RISK ANALYSIS OF FOREST FIRES IN CHINA BASED ON INFORMATION DIFFUSION THEORY

Zhang Ying, Zhang Zixuan
School of Economics & Management, Beijing Forestry University, P.R. China
zhangyin@bjfu.edu.cn , rychou.chn@qq.com

Abstract. Forest fire is an important influencing factor in the forest ecosystem, which has an important influence on the stability and balance of the ecosystem. It is of great significance to study the risk of forest fire to improve the management ability and countermeasures of forest resources risk as well as forest resources protection. The study collected data on the number of forest fires in China from 1990 to 2020 and analysed the risk of forest fires in China using the method of information diffusion theory, and the protection of forest resources is discussed. The study points out that the number of forest fires and the area of forest damage are generally decreasing, all these are closely related to the protection of resources and the construction of ecological civilization and the relatively perfect monitoring system of resources and environment etc. in China. The study results show that China has one general and large forest fire every 3.08 years, a major forest fire occurs in more than 10 years, a huge forest fire occurs in about 7 years, and a general and larger forest fire is in about 5 years. The study mainly provides reference for the forest risk management and resources protection and puts forward some policy suggestions for disaster prevention and control in China, especially in the protection of forest resources, there should be a clear technical and economic policy for forest disaster management and control, and a clear path for the formulation of technical and economic policy for it in China, so as to promote the development of environmental protection.

Key words: forest fire; risk analysis; information diffusion theory; ecosystem management; natural resources protection.

Introduction

Resources and environmental protection are hot issues in current research. Risk management and control is an important research content of environmental protection. At present, the research on risk management and control has made some progress both in theory and practice. Especially in theoretical research, some theories have certain reference significance for environmental protection, including the Information Diffusion Theory [1]. The theory was first proposed by Professor Everett M. Rogers in the United States [2]. It is a theory that studies risk estimation under the condition that the observed samples may have information incompleteness. The information diffusion theory is widely used in the risk assessment of specific disasters such as fire, earthquake, flood, and meteorological disasters, and also in resources and environmental protection [3]. In recent years, many experts and scholars have begun to pay attention to the risk assessment of natural disasters and published some articles on risk assessment based on the information diffusion theory. In 2005, Professor Huang Chongfu proposed the calculation of the probability of forest fires occurring under different risks [4]. Wang Jiayi used the normal information diffusion calculation method to evaluate the agricultural flood risk in Fujian Province [1]. Jin Xu and LIAO Shangang established a forest fire risk assessment model based on three indicators of forest fire occurrence rate, number of major fires and damaged area by applying the information diffusion theory, and quantitatively assessed the forest fire risk in Fujian Province [5]. Li Binghua *et al*. used the information diffusion method to study the influence of fire starting point, step size, diffusion coefficient and other factors on the diffusion results, and used the data of major fires in Japan from 1995 to 2008 to estimate the major fire frequency in order to better protect forest resources [6]. Based on the information diffusion theory, Zhou Xue and Zhang Ying estimated the occurrence probability, disaster scope, risk probability and occurrence period of forest fires in China [7]. Zhang Lijuan *et al*. calculated the risk values of different grades of meteorological disasters in Heilongjiang Province and compared the calculation results with the risk index method and the subjective frequency method [8]. Lu Fengben *et al*. applied fuzzy mathematics based on the information diffusion theory to study the different levels of tropical cyclone disasters along the coast of Guangxi [9]. However, the relevant research data of forest fire risk assessment in China are relatively old, and most of them are regional forest fire risk assessments. They are not targeted and the policy path for resources and environmental protection is not clear [10]. Therefore, based on the relevant research and the official statistics of forest fires, this paper mainly uses the method based on the information diffusion theory to analyze the risk of general, large, major and huge forest fires in China and discusses the policy path of forest resource protection in order to provide reference and basis for relevant management and decision-making.

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1. Information diffusion theory and evaluation model

Information diffusion theory maps traditional data sample points into a fuzzy set, expands the information quantity of sample points and evaluates the relevant risk probability [11].

