

Review

A Focused Review on Wildfire Evacuation and Infrastructure Resilience in Canada: Trends and Insights (2013–2023)

Nima Karimi 

Department of Renewable Resources, University of Alberta, 751 General Service Building, Edmonton, AB T5G 2H1, Canada; nkarimi1@ualberta.ca; Tel.: +1-(306)-450-9299

Abstract: This review paper investigates the landscape of wildfire-related studies with a focus on infrastructure and evacuations across Canadian provinces, revealing a predominant focus on Alberta, particularly after the 2016 Fort McMurray wildfire. The aftermath of this event has heightened attention to the unique challenges faced during evacuations, emphasizing the urgent need for heightened awareness and preparedness, especially in the vulnerable northern communities of Alberta. Studies beyond Alberta contribute to understanding Canadian wildfire dynamics. However, a noticeable research gap in British Columbia raises concerns about research prioritization and resource allocation despite heightened wildfire activity. The fact that some provinces are contributing less than 4.2%, such as Quebec, Saskatchewan, Ontario, Northwest Territories, Yukon, and the Prairies, might be attributed to regional variations influenced by historical wildfire frequency and population density. Thematic analysis categorizing studies into “community support/resilience”, “evacuation efficiency”, and “infrastructure protection/raising awareness” provides nuanced insights. The dominance of the “community support/resilience” category, comprising over 40% of studies, signifies a societal shift towards proactive community engagement. Balanced representation in the “evacuation efficiency” and “infrastructure protection/raising awareness” categories, each contributing over 29%, reflects a collective effort to glean lessons from past evacuations and enhance community preparedness. Temporal trends and thematic analyses spotlight a commitment to continuous improvement, adaptability to emerging challenges, and a growing recognition of the multifaceted aspects of wildfire management. The evolving emphasis on community involvement, responsiveness to changing evacuation dynamics, and heightened awareness of infrastructure protection underscores the proactive stance of the research community, providing insights for shaping future research priorities, policy frameworks, and community resilience strategies in the face of evolving wildfire threats in Canada.

Keywords: wildfire management; wildland–urban interface (WUI); evacuation strategies; community resilience; emergency planning; infrastructure protection; wildfire risk assessment



Citation: Karimi, N. A Focused Review on Wildfire Evacuation and Infrastructure Resilience in Canada: Trends and Insights (2013–2023). *Fire* **2024**, *7*, 161. <https://doi.org/10.3390/fire7050161>

Academic Editor: Natasha Ribeiro

Received: 16 March 2024

Revised: 1 May 2024

Accepted: 3 May 2024

Published: 6 May 2024



Copyright: © 2024 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Increased wildfire frequencies rooted in global climate changes coupled with developed anthropogenic activities and exposure introduced new challenges in wildfire management globally [1,2]. Across the globe, there has been a worrisome surge in unprecedented fire seasons, resulting in significant repercussions for both individuals and their properties [3,4]. Despite substantial investments aimed at strengthening the ability of communities and ecosystems to withstand wildfires, the scale of these large fires remains exceptionally high [5–7]. As a result, there is a growing consensus that current strategies for managing land and combating fires are inadequate in effectively tackling the escalating difficulties brought about by shifting climate patterns and urban development. These challenges further contribute to the increased risks and dangers faced by human populations.

It is believed that adopting a comprehensive approach that encompasses a range of resilience dimensions might be a potential factor in fostering social–ecological resilience

in landscapes that are vulnerable to wildfires. Adverse consequences of wildfire are more dominant in areas where communities are located and might not be fully measured [8–10]. For example, a scoping review about the medium-to-long-term health effects of wildfire reported increased mortality, developed respiratory deficiencies (including lung cancer), and reduced mental health [11]. In addition, wildfire researchers soon realized that the consequences of wildfire cannot be either explained or measured only by visible destructions for ecosystems or infrastructure [12,13].

While wildfires are a global issue, their impact in Canada, particularly in provinces such as Alberta and British Columbia, warrants specific attention. These regions are seeing an increased frequency and severity of wildfire events, influenced by climate change and human encroachment into forested areas. Considering the practical significance of the topic, numerous published articles have delved into various facets of wildfires, particularly focusing on the wildland–urban interface where human and natural landscapes intersect. This intersection poses unique challenges, as demonstrated by Beverly et al. [14], who evaluated the directional vulnerability of 986 communities in Alberta (AB), Canada. Their study highlighted how the presence of combustible materials like coniferous trees can exacerbate the wildfire threat to these communities. Other research has explored community responses to evacuation orders, revealing a complex decision-making process influenced by a range of socio-economic factors. For example, a study in the Mt. Lorne community in Yukon, Canada, showed that despite evacuation orders, many residents chose to stay to protect their properties, livestock, and other valuable resources [15]. This decision often stems from past experiences and the availability of resources, underscoring the need for tailored evacuation strategies that consider local contexts. Further emphasizing the need for effective evacuation planning, McGee’s study of the 2016 Fort McMurray wildfire evaluates the logistical challenges encountered during large-scale evacuations. Traffic congestion, and shortages of essential supplies like fuel, food, and water, were prevalent, causing the stress on evacuees. Additionally, the study highlighted systemic issues such as financial constraints, inadequate accommodation, lack of insurance, and insufficient evacuation information, which collectively hinder effective emergency responses [16].

These studies illustrate the critical need for integrated fire management and evacuation plans that address both the physical and human elements at risk, ensuring that communities are better prepared and more resilient to wildfire threats. This review paper aims to explore the most current research directions and identify areas where knowledge is lacking in the field of wildfire research in relation to the presence of communities from 2013 to 2023 in Canada. In this review, the focus is on infrastructure and evacuation in the Canadian context. This is driven by the recognition that these aspects are critical in understanding and managing wildfire risks in the wildland–urban interface (WUI). Infrastructure and evacuation are integral components of community resilience and emergency response, directly affecting the safety and well-being of residents during wildfire events. The decision to narrow the scope to these topics was based on the premise that a targeted review could provide more in-depth insights into the specific challenges and solutions related to infrastructure and evacuation strategies in Canada. This approach allowed for a concentrated examination of the most relevant and recent studies, ensuring that the review remains focused and coherent, while still contributing valuable knowledge to the broader field of wildfire research.

