	99.4837	0.0068	0.0106	0.3491	0.0225	0.0014	0.0000	0.0292
2017	16,780	0.5298	0.0230	99.0777	0.0059	0.0090	0.3300	0.0224	0.0014	0.0000	0.0008
2018	6120	0.5382	0.0214	99.0931	0.0071	0.0094	0.3058	0.0224	0.0013	0.0000	0.0012

5. Discussion

Based on the above research results, this paper puts forward targeted suggestions related to different forest fire economic loss characteristics, forest resource endowments, and geographical locations. The low level of economic development and the small and scattered distribution of forest resources are the main reasons for the low economic loss levels in Xinjiang, Tibet, and other western provinces. Therefore, the main focus should be on strengthening forest fire monitoring and timely fire suppression, as well as steadily promoting fire adaptation in forests and communities according to their economic capacity. Jiangsu, Shandong, Beijing, and other economically developed areas in the east of China have small forest areas, large population densities, high levels of economic development, higher levels of science and technology than the national average, and strong disaster prevention, reduction, and carrying capacities, resulting in lower forest-fire-related losses in these regions. Similarly, in addition to maintaining their own forest fire prevention capabilities, Shaanxi and Chongqing should use their own economic and technological advantages to expand the exportation of scientific, technological, experiential, and educational resources to surrounding areas with high forest fire loss levels, so as to form a good "radiation area", which can benefit the whole region and accelerate the minimization of forest fire losses in China. The decrease trend of forest fire loss in Heilongjiang Province and Sichuan Province is obvious, indicating that the capacity for and consciousness of fire prevention and disaster relief in these areas are strong. At the same time, due to the large forest areas and forest reserves in Heilongjiang, Sichuan, and other regions, it is more difficult to monitor and respond to forest fires, resulting in greater volatility in forest-fire-related losses in these areas. Therefore, these areas should strengthen their investment in real-time forest fire monitoring technology and improve the emergency response abilities of professionals. The forest-fire-related economic losses in eastern and southern provinces of China, such as Fujian, Zhejiang, Jiangxi, and Hunan, have decreased significantly, with less volatility, indicating the formation of a linkage region from the coast to the inland. Therefore, these regions should maintain their current rate of progress in developing forest fire prevention technology and education while gradually increasing the linkage of areas, increasing inter-regional communication and fire prevention cooperation, continuously enhancing their ability to adapt to forest fires, and improving their damage reduction mechanisms, so that the surrounding areas can reduce their own economic losses from forest fires while eliminating the hidden dangers related to fighting fires.

In observing the value of each loss caused by forest fires in this study, we find that the proportion of forest ecological benefit loss caused by forest fires out of the total economic loss is above 96%—slightly higher than in existing studies [74]. However, the existing studies on the ratio of direct economic loss to indirect economic loss focus on forest biological disasters and forest freezing disasters [79,80]. Although forest fire is a type of forest disaster, as are forest biological disasters and forest freeze disasters, their impacts on trees, the environment, and the whole forest ecosystem are different. Forest biohazards mainly affect the quality of the trees themselves and the output of crops, while they have little impact on the ecological benefits of forests. The ability of forests to hold soil and fertilizer, for example, relies mainly on the soil-holding capacities of the well-developed root systems of trees, and in most cases, biogenic disasters only cause damage to the leaves and trunks of trees and rarely have a negative impact on the root system. It is equally difficult for a forest freeze disaster to cause destructive and permanent damage to the forest ecosystems. This is not the case with forest fires. After a forest fire, burnt wood can completely lose its physiological function and all the benefits it can bring to the tree. The cost of time required to dispose of burnt wood residues and for newly planted trees to attain the pre-fire capacity levels is very expensive. All capacities of burnt wood are reduced by fires and will require time to recover, during which time the damage caused by forest fires can become very significant [81]. The above analysis shows that the damage caused by forest fires to the forest environment and ecology is much more serious than that of other forest disasters, which means that the proportion occupied by forest ecological benefit losses in the total economic loss related to forest fires should be larger. Meanwhile, Lin et al. and Meng [82,83] showed that the importance of ecological functions of Chinese forests is increasing and is now much higher than their economic functions. Li et al. and Bai et al. [84,85] found through calculations that the value of the forest ecosystem's service function accounts for about 95% of the total forest value, and this figure is rising. This shows that the results and conclusions of this paper are reasonable and have some reference value.

