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MDPI

Perspective

Weighing Policy Effectiveness Through Recent Forest Fire Status

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Abstract: Forest fires pose a great threat to the global ecological environment as well as human life and the safety of property. Formulating effective policies for preventing forest fires is not only a scientific concern but also an urgent need for government management. Canada and China both have extensive forest areas but have different fire management strategies. Canada primarily focuses on fire suppression while China pays more attention on fire prevention. This difference led to significant discrepancies in the forest fire regimes between the two countries, providing an opportunity to explore the impact of fire management policies on forest fire. By analyzing the fire occurrences in Canada and China since 1990, combining the fire prevention funds and fire management strategies, this paper discussed the influence of different policies on fire occurrence. Previously, Canada's forest suppression strategy has been widely recognized internationally, but recent widespread fires indicate that its fire management policy may still require further improvement to cope with future global warming. Although China's fire prevention strategy can effectively control current forest fires, the lack of fundamental theories on forest fires and the backwardness of fire prevention technology and equipment may increase the likelihood of major forest fires in the future. As global warming continues to intensify in the future, the length of the forest fire season and the intensity of fires will increase, making it urgent to develop more effective forest fire prevention and suppression policies to achieve sustainable development.

Keywords: forest fire; management policy; Canada; China

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1. Introduction

In 2023, Canada witnessed the most destructive forest fire in terms of burned area and broke the burned area record set in 1989 [1]. The 2023 Canadian wildfire was remarkable due to its wide scale and high intensity, lasting from mid-April to late October, and it affected much of the forested regions from western to eastern Canada [2], resulting in a record-breaking burned area of approximately 17 million hectares (CIFFC, Canada Report 2023, https://www.ciffc.ca/ (accessed on 21 November 2024)) and carbon emissions of 647 TgC [3]. Besides the catastrophic damage to the ecosystem, the 2023 Canadian wildfire also had profound socio-economic impacts through the loss of livelihood, property and infrastructure [1]. The substantial air pollutants released from wildfires traveled far away, impacting the United States and Europe and sparking significant international concern [4]. Previously, Canada was renowned for its advanced fire warning and monitoring systems and was equipped with many efficient and modern firefighting tools like huge aircraft. However, when faced with the massive fire in 2023, Canada's ability in fire control seemed inefficient. Therefore, this raises the question: Despite Canada's advanced theories and technologies in fire prevention and suppression, why were these fires still unable to be effectively controlled?

Currently, many studies attributed the serious forest fires in Canada during 2023 to the impact of extreme weather [5,6], with the average temperature having increased by approximately 2.2 °C from May to October compared to the average of the past decade [2]. Generally, extreme heat and drought make forest fires more likely to occur, especially under the frequent influence of lightning weather during the summer season in Canada. How to mobilize firefighting forces and then quickly extinguish or control the forest fire to minimize its impact on ecology and residents is closely related to the local fire prevention policies.

There exists a specific convergence in spatial distribution over latitudes from 40° N to 55° N between Canada and Northeast China, where the vegetation types predominantly feature deciduous broadleaf and coniferous forests. Additionally, both Canada and China boast vast forest resources, with forest areas of 346.93 and 219.89 million hectares, respectively, ranking third and fifth globally [7]. However, despite widespread global warming, the numbers of forest fires and the burned area in China have not demonstrated a significant upward trend, unlike the recent situation in Canada. It is well known that Canada and China adopt different approaches to forest fire prevention and suppression, with Canada emphasizing fire suppression and China prioritizing fire prevention. Therefore, this study intends to compare and analyze these different policies and delve into their implications on current and future forest fire regimes. We hope this study can serve as a valuable reference in formulating forest fire prevention and control policies to cope with the challenges of potential forest fires brought by global warming in the future.

