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Wildfire Operations

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JASPER WILDFIRE:

COMMUNITY IMPACT RESEARCH

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October 2025

On July 22, 2024, Parks Canada responded to multiple wildfire starts within Jasper National Park and an evacuation order was jointly issued by Parks Canada and the Municipality of Jasper for the townsite and Jasper National Park. Highways in the area were closed for the safety of the public and property. At approximately 17:45 on July 24, 2024, there was a change in the wildfires' column dynamics and it collapsed on the town, bringing a considerable ember shower into and around the southwest end of town. After the situations in the urban areas were brought under control, Parks Canada recognized the opportunity to collect valuable data to help inform and better protect Jasper and other communities from similar events in the future. A research team led by FPInnovations was established to conduct wildfire community impact research to determine (1) how the fire entered the affected wildland urban interface (WUI) areas, (2) how the fire spread through the affected WUI areas, and (3) characteristics of burned, adjacent unburned, and partially burned structures.

To accomplish this, sampling plots were established around the affected WUI areas to determine wildfire spread directions and intensity for identifying potential sources of flame, radiant heat, and embers that could lead to structure loss. The plots allowed for the impacted structures to be assigned a general mode of exposure to wildfire. Burned and adjacent unburned pairs were assessed in the affected areas to establish a dataset where differences in structural characteristics may be observed between burned and unburned structures. Partially burned properties were assessed since they often have more information remaining on the property regarding the pre-fire state of the structure.

Firefighters present during impingement were interviewed to attempt to determine the presence of any defensive actions on specific structures. Images with timestamps and videos helped to recreate the environment that the structures were exposed to, both initially as structures started to ignite primarily from wildfire generated embers and later when structure generated embers contributed to further ignitions.

Through analysis of the data, researchers were able to determine statistically significant differences in characteristics of the burned and unburned structures. Features such as roofing material, spacing between structures, combustible items around the base of the structure, and continuous pathways of wildland fuels up to the structure were identified as potential risk factors associated with structure loss. The data and findings from this research contribute to a growing body of empirical evidence concerning structural characteristics and their risks during wildfire.

Project number: 301016432
Report number: WF TR 2025 N4

ACKNOWLEDGEMENTS

This project was financially supported by Parks Canada

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Table of contents

List of figures

List of tables

1 ACKNOWLEDGEMENTS

The following individuals and organizations are recognized for their contributions to this project. The research as presented could not have been accomplished without the excellent collaborative environment present during planning, data collection, data analysis, and production of this final report.

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2 EXECUTIVE SUMMARY

On the evening of July 24, 2024, the Municipality of Jasper and surrounding locations were exposed to a devastating wildfire that destroyed hundreds of structures. In the aftermath of the structure loss event, Parks Canada established an initiative to understand the factors that contributed to the substantial impacts to the community of Jasper. Two complimentary projects were established, the first focused on documentation and reconstruction of landscape level fire behaviour and the second focused on understanding how the fire entered and impacted the Municipality of Jasper and surrounding areas. This report presents the findings of the second project. The main objectives of this research were to (1) determine how the fire entered the affected wildland urban interface (WUI) areas, (2) determine how the fire spread through the affected WUI areas, and (3) document characteristics of burned, adjacent unburned, and partially burned structures and attempt to identify where and when defensive actions took place around them.

There were distinct differences in the way fire entered and spread through the densely built-up neighbourhoods of the Jasper townsite and the resorts and communities surrounding the town. In the Jasper townsite, collapse of the convective column and long-range spotting allowed wildfire

embers to enter neighbourhoods in the southwest portion of town. Wildfire embers ignited many structures directly (e.g., ignition of combustible roofs) and indirectly (e.g., via flammable items surrounding a structure). Once structures ignited, strong winds drove fire growth through the densely built-up neighbourhoods, with structure-to-structure ignition dominating the spread. In the areas surrounding the townsite, continuous fuel pathways were often present between the wildland and structures. Consequently, a high proportion of ignitions were likely caused by direct flame contact and radiant heat emanating from burning wildland fuels.