It is worth noting that although this paper supplemented and improved the economic loss assessment indicators related to forest fires and corrected for the differences between different regions in the same forest, there are still many types of losses that are difficult to measure at the provincial level. Take the loss of forest tourism as an example. Generally, the loss of forest tourism is measured based on the tourism income of forest parks and forest scenic spots [56,86] during the loss measurement of small-scale forest fires. However, the loss of tourism income in forest scenic spots at the provincial level cannot be calculated accurately, resulting in large errors. In addition, it is difficult to estimate the losses caused by forest fires in farmland protection [36] on a large scale. In general, the current research on economic loss evaluation systems for forest fires is deepening, and the theoretical framework is also improving. Furthermore, there are relatively few empirical studies on forest fire loss assessment; their assessment objectives and application scopes are still deficient, and the analyses of the assessment results are very one sided, so the statistical and measurement systems, as well as the assessment perspective, of forest fire loss need to be improved further.

6. Conclusions

Based on the economic loss assessment system of forest fires in China, this paper calculates the losses caused by forest fires in 31 provinces from 2006 to 2018 and analyzes their change trends and spatial distribution characteristics. The results show the following. Firstly, with the exception of the 2006 Heilongjiang mega-fire, which caused the total forest fire loss in China for this year to far exceed that of other years, the overall trend of forest fire loss in China is basically characterized by a "fluctuating decline", indicating that China has scored significant achievements in building forest fire resilience. However, the potential risks associated with the rapid suppression of natural fires still exist. Secondly, China's forest fires cause the greatest damage to forest ecological benefits, so we should pay more attention to forest ecological reconstruction and restoration after fires. Thirdly, the change patterns in economic losses related to forest fires in eastern and western China are basically the same. Before 2011 and 2012, the loss levels were high and volatile, but afterward, the loss was effectively controlled and showed a downward trend year by year. However, the loss in central China has been consistently higher than in other regions, and the fluctuation in the loss has been strong. The overall distribution characteristic of forest fire loss is "low on both sides and high in the middle". Fourthly, from the perspective of spatial distribution change, the regions showing large changes in forest-fire-related economic losses are mainly concentrated in the eastern and southern coastal regions and adjacent areas. With the development of the economy, as well as science and technology, the number of areas suffering high economic losses is decreasing, showing a spatial decline from coastal to inland areas. Finally, the change in economic loss caused by forest fires in Inner Mongolia is very unique. The areas and losses of forest fires show sudden increases over an average of 3–4 years, in sharp contrast to the overall law of decline and fluctuation in forest fire loss in China. On the one hand, this phenomenon shows that Inner Mongolia lacks a fundamental understanding related to reducing forest fire loss—specifically, that it is not feasible to use fire extinguishing as the main method of reducing loss. This region should change its thinking on disaster reduction and strengthen the fire adaptation capacity of its forest ecosystems and economic communities. For forest ecosystems, the main focus should be on adjusting the structures of forests to increase their resistance to fire, reducing the rate of accumulation of forest fuels, and speeding up post-disaster soil recovery. For economic communities, their distance from forest edges should be reasonably adjusted to reduce the susceptibility of the infrastructure, such as houses, to fire. On the other hand, this case also serves as a warning to other regions in China; the hidden dangers associated with rapid fire suppression are enormous, while moderate small fires help to consume forest fuels and remind us of the need for timely interventions to control fire sources in response to meteorological factors, such as climate warming, in order to prevent fires from developing at a higher intensity.