2. Materials and Methods

2.1. Collected Studies

In this study, a total of 64 peer-reviewed journal articles were collected from the Web of Science database, excluding conference papers. Studies published between January 2013 and December 2023 are included in this review. This eleven-year period was specifically chosen to capture the most recent and relevant developments in wildfire research, particularly in the context of WUI areas. To ensure a comprehensive range of studies on Canadian wildfires, a Boolean string approach was employed. This approach used “Canad*

wildfire*" AND "infrastructure OR evacuation" as additional keywords in the search topic, allowing for the inclusion of studies that may not have directly aligned with the study objectives. Subsequently, a screening process with criteria including relevance, country of interest, and the English language, was used to refine the article selection. Figure 1 illustrates the schematic workflow of this review study, with 47 out of 64 studies (73.4%) successfully screened. Detailed discussions of the screened studies are provided separately in Section 2.2. Including definitions for key terms, as below, ensures that these terms are clearly understood from the start, enhancing the clarity of our selection criteria and analytical framework.

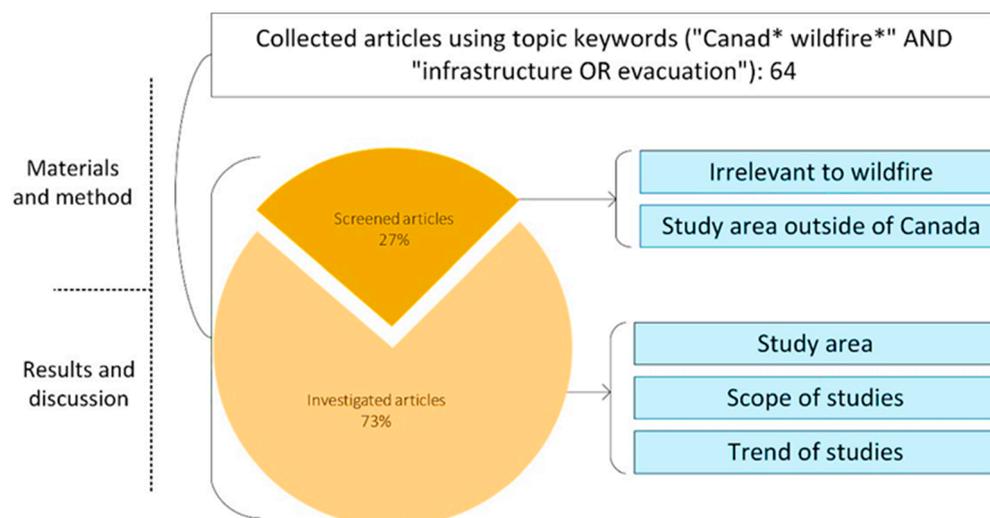


Figure 1. Workflow of the current review study.

- * Community Resilience: refers to the capacity of communities, systems, and natural environments to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a wildfire in a timely and efficient manner. This includes preserving and restoring essential basic structures and functions and the ability to withstand and bounce back from disruptive events [17].
- * Evacuation Efficiency: relates to the effectiveness and speed with which a community can relocate individuals to safer areas in response to a wildfire threat. It encompasses the planning, communication, and execution aspects of evacuation processes, ensuring that they are carried out in a way that minimizes risk and maximizes safety for all individuals involved [18].
- * Infrastructure Protection: involves the strategies and measures implemented to safeguard physical and organizational structures critical for a community's functioning and recovery. This includes enhancing the fire resistance of buildings, maintaining essential services such as water and electricity, and protecting transportation routes crucial for evacuation and access by emergency services [19].

2.2. Screened Articles

Among all the collected articles, 26.6% were excluded from further investigation because they were either irrelevant to wildfires or focused on areas outside of Canada. For instance, Asif et al. [20] discussed the susceptibility of various North American regions, including the Canadian prairies, to severe events like droughts, destructive floods, anomalous precipitation patterns, and wildfires, with far-reaching consequences on water resources. Another study examined the effects of recurrent spring flooding on the Kashechewan First Nation in Canada, highlighting the increased vulnerability of communities, infrastructure damage, disruption of traditional activities, and resident stress [21]. These events were not solely attributed to wildfires. Likewise, a study examined the Northeastern and Great Lakes of North America, with Canada not within its study area. It analyzed the influence

of climate change on wildfires using regional climate models and the Canadian Forest Fire Weather Index System, showing a moderate increase in fire weather indices during the summer season [22]. Among the collected materials, one study, not within Canada, examined the link between road networks and wildfires in a Siberian boreal forest. It found that roads serve as vital barriers and access points for firefighting, aiding wildfire suppression [23].

2.3. Investigated Articles

The selected studies, 73%, specifically focused on wildfires and their impacts within the Canadian context. The research findings and gaps in knowledge are discussed separately based on the study region and the scope of the studies, and include “community support/resilience”, “evacuation efficiency”, and “infrastructure protection/raising awareness”. Additionally, the trends in these categories are analyzed, examining the changes in the total number of studies conducted between 2013 and 2023. This classification approach helps identify potential limitations in previous studies and provides valuable insights to guide future research in the field.

NVivo package, version 14, was adopted for qualitative data analysis, node formation, study categorization, and query analysis in the current review. NVivo aims to support various qualitative techniques, regardless of the research methodology employed. It is noteworthy to mention that while NVivo can assist in managing, exploring, and identifying patterns in data, it cannot substitute for analytical expertise and data-driven implications [24].

