Forest fires In Alberta, Canada: 2006 - 2023

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Wildland fires are one of the most significant natural disasters in Alberta, Canada, with far-reaching environmental, economic, and social impacts. The 2024 wildfires destroyed a third of the popular tourist destination of Jasper, Alberta. The occurrence of wildland fires has increased, presenting challenges to ecosystems, communities, and economic stability. This project aims to analyze the factors that influence the size and behavior of wildland fires in Alberta, including weather conditions, fuel loads, and land management practices. By examining wildland fire data from 2006 to 2023, this study provides information on the nature, frequency, and severity of these events, uncovering challenges and opportunities to mitigate their impacts. Understanding these factors is crucial for developing effective policies and strategies to reduce the negative effects of wildland fires on the environment, economy, and society.

CCS Concepts: • **Social and professional topics → Geographic characteristics**.

Additional Key Words and Phrases: Wildland fire, Alberta, fire behavior, environmental impact, economic impact, social impact, wildfire mitigation

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1 Introduction

Wildland fires have become one of the most significant natural disasters in Alberta, Canada, exerting substantial environmental, economic, and social impacts. Over the past decades, Alberta has witnessed a rise in the frequency and severity of wildland fires, with recent incidents, such as the 2024 wildfire in Jasper that destroyed a third of the town, underlining the growing threat posed by these events (Williams, 2024). This project aims to conduct a comprehensive analysis of wildland fires in Alberta from 2006 to 2023, focusing on understanding the key factors influencing fire behavior, such as weather conditions, fuel loads, and land management practices. The study aims to identify the primary factors that influence the size, intensity, and behavior of wildland fires in Alberta and provide valuable insights into fire management strategies to mitigate future risks.

2 Literature Review

The increasing prevalence of wildland fires in Alberta, Canada, has prompted extensive research into their causes, impacts, and mitigation strategies. Robinne et al. (2016) highlight the significant role of anthropogenic activities in shaping wildfire activity in Alberta, noting that human-induced changes to landscapes, including resource extraction and urban expansion, have contributed to the frequency and intensity of wildfires. These findings align with Nekrich (2022), who identifies landscape features, climate conditions, and human activities as key determinants of wildfire scale. Nekrich's research reveals that wildfires tend to occur more frequently in regions characterized by specific landscape features, particularly during extended dry periods, underscoring the complex interplay between natural and human-induced factors in wildfire behavior.

Stralberg et al. (2018) provide a critical perspective on the ecological impacts of wildland fires, focusing on Alberta's boreal forests. Their study predicts significant shifts in forest composition by 2100 due to wildfire-induced vegetation changes, which are heavily influenced by current fire management practices. This shift in vegetation composition poses challenges to maintaining biodiversity and highlights the need for adaptive management strategies to mitigate the long-term ecological effects of wildfires.

The social and psychological impacts of wildland fires have also been a focus of research. Drolet et al. (2020) analyze the mental health effects of wildfires on children and adolescents, emphasizing the long-term need for sustained funding and support for affected populations. Similarly, Obuobi-Donkor et al. (2024) examine the broader social and health effects of the 2023 wildfires in Alberta, revealing a significant correlation between residing in wildfire-affected areas and experiencing generalized anxiety disorder. These findings highlight the importance of addressing not only the physical but also the psychological repercussions of wildland fires on vulnerable populations. In addition to the human and ecological impacts, Stralberg et al. (2018) and Robinne et al. (2016) emphasize the influence of current fire management practices on both vegetation dynamics and wildfire frequency. Effective fire management is crucial in reducing the adverse effects of wildfires and supporting long-term ecosystem resilience. The integration of sustainable fire management practices is, therefore, necessary to balance ecological health and reduce the vulnerability of communities in wildfire-prone areas.