Author Contributions: Conceptualization, Z.H. and G.G.; methodology, Z.H. and G.G.; software, Z.H.; formal analysis, Z.H. and G.G.; validation, Z.H., G.G. and Z.Y.; resources, Z.Y. and X.C.; writing—original draft, Z.H. and G.G.; visualization, Z.H.; supervision, G.G., Z.Y. and X.C.; writing—review and editing, Z.H., G.G. and Z.Y.; funding acquisition, Z.H., Z.Y. and G.G. All authors have read and agreed to the published version of the manuscript.

Funding: Institute Scientific Research Grants for the Key Research Bases of Humanities and Social Sciences of Guangxi Colleges and Universities (grant number ZX2022002), The Science and technology project of Guangxi (grant number Guike AD21220114), National Natural Science Fund of China (grant number 11901124), Guangxi University Fundamental Ability Improvement Project for Young and Middle-aged Teachers of China (grant number 2021KY1798), Innovation Project of Guangxi Graduate Education (grant number XYCSZ2022006, JGY2020031), Study on the Characteristics and Influence Mechanism of Residents' Asset Liability Behavior (grant number XKY2018202).

Data Availability Statement: Not applicable.

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

References

1. Gao, L.; Kong, F.W.; Guang, C.X.; Du, Y.S. Research on the economic evaluation method of forest fires. *For. Econ.* **1993**, *4*, 46–59. [CrossRef]
2. Boustras, G.; Boukas, N. Forest fires impact on tourism development: A comparative study of Greece and Cyprus. *Manag. Environ. Qual.* **2013**, *24*, 498–511. [CrossRef]