The risk evaluation model of the information diffusion theory is as follows:

Firstly, a series of observational indices $y_j$is established, y_j is actual disaster observations within *m* years.

$$y_j = \{y_1, y_2, \cdots, y_m\} \tag{1}$$

Secondly, the discrete universe of discourse u_i of the disaster observation index y_i is set, that is, the control point space is determined according to the maximum and minimum values of the observation index series.

$$u_i = \{u_1, u_2, \cdots, u_n\} \tag{2}$$

Then, the information of y_i is diffused into each composition of the universe u_i, the equation of information diffusion is:

$$f_j(u_i) = \frac{1}{h\sqrt{2\pi}} exp[-\frac{\left(y_j - u_i\right)^2}{2h^2}]. \tag{3}$$

In (3), *h* is the diffusion coefficient, which is determined by the maximum value *b*, the minimum value *a*, and the number of samples *m* in the sample set. The diffusion coefficient reflects the extent to which the information of the sample point diffuses to the surroundings. The calculation formula is:

$$h = \begin{cases} 0.8146(b-a) & m = 5 \\ 0.5690(b-a) & m = 6 \\ 0.4560(b-a) & m = 7 \\ 0.3860(b-a) & m = 8 \\ 0.3362(b-a) & m = 9 \\ 0.2986(b-a) & m = 10 \\ 2.6851(b-a)/(m-1) & m \geq 11 \end{cases} \tag{4}$$

Let,

$$C_j = \sum_{i=1}^{n} f_j(u_i) , \tag{5}$$

At this time, the single-valued observation sample becomes a fuzzy set of membership functions, which are expressed as follows:

$$u_{yj}(u_i) = f_j(u_i)/c_j. \tag{6}$$

In (6), c_j is the sum of $f_j(u_i).u_{yj}(u_i)$ is the normalized information distribution function of the sample y_i. The m sample points $y_i$are normalized on u_i, and then sum them up. Formally,

$$q(u_i) = \sum_{j=1}^{m} \mu_{yj}(u_i) , \tag{7}$$

At this time, the number of samples spread from m sample points $y_i$to u_i has $q(u_i)$, then sum up $q(u_i)$. Formally,

$$Q = \sum_{i=1}^{n} q(u_i) , \tag{8}$$

In (8), we get the total samples number of n control points u_i. Theoretically, $Q = m$, $P(u_i)$ is the probability density of m sample points y_i on u_i.

$$P(u_i) = q(u_i)/ Q \tag{9}$$

The cumulative probability is:

$$F(u_i) = \sum_{k=1}^{i} p(u_i), \tag{10}$$

Let,

$$P(u \geq u_i) = \sum_{k=i}^{n} p(u_i), \tag{11}$$

Then $P(u \geq u_i)$ is exceedance probability estimate. Let,

$$Z(u_i) = \frac{1}{P(u \geq u_i)}, \tag{12}$$

$Z(u_i)$ is the period in which the actual value exceeds u_i. The theory above seems to be a simple risk probability assessment model. In fact, it contains the logic of the development of major disaster management policies and also includes the technical path of resources and environmental disaster prevention and control [12].

2. Data collection and processing

All the data in this paper are from *China Forestry Statistical Yearbook (1990-2017)* [13; 14], *China Forestry and Grassland Statistical Yearbook (2018-2020)* [15]. To be specific, data for 2017 and before 2017 mainly came from the China Forestry Statistical Yearbook; the data after 2017 are mainly from the China Forestry and Grassland Statistical Yearbook. Due to the different statistical calibres and indicators, this paper mainly selects the number of forest fires and the damaged forests area in 1990-2020, and evaluates and analyzes the risk of forest fires nationwide.

Based on Article 40 of *State Council's Forest Fire Prevention Regulations* [16-17], according to the area of damaged forests and the number of casualties, forest fires can be divided into general forest fires, large forest fires, major forest fires and huge forest fires. The specific classification criteria are shown in Table 1.

Table 1

Specific classification criteria of forest fires

Forest fires type	Damaged area	Death toll	Serious injury
General forest fires	Less than 1 hectare or other woodland	1-3 people	1-10 people
Large forest fires	1-100 hectares	3-10 people	10-50 people
Major forest fires	100-1000 hectares	10-30 people	50-100 people
Huge forest fires	More than 1000 hectares	More than 30 people	More than 100 people

Source: General Office of the State Council, 2008.