3 Materials and Methods

3.1 Dataset Description

This study utilizes historical wildfire data collected through archival research from publicly available sources. The dataset encompasses information on wildfires in the province of Alberta from 2006 to 2023, providing comprehensive details for each fire event. The dataset includes 25,322 records and contains 50 features that capture various aspects of wildfire events, including the cause of the fire, its size, and its location, specified by latitude, longitude, legal land description, and forest area. Additionally, it includes information on the time and duration of each fire, weather conditions at the time of the fire, staffing and physical resources used for fire suppression, and the area burned. The dataset is provided in Excel format and was obtained from Forestry and Parks, Alberta (Forestry and Parks, 2024).

The data collection techniques employed in this research involved both quantitative and qualitative analyses to understand the factors contributing to wildland fires and their impacts. Quantitative analysis was conducted using descriptive statistics and regression models to examine relationships between weather conditions and fire size. This approach allowed for an exploration of how environmental variables such as temperature, humidity, and wind speed correlate with wildfire behavior. Additionally, qualitative content analysis was utilized to review relevant literature, providing context for the impact of wildfires on ecosystems and communities.

3.2 Data Preprocessing

The data preprocessing phase was essential to ensure that the dataset was clean, manageable, and suitable for analysis. Key steps included examining the dataset, handling missing values, feature selection, and dimensionality reduction. Initially, the data was checked for completeness, ensuring necessary columns were present and assessing data quality. Columns with more than 50% missing values were dropped to improve data reliability. Based on domain knowledge and the data dictionary, less relevant features were manually removed to reduce dimensionality.

Feature importance was further refined using a Random Forest model, which identified temperature, relative humidity, wind speed, and distance from water source as the most impactful features for predicting wildfire size (Figure 1). These features were then used in the final prediction model, emphasizing the significance of environmental conditions in influencing wildfire behavior. Generally, data preprocessing streamlined the dataset and enhanced its quality, setting the stage for effective modeling and analysis.

3.3 Data visualization and Analysis

3.3.1 Wildfire Size Time Series (2006 - 2023)

This section examines the size of wildfires at the time when the Incident Commander officially changed the fire's status to "Under Control" (UC), as well as the overall trend in wildfire sizes over the years. The size of the wildfire, recorded to the nearest hectare or to a hundredth (0.01) of a hectare, provides important insights into the evolution of wildfire management over the study period from 2006 to 2023

Between April 2006 and April 2024, the total area of wildfires marked as under control increased significantly, resulting in an overall rise of 2,481.82%. This trend reflects not only the growing intensity of wildfire incidents but also the

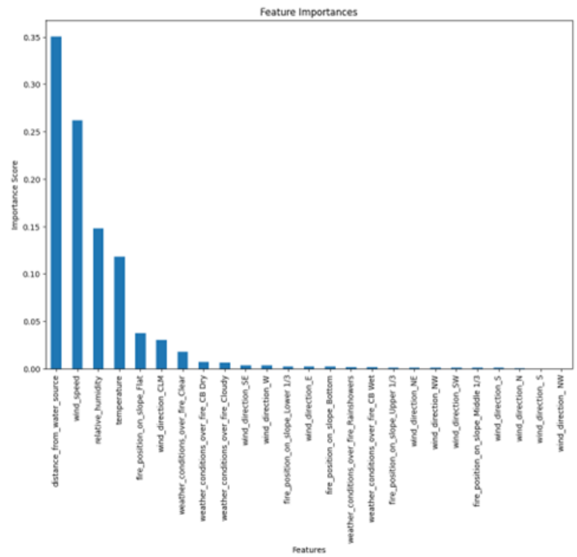

Fig. 1. Feature Importance Selection identified temperature, relative humidity, wind speed, and distance from water source as the most impactful features for predicting wildfire size.