3. Rice, M.B.; Henderson, S.B.; Lambert, A.A.; Cromar, K.R.; Hall, J.A.; Cascio, W.E.; Smith, P.G.; Marsh, B.J.; Coefield, S.; Balmes, J.R.; et al. Respiratory Impacts of Wildland Fire Smoke: Future Challenges and Policy Opportunities. An Offi-cial American Thoracic Society Workshop Report. *Ann. Am. Thorac. Soc.* **2021**, *18*, 921–930. [CrossRef] [PubMed]
4. Romanov, A.A.; Tamarovskaya, A.N.; Gusev, B.A.; Leonenko, E.V.; Vasiliev, A.S.; Krikunov, E.E. Catastrophic PM2.5 emissions from Siberian forest fires: Impacting factors analysis. *Environ. Pollut.* **2022**, *306*, 119324. [CrossRef] [PubMed]
5. Jiao, Y.; Hu, H.Q. Estimation of Carbon Emission from Forest Fires in Heilongjiang Province during 1980–1999. *Sci. Silvae Sin.* **2005**, *6*, 112–116.
6. Randerson, J.T.; Liu, H.; Flanner, M.G.; Chambers, S.D.; Jin, Y.; Hess, P.G.; Pfister, G.; Mack, M.C.; Treseder, K.K.; Welp, L.R.; et al. The Impact of Boreal Forest Fire on Climate Warming. *Science* **2006**, *314*, 1130–1132. [CrossRef] [PubMed]
7. Wang, Z.S.; Zhou, Y.F.; Wu, Z.P.; Li, S.C.; Li, X.W. Investigation and analysis of ground-litters decrement and CO2 emission during forest fires in Guangdong province. *J. Cent. South Univ. For. Sci. Technol.* **2015**, *35*, 93–96.
8. Huang, L.; Shao, Q.Q.; Liu, J.Y. Carbon losses from forest fire in Jiangxi Province, China in 1950–2008. *Chin. J. Appl. Ecol.* **2010**, *21*, 2241–2248. [CrossRef]
9. Lal, R. Forest soils and carbon sequestration. *For. Ecol. Manag.* **2005**, *220*, 242–258. [CrossRef]
10. Ruiz-Peinado, R.; Bravo-Oviedo, A.; López-Senespleda, E.; Bravo, F.; del Rio, M. Forest management and carbon sequestration in the Mediterranean region: A review. *For. Syst.* **2017**, *26*, 10. [CrossRef]
11. Onda, Y.; Dietrich, W.E.; Booker, F. Evolution of overland flow after a severe forest fire, Point Reyes, California. *CATENA* **2008**, *72*, 13–20. [CrossRef]
12. Evelpidou, N.; Tzouxanioti, M.; Gavalas, T.; Spyrou, E.; Saitis, G.; Petropoulos, A.; Karkani, A. Assessment of Fire Effects on Surface Runoff Erosion Susceptibility: The Case of the Summer 2021 Forest Fires in Greece. *Land* **2021**, *11*, 21. [CrossRef]
13. Wang, D.X. Analysis of forest fire prevention education in China. *For. Fire Prev.* **2003**, *1*, 13–14.
14. Wang, H.; He, M.; Ran, N.; Xie, D.; Wang, Q.; Teng, M.; Wang, P. China's Key Forestry Ecological Development Programs: Implementation, Environmental Impact and Challenges. *Forests* **2021**, *12*, 101. [CrossRef]
15. Mi, F. A Study on the Estimation of Forest Resources Loss—The Quantitative Estimation of Forest Tree Loss in Beijing. Ph.D. Thesis, Beijing Forestry University, Beijing, China, 2006.
16. Han, Y.J. Research on forest fire loss assessment methods. *Green Financ. Account.* **2022**, *4*, 15–18. [CrossRef]
17. Li, C.H.; Zhao, X.G.; Jin, Z.Y. A preliminary study on the economic statistical index system of forest fires. *For. Fire Prev.* **1993**, *2*, 15–17.