2. Status of Forest Fires in Canada and China

Figure 1a shows the Moderate Resolution Imaging Spectroradiometer (MODIS) identified hotspots over Canada and China in 2023, which gives an obvious comparison of the forest fire status between the two nations. Furthermore, from Figure 1b, it can be observed that the annual variation trend of forest fire occurrence in Canada is consistent with that of China. Specifically, from 1990 to 2006, forest fires in both countries showed an increasing trend and peaked around 2006 to 2008 and then decreased. This finding also aligns with the global forest fire variations trend from 1998 to 2015 [8]. However, forest fire characteristics also vary significantly between Canada and China. First, the number of forest fires in China decreased more rapidly since 2008 due to the stricter requirements for forest fire prevention and suppression. The Office of National Forest Fire Prevention Headquarters was also established around 2008, which is responsible for organizing, guiding and coordinating the firefighting of major forest fires across China. Second, forest fires occur more frequently in Canada. Over the past decade (2014–2023), Canada experienced an average of about 5512 forest fires per year, compared to only 1952 in China. Third, forest fires in Canada usually result in a larger burned forest area and more severe damage to forest. The annual average burned forest area in Canada was about 4.2 million hectares over the past decade, approximately 367 times larger than that of China. Finally, despite the decrease in forest fire occurrences, the total burned area in Canada has gradually increased in recent years. Especially in 2023, the burned area in Canada reached 17 million hectares, more than four times the annual average over the past decade. In contrast, the burned forest area in China remained at a relatively low level, below 0.01 million hectares.

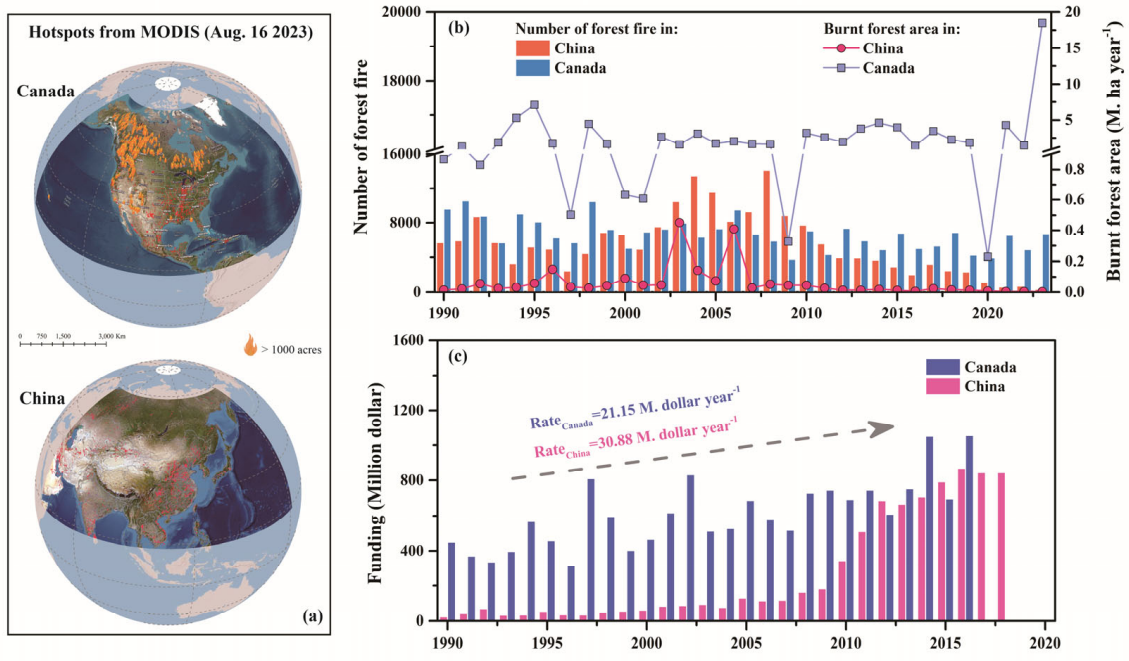

Figure 1. (**a**) Hotspots at Canada and China observed by MODIS (16 August 2023). The image was downloaded from Fire Information for Resource Management System. (**b**) The annual number of forest fire and burned area in Canada and China over the year of 1990~2023. (**c**) Variation trend of total funding for forest fire prevention and suppression in Canada and China over the period from 1990 to 2018.