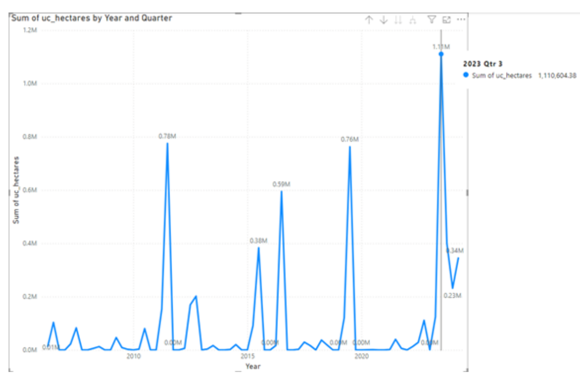

Fig. 2. Total Area of Wildfires each Year in Alberta from 2006 to 2023.

evolving response strategies employed to manage them. The most notable increase began in October 2022, when the sum of UC hectares began trending upward, rising by 210.37% (from 233,781.14 hectares) over the next six quarters. This dramatic increase underscores the escalating scale of wildfires in recent years, possibly driven by changes in climate conditions, vegetation patterns, or the availability of firefighting resources. The steepest incline in the sum of UC hectares occurred between October 2022 and April 2024, when the area jumped from 111,130.46 to 344,911.60 hectares. This rapid growth suggests that the size of fires reaching the point of being declared under control has become much larger, indicating more severe wildfire conditions and perhaps more prolonged firefighting efforts. The variation in wildfire sizes is also reflected in the summary statistics, with a standard deviation of 1.83, a minimum size of 0.01 hectares, and a maximum size of 251.8 hectares. These figures illustrate the wide range of wildfire sizes encountered, highlighting the unpredictable nature of wildfire behavior and the challenges in managing such incidents effectively.

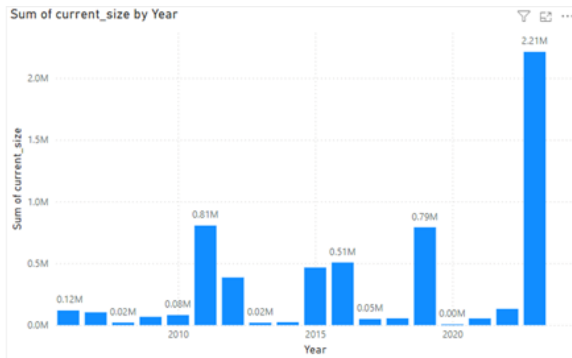

Fig. 3. Total Numbers of Wildfire Each Year in Alberta from 2006 To 2023

The analysis also reveals that the sum of current wildfire sizes has shown a significant upward trend over the years (Figure 3). Between 2006 and 2023, the total area affected by wildfires increased by 1,762.56%. A notable upward trend began in 2019, with the sum of current wildfire sizes rising by 179.33% (from 1,420,034.82 hectares) over the next four years. This trend highlights the increasing intensity and frequency of wildfires in recent years, potentially influenced by changes in climate, land use, and forest management practices. The steepest incline in the sum of current wildfire sizes occurred between 2019 and 2023, with the total area jumping from 791,838.41 to 2,211,873.23 hectares. This rapid increase suggests that wildfires are not only becoming more frequent but also growing larger in size, which presents greater challenges for fire management and mitigation efforts. These findings demonstrate a significant upward trend in the size of wildfires both at the time of being declared under control and in terms of overall area affected, particularly in recent years.

3.3.2 Wildfire Size Distribution by Size Class

A bar chart depicting the distribution of wildfire sizes by size class provides additional insights into the nature of wildfires from 2006 to 2023 (Figure 4). The size classes are grouped based on the final area burned, and the size class can change as the wildfire grows until the final area burned is determined after extinguishment. The breakdown of wildfire size classes is as follows:

- **A class**: 0 to 0.1 hectares
- **B class**: > 0.1 hectares to 4.0 hectares
- **C class**: > 4.0 hectares to 40.0 hectares
- **D class**: : > 40.0 hectares to 200 hectares
- **E class**: > 200 hectares