18. Xu, Y.; Ding, J.F. A Review of Forest Fire Damage Assessment Index and Classification Methods. *For. Econ.* **2015**, *37*, 134–137. [CrossRef]
19. Cai, T.J.; Yang, C.; Liu, Q. Evaluation of forest fire damage to trees and water resources. *For. Fire Prev.* **1995**, *4*, 10–11.
20. Mi, F.; Li, J.Y.; Yang, J.W. Review on research of evaluation on forest ecological benefits. *J. Beijing For. Univ.* **2003**, *6*, 77–83. [CrossRef]
21. Sun, Y.R.; Chen, A.B.; Lin, Y.G. Analysis of development characteristics of forest fire loss in Hunan. *J. Nat. Hazards* **2013**, *22*, 70–75. [CrossRef]
22. Zhang, J.Z.; Zou, J.; Sun, J.B. Calculation of forest resources loss due to forest fire in Greater Khingan Range. *For. Sci. Technol.* **2001**, *2*, 28–31.
23. Di, X.Y.; Sui, K.; Cai, H.Y.; Yang, G. A Comparison of the Methods for Post-fire Forest Resources Loss Assessment. *For. Eng.* **2014**, *30*, 14–17. [CrossRef]
24. Liu, Z.J. Discussion on Issues Related to Forest Fire Damage Assessment. *Issues For. Econ.* **2016**, *36*, 412–416. [CrossRef]
25. Kang, W.X.; Tian, D.L. Economic Evaluation of the Public Benefits of the Forests in Hunan: III Benefits of Air-Cleaning. *J. Cent. South Univ. For. Technol.* **2002**, *1*, 7–10. [CrossRef]
26. Moreira, F.; Ascoli, D.; Safford, H.; Adams, M.A.; Moreno, J.M.; Pereira, J.C.; Catry, F.X.; Armesto, J.; Bond, W.J.; González, M.E.; et al. Wildfire management in Mediterranean-type regions: Paradigm change needed. *Environ. Res. Lett.* **2020**, *15*, 011001. [CrossRef]
27. Calkin, D.E.; Cohen, J.D.; Finney, M.A.; Thompson, M.P. How risk management can prevent future wildfire disasters in the wildland-urban interface. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 746–751. [CrossRef] [PubMed]
28. Zhang, C.H.; Ju, W.M.; Wang, D.J.; Wang, X.J.; Wang, X. Biomass carbon stocks and economic value dynamics of forests in Shandong Province from 2004 to 2013. *Acta Ecol. Sin.* **2018**, *38*, 1739–1749. [CrossRef]
29. Yang, Y.S.; Guo, J.F.; Chen, G.S.; Chen, G.S.; Xie, J.S.; Cai, L.P.; Lin, P. Litterfall, nutrient return, and leaf-litter decomposition in four plantations compared with a natural forest in subtropical China. *Ann. For. Sci.* **2004**, *61*, 465–476. [CrossRef]
30. Xu, F.W.; Gao, Y.P.; He, K.Q.; Ding, W.J.; Dai, Q.H. Study on Biomass and Net Productivity of Pinus massoniana of Stand at Different Forest Ages. *Hubei Agric. Sci.* **2013**, *52*, 1853–1858. [CrossRef]
31. Kong, W.J.; Zheng, Z. The Aboveground Biomass and Net Primary Productivity of Degraded and Artificial Communities in Maoxian, Upper Reach of Minjiang River. *J. Mt. Sci.* **2004**, *4*, 445–450. [CrossRef]
32. Sun, M.M.; Song, C.L.; Shi, W.Y. Characteristics of Carbon Sink in Black Locust Plantation and Oak Natural Secondary Forest in Loess Hilly Region. *Res. Soil Water Conserv.* **2020**, *27*, 55–61. [CrossRef]
33. Liu, S.J.; Li, W.G.; Chen, X.M.; Tong, J.H. Prediction of Net Primary Productivity of Vegetation in Main Rubber Areas of China under Future Climate Change. *Chin. J. Trop. Crops* **2020**, *41*, 622–626. [CrossRef]