3. Results

3.1. Wildfire Studies on Provincial and National Scales (Distribution of Studies over Canada)

It is noteworthy to mention that the communities involved in our study are notably diverse, spanning from densely populated urban fringes to remote and rural areas across Canada. These communities vary in demographics, geographic characteristics, and levels of wildfire awareness. Therefore, some communities have integrated their cultural knowledge of fire management into contemporary firefighting techniques and can provide a unique approach to their resilience and response strategies to wildfires. Figure 2a illustrates the distribution of wildfire-related studies across different regions. Out of the 47 selected studies, 24 (51.0%) were conducted in AB, while Canada and British Columbia (BC), ranked second and third, accounted for 10 studies (21.2%) and 4 studies (8.5%), respectively. The significant focus on AB can be attributed to its recent history of substantial wildfire events near developed areas, such as WUI. For instance, the 2016 Fort McMurray wildfire in northern AB, which consumed over 589,000 hectares, destroyed approximately 2400 homes and led to the evacuation of over 90,000 individuals, and is considered one of the costliest natural disasters in Canadian history [25]. Another study conducted a survey with 447 individuals who were evacuated during the 2016 Fort McMurray Horse River Wildfire; it revealed that many evacuees were unprepared for the wildfire risk and received limited advance notice, and it highlighted some challenges like traffic congestion causing supply shortages [16]. Despite support from various sources, increased awareness and preparedness are vital for addressing future evacuation challenges. Similarly, Woo et al. [26] analyzed the evacuation pattern for the Fort McMurray wildfire and underscored the effectiveness of evacuating residents to temporary shelters and the potential for enhancing traffic management strategies. They emphasized the unpredictable nature of wildfires compared to hurricanes and stressed the critical role of air transportation, particularly for remote communities.

In addition to the predominant emphasis on Fort McMurray in Alberta, the second-largest portion of studies in AB, 17% as illustrated in Figure 2b, concentrated on Albertan remote northern communities. One notable study explored the impact of the 2011 Slave Lake wildfire on 19 families, revealing significant changes in life goals, priorities, routines, attitudes, and interactions [27]. This research clearly demonstrated the vital role of parents in supporting their family’s recovery process. The inclination to study northern AB may

stem from the region’s higher frequency of wildfires and the evident impact of these fires in comparison to the southern regions of the province [28].

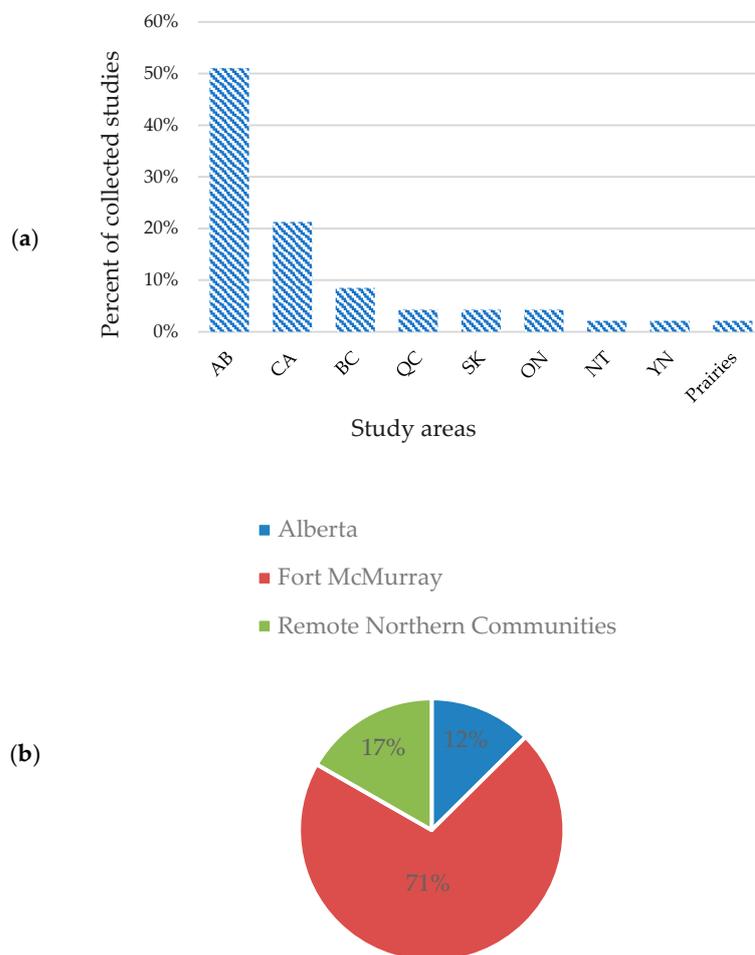


Figure 2. (a) Percent of collected studies in each Canadian region; (b) percent of collected studies in AB.

Not all studies in AB exclusively focused on northern regions or specific wildfires. For instance, Ohi and Kim [29] introduced a novel approach that identifies critical network locations for community evacuation, with a focus on communities across central and northern AB, including Jasper, Edson, Whitecourt, Grande Prairie, Slave Lake, Lac La Biche, Peace River, Fort McMurray, and High Level. Their method is designed to help the government prioritize communities for evacuation studies and address transportation deficiencies through infrastructure investments. Similarly, Beverly and Forbes [14] developed a method called directional vulnerability to assess the extent of wildfire impact on 913 communities in AB based on their surrounding land cover within a 15 km radius. This method has various potential applications, such as planning fuel reduction and treatment for communities, evaluating transportation network vulnerabilities during evacuations, and identifying operational sites during wildfires.

In Canadian studies, no specific province or community is addressed, including 21.2% of all collected papers, as is depicted in Figure 2a. Studies which targeted a specific group of people or a threatened type of area are among this group. For example, McGee [30] highlighted the concerns of Canadian First Nations during the wildfire. Findings revealed that First Nation communities lacked up-to-date emergency plans for evacuations, experienced distress due to family separation and property loss, suffered from wildfire smoke, and expressed financial challenges stemming from evacuation. Johnston and Flannigan [31] mapped Canadian WUI areas with regard to residential, industrial, and infrastructure units

and identified over 32 million hectares of susceptible footprints. Another study used Moderate Resolution Imaging Spectroradiometer (or MODIS) satellite data for 41 smoke-related evacuations in Canada from 2000 to 2007, aiming to showcase how remote sensing data can evaluate and support evacuation decisions in near real-time [32]. Their results indicated that a significant number of evacuations may have been suboptimal, with post-evacuation aerosol levels often exceeding pre-evacuation levels. In addition, Tepley et al. [33] examined over 1000 wildfire evacuations from 1980 to 2019, identifying patterns based on geography, fire characteristics, and evacuation methods. In remote coniferous areas, summer evacuations were linked to lightning-ignited fires, requiring air evacuation. Less remote mixed-wood forest areas saw human-ignited fires in spring, with road access for evacuations. It is believed that understanding these patterns can enhance preparedness for future fire seasons.