In the study, in order to facilitate the analysis, general forest fires and large forest fires were counted as one category, and the other two categories were major forest fires and huge forest fires. The relevant data collected from different grades of forest fires in China from 1990 to 2020 are shown in Table 2. Between 1990 and 2020, there were 180,524 general and large forest fires in China, 544 major forest fires and 62 huge forest fires.

Table 2

Number of different types of forest fires in China from 1990 to 2020

Year	Total number of fires	General and large forest fires	Major forest fires	Huge forest fires
1990	4650	4645	5	0
1991	5019	4996	23	0
1992	7956	7922	34	0

Table 2 (continued)

Year	Total number of fires	General and large forest fires	Major forest fires	Huge forest fires
1993	4206	4199	6	1
1994	2973	2968	4	1
1995	4444	4365	73	6
1996	5055	4995	57	3
1997	2187	2175	10	2
1998	4455	4440	14	1
1999	6847	6820	27	0
2000	5934	5866	60	8
2001	4933	4913	17	3
2002	7527	7496	24	7
2003	10463	10442	14	7
2004	13466	13425	38	3
2005	11542	11523	16	3
2006	8170	8158	7	5
2007	9260	9256	4	0
2008	14144	14131	13	0
2009	8859	8823	35	1
2010	7723	7697	22	4
2011	5550	5541	9	0
2012	3966	3965	1	0
2013	3929	3929	0	0
2014	3703	3700	2	1
2015	2936	2930	6	0
2016	2034	2033	1	0
2017	3223	3216	4	3
2018	2478	2473	3	2
2019	2345	2336	8	1
2020	1153	1146	7	0
Total	181130	180524	544	62

Source: *China Forestry Statistical Yearbook (1990-2017)*, *China Forestry and Grassland Statistical Yearbook (2018-2020)*.

3. Index sequence selection and risk analysis

3.1. Index sequence selection

According to the data collected above, first of all, three observation index series were established based on the number of forest fires of different types from 1990 to 2020. Secondly, the step size is determined according to the maximum and minimum values of samples in each sequence and the research need. Finally, three discrete domains are constructed by referring to relevant research [17].

The three discrete domains are: $u_1 = \{2000,3000,\cdots 15000\}$, step size is 1000, control points are 14. $u_2 = \{0,5,\cdots 75\}$, step size is 5, control points are 16. $u_3 = \{0,1,\cdots 10\}$, step size is 1, control points are 9. Three diffusion coefficients h_1,h_2,h_3 are calculated according to the maximum, minimum and sample number of each observation index sequence.h_1,h_2,h_3 are 1249.397685, 7.538934615 and 0.826184615. Finally, the frequency, exceeding probability and occurrence period of three grades of forest fires are calculated respectively.

3.2. Risk analysis

Frequency of forest fires

According to the statistical data in Table 2, there were 180,524 general and large forest fires, 544 major fires and 62 huge fires in China during 1990-2020 (Figure 1). During this period, the number of general and large forest fires in China increased first, then gradually decreased, and fell to 1146 in 2020. In this process, 1992 and 2002-2010 were the years of frequent general and large forest fires. The number of major forest fires varies greatly in China. 1991-1992, 1995-1996, 1999-2000, 2002, 2004 and 2009-2010 were the years of frequent major forest fires. Because of the few occurrences of huge fires, even no huge fires in some years, huge fires' changes are relatively non-trend. Except for eight, seven, seven and six huge forest fires in 2000, 2002, 2003 and 1995, the number of huge forest fires in other years remained basically below five. In addition, no huge forest fires occurred in 1990-1992, 1999, 2007-2008, 2011-2012 and 2015-2020.