34. Xie, B.N.; Qin, Z.F.; Wang, Y.; Chang, Q.R. Spatial and temporal variation in terrestrial net primary productivity on Chinese Loess Plateau and its influential factors. *Trans. Chin. Soc. Agric. Eng.* **2014**, *30*, 244–253. [CrossRef]
35. Zhang, N.; Yang, Z.J.; Xu, C.; Liu, X.F.; Xiong, D.C.; Lin, C.F. Effects of forest conversion on litterfall nutrient return and nutrient use efficiency in Mid-subtropical China. *Chin. J. Appl. Ecol.* **2022**, *33*, 321–328. [CrossRef]
36. Kang, W.X.; Tian, D.L. Economic Evaluation of the Public Benefits of the Forests in Hunan: I Benefits of timber production and water holding. *J. Cent. South Univ. For. Technol.* **2001**, *3*, 13–17. [CrossRef]
37. Kang, W.X.; Tian, D.L. Economic Evaluation of the Public Benefits of the Forests in Hunan: II Benefits of Preventing Soil Erosion, Keeping Fertility and Cleaning Air. *J. Cent. South Univ. For. Technol.* **2001**, *4*, 7–10. [CrossRef]
38. Wang, F. Feasibility study of typhoon disaster economic loss assessment based on random forest. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, Britain, 2020; Volume 546, p. 032004. [CrossRef]
39. Wu, Y.D.; Meng, J.J. Quantifying the spatial pattern for the importance of natural resource ecosystem services in China. *J. Nat. Resour.* **2022**, *37*, 17–33. [CrossRef]
40. Wei, F.; Zhan, X.W. Delineating urban growth boundaries with ecosystem service evaluation. *Sustainability* **2019**, *11*, 5390. [CrossRef]
41. Chiriacò, M.V.; Perugini, L.; Cimini, D.; D'Amato, E.; Valentini, R.; Bovio, G.; Corona, P.; Barbati, A. Comparison of approaches for reporting forest fire-related biomass loss and greenhouse gas emissions in southern Europe. *Int. J. Wildland Fire* **2013**, *22*, 730–738. [CrossRef]
42. Bento-Gonçalves, A.; Vieira, A.; Úbeda, X.; Martin, D. Fire and soils: Key concepts and recent advances. *Geoderma* **2012**, *191*, 3–13. [CrossRef]
43. Wang, X.; Zhou, H.J. Progress and Prospect of Statistics and Assessment of Large-scale Natural Disaster Damage and Losses. *Adv. Earth Sci.* **2018**, *33*, 914–921. [CrossRef]
44. Che, K.J.; Fu, H.E.; He, H.Y. Metrological Research on Synthetical Efficiency of Water Conservation Forest in the Qilian Mountains. *Sci. Silvae Sin.* **1992**, *4*, 290–296.
45. Huang, L.S.; Wang, B.; Niu, X.; Song, Q.F. Evaluation on the influence of natural forest protection program on soil conservation and ecological benefits in Key State-owned Forest Districts in Northeast China-Inner Mongolia Area. *Sci. Soil Water Conserv.* **2017**, *15*, 67–77. [CrossRef]
46. Shao, X.K.; Xin, Z.; Liu, Z.C.; Wang, Y.B.; Tang, B.S. Assessment methods of economic losses of forest pests and diseases. *J. Liaoning For. Sci. Technol.* **2007**, *1*, 39–40+51.
47. Wang, X.K.; Feng, Z.W.; Zhuang, Y.H. CO_2, CO and CH4 Emissions from Forest Fires in China. *Sci. Silvae Sin.* **2001**, *1*, 90–95.