The bar graph shows that size C has the highest number of cases, with 479 incidents (32. 3%), followed by size E with 417 incidents (28.12%). Size D accounts for 289 incidents (19.49%), and size B has 288 incidents (19.42%). Size A is the

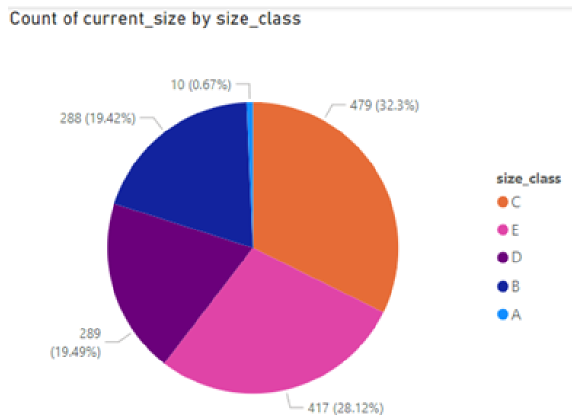

Fig. 4. Distribution of Wildfire Sizes by Size Class Provides Additional Insights into The Nature of Wildfires in Alberta From 2006 To 2023

least common, with only 10 incidents (0.67%). This distribution indicates that most wildfires fall into medium to large categories (C, D, and E), suggesting a trend toward larger fires over time. The predominance of Size C and Size E fires highlights the significant scale of wildfires that have occurred, emphasizing the need for effective firefighting strategies and resource allocation to manage such large-scale incidents. The relatively small proportion of size A fires suggests that smaller fires are either more easily controlled or less frequent in occurrence. These findings underscore the importance of targeted mitigation strategies to address the specific challenges posed by larger wildfires, which have a more substantial impact on the environment and communities.

3.3.3 Factors Affecting Wildfire Size

The size of wildfires is influenced by several environmental factors, including temperature and humidity. The average temperature by fire year provides a clear picture of how temperature trends may correlate with wildfire behavior.

Fig. 5. Average Temperature by Fire Year in Alberta

In 2018, the average temperature was 19.77°C, making it the year with the highest average temperature in the study period (Figure 5). This value was 29.94% higher than the average temperature in 2011, which had the lowest average at 15.21°C. Across all 18 fire years, the average temperature ranged from 15.21°C to 19.77°C, indicating significant variability in temperature, which may contribute to the fluctuations in wildfire sizes and frequency.

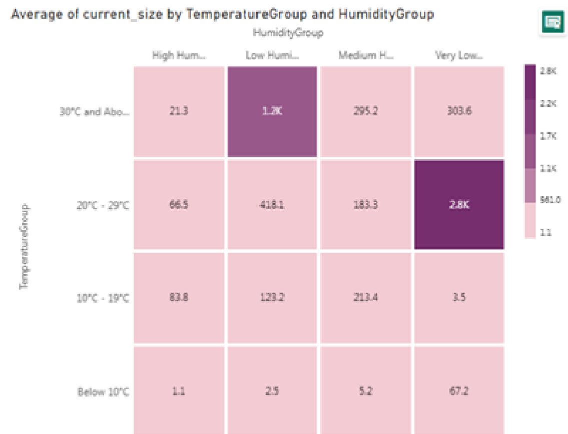

Fig. 6. Average of Wildfire Size by Temperature and Humidity Groups

Moreover, the analysis shows that very large wildfires, with an average size of 2,800 hectares, tend to occur under conditions of very low humidity and high temperatures ranging between 20-29°C. These conditions create an environment conducive to rapid fire spread, as the dry atmosphere and elevated temperatures facilitate the ignition and propagation of fires. Similarly, large wildfires, with an average size of 1,200 hectares, are associated with low humidity and very high temperatures of 30°C and above (Figure 6). These findings suggest that extreme heat, coupled with dry conditions, significantly contributes to the severity of wildfires.