The third group of studies focused on BC, a western province in Canada, with only four studies, 8.5% of the collected articles. For example, Brachman and Dragicevic [34] used the NetSEEM model for diverse emergency evacuation scenarios in the city of Burnaby by incorporating biological and social variables, and highlighted the need for nuanced evacuation planning. They also underscored the importance of considering downstream traffic flow, cautioning even in seemingly safe areas during evacuations. Kirchmeier-Young et al. [35] focused on the summer of 2017 in the Southern Cordillera region of BC which experienced unprecedented warmth and extensive wildfires partially associated with anthropogenic contributions to the fire weather factors. As global warming continues, the likelihood of such an extreme wildfire season is expected to rise, emphasizing the need for attention in various sectors, including forest management, public health, and infrastructure. The relatively low number of studies on wildfires in BC could be attributed to factors such as research prioritization, fewer high-severity historical wildfire trends, limited interdisciplinary collaboration, restricted perception of wildfire severity, and lack of allocated financial resources for wildfire prevention [36]. For example, a study in BC elaborated on the results of 77 collected surveys from community leaders and highlighted the vulnerability of communities in WUI areas due to diverse individual and sociopolitical factors affecting engagement [37]. In addition, financial and social-capacity barriers are identified as key factors limiting proactive wildfire management engagement, spotlighting the crucial need for targeted support to address these inequalities.

Each province, including Quebec (QC), Saskatchewan (SK), Ontario (ON), Northwest Territories (NT), and Yukon (YN), as well as a study focusing on the Prairies, contributes to less than 4.2% of the compiled literature. This can be attributed to a variety of factors, including but not limited to a historically lower frequency and severity of wildfires, such as the Fort McMurray fire in AB in 2016, lower population density, and a lack of recorded data in provinces in northern Canada, such as Northwest Territories and Yukon. Additionally, more favorable climatic conditions in provinces in southern Canada, such as Ontario and Quebec, may play a role. For instance, there has been an increase in precipitation, particularly the number of days with heavy rainfall, since the 1940s in areas like southern Ontario, southern Quebec, and the eastern provinces [38].

3.2. Wildfire Research Themes

Collected papers were classified into three major research themes including “community support/resilience”, “evacuation efficiency”, and “infrastructure protection/raising awareness”. Over 40.4% of the studies, as is shown in Tables 1 and 2, are in the “community support/resilience” group. “Community support/resilience” mostly focused on either assessing the support received by communities during the wildfire event or evaluating the community’s recovery and individual experiences after the wildfire event. For example, a qualitative study examined the effects of family, social support, and place attachment on indigenous residents during a wildfire evacuation in remote northern Ontario. The evacuation scattered residents to twelve neighbouring communities, resulting in communication difficulties, family separations, disrupted community cohesion, and a negative impact

on place attachment [39]. The study emphasizes the need to consider social and cultural factors in wildfire evacuation planning for indigenous communities to reduce adverse consequences and enhance resilience. Five years post the Fort McMurray wildfire, another study found a 45% likelihood of major depressive disorder (or MDD) and a 39% probability of post-traumatic stress disorder (or PTSD) among residents. The study highlights the significance of family support and advocates for further research and preparedness plans in high-risk areas [40]. Another study explored the impact of the 2014 wildfire season in the Northwest Territories from 30 interviews in four communities and highlighted the negative effects of wildfire on mental and emotional well-being, respiratory deficiencies due to prolonged exposure to smoke, and disruptions to livelihoods [41]. The pre-eminence of studies focusing on “community support/resilience” reflects a societal shift towards proactive community engagement and highlights the recognition of the role communities play in fostering resilience [41–43].

Table 1. Research themes in different research areas across Canada in percent.

| Research Area | Research Themes | | | Total |
|---------------|----------------------------------|-----------------------|---|-------|
| | Community Support/ Resilience | Evacuation Efficiency | Infrastructure Protection/ Raising Awareness | |
| AB | 29.79 | 10.64 | 10.64 | 51.06 |
| CA | 4.26 | 8.51 | 8.51 | 21.28 |
| BC | 2.13 | 4.26 | 2.13 | 8.51 |
| ON | 2.13 | 2.13 | 0 | 4.26 |
| QC | 0 | 0 | 4.26 | 4.26 |
| SK | 0 | 0 | 4.26 | 4.26 |
| NT | 2.13 | 0 | 0 | 2.13 |
| Prairies | 0 | 2.13 | 0 | 2.13 |
| YN | 0 | 2.13 | 0 | 2.13 |
| Total | 40.43 | 29.79 | 29.79 | 100 |

Colors are aligned with values showing 0 (Red) to smaller values (ranging from White to Lighter Green) and Greater values (Dark Green).

Table 2. Temporal trends of different research themes from 2013 to 2023 in percent.

| Research Themes | Temporal Trends | | | | | | | | | | |
|---|-----------------|------|------|------|-------|-------|-------|-------|-------|------|-------|
| | 2013 | 2014 | 2015 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | Total |
| Community support/resilience | 2.13 | 2.13 | 0 | 0 | 6.38 | 12.77 | 0 | 12.77 | 2.13 | 2.13 | 40.43 |
| Evacuation efficiency | 0 | 4.26 | 2.13 | 2.13 | 2.13 | 4.26 | 6.38 | 4.26 | 4.26 | 0 | 29.79 |
| Infrastructure protection/raising awareness | 0 | 0 | 0 | 2.13 | 2.13 | 6.38 | 4.26 | 8.51 | 4.26 | 2.13 | 29.79 |
| Total | 2.13 | 6.38 | 2.13 | 4.26 | 10.64 | 23.40 | 10.64 | 25.53 | 10.64 | 4.26 | 100 |

Colors are aligned with values showing 0 (Red) to smaller values (ranging from White to Lighter Green) and Greater values (Dark Green).