Assessments of burned and unburned structures identified several factors that were influential in determining the patterns of structure loss in both the Jasper townsite and surrounding areas. Key findings from the Jasper townsite included:

- Wooden roofing materials and their commonly associated structural characteristics likely increased the risk of ignition for individual structures and clusters of structures within neighbourhoods.
- Structure-to-structure ignition was facilitated by small spacing between structures in densely built-up neighbourhoods. When spacing between structures was less than 5 m there was a high likelihood of structure-to-structure ignition.
- Building materials and landscaping had little influence on structure survival during the urban conflagration due to widespread structure-to-structure ignition.
- The highest rates of structure loss occurred in neighbourhoods with many combustible roofs, high (>20%) woody vegetation cover, and small spacing between structures.

These findings suggest that vulnerable structures (i.e., those with combustible roofs and hazardous vegetation) embedded within neighbourhoods were important for initiating the urban-fire, while closely spaced structures facilitated urban-fire spread and the development of the urban conflagration. These findings are consistent with prior research from urban fire disasters and contemporary understanding of the factors driving the occurrence of urban conflagrations.

Common traits of burned or partially burned structures/properties in the areas surrounding the townsite included:

- Combustible roofing material,
- Proximity to another burned structure,
- Continuous pathways of fuels up to the structure,
- Combustible materials near and at the base of the structure such as mulch, trees, and shrubs,
- Combustible material under and around decks, and
- Long dead grass or other fuels leading to combustible vertical surfaces on the structure.

These findings highlight that there are many vulnerabilities that can lead to the ignition of a structure. Effective risk reduction will require the mitigation of vulnerabilities that can facilitate structure exposure, ignition of built surfaces, and the entry of fire inside the structure.

3 INTRODUCTION

On July 22, 2024, Parks Canada responded to multiple wildfire starts and issued an evacuation alert for the Municipality of Jasper and Jasper National Park. Highways in the area were closed for the safety of the public and property. Beginning on the evening of July 22 and continuing into July 23, the Municipality of Jasper and Jasper National Park were evacuated due to the increasing wildfire activity that was moving towards town and other values. By early morning on July 23, the evacuation of the townsite was complete, however crews were still completing evacuation of backcountry hikers until the early afternoon of July 24. Simultaneously, structure protection crews worked to setup sprinkler and hose lines throughout the community, around its western perimeter, and around critical infrastructure. In addition, a contracted high-volume system was established along the southwest portion of the townsite to enhance an existing road for an improved control line. Resources began arriving constantly starting early on July 23 and began assisting in the efforts. At this time, the head of the wildfire south of town was near Wabasso Lake. On the afternoon of July 24, the wildfire continued to move north towards the townsite and at around 13:30 it was approximately 8 km south of the Municipality of Jasper.

During this time, crews continued to work to remove potential sources of ignition around structures. After a change in the dynamics of the convective column for the western portion of the south wildfire it collapsed at approximately 17:45, bringing a considerable ember shower into and around the west end of the townsite. Initial ignitions were reported by crews on rooftops in Brewster Crescent and at Maligne Lodge and several spots on the benchlands north of town began to burn. Other initial ignitions were noted in mulch beds around structures. The Petro Canada station roof ignited shortly after, and crews started to see spot fires crossing the train tracks. As time progressed, more ignitions occurred in the commercial area of town on the wood shake roofs and through other southwest end neighbourhoods. Ignitions due to radiant heat transfer as well as embers cast from structures throughout the neighbourhoods began to dominate as time progressed. Due to the high velocity wind gusts, flames from some of the structures were extending halfway across adjacent streets.

At around 20:30, the toxic smoke conditions in town became highly hazardous to individuals without structural fire safety gear and thus some of the first responders were relocated to Hinton, Alberta. First responders, primarily with WUI safety gear remained in town to action the burning structures and continue to extinguish subsequent spot fires. The limited visibility due to the dark, toxic smoke made early spot fire detection difficult. Firefighters reported embers approximately the size of a computer mouse and many smaller embers that required them to wear eye protection. As more structures became involved, the water required to extinguish them increased exponentially. Eventually, water suppression was not effective at restricting fire growth from structures that were fully engulfed in flame. To cope with this increased demand for water, and lack of success restricting radiant heat transfer to adjacent structures, heavy machinery was utilized to interrupt structure-to-structure spread.