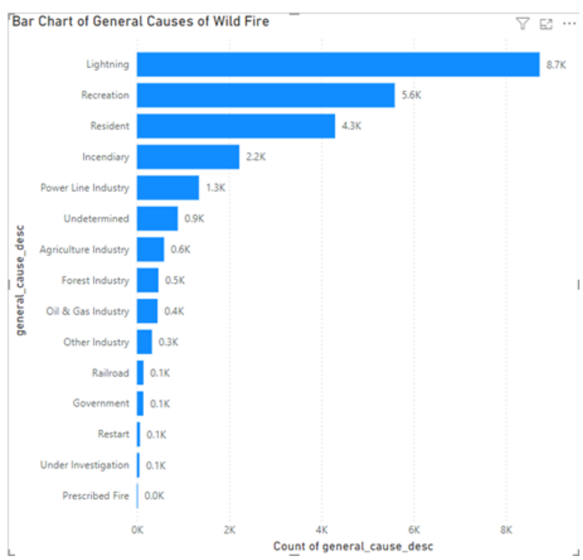

Fig. 7. General Causes of Wildfire

In terms of causes (Figure 7), lightning was the most significant factor, accounting for 8,734 incidents, which is 45,868 42% higher than prescribed fire, the category with the lowest count of 19 incidents. Lightning accounted for 34.49% of all wildfire causes, making it the leading natural cause of wildfires. Other human-related factors, such as recreation and residential activities, also played a significant role. Recreation accounted for 22.08% of wildfire causes (5,590 incidents), while residential activities contributed to 4,300 incidents (16.97%). This distribution indicates that both natural and human activities are major contributors to wildfire occurrence, highlighting the need for better preventive measures targeting both human behavior and environmental factors.

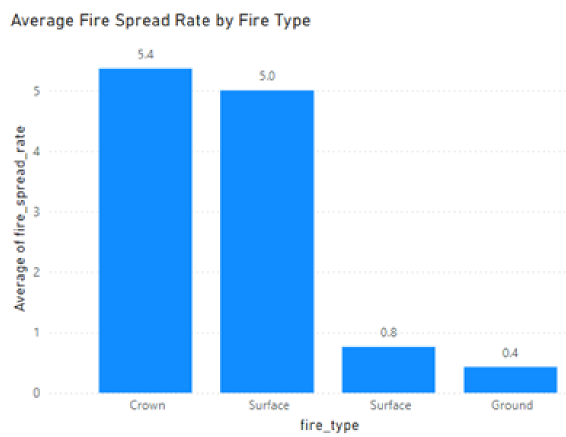

Fig. 8. Average Fire Spread Rate by Fire Type

The average fire spread rate also varied significantly depending on the fire type (Figure 8). At 5.37, Crown Fires had the highest average fire spread rate, which was 1,143.79% higher than Ground Fires, which had the lowest average spread rate of 0.43. Crown fires are characterized by their ability to advance through the crown fuel layer, involving more than 10% of the tree crowns, making them particularly fast moving and destructive. Surface fires - fires that burn in surface fuels and involve less than 10% of the tree burning - had a moderate spread rate compared to crown fires. Ground Fires, which burn in the ground fuel layer, exhibited the slowest spread rate. This distinction in fire behavior is crucial to understanding how different types of fire spread and the challenges they present in terms of containment and control. Understanding these relationships between temperature, humidity, general causes, and fire type is crucial for predicting fire behavior and implementing timely firefighting measures. The clear correlation between higher temperatures, specific causes, and larger wildfire sizes underscores the importance of monitoring climatic conditions and human activities as part of wildfire management and prevention strategies. By focusing on periods and regions with high temperatures, low humidity, and high-risk activities, fire management teams can allocate resources more effectively and potentially mitigate the impact of large-scale wildfires.

3.3.4 Fire by Geography

Wildfires in Alberta have also shown a notable variation based on geography (Figure 9). Provincial Land had the highest number of wildfire cases, with 18,031 incidents, making it 901,450.00% higher than National Parks, which had the lowest count of wildfire cases. Provincial Land accounted for 71.25% of all wildfire cases during the study period.