The number of articles on “evacuation efficiency” and “infrastructure protection/raising awareness” is equal, with each category representing over 29% of the total number of documents, as is shown in Tables 1 and 2. “Evacuation efficiency” shows either learned lessons from previous evacuations or improved preparedness of communities for potential evacuations in the future. For example, in the 2011 wildfire evacuation of Mishkeegogamang Ojibway Nation, Ontario, residents resisted due to perceived low risk, a desire to protect homes, and a strong indigenous inclination to stay home. The study suggests allowing First Nations to stay in traditional territories during wildfires or coordinating evacuations to neighbouring indigenous communities to enhance resilience [44]. Another research study highlights the evacuation difficulties faced by WUI communities, citing limited routes and numerous WUI interfaces [45]. Utilizing the PTV VISSIM simulation method, the study demonstrated that incorporating an extra highway-access road can decrease evacuation times by up to 80 min, emphasizing the need for a more comprehensive strategic evacuation plan for at-risk communities.

“Infrastructure protection/raising awareness” incorporates all studies about either evaluating and improving the preparedness of infrastructures/facilities or informing com-

munities about the disastrous effects of wildfire on infrastructures and populated areas. For example, a study for assessing wildfire impacts on structures in WUI communities in northern boreal forests incorporates hazard, inventory of buildings, level of exposure, and impact components. This approach facilitates a thorough evaluation of potential losses and supports the exploration of hypothetical wildfire scenarios to enhance emergency response and mitigation planning [46]. Another study evaluates the implementation of a policy called “Let-it-Burn” in Saskatchewan, and explores the effects of the reintroduction of fire with ecological and financial attributes. While the policy seems ecologically sound, it faces opposition from locals who see it as a challenge to indigenous sovereignty and underscores the need for indigenous leadership and partnership in fire management, challenging the erasure of settler colonial impacts and emphasizing the ongoing life in forested areas [47]. Moreover, a survey of 24 professionals in the Regional Municipality of Wood Buffalo, AB, who lived through the 2016 Horse River Fire from June 2020 to 2021, showed robust support for suggested wildland fire mitigation strategies. The findings indicated a consensus on measures like preserving and expanding a vegetation-free buffer zone 30m to 70m from the WUI [48]. Diverse opinions also emerged, endorsing non-combustible construction materials and proposing the transformation of the buffer zone into a recreational space [48].

3.3. Trends

As is shown in Table 2, an upward trajectory trend in studies related to “community support/resilience”, with percentages increasing from 2.13% in 2013 to peaks of 12.77% in 2019 and 2021, aligns with an evolving societal emphasis on community involvement in disaster resilience [49–51]. The emphasis on “evacuation efficiency” in recent years fluctuated from 0% in 2013 to a peak of 6.38% in 2020, reflecting a dynamic response to evolving challenges in evacuation procedures. This variability suggests a commitment to continuous improvement, adapting plans before wildfires for enhanced community preparedness or after wildfires to identify and improve evacuation aspects. Peaks in studies related to “infrastructure protection/raising awareness” in 2019 and 2021, accounting for 6.38% and 8.51%, highlight a responsive research community emphasizing a temporal adaptation to the changing threat landscape. This trend is aligned with a growing recognition of the importance of infrastructure protection and awareness-raising measures in the context of wildfire, which can gradually improve community resilience over the years [52–54].

4. Discussion

This review synthesizes the landscape of wildfire research in Canada, with a particular focus on evacuation efficiency, infrastructure protection, and community support/resilience from 2013 to 2023. Our analysis has revealed a pronounced focus on community support/resilience, constituting over 40% of the studies reviewed [14,16,40,41]. This indicates a shift towards prioritizing community-based strategies in wildfire management, recognizing the critical role of socio-economic factors and community engagement in enhancing resilience.

The significant emphasis on Alberta, especially post-2016 Fort McMurray wildfire, highlights the region’s unique challenges and the evolution of research post disaster [16,26]. Comparatively, the sparse research output from British Columbia, despite its similar risks, suggests an area ripe for future investigations, potentially aligning the geographic focus of wildfire studies more evenly across Canada [36,37].

Our findings underscore the necessity of integrating evacuation efficiency and infrastructure protection with strong community ties to bolster wildfire management strategies. Effective evacuation plans are crucial, as demonstrated by studies that analyze the complexities of evacuation logistics and the importance of timely and clear communication to the public during emergencies [16,26,45]. Infrastructure resilience, similarly, benefits from continual community involvement, ensuring that recovery and preparedness measures resonate with the needs and experiences of local populations [29,46,47].

Moreover, the integration of these thematic areas—evacuation efficiency, infrastructure protection, and community resilience—suggests a comprehensive approach to wildfire management. This approach combines tactical and strategic measures with robust community engagement, essential for developing adaptable and resilient policies that respond effectively to both immediate challenges and promote long-term recovery [14,16,26]. The growing acknowledgment of the socio-economic impacts of wildfires and the pivotal role of community-centered strategies in disaster resilience provides valuable insights for shaping future research directions and policy frameworks.

In light of these findings, future research should focus on underrepresented regions like British Columbia to better understand and mitigate wildfire risks across all affected areas of Canada. Furthermore, exploring the integration of indigenous knowledge and practices in wildfire management could offer novel and culturally appropriate approaches to enhancing community resilience, particularly as indigenous communities often possess unique strategies that are crucial in the context of local wildfire management [30,47].

The review also identifies the need for ongoing studies that examine the long-term psychological and social impacts of wildfires on communities, such as post-traumatic stress and community cohesion post-evacuation, to better inform future resilience and recovery strategies [40,41]. This holistic view is crucial for developing adaptable and robust wildfire management policies that can effectively respond to the immediate challenges of wildfire incidents while also promoting long-term recovery and resilience.