At approximately 22:45, forecasted rain hit the town providing some reduction in the fire's intensity. Throughout the night and into the early hours of the following day, crews worked to interrupt structure-to-structure ignition and prevent ignitions of other values from radiant heat transfer and structure produced embers. Incredibly, despite the hundreds of firefighters and first

responders who participated in the wildfire response from the fires' ignition, through evacuation, impingement, and into the following day, no serious injuries were sustained. After the suppression operation in town and the surrounding areas began to calm down two contingents working collaboratively were mobilized to collect valuable time sensitive data regarding landscape level fire behaviour and the WUI. The Canadian Forest Service (CFS) contingent was focused on the landscape level fire behaviour documentation and reconstruction, and the contingent led by FPInnovations was focused on the WUI and structure characteristics influencing ignitions within the urban areas.

FPInnovations has previously completed wildfire community impact research in British Columbia, most notably on the 2023 Grouse Complex Wildfires that burned portions of West Kelowna (Baxter et al., 2024) and the 2023 Adams Complex Wildfires. Furthermore, an assessment was completed on the Hamlet of Enterprise in the Northwest Territories after substantial portions of the community burned down in 2023. Building upon the lessons learned in previous research, FPInnovations developed a methodology to collect valuable data in and around the affected areas in Jasper National Park.

4 METHODS

Many of the methods utilized were previously implemented and refined on other wildfire community impact research events completed by FPInnovations. Furthermore, past methods developed during similar research that was completed in Canada and internationally were incorporated, when possible, to ensure robust data collection methodology (Westhaver, 2017; Cohen and Westhaver, 2022). The data collection methods involved two main components that focused on characteristics of the structures and classifying their exposure to wildfire. In addition to these two main objectives a unique dataset of trailers left in campgrounds and vehicles left in the townsite provided an opportunity to better classify the ignition potential of these items during a wildfire event.

The main objectives were to:

- Determine how the fire entered the affected WUI areas,
- Determine how the fire spread through the affected WUI areas, and
- Document characteristics of burned, adjacent unburned, and partially burned structures and attempt to identify where and when defensive actions took place around them.

4.1 Fire spread into and within the affected areas

Wildfire agencies commonly use various techniques to determine the potential ignition location of wildfires. Those same techniques can be used to determine the direction of spread and give some indication of the wildfires intensity as it moves through an area (National Wildfire Coordinating Group, 2025). Furthermore, these metrics can be used to determine the potential source areas for wildfire embers, flames, and radiant heat in WUI areas. The main spread direction and fire intensity indicators utilized are described in Table 1.

Table 1: The main wildfire spread direction and intensity indicators used to determine potential sources of embers, flames, and radiant heat.

Fire behaviour	Indicator	Description
Direction	Angle of char	As wildfire moves through the forest the windward side of the tree experiences a lower flame height than the leeward side of the tree due to turbulence behind the tree allowing flames to travel up the backside. This leaves evidence of the direction the surface fire and winds were travelling.
	Foliage freeze	As the foliage and branches are exposed to heat in conjunction with the winds, they are dried out very quickly. When the branches are moist, they can bend more easily and when they are heated and dried, they get "frozen" into the position that the wind was blowing at the time they were heated and dried.
	Sooting	The windward side of objects has increased exposure to carbon released during combustion, and thus more soot would be deposited on the windward side of an object. In contrast, the leeward side has more turbulence, and less soot is likely to form on those sides.
	"V" patterns	When ignitions occur in wildland fuels and even in structural fires, the charred or burned area often resembles a widening "V" pattern in the direction that the fire was moving and gaining intensity.
Intensity	Low char height (m)	On the windward side of the tree indicating the average flame height above the ground in that area.
	High char height (m)	On the leeward side of the tree and provides some indication of the flame length and associated wind speed in that area.
	Surface consumption (% volume)	An indication of burning intensity and amount of fuel available to contribute to the head fire intensity.
	Canopy consumption (% volume)	An indication of burning intensity and amount of fuel available to contribute to the head fire intensity.
	Secondary wind direction	Large scale blowdown or snapped trees used in conjunction with the items listed previously allow for piecing together the sequence of events and determining whether additional wind events caused by other portions of the fire occurred before or after the fire moved through that area. The timing of the trees being blown down or snapped influences how the other indicators present themselves.