3. Fire Management Policy in Canada and China

More than 70% of the forests are flammable coniferous forests in Canada, making Canada susceptible to forest fires. As a result, the Canadian government has placed significant emphasis on forest fire management since the 1920s [9]. Now, Canada has one of the world's leading systems for predicting, detecting and controlling forest fires. The Canadian Forest Fire Danger Rating System (CFFDRS, https://natural-resources.canada.ca/home (accessed on 21 November 2024)) provides qualitative and numerical information of fire potential based on various elements analysis (e.g., weather conditions, fuel types) [9]. Two subsystems of CFFDRS are the Canadian Forest Fire Weather Index (FWI) System and the Canadian Forest Fire Behavior Prediction System (FBP, https://cwfis.cfs.nrcan.gc.ca/maps/fb (accessed on 21 November 2024)), which have been widely adopted by numerous countries to assist in wildfire management (e.g., New Zealand, Indonesia and the United States) [10]. The FWI system provides a fire danger degree based on an analysis of fuel moisture and weather conditions. The FBP system gives a quantitative prediction of fire behavior among fuel types, such as the rate of spread, fuel consumption and frontal fire intensity [9]. The adoption of the CFFDRS by other countries could help them enhance their early warning system and efficiently allocates firefighting resources, and it promotes more sustainable forest management. Furthermore, the Canadian government recognizes the importance of sharing secure information and has developed a National Information Exchange Model that facilitates information transfer and enables effective collaboration among various departments.

As seen in Figure 1c, Canada has annually invested over one billion dollars in fire management since 2015, with most of funds allocated to fire suppression. This includes the cost of advanced equipment and the increased costs associated with protecting the expanding Wildland–Urban Interface areas. However, this does not mean that Canada adopts a suppression strategy for all forest fires; instead, it employs a risk-based appropriate response strategy. The Canadian government recognizes that forest fires are part of the natural ecosystem process and only takes rapid and aggressive initial action against fires that

threaten valuable or sensitive targets, such as human lives, property and communities. For other forest fires, modified or monitored responses are adopted to observe and assess their potential impacts on protected targets and contain them within specific ranges [11,12]. This approach reflects a balanced consideration between suppressing fires that pose immediate threats and allowing fires to play their natural role in forest ecosystems.

From the perspective of forest fire suppression organization, Canada consists of a federal government, ten provinces and three territories. The provinces and territories are responsible for the management of about 90% of forest lands, while the federal government is only responsible for about 4%, mainly consisting of national parks, Indigenous reserves and the Department of National Defense lands [12]. When faced with extreme forest fires that local governments are unable to effectively handle, the federal government will provide necessary assistance upon request from local governments.

The Chinese government adheres to the principle of "prevention first, active suppression". Over the past decades, the funding for forest fire management has been steadily increasing in China. The average annual growth rate reached USD 30.88 million from 1990 to 2017. Particularly after 2009, the growth rate of investment accelerated to USD 61.74 million per year, and the total investment exceeded USD 800 million in 2017. Most of these funds were used for purchasing firefighting equipment, building fire-resistant roads and fire barriers, implementing video surveillance systems and so on. According to the National Forest Fire Prevention Plan, China aims to establish a total of 310,000 kilometers of forest fire barriers and construct or upgrade 327,000 kilometers of fire emergency roads from 2016 to 2025. By the end of the plan, the density of forest fire barriers in key forest areas will reach 4.7 m per hectare, and the road network in state-owned forest areas will reach 3.1 m per hectare.

Apart from financial investments, China also emphasizes the improvement in institutional, legal and ideological constructions. As early as 1984, the "Forest Law of the People's Republic of China" stipulated the legal responsibilities of local governments for controlling forest fires. After the catastrophic forest fire in the Daxing'an Mountains on 6 May 1987, China established the National Forest Fire Prevention and Suppression Command Organization and promulgated the first specific regulation guiding forest fire administrative enforcement, namely, the "Forest Fire Prevention Regulation". Subsequently, local governments also compiled their corresponding forest fire prevention regulations, marking the beginning of the formalization and institutionalization of forest fire management in China. Forest fire prevention also requires relevant education to raise public awareness. Various approaches such as broadcasting, text messages and billboards are used in China, in an effort to deeply implant the concepts of forest fire prevention and suppression into the public mind. Facing the new challenges brought by global warming, China issued a new guidance document for forest and grassland fire management in October 2022, namely, the Opinions on Comprehensively Strengthening Forest and Grassland Fire Prevention and Suppression in the New Situation. This document further clarified a series of important deployments such as strengthening fire source control, promoting community prevention and control and scientifically planning infrastructure construction, pointing out a direction for the sustainable development of forest fire management in China.