5. Conclusions

The analysis of wildfire-related studies across Canadian provinces addressing community resilience, evacuations and infrastructure underscores a significant focus on AB, particularly in the aftermath of the impactful 2016 Fort McMurray wildfire. This attention reflects the unique challenges faced during evacuations, emphasizing the critical need for heightened awareness and preparedness. The specific focus on northern communities within AB recognizes the region's heightened vulnerability to frequent wildfires, especially impacting families. While studies outside AB contribute significantly to the broader understanding of wildfire dynamics in Canada, a notable gap in research on BC hints at challenges such as research prioritization and resource allocation, despite facing increased wildfire activity. Provinces contributing less than 4.2%, including Quebec, Saskatchewan, Ontario, Northwest Territories, Yukon, and the Prairies, showcase regional variations influenced by factors like historical wildfire frequency and population density.

The thematic analysis, categorizing studies into “community support/resilience”, “evacuation efficiency”, and “infrastructure protection/raising awareness”, provides a nuanced perspective on the research landscape. The dominance of the “community support/resilience” category, comprising over 40.4% of total studies, signifies a societal shift towards proactive community engagement. Balanced representation in the “evacuation efficiency” and “infrastructure protection/raising awareness” categories, each contributing over 29%, demonstrates a concerted effort to learn from past evacuations and enhance community preparedness. The temporal trends and thematic analyses underscore a commitment to continuous improvement, adaptability to emerging challenges, and a growing recognition of the multifaceted aspects of wildfire management. The evolving emphasis on community involvement in disaster resilience, the responsiveness to changing dynamics in evacuation procedures, and the heightened awareness of infrastructure protection signify the research community's proactive approach. These insights are pivotal for shaping future research priorities, policy frameworks, and community resilience strategies as Canada navigates the evolving threats posed by wildfires.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data generated or analyzed during this study are included in this article.

Conflicts of Interest: The author declares no conflict of interest.

Abbreviations

| | |
|---------|---|
| AB | Alberta |
| BC | British Columbia |
| CA | Canada |
| MDD | Major Depressive Disorder |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| NetSEEM | Network Science Emergency Evacuation Model |
| NT | Northwestern Territories |
| On | Ontario |
| PTSD | Post Traumatic Stress Disorder |
| QC | Quebec |
| SK | Saskatchewan |
| WUI | Wildland–Urban Interface |
| YN | Yukon |

References

- Dupuy, J.; Fargeon, H.; Martin-StPaul, N.; Pimont, F.; Ruffault, J.; Guijarro, M.; Hernando, C.; Madrigal, J.; Fernandes, P. Climate change impact on future wildfire danger and activity in southern Europe: A review. *Ann. For. Sci.* **2020**, *77*, 35. [CrossRef]
- Williams, A.P.; Abatzoglou, J.T.; Gershunov, A.; Guzman-Morales, J.; Bishop, D.A.; Balch, J.K.; Lettenmaier, D.P. Observed impacts of anthropogenic climate change on wildfire in California. *Earth's Future* **2019**, *7*, 892–910. [CrossRef]
- Erni, S.; Johnston, L.; Boulanger, Y.; Manka, F.; Bernier, P.; Eddy, B.; Christianson, A.; Swystun, T.; Gauthier, S. Exposure of the Canadian wildland–human interface and population to wildland fire, under current and future climate conditions. *Can. J. For. Res.* **2021**, *51*, 1357–1367. [CrossRef]
- Ganteaume, A.; Barbero, R.; Jappiot, M.; Maillé, E. Understanding future changes to fires in southern Europe and their impacts on the wildland-urban interface. *J. Saf. Sci. Resil.* **2021**, *2*, 20–29. [CrossRef]
- Duane, A.; Castellnou, M.; Brotons, L. Towards a comprehensive look at global drivers of novel extreme wildfire events. *Clim. Chang.* **2021**, *165*, 43. [CrossRef]
- Girardin, M.P.; Ali, A.A.; Carcaillet, C.; Mudelsee, M.; Drobyshev, I.; Hely, C.; Bergeron, Y. Heterogeneous response of circumboreal wildfire risk to climate change since the early 1900s. *Glob. Chang. Biol.* **2009**, *15*, 2751–2769. [CrossRef]
- Mansoor, S.; Farooq, I.; Kachroo, M.M.; Mahmoud AE, D.; Fawzy, M.; Popescu, S.M.; Alyemeni, M.N.; Sonne, C.; Rinklebe, J.; Ahmad, P. Elevation in wildfire frequencies with respect to the climate change. *J. Environ. Manag.* **2022**, *301*, 113769. [CrossRef] [PubMed]
- Capitanio, J.P.; Del Rosso, L.A.; Gee, N.; Lasley, B.L. Adverse biobehavioral effects in infants resulting from pregnant rhesus macaques' exposure to wildfire smoke. *Nat. Commun.* **2022**, *13*, 1774. [CrossRef]
- Gill, A.M.; Stephens, S.L.; Cary, G.J. The worldwide “wildfire” problem. *Ecol. Appl.* **2013**, *23*, 438–454. [CrossRef]
- Moore, P.F. Global wildland fire management research needs. *Curr. For. Rep.* **2019**, *5*, 210–225. [CrossRef]
- Grant, E.; Runkle, J.D. Long-term health effects of wildfire exposure: A scoping review. *J. Clim. Chang. Health* **2022**, *6*, 100110. [CrossRef]
- Roos, C.I.; Scott, A.C.; Belcher, C.M.; Chaloner, W.G.; Aylen, J.; Bird, R.B.; Coughlan, M.R.; Johnson, B.R.; Johnston, F.H.; McMorrow, J. Living on a flammable planet: Interdisciplinary, cross-scalar and varied cultural lessons, prospects and challenges. *Philos. Trans. R. Soc. B Biol. Sci.* **2016**, *371*, 20150469. [CrossRef] [PubMed]
- BC Wildfire Services. What Is Wildfire Land-Based Recovery? 2023. Available online: <https://blog.gov.bc.ca/bcwildfire/what-is-wildfire-land-based-recovery/> (accessed on 23 May 2023).
- Beverly, J.L.; Forbes, A.M. Assessing directional vulnerability to wildfire. *Nat. Hazards* **2023**, *117*, 831–849. [CrossRef]
- Cote, D.W.; McGee, T.K. An exploration of residents' intended wildfire evacuation responses in Mt. Lorne, Yukon, Canada. *For. Chron.* **2014**, *90*, 498–502. [CrossRef]
- McGee, T.K. Preparedness and experiences of evacuees from the 2016 Fort McMurray Horse River wildfire. *Fire* **2019**, *2*, 13. [CrossRef]
- Norris, F.H.; Stevens, S.P.; Pfefferbaum, B.; Wyche, K.F.; Pfefferbaum, R.L. Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *Am. J. Community Psychol.* **2008**, *41*, 127–150. [CrossRef] [PubMed]
- Sorensen, J.H. Hazard warning systems: Review of 20 years of progress. *Nat. Hazards Rev.* **2000**, *1*, 119–125. [CrossRef]