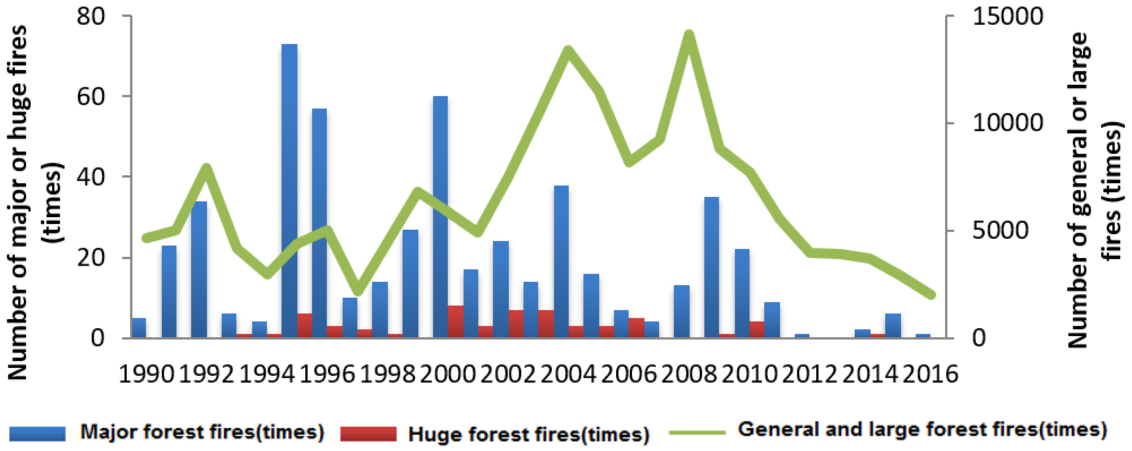

Fig. 1. **Number of different types of forest fires in China from 1990 to 2016**

Probability and period of forest fire

Firstly, using formulas (4) - (7) of risk evaluation models of the information diffusion theory to calculate the number of general, large, major and huge forest fires and obtain the distribution sequence of normalized information; secondly, using formulas (8) - (11) to calculate the probability of occurrence of general, large, major and huge forest fires under different fire levels, and using formula (12) to calculate the corresponding exceeding probability and occurrence period (year) of different fire levels. The final calculation results are shown in Table 3. Here we mainly calculate the exceeding probability and occurrence period of forest fires in China from 1990 to 2020. The exceeding probability is the probability that the required value exceeds the given value. In other words, during 1990-2020, the forest may encounter a probability greater than or equal to the standard value of the actual fire classification type or the value of the fire damage parameter. It is also the distribution probability of actual forest fires.

From Table 3, we can see that the exceeding probability of forest fires in China decreases with the increase of the risk level, that is, the number of forest fires, while the occurrence period increases with the increase of the risk level. Therefore, when the number of general and large forest fires is 8000, the corresponding exceeding probability is 32.45%, and the corresponding occurrence period is 3.08 years, which means, there is a general and large forest fires about every 3.08 years in China. At this time, the cumulative number of general and large forest fires is about 8000. Using the same method, the number of major forest fires occurring in China in 10.35 years is 55, and the exceeding probability is 9.66%. The number of huge forest fires occurring every 6.79 years is 6, the exceeding probability is 14.72%. Therefore, from the calculation results, it can be seen that with the increase of forest fire disaster severity, the number of fire occurrences tends to decrease, and the probability of fire occurrence also tends to decrease.

Furthermore, the probability maps of forest fires in China from 1990 to 2020 are drawn, and the probability and density of different types of forest fires are analyzed.

Table 3

Risk probability table

General and large forest fires		
Count	Exceedance probability, %	Occurrence period, year
2000	100.00	1.00
3000	92.44	1.08
4000	80.57	1.24
5000	65.92	1.52
6000	51.97	1.92
7000	41.19	2.43
8000	32.45	3.08
9000	24.46	4.09
10000	17.92	5.58
11000	13.30	7.52
12000	9.97	10.03
13000	7.19	13.90
14000	4.37	22.89
15000	1.69	59.20

Major forest fires		
Count	Exceedance probability, %	Occurrence period, year
0	100.00	1.00
5	87.20	1.15
10	71.31	1.40
15	56.02	1.79
20	43.48	2.30
25	33.82	2.96
30	26.40	3.79
35	20.62	4.85
40	16.18	6.18
45	13.15	7.61
50	11.25	8.89
55	9.66	10.35
60	7.71	12.97
65	5.49	18.22
70	3.37	29.70
75	1.49	67.02

Huge forest fires		
Count	Exceedance probability, %	Occurrence period, year
0	100.00	1.00
1	68.95	1.45
2	45.76	2.19
3	34.60	2.89
4	25.11	3.98
5	18.81	5.32
6	14.72	6.79
7	10.07	9.93
8	4.28	23.39

General and large forest fires

Maps of the probability and density of general and large forest fire risk probabilities are given as shown in Figure 2.