China emphasizes the joint efforts of the entire society in forest fire management. The executive heads of Chinese administrative agencies are fully responsible for the forest fire prevention and suppression in their management regions. A responsibility tracing system has also been established, where forest fires may even affect the appointment and dismissal of local government leaders. In terms of firefighting forces, professional forest firefighting teams have been established at the national and provincial, municipal and county levels. According to the statistics from the Ministry of Emergency Management in 2023, the personnel number in the Chinese national comprehensive firefighting and rescue team has reached 0.22 million. Besides the professional teams, Chinese forest fire suppression forces also include semi-professional firefighting teams and local forest rangers, which play an important role in the early detection and handling of forest fires.

4. Impact of Management Policy on Fire Regime

The occurrence patterns of forest fires are intricately linked with natural environmental factors such as vegetation, climate and terrain, as well as human factors like population distribution and cultural differences. Hence, evaluating the effectiveness of forest fire management across different countries remains a challenge. From the perspective of forest fire prevention, accurate and reliable warning systems play a pivotal role in early response. The Canadian government, for instance, has invested abundantly in developing and enhancing forest fire monitoring and early warning systems. These include forest fire danger rating systems such as the Forest Fire Weather Index System, the Forest Fire Behavior Prediction System and the Fire Effect Models. Additionally, the Canadian government collaborates closely with scientific researchers to jointly develop advanced fire prediction models through information sharing. These forest fire warning and monitoring systems in Canada have been well developed and widely employed in fire prediction and early response.

Compared to Canada, forest fire management in China relatively lags behind in terms of informatization and intelligence. Therefore, the forest fire suppression strategy often relies heavily on the personal experience and judgment of frontline firefighters. However, due to the limitations of individual cognition and analysis abilities, strategies based solely on subjective judgments may have flaws and could even lead to serious casualties. Strengthening the intelligence of forest fire monitoring and early warning systems and integrating them into decision-making processes is crucial for reducing firefighting casualties. Nevertheless, the establishment and improvement of such systems require the accumulation of long-term observational data, significant efforts from scientific researchers and government funding. There is still a long way to go for the development of informatized and intelligent forest fire prevention and suppression in China.

It is worth noting that forest fire prevention requires diverse approaches. Enhancing public awareness and education on fire prevention is a crucial approach, as human factors account for a large proportion of forest fires. In Canada, approximately 49% of forest fires are attributed to human factors [11], while in China, this proportion ranges from 50% to 95% [13]. China has implemented strict control of wildfire sources and educational campaigns, spanning from national to local levels. Each village or forest farm with fire prevention responsibilities has a certain number of forest rangers dedicated to patrolling and monitoring wildfire within their designated areas. They will take immediate actions to extinguish the wildfire once identified. Such strict control of wildfire sources has been proven to be an effective strategy in reducing the occurrence of forest fires in China over the past decades. Before 1987, China did not attach sufficient importance to forest fire management, resulting in inadequate organizational structures and firefighting forces. Consequently, the annual forest fire occurrences nationwide exceeded 10,000. After the serious forest fire in the Daxing'an Mountains in 1987, China placed greater emphasis on forest fire management by gradually improving relevant institutions and laws. Over the period from 1990 to 1999, the annual forest fires decreased by approximately two-thirds and the burned area was reduced by nearly four-fifths.

In forest fire suppression, firefighting resources are mainly divided into firefighters, firefighting equipment and firefighting technology. Among them, firefighters are the key forces determining the effective utilization of firefighting equipment and technology. The forest fire management in China tends to widely mobilize professional firefighters, semi-professional firefighters, forest rangers and volunteer citizens. Different personnel have different responsibilities in forest fire prevention and suppression based on their respective abilities. Professional firefighters are the main forces in fire suppression, while semi-professional firefighters are effective supplements and play a crucial role in clearing burned areas to extinguish the residual fire. Forest rangers and volunteer citizens are mainly responsible for routine patrol and play a vital role in the initial stages of fire identification and suppression. Through the combination of different types of firefighters, the strategy of "fighting fires early, fighting fires small and suppressing fires thoroughly"

can be implemented by fully using their respective advantages. Simultaneously, we must acknowledge that the human ability to face natural disasters such as forest fires is limited. Therefore, it is also necessary to employ modern technological equipment to compensate for the disadvantages of humans. Owning to technological advancements, Canada places emphasis on the application of high-tech equipment in forest fire prevention and suppression, such as firefighting aircraft. The commonly used CL-415 firefighting aircraft has a maximum flying speed of 376 km per hour and a maximum water-carrying capacity of 6 tons per sortie, which is unmatched by human capabilities in terms of both speed and carrying capacity. Moreover, by adopting a large number of modern firefighting equipment, the direct engagement of frontline firefighters with forest fires can be minimized, which can reduce the potential harm from forest fires. Therefore, through the combination of modern firefighting equipment with firefighters, coupled with advanced technologies such as remote sensing and video surveillance, the ability to prevent and control major forest fires will be significantly improved.