19. Paton, D.; Johnston, D. *Disaster Resilience: An Integrated Approach*; Charles C Thomas Publisher: Springfield, IL, USA, 2006. Available online: https://www.google.ca/books/edition/Disaster_Resilience/oZknDwAAQBAJ?hl=en&gbpv=1&dq=Disaster%20Resilience:%20An%20Integrated%20Approach.%20Charles%20C%20Thomas%20Publisher&pg=PP1&printsec=frontcover (accessed on 1 May 2024).
20. Asif, Z.; Chen, Z.; Sadiq, R.; Zhu, Y. Climate change impacts on water resources and sustainable water management strategies in North America. *Water Resour. Manag.* **2023**, *37*, 2771–2786. [[CrossRef](#)]
21. Khalafzai, M.K.; McGee, T.K.; Parlee, B. Spring flooding and recurring evacuations of Kashechewan First Nation, northern Ontario, Canada. *Int. J. Disaster Risk Reduct.* **2021**, *63*, 102443. [[CrossRef](#)]
22. Kerr, G.H.; DeGaetano, A.T.; Stoof, C.R.; Ward, D. Climate change effects on wildland fire risk in the Northeastern and Great Lakes states predicted by a downscaled multi-model ensemble. *Theor. Appl. Climatol.* **2018**, *131*, 625–639. [[CrossRef](#)]
23. Kuklina, V.; Sizov, O.; Bogdanov, V.; Krasnoshtanova, N.; Morozova, A.; Petrov, A.N. Combining community observations and remote sensing to examine the effects of roads on wildfires in the East Siberian boreal forest. *Arct. Sci.* **2022**, *9*, 393–407. [[CrossRef](#)]
24. Kent State University. Statistical & Qualitative Data Analysis Software: About Nvivo. 2023. Available online: <https://libguides.library.kent.edu/statconsulting/NVivo> (accessed on 31 May 2023).
25. Government of Canada. Canadian Disaster Database, Public Safety Canada, Wildfire Event. 2023. Available online: <https://cdd.publicsafety.gc.ca/dtprnt-eng.aspx?cultureCode=en-Ca&eventTypes='WF'&normalizedCostYear=1&dynamic=false&eventId=1135&prnt=both#:~:text=In%20total,%20the%20Fort%20McMurray,other%20buildings%20that%20were%20damaged> (accessed on 31 May 2023).
26. Woo, M.; Hui, K.T.; Ren, K.; Gan, K.E.; Kim, A. Reconstructing an emergency evacuation by ground and air the wildfire in Fort McMurray, Alberta, Canada. *Transp. Res. Rec.* **2017**, *2604*, 63–70. [[CrossRef](#)]
27. Pujadas Botey, A.; Kulig, J.C. Family functioning following wildfires: Recovering from the 2011 Slave Lake fires. *J. Child Fam. Stud.* **2014**, *23*, 1471–1483. [[CrossRef](#)]
28. Stralberg, D.; Wang, X.; Parisien, M.; Robinne, F.; Sólymos, P.; Mahon, C.L.; Nielsen, S.E.; Bayne, E.M. Wildfire-mediated vegetation change in boreal forests of Alberta, Canada. *Ecosphere* **2018**, *9*, e02156. [[CrossRef](#)]
29. Ohl, S.J.; Kim, A.M. Identifying critical corridors during an area-wide disruption by evaluating network bottleneck capacity. *Int. J. Disaster Risk Reduct.* **2021**, *64*, 102487. [[CrossRef](#)]
30. McGee, T.K. Evacuating first nations during wildfires in Canada. *Fire Saf. J.* **2021**, *120*, 103120. [[CrossRef](#)]
31. Johnston, L.M.; Flannigan, M.D. Mapping Canadian wildland fire interface areas. *Int. J. Wildland Fire* **2017**, *27*, 1–14. [[CrossRef](#)]
32. Krstic, N.; Henderson, S.B. Use of MODIS data to assess atmospheric aerosol before, during, and after community evacuations related to wildfire smoke. *Remote Sens. Environ.* **2015**, *166*, 1–7. [[CrossRef](#)]
33. Tepley, A.J.; Parisien, M.; Wang, X.; Oliver, J.A.; Flannigan, M.D. Wildfire evacuation patterns and syndromes across Canada's forested regions. *Ecosphere* **2022**, *13*, e4255. [[CrossRef](#)]
34. Brachman, M.L.; Dragicevic, S. A spatially explicit network science model for emergency evacuations in an urban context. *Comput. Environ. Urban Syst.* **2014**, *44*, 15–26. [[CrossRef](#)]
35. Kirchmeier-Young, M.C.; Gillett, N.P.; Zwiers, F.W.; Cannon, A.J.; Anslow, F.S. Attribution of the influence of human-induced climate change on an extreme fire season. *Earth's Future* **2019**, *7*, 2–10. [[CrossRef](#)]
36. Daniels, L.D.; Hagerman, S.M.; Ravensbergen, S. Wildfire Prevention and Fuels Management in the Wildland-Urban Interface: BC Community Perceptions. Report to the Union of BC Municipalities, First Nations' Emergency Services Society, BC Community Forest Association and BC Wildfire Service. 2018. Available online: <https://bccfa.ca/wp-content/uploads/2018/06/smallLori-Daniels-Community-Wildfire-Prevention-Summary-Report-May-2018.pdf> (accessed on 5 December 2023).
37. Copes-Gerbitz, K.; Dickson-Hoyle, S.; Ravensbergen, S.L.; Hagerman, S.M.; Daniels, L.D.; Coutu, J. Community engagement with proactive wildfire management in British Columbia, Canada: Perceptions, preferences, and barriers to action. *Front. For. Glob. Chang.* **2022**, *5*, 829125. [[CrossRef](#)]
38. Vincent, L.A.; Zhang, X.; Mekis, É.; Wan, H.; Bush, E.J. Changes in Canada's climate: Trends in indices based on daily temperature and precipitation data. *Atmos.-Ocean* **2018**, *56*, 332–349. [[CrossRef](#)]
39. Asfaw, H.W.; McGee, T.; Christianson, A.C. The role of social support and place attachment during hazard evacuation: The case of Sandy Lake First Nation, Canada. *Environ. Hazards* **2019**, *18*, 361–381. [[CrossRef](#)]
40. Mao, W.; Adu, M.; Eboreime, E.; Shalaby, R.; Nkire, N.; Agyapong, B.; Pazderka, H.; Obuobi-Donkor, G.; Owusu, E.; Oluwasina, F. Post-traumatic stress disorder, major depressive disorder, and wildfires: A fifth-year postdisaster evaluation among residents of Fort McMurray. *Int. J. Environ. Res. Public Health* **2022**, *19*, 9759. [[CrossRef](#)] [[PubMed](#)]
41. Dodd, W.; Scott, P.; Howard, C.; Scott, C.; Rose, C.; Cunsolo, A.; Orbinski, J. Lived experience of a record wildfire season in the Northwest Territories, Canada. *Can. J. Public Health* **2018**, *109*, 327–337. [[CrossRef](#)] [[PubMed](#)]
42. Kikkert, P.; Lackenbauer, P.W. The Canadian Rangers: Strengthening Community Disaster Resilience in Canada's Remote and Isolated Communities. *North. Rev.* **2021**, *51*, 35–67. [[CrossRef](#)]
43. McGee, T.; Healey, D. Interpreting and responding to wildfire smoke in western Canada. *Environ. Hazards* **2022**, *21*, 361–377. [[CrossRef](#)]
44. McGee, T.K.; Nation, M.O.; Christianson, A.C. Residents' wildfire evacuation actions in Mishkeegogamang Ojibway Nation, Ontario, Canada. *Int. J. Disaster Risk Reduct.* **2019**, *33*, 266–274. [[CrossRef](#)]