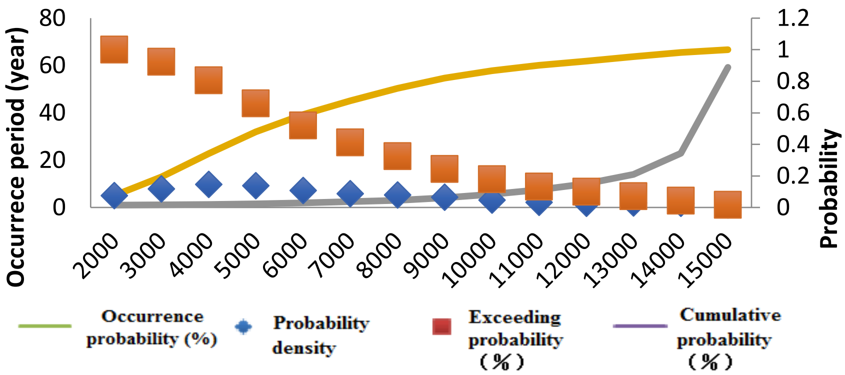

Fig. 2. **General and large forest fire risk probabilities**

From Figure 2, we can see that the probability of 4,000 times of general and large forest fires in China is the highest, and after the occurrence of more than 8,000 times, the curve tends to be smooth, the probability is small, and the slope of the exceeding probability curve of general and large forest fires is relatively gentle, which indicates that the risk of general and large forest fire occurrences in China is relatively dispersed. Within a certain number of times, the risk is higher. Specifically, when the number of general and large forest fires is less than or equal to 12000, the cumulative probability F(12000) is 0.92808, the corresponding occurrence period Z(12000) is 10.03089, and P(12000) is 0.09969, that is, the probability of 12,000 general and large forest fires occurring in a year is 0.09969. And only in about 10 years will be a case of 12,000 times of general or large forest fires.

Similarly, it can be seen that the probability of 10,000 times of general and large forest fires is 0.17924, and the cumulative probability of less than or equal to 10,000 times is 0.8670. In about five years will be a case of 10,000 times of general and larger forest fires.

Major forest fires

Similarly, maps of probability density, cumulative probability density and occurrence period of major forest fires are shown in Figure 3. From the probability density curve of Figure 3, it can be seen that the probability of major forest fires occurring 0-15 times a year in China is higher, after the occurrence of more than 15 times, the curve tends to be gentle and the probability of occurrence is smaller, which is basically consistent with the analysis conclusion of major forest fires by direct occurrence frequency method. Specifically, when the number of major forest fires is less than or equal to 50, the cumulative probability F(50) is 0.90341, the corresponding occurrence period Z(50) is 12.9693, and P(50) is 0.02221, that is, the probability of 50 major forest fires occurring in a year is 0.02221, and the corresponding occurrence period is about 13 years. It can also be concluded that the probability of 35 major forest fires occurring in a year is 0.04432, which will occur once in about five years.

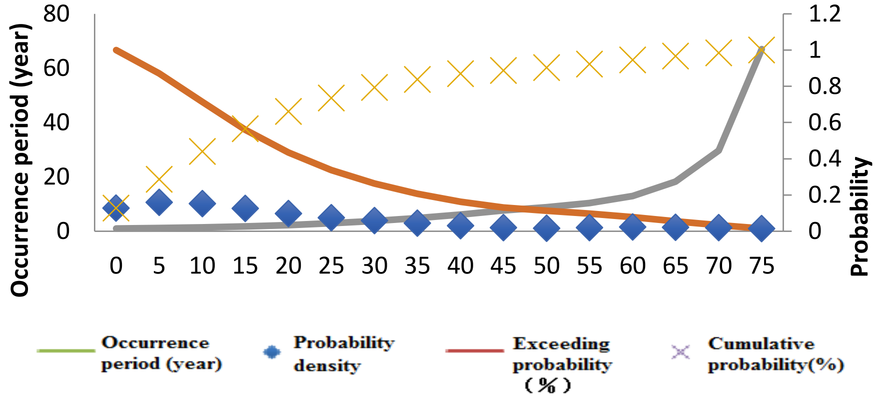

Fig. 3. **Major forest fire risk probability**

Huge forest fires

Furthermore, the probability density, cumulative probability density and occurrence period of huge forest fires are given as shown in Figure 4. As it can be seen from Figure 4, the probability of no huge forest fires in China is the largest, which is 0.32. This result is basically consistent with the actual statistics. During the 31 years from 1990 to 2020, there were 12 years in which there were no huge forest fires in China, and the possibility of occurrence of huge forest fires was relatively small. Specifically, when the number of huge forest fires is less than or equal to 7, the cumulative probability F(7) is 0.95723, the corresponding occurrence period Z(7) is 9.93, P(7) is 0.05791, that is, the probability of 7 huge forest fires occurring in a year is 0.05791, which will occur once in about 10 years.