48. Xu, H.Z.; Zhang, J.G.; Zheng, P. Evaluation of Carbon Sequestration Value of Forest Ecosystem in Yunnan Province Based on Market Mechanism of Carbon Trading. *Ecol. Econ.* **2019**, *35*, 33–38.
49. Zhou, Y.C.; Xu, S.G.; Zhang, Y.Q. Effects of Forest fire on the Watershed Hydrological Cyde. *South-North Water Transf. Water Sci. Technol.* **2013**, *11*, 116–120+145.
50. Zhao, X.Q.; He, C.L.; Yi, Q. Soil Moisture and Water Conservation in Eucalyptus uraphylla spp. Introduction Mountain Area. *J. Soil Water Conserv.* **2012**, *26*, 205–210. [CrossRef]
51. Chen, G.Q.; Kang, X.G. Valuation of eco-benefit value and adjustment in Wudaohe Forest. *J. Beijing For. Univ.* **2001**, *3*, 56–59. [CrossRef]
52. Wang, J.L.; Yang, L.; Zhang, D.H.; Peng, Q. Research on Measurement of Ecological Benefit of Water Conservation Forests in Beijing and Hebei Province: Based on the Theory of Forest Ecosystem Service Value. *Ecol. Econ.* **2016**, *32*, 186–190.
53. Qin, W.; Zhu, Q.K.; Lai, Y.F. Evaluation and compensation of ecological value in the land conversion project: A case study of Wuqi County, Shaanxi Province. *J. Beijing For. Univ.* **2008**, *5*, 159–164. [CrossRef]
54. Lu, Z.Q.; Yi, L.T.; Qian, Y.F.; Dou, P.M.; Ying, B.G.; Yu, S.Q. Evaluation on efficiencies of water, soil and fertilizer conservation of public welfare forests in Jinyun County, Zhejiang Province. *Acta Agric. Zhejiangensis* **2012**, *24*, 92–98.
55. Li, X.M.; Wang, N.A.; Zhao, Q. Evaluation of Forest Ecosystem in Xinglongshan Mountain Nature Reserve. *J. Arid. Land Resour. Environ.* **2008**, *10*, 91–95. [CrossRef]
56. Zhong, X.S.; Tan, S.Q. The study of the evaluation method on the losing of the ecological benefits of forest fire. *Hunan For. Sci. Technol.* **2005**, *2*, 73–75.
57. Liu, R.B.; Li, L.; Chen, P.D.; Xian, X.Y.; Zhao, X.; Hou, Y.P. Effects of Forest Fire on Soil Properties of Secondary Forests on Zhenshan Mountain in Yantai, Shandong Province. *Ecol. Environ. Sci.* **2016**, *25*, 1300–1305. [CrossRef]
58. Lin, C.F.; Li, Z.; Niu, Z.P.; Zhang, Y.L.; Han, Y.G.; Chen, G.S. Litterfall nutrient dynamics in Fokienia hodginsii plantation. *J. Fujian Agric. For. Univ. (Nat. Sci. Ed.)* **2005**, *1*, 63–66.
59. Jia, H.; Pan, D.; Zhang, W. Health assessment of wetland ecosystems in the Heilongjiang River Basin, China. *Wetlands* **2015**, *35*, 1185–1200. [CrossRef]
60. Goldsmith, K.A.; Granek, E.F.; Lubitow, A. Information needs assessment for coastal and marine management and policy: Ecosystem services under changing climatic, land use, and demographic conditions. *Environ. Manag.* **2015**, *56*, 1502–1513. [CrossRef] [PubMed]
61. Melvin, A.M.; Mack, M.C.; Johnstone, J.F.; McGuire, A.D.; Genet, H.; Schuur, E.A.G. Differences in ecosystem carbon distribution and nutrient cycling linked to forest tree species composition in a mid-successional boreal forest. *Ecosystems* **2015**, *18*, 1472–1488. [CrossRef]