This significant difference between the number of fires on Provincial Land compared to National Parks highlights the varying risk profiles and management practices in different types of land. Provincial Lands are often more accessible

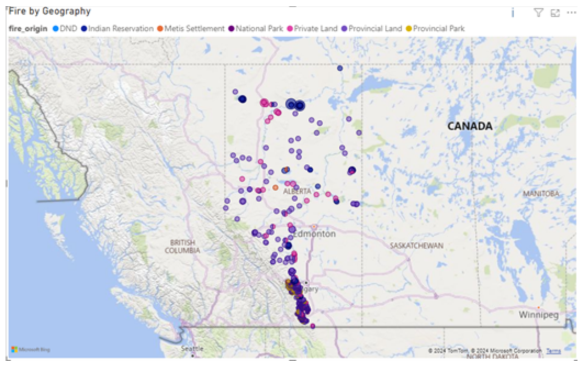

Fig. 9. Fire by Geography in Alberta from 2006 to 2023

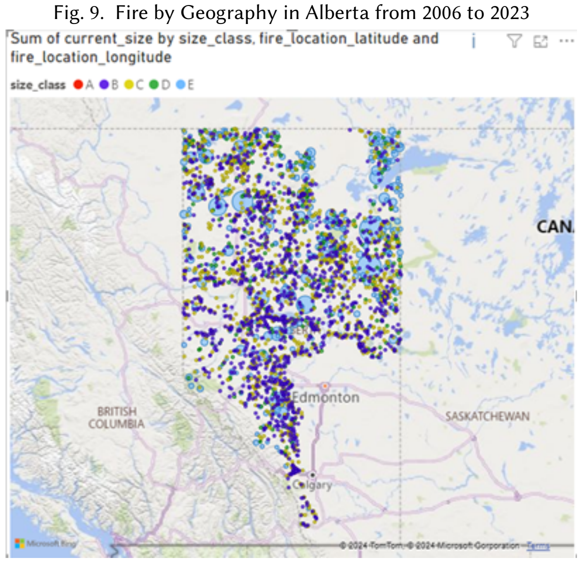

Fig. 10. Map of Wildfire Size Class in Alberta from 2006 to 2023

and may be subject to greater human activity, such as recreation or resource extraction, which could increase the likelihood of ignition. National Parks, on the other hand, are typically more protected and may have stricter regulations in place to prevent human-induced fires. Understanding the geographical distribution of wildfire incidents is essential for implementing targeted fire management strategies. Areas like Provincial Lands, which experience a higher number of incidents, may benefit from increased monitoring, stricter regulations, and more robust firefighting resources to prevent and control wildfires effectively. These targeted approaches can help mitigate the impact of wildfires in areas that are more prone to ignition and spread due to their geography and associated human activities.

3.4 Wildfire Size Prediction Model

The predictive model for wildfire size was built using a Decision Tree Classifier to evaluate the effectiveness of key environmental factors in predicting the wildfire size class. Below, we outline the steps involved in building the decision tree prediction model and discuss the results and evaluation metrics obtained.

3.4.1 Steps for Building the Decision Tree Prediction Model

To develop the decision tree model, we selected the top four most important features—temperature, relative humidity, wind speed, and distance from water source—based on their significant influence on wildfire size. The dataset was split into training and testing sets (80% and 20%, respectively) to train the model and validate its performance. A Decision Tree Classifier was then used for its ability to capture non-linear relationships between features. Cross-validation was performed to evaluate model generalizability, and metrics such as accuracy, confusion matrix, and classification report provided insights into the model's performance. In addition, the decision tree was plotted to provide a visual representation of how the model makes predictions based on different feature values. By doing all these steps, it helped us build a model that predicts wildfire size based on key environmental factors.