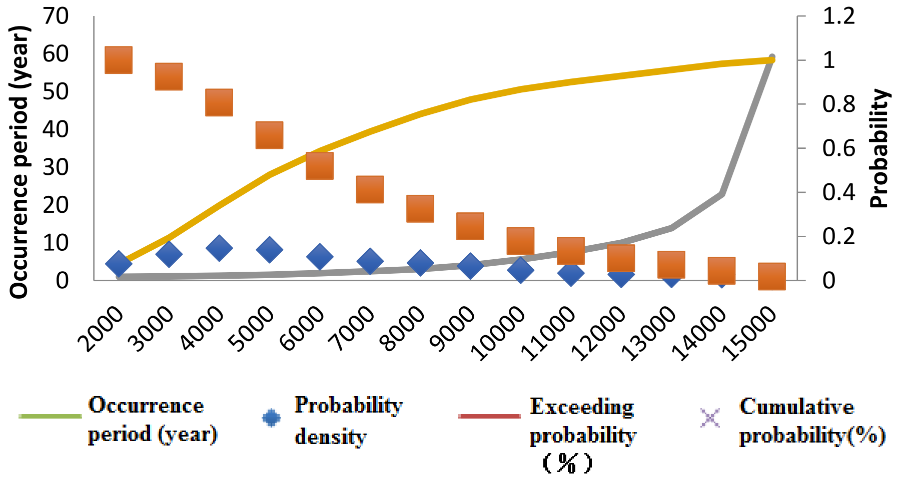

Fig. 4. **Huge forest fire risk probability**

Taking forest fires as an example, the period and probability of different types of forest fires in China from 1990 to 2020 were calculated respectively. The main purpose is to judge the period of different types of forest fires, grasp the regular pattern of disaster occurrence, allocate people and property for disaster prevention and control, formulate relevant policies, strengthen resource management, and promote the development of environmental protection [18].

4. Discussion on forest resources protection and related policies

China's forest resources are expanding, and the overall area affected by forest fires is declining. In the prevention and control of forest disasters, especially in the prevention and control of forest fires, it is worth discussing to strengthen investment every year, increase investment in human and financial resources, and formulate corresponding policies as a guarantee [19].

(1) The protection of forest resources is mainly to control major disasters. From the point of view of ecology and ecological management, forest disasters are also important ecological factors. In disaster prevention and control, we should focus on strengthening the prevention and control of major disasters, as well as forest fires. Therefore, we should strengthen the protection of forest resources. In the prevention and control of resource disasters, we should mainly strengthen the prevention and control of major and huge forest fires, especially in key regions, and avoid the equal use of prevention and control means and the low efficiency of prevention and control. This requires that certain policies, laws and regulations must be formulated as institutional safeguards. The prevention and control of forest disasters are closely related to the protection of resources and the construction of ecological civilization [19]. The government should take the lead and formulate corresponding policies, laws and regulations as a guarantee to benefit future generations.

(2) To protect resources and environment, we must first develop a relatively perfect monitoring system of resources and environment. The monitoring system of resources and environment includes disaster warning and forecasting system of resources and environment. It also includes the theoretical system of disaster warning and prediction. The information diffusion theory has its unique advantages in disaster risk assessment, disaster early warning and prediction [20]. It can be used as a theoretical component of China's resource and environmental monitoring system and be incorporated into the existing monitoring system of resources and environment. The analysis of forest fires in China shows that the analysis results of forest fires based on the information diffusion theory are in good agreement with the actual frequency of forest fires in China, and can be better applied to the disaster monitoring and protection of forest resources and promote the development of forest resources management.