45. Yerushalmi, A.; Folk, L.; Carton, H.; Gales, J.; Khan, A.; Weckman, B. Fire evacuation modelling of a Canadian wildland urban interface community. *Can. J. Civ. Eng.* **2022**, *49*, 31–40. [[CrossRef](#)]
46. El Ezz, A.A.; Boucher, J.; Cotton-Gagnon, A.; Godbout, A. Framework for spatial incident-level wildfire risk modelling to residential structures at the wildland urban interface. *Fire Saf. J.* **2022**, *131*, 103625. [[CrossRef](#)]
47. Zahara, A. Breathing fire into landscapes that burn: Wildfire management in a time of alterlife. *Engag. Sci. Technol. Soc.* **2020**, *6*, 555–585. [[CrossRef](#)]
48. Hassan, Q.K.; Rahaman, K.R.; Ahmed, M.R.; Hossain, S.M. Examining post-fire perceptions of selected mitigation strategies after the 2016 horse river wildland fire in alberta, Canada. *Appl. Sci.* **2021**, *11*, 10155. [[CrossRef](#)]
49. Boulianne, S.; Minaker, J.; Haney, T.J. Does compassion go viral? Social media, caring, and the Fort McMurray wildfire. *Inf. Commun. Soc.* **2018**, *21*, 697–711. [[CrossRef](#)]
50. Lalani, N.; Drolet, J.L.; McDonald-Harker, C.; Brown, M.R.; Brett-MacLean, P.; Agyapong, V.I.; Silverstone, P.H. Nurturing spiritual resilience to promote post-disaster community recovery: The 2016 Alberta Wildfire in Canada. *Front. Public Health* **2021**, *9*, 682558. [[CrossRef](#)] [[PubMed](#)]
51. Mamuji, A.A.; Rozdilsky, J.L. Canada’s 2016 Fort McMurray wildfire evacuation: Experiences of the Muslim community. *Int. J. Emerg. Manag.* **2019**, *15*, 125–146. [[CrossRef](#)]
52. Ergibi, M.; Hesseln, H. Awareness and adoption of FireSmart Canada: Barriers and incentives. *For. Policy Econ.* **2020**, *119*, 102271. [[CrossRef](#)]
53. Gatti, E.; McGee, T. *Survey of Municipal Land Use Planning for Wildfire Risk Mitigation in Alberta*; University of Alberta, Department of Earth and Atmospheric Sciences: Edmonton, AB, Canada, 2021. Available online: https://firesmartalberta.ca/wp-content/uploads/2023/09/Gatti_2021_Alberta-survey-planning-wildfire-mitigation-Alberta.pdf (accessed on 6 December 2023).
54. Kurowski, M.; Eng, P.; Allan Bradley, R. Wildfire Adaptations for Resource Roads in British Columbia. 2022. Available online: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/resource-roads/engineering-publications-permits/fpinnovations/wildfire_adaptations_for_resource_roads.pdf (accessed on 6 December 2023).

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.