3.4.2 Model Performance and Evaluation

The model achieved an accuracy of 60% on the test data, indicating that it correctly predicted the wildfire size class in 60% of cases. While this accuracy is a reasonable starting point, it suggests room for improvement. Cross-validation scores ranged from 57.9% to 62.6% , suggesting consistent performance across different data splits and providing confidence in the model's generalizability. **Table 1:** Classification Report

Wildfire Size Class	Precision	Recall	F1-score
A	0.73	0.78	0.76
B	0.34	0.31	0.32
C	0.14	0.12	0.13
D	0.03	0.03	0.003
E	0.14	0.07	0.09

Table 1. Classification Report for Wildfire Size Classes

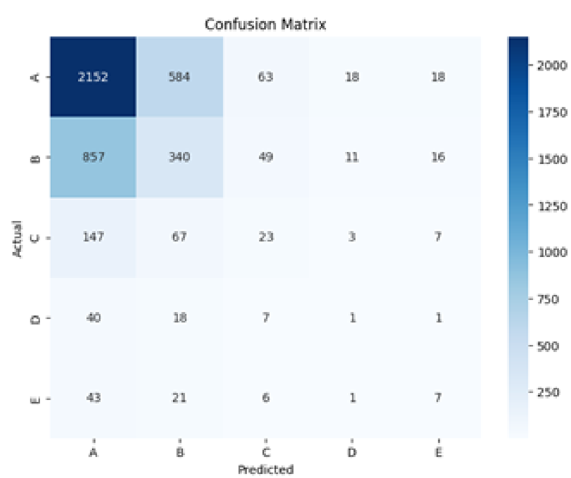

Fig. 11. Confusion Matrix of Prediction in Wildfire Size Classes

A detailed classification report revealed variation in model performance across different wildfire size classes (Table 1). For instance, the model performed well in predicting Size A fires, achieving a precision of 0.73, recall of 0.78, and an F1-score of 0.76. However, it struggled with larger and less frequent classes, such as Size D and Size E (Figure 11), which had relatively low precision and recall values. The confusion matrix further confirmed this trend, indicating that the model had difficulty accurately predicting minority classes, which represent larger wildfires. The wildfire size classes, ranging from A (0 to 0.1 hectares) to E (> 200 hectares), showed varying degrees of prediction accuracy. The model performed better for smaller classes, such as Size A, while it faced challenges predicting larger classes like Size D and E, which are less frequent in the dataset. The overall weighted average F1-score was 0.59, reflecting that while the model performed reasonably well for the majority class, there is still significant room for improvement in handling larger, minority classes.

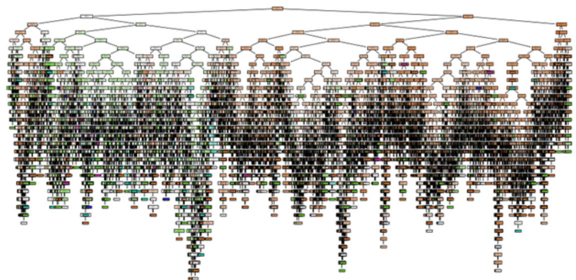

Fig. 12. Decision Tree for Predicting Wildfire Size Classes Using Key Environmental Features

In conclusion, the decision tree model provided a foundational approach for predicting wildfire size classes using key environmental features (Figure 12). Despite achieving a 60% accuracy and consistent cross-validation results, further refinement is needed, particularly in improving predictions for larger wildfires. Enhancements could involve addressing class imbalance and incorporating additional data to improve model performance for these challenging cases.