5. Perspective

The total forest area of Canada and China is approximately 560 million hectares, accounting for about 13.9% of the global forest area, according to the statistical analysis by the Food and Agriculture Organization of the United Nations in 2020. Their forest protections are crucial for the ecosystem balance of the Earth. A comparative analysis of the current situation of forest fires and management policies in Canada and China can reveal the advantages and disadvantages between different kinds of fire management. Based on the above discussion, Canada's forest fire management focuses on suppression, adopting multiple-level responses based on risk to protect important targets such as residents, communities and buildings. Despite Canada's establishment of advanced fire warning and monitoring systems, along with the deployment of high-tech firefighting equipment, the number and burned area of forest fires in 2023 have still surpassed previous records. This indicates that Canada's forest fire management strategy still needs further optimization to adapt to the current climate change. In fact, according to recent reviews, climate change impacts and increasing interface values-at-risk, as well as limited government program budgets, have driven Canada's wildfire management agencies to a tipping point. Stronger horizontal collaboration, enhanced resource sharing and more smart decision support tools are needed in the future [11,12].

Compared to Canada, China's fire management focuses on strict fire source control. Once a forest fire is detected, a suppression action will be taken until the fire is completely contained. Due to the strict source control, forest fires have been effectively controlled. However, this also raises a concern that a large accumulation of combustibles increases the risk of major forest fires in the future [14]. Meanwhile, China lacks high-tech firefighting equipment, and its model prediction and fire-monitoring capabilities are relatively weak. Given the ongoing and intensifying global warming trend [15], China requires long-term and sustained personnel and material resources to maintain its current fire control efforts. Therefore, although China's current forest fire management strategy seems efficient, it may not be suitable for widespread global promotion, especially for application in economically underdeveloped countries.

The National Centers for Environmental Information [16] reported that the Earth's average surface temperature in 2023 was about 1.18 degrees Celsius higher than in the 20th century, a record unprecedented since 1850. With the background of global warming, the frequency and burned area of forest fires, especially major and catastrophic fires, have been on the rise, with the fire season extending [17–19]. Currently, the annual burned area of forest fires has increased by 3 million hectares of tree cover each year compared to that in 2001, an area approximately equal to the size of Belgium [19]. It is urgently needed to develop effective forest fire management strategies to address the potential threats from forest fires in the future. Based on the above discussion, we think that the following factors should be given priority when formulating future forest fire management strategies:

1. It should be noted that wildfires are a natural process on Earth and cannot be totally avoided. The best way is to live in harmony with forest fires. For this purpose, it is essential to educate the public about the formation mechanisms of forest fires and to share with them how to escape when caught in forest fires. Improving the public's awareness of forest fire prevention through education can reduce the occurrence of man-made fires and even stimulate the public to actively participate in forest fire prevention and rescue efforts.
2. For forest fire prevention and control, the development and application of monitoring and early warning technology is essential. Risk assessment models should also be developed to determine the threat of forest fires to residents and critical protection facilities. For forest fires with a high threat degree, it is necessary to mobilize the surrounding forest rescue forces to extinguish or control them in time. While for the low-threat fires, close monitoring may be enough unless they are getting worse.
3. The process of forest firefighting is complicated and challenging, and the fire could be reignited at some time, which requires comprehensive forces to completely control forest fires. Not only do we need efficient firefighting equipment like large helicopters, but we also need to strengthen the ground firefighting personnel in order to achieve the effective cooperation and supplementation of different firefighting strategies.
4. From the perspective of inflammable material management, it is necessary to formulate prescribed burning plans and take active actions to reduce the accumulation of understorey fuel, especially in the densely populated Wildland–Urban Interface regions, so as to reduce the risk of major forest fires in advance.

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