(3) The protection of forest resources should also start with the technical and economic policies of disaster prevention and control. Technical and economic policies for disaster prevention and control include technical and economic policies for disaster prevention, monitoring and monitoring engineering design; technical and economic policies for disaster prevention, monitoring and monitoring equipment, personnel; technical and economic policies for disaster prevention, monitoring and monitoring engineering implementation, evaluation of technical and economic policies, and technical and economic policies for disaster prevention, monitoring and management etc. [21]. The connotation of information diffusion theory tells us that in resource and environmental protection, when assessing the risk of different disasters, we should have clear technical and economic policies for disaster prevention and control. In other words, we should start from the major and urgent disaster management, prevention and control. So that when facing disaster prevention and control, we can achieve twice the result with half the effort and avoid considering all disasters in the same emergency level. Therefore, in the protection of forest resources, there should also be a clear technical and economic policy for forest disaster management and control, and a clear path for the formulation of technical and economic policy for forest disaster prevention and control [12], so as to promote the development of environmental protection.

Conclusions

In conclusion, the management of resource risk is an important part of environmental protection, and it is also a hot issue in the research of resource and environmental disaster management and control. On the basis of relevant research, this paper collects the relevant data of forest fires in China from 1990 to 2020 and uses the method of information diffusion theory to analyze the risk of forest fires in China at the national level. The research shows the following.

1. During 1990-2020, the number of general and large forest fires in China increased first in a fluctuating manner, then gradually decreased, and in 2020 it dropped to 1146, and maintained this downward trend. Not only the number of forest fires decreased, but also the affected forest area showed a general downward trend. 1992, 2002-2010 are the frequent years of general and large forest fires. What are the causes of these frequent years? From the point of view of resource and environment management, further research is needed, and new theories, methods and means should be used. From the perspective of technical and economic policies, we should do a good job in the prevention and control of natural resources disasters, especially in strengthening the formulation of relevant policies for the prevention and control of forest resources disasters. We should start from the prevention and monitoring of disasters, and prevent disasters in the near future, strengthen the protection of forest resources, and provide favourable guarantees from the government’s policy and system level.
2. The probability of major forest fires occurring 0-15 times a year in China is higher, after the occurrence of more than 15 times, the curve tends to be gentle and the probability of occurrence is smaller, which is basically consistent with the analysis conclusion of major forest fires by the direct occurrence frequency method. The probability of 50 major forest fires occurring in a year is 0.02221, and the probability of 35 major forest fires occurring in a year is 0.04432. The occurrence periods of these two fires are 13 years and 5 years, respectively. According to these results, we can draw a conclusion that from the point of view of ecology and ecological management, different types of disasters should be treated differently in the disaster management and control of resources and environment, the allocation of human and financial resources for disaster prevention should be done well, and the maximum benefits of disaster management and control should be brought into play. This conclusion also emphasizes that the scientific prevention and control of forest fires should be enhanced. Only by giving full play to the important role of the government in the prevention and control of forest disasters, mastering the law of forest fires, focusing on the allocation of resources for disaster prevention and control, and strengthening the prevention, monitoring of different disasters by science and technology means, can the efficiency of disaster prevention and control be improved, and forest resources be well protected.
3. During the 31 years from 1990 to 2020, there were 12 years in which there were no huge forest fires in China, and the possibility of occurrence of huge forest fires was relatively small. The probability of huge forest fire occurrence is 0.05791, and the occurrence period is about 10 years. This conclusion is also consistent with that obtained by the frequency method. The conclusion also shows that the number and area of forest fires in China are decreasing. In the management of forest resources protection, the prevention and control of major and huge forest fires should be strengthened, which is of great significance to the management of forest resources, the management and control of forest fires and the protection of forest resources. From the policy level, the prevention and control of forest disasters is the issue of whether the government functions can be normally played, which is related to environmental protection, environmental equity, ecological environmental responsibility and the construction of ecological civilization.

Forest resources are affected by forest fires. The main body of resources is the state and the broad masses of the people. Only by strengthening the prevention and control of resource disasters, we can protect resources, give full play to the role of resources in environmental protection, solve the problems of environmental fairness and responsibility of ecological environment, and then do a good job in the construction of ecological civilization, and truly implement the development of “Lucid waters and lush mountains are invaluable assets”, as well as to prevent climate change.

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