4 Discussion

4.1 Challenges and Future Directions

The predictive modeling process faced several challenges that impacted model performance and accuracy. One significant challenge was the presence of missing data, which led to the removal or imputation of several features, potentially resulting in information loss and reduced prediction accuracy. Wildfire behavior is inherently complex, influenced by numerous interrelated factors such as weather conditions, terrain, fuel type, and human activities; however, the dataset only captured a limited subset of these factors. Additionally, class imbalance in the dataset—where smaller wildfire sizes were much more frequent than larger ones—made it difficult for the model to accurately predict minority classes. The static nature of the dataset also limited the ability to reflect the dynamic environmental variability affecting wildfires. Lastly, the scope of this research was constrained by limited time, human resources, and available technology, which further impacted the model's development and evaluation. The opportunities to solve these challenges are that our future research would require more sophisticated models, better data quality, and methods to handle class imbalance, along with additional environmental variables to capture the complexity of wildfire behavior more effectively.

4.2 Impacts of Wildland Fires in Alberta from 2006 to 2023

Based on our research, the period between 2006 and 2023 saw significant increases in both the frequency and size of wildland fires in Alberta, reflecting the growing intensity of wildfire incidents. The total area of wildfires marked as under control rose by 2,481.82% from April 2006 to April 2024, with a particularly steep increase of 210.37% beginning in October 2022. This trend suggests a greater intensity of fire incidents and evolving strategies in managing them. The most notable rise in wildfire sizes occurred between October 2022 and April 2024, with the area increasing from 111,130.46 to 344,911.60 hectares, indicating more severe wildfire conditions and longer firefighting efforts. Additionally, the total area affected by wildfires increased by 1,762.56% from 2006 to 2023, with a notable upward trend beginning in 2019. This trend points to an increase in both frequency and intensity of wildfires, likely driven by changing climate conditions, land use patterns, and forest management practices. The distribution of wildfire sizes revealed that the majority of incidents fell into medium to large categories, with Size C and Size E being the most frequent. Lightning was the leading natural cause of wildfires, contributing to 34.49% of all incidents, while recreation and residential activities were significant human-related factors. The variation in fire spread rates further highlighted the challenges of managing different types of fires, with Crown Fires having the highest spread rate. These findings underscore the growing scale and complexity of wildfires in Alberta, emphasizing the need for effective firefighting strategies, targeted mitigation measures, and enhanced collaboration among stakeholders.

Above finding aligns with the report of Huggard et al. (2024), a total of 32,769 km^2 had burned by mid-October 2023, which is equivalent to roughly the size of Vancouver Island or about 5.0% of Alberta's total area. Forests of all ages were affected, though a higher proportion of younger stands (10–60 years) burned compared to older ones. Most of the significant fires in 2023 occurred in the north and west-central parts of Alberta. Current sustainable forestry practices, which aim to resemble natural wildfire-induced landscape patterns, faced challenges as some forestry companies reported up to 33% of harvestable-age forest areas burned.

We can conclude that the level of impact represents the equivalent of more than a decade's worth of forest harvest, posing challenges for the sustainability of forest resources in the future. Tymstra et al. (2020) emphasize that current wildfire management in Canada is under strain due to increasing costs, decreasing budgets, and escalating climate-related threats. The need for community-based prevention measures and a shift from short-term solutions to long-term transformational strategies is crucial to effectively address the growing wildfire threat. Collaborative efforts among agencies, local governments, and other stakeholders, as well as improvements in data sharing, preparedness, and resource allocation, are essential to meet the increasing challenges of wildfire management.

5 Conclusion

The analysis of wildfire sizes at the point of incident commander status change from 2006 to 2023 reveals a significant upward trend, particularly in recent years. This growth is likely influenced by a combination of factors, including changing climate conditions, increased fuel loads, and evolving firefighting strategies. Enhancing the current predictive model requires incorporating more robust data features, fine-tuning hyperparameters, and allocating greater resources, including time and human expertise. This study underscored the urgent need for more effective and efficient wildfire management strategies in Canada, particularly in Alberta. Recommended measures include implementing stricter regulations during fire seasons, increasing public education on forest protection, enforcing compliance and risk management protocols for forest harvesting companies, and developing proactive initiatives to safeguard forests and mitigate wildfire impacts.

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