62. Singh, S. Implications of forest fires on air quality–a perspective. *Bull. Environ. Sci. Res.* **2016**, *5*, 3–4. Available online: http://besr.org.in/index.php/besr/article/view/71 (accessed on 27 December 2016).
63. Sun, Z.Y.; Guan, J.; Cao, R.F.; Wang, Z.M.; Qu, H.H.; Cao, G.Y.; Yang, M.S.; Wei, C.C.; Si, C.Q.; Su, A.F. Function Evaluation of Nutrient Accumulation of Forest Ecosystem Based on ArcGIS in Yantai City. *J. Northwest For. Univ.* **2021**, *36*, 156–162. [CrossRef]
64. Miao, Y.X.; Wang, S.L.; Wang, R.X.; Cheng, C.X.; Ma, Y.; Liu, S.R.; Dong, X.L. Nutrient elements accumulation of forest dominant species and its ecological service value in Gansu Province. *J. Gansu Agric. Univ.* **2012**, *47*, 108–113. [CrossRef]
65. Ma, K.P. New opportunities for mainstreaming biodiversity conservation. *Biodivers. Sci.* **2015**, *23*, 557–558. [CrossRef]
66. Xue, D.Y. Valuation on non-use values of biodiversity by contingent valuation method in Changbai Mountain Biosphere Reserve in China. *China Environ. Sci.* **2000**, *2*, 141–145.
67. Chang, J.H.; Lu, M.C. Ecological economic Research into the Preservation of Biodiversity. *Ecol. Econ.* **2001**, *7*, 60–63.
68. Yu, G.X.; Jiang, N.L.; Yu, Q.G.; Lu, W.Z. The Effects of the Scenic Forest Transformation on the Ecological Service Function Value in Qiandao Lake. *J. Fujian For. Sci. Technol.* **2014**, *41*, 145–150. [CrossRef]
69. Gao, Y.F.; Zeng, X.G.; Jiang, W.T. Evaluation of non-use value of forest resources in mountainous areas of Beijing and analysis of its influencing factors. *J. Agrotech. Econ.* **2005**, *3*, 6–11. [CrossRef]
70. Wang, B.; Zheng, Q.H.; Guo, H. Economic Value Assessment of Forest Species Diversity Conservation in China Based on the Shannon-Wiener Index. *For. Res.* **2008**, *2*, 268–274.
71. Li, B.S. Legal and economic analysis of the value of life-the reform path of life compensation law in China. *Soc. Sci. China* **2011**, *6*, 79–94+222.
72. Li, W.H.; Cheng, Q.Z. Mathematics Model of Life Value Evaluation Based on Willingness to Accept Method. *J. Jianghan Univ. (Nat. Sci. Ed.)* **2014**, *42*, 27–30. [CrossRef]
73. Fu, C.; Chen, J.; Zhang, Y.P. Study on Relationship between Loss of Flood Disaster and Development of Social Economy in Poyang Lake Area. *J. Jiangxi Norm. Univ. (Nat. Sci.)* **2007**, *5*, 541–544. [CrossRef]
74. Sheng, Z.H.; Chen, M.; Liu, Z.J.; Liu, P.; Liao, L.F.; Yang, Y.G. Importance of loss evaluation indexes of rodent disaster in the desert forests in Changji, Xinjiang Uygur Autonomous Region. *For. Pest Dis.* **2015**, *34*, 14–17+22.
75. Yu, H.; Yang, J.; Qiu, M.; Liu, Z. Spatiotemporal Changes and Obstacle Factors of Forest Ecological Security in China: A Provincial-Level Analysis. *Forests* **2021**, *12*, 1526. [CrossRef]
76. Zhang, M.Y.; Yuan, Y.B.; Zhou, J. Research on harmony between urban's integrated disaster bearing capacity and economic development. *J. Nat. Disasters* **2010**, *19*, 1–6. [CrossRef]
77. Wang, J.; Gong, Q.H.; Yu, Y.; Yuan, S.X.; Chen, J.; Huang, G.Q. Evaluation of comprehensive disaster-bearing capacity of urban natural disasters in the Guangdong-Hong Kong-Macao Greater Bay Area. *Geogr. Res.* **2020**, *39*, 2189–2199. [CrossRef]
78. Zhao, Q.; Luo, M.S.; Cao, S.Y.; Liu, X.N. Research on the Recovering Measures and Economic Loss Evaluation of Soil Erosion and Water Loss in Wenchuan-Earthquake-hit areas of Sichuan Province. *J. Sichuan Univ. (Eng. Sci. Ed.)* **2009**, *41*, 289–293. [CrossRef]
79. Zhang, X.; Zhao, J.J.; Yan, J.; Fang, G.F.; Huang, J.X. Economic loss assessment of pine wilt disease in mainland China in 2017. *J. Beijing For. Univ.* **2020**, *42*, 96–106.
80. Xu, F.L.; Qian, G.Q.; Yang, L.Z. Economical Assessment of the Lose's Value Brought by the Blizzard and Frozen Disasters to the Forest in the Ecosystem Services—Take the Disaster Forest of Fujian Province as the Example. *Sci. Silvae Sin.* **2008**, *44*, 193–201.
81. Luo, J.C. Influence of forest fire disaster on forest ecosystem in Great Xing'anling. *J. Beijing For. Univ.* **2002**, *Z1*, 105–111. [CrossRef]
82. Lin, M.Z.; Ma, X.F.; Yang, M.Z.; Cai, D.; Chen, Z.Y.; Jiang, X.D. Dynamic Evaluation of Forest Eco-system Services in Guangdong Province. *Resour. Sci.* **2009**, *31*, 980–984.
83. Meng, Y.Y.; He, Z.B.; Liu, B.; Chen, L.F.; Liu, B. Changes of spatial distribution and ecosystem service value of oasis wetlands in arid areas: Taking three typical inland river basins as examples. *Resour. Sci.* **2020**, *42*, 2022–2034. [CrossRef]
84. Li, C.; Hymit, Y.; Li, X.D. Evaluation of the service value of the forest ecosystem in Kanas Natural Reserve. *J. Arid. Land Resour. Environ.* **2011**, *25*, 92–97. [CrossRef]
85. Bai, Z.Q.; Wang, W.D.; Li, H.; Liu, D.; Guo, Z.J. Evaluation of Forest Ecosystem Service Function of Kanas National Nature Reserve. *J. Northwest For. Univ.* **2018**, *33*, 292–296. [CrossRef]
86. Li, S.N.; Wang, B.; Guo, H.; Qu, H.; Li, B.B.; Zhang, L.R. Assessment of forest ecosystem services value in Dagangshan. *Sci. Soil Water Conserv.* **2007**, *6*, 58–64. [CrossRef]