Using the spread indicators in conjunction with the intensity indicators allows for reconstruction of the wildfire as it moved into the affected areas. The spread indicators show the wind direction at the time that area was burning and the intensity indicators allow for a general classification of potential ember, flame, and radiant heat sources. With higher wind and higher canopy consumption likely leading to the production of more embers, radiant heat, and larger flames.

Plots were established around affected areas to determine potential sources of radiant heat, flames, and embers. A rough 100 m x 100 m grid was used for guidance, but the location and density of sampling locations was modified due to heterogeneity of the wildland fuels and burn severity. Furthermore, resource limitations led to prioritizing areas immediately surrounding affected areas, with plots added at further distances as resources and site priority allowed. Spread direction and intensity plot locations were coordinated with the CFS led contingent to ensure smooth transition of data from the wildland to the affected urban areas. FPInnovations established the plots surrounding the townsite to the Miette River and for the case study areas, plots were established additionally to the CFS plots to provide a more complete description of structure exposure to wildfire.

Wildfire impacts to tree crown foliage, such as the degree of canopy consumption, can be reliably detected with moderate to high resolution optical satellite imagery (e.g., Landsat, Sentinel 2) (Collins et al., 2018; Gibson et al., 2020). Sentinel 2 imagery (20 m resolution) was used to create a canopy consumption map for the full extent of the wildfire. Imagery was collected over two 45-day windows, beginning August 8, 2023 ('pre-fire' collection) and August 8, 2024 ('post-fire' collection). Pixels affected by cloud or snow were masked from images. Spectral indices with known sensitivity to canopy biomass and vegetation vigour (e.g., normalised difference vegetation index), and fire impacts (e.g., mid-infrared burn index) were calculated for every image in the pre- and post-fire collections. Composite index values (median) were derived for each collection, and the difference in index values pre- and post-fire were calculated for the vegetation indices to account for changes to the crown foliage caused by the fire. Areas of non-woody vegetation were excluded from the composite images using land cover mapping derived by Hermosilla et al. (2022). The Google Earth Engine cloud computing platform was used for image acquisition and processing (Gorelick et al., 2017).

Canopy consumption (%) was modelled using the random forest machine learning algorithm. Random forest combines output from an ensemble of decision trees to assign a single value or class. Each tree is trained using a random subset of the available data, selected with replacement, with a random subset of the predictor variables being considered at each node of the decision tree. This approach generates a forest of decision trees with a low correlation. Model estimates are derived by calculating the majority (classification) or average (regression) prediction across all trees (Breiman, 2001). Canopy consumption data collected from the fire spread and intensity assessment plots described above ($n = 300$) were used to train and validate the random forest. A subset of spectral indices that were not highly correlated ($r < 0.8$) were included as predictors in the model. These indices included the mid-infrared burn index, normalised difference vegetation index, visible active radiation index, modified soil and vegetation index, and the burned area index. K-fold cross validation was used to quantify model performance, with every sampling location being randomly assigned to one of ten folds. Cross validation found that the model explained 65.1% of the variation in canopy consumption, with a mean absolute error of 14.7%, indicating that the model had very good predictive performance. The model was used to map canopy consumption across the forested extent of the Jasper Wildfire. Models and maps were produced using the R Statistical Software (R Core Team 2020). The 'randomForest' (Liaw and Wiener 2002), and 'terra' (Hijmans, 2022) packages were used to fit the random forest and make spatial predictions, respectively.

4.2 Structure characteristics and selection

4.2.1 Paired structure assessment

One of the most difficult but most crucial parts of assessing which characteristics of a structure could have contributed to its ignition is quantifying the exposure of each structure to wildfire. In an ideal situation, researchers would have cameras and sensors around all affected structures to determine the type (i.e., flame impingement, radiant heat, embers) and magnitude of exposure, the surfaces of the structure that were exposed (e.g., the windward exterior wall or deck, roof), and the characteristics of those exposed surfaces. It is important to attempt to quantify any direct flame contact, radiant heat exposures, and the total number, size, and intensity of ember flux into a given area. However, given many constraints such as timing, resources, and access, quantifying these exposures is often difficult. This is especially true for embers as they tend to continue to smoulder until there is little evidence left.

As a result, a paired structure approach was implemented to sample structures that are more likely to have similar exposure to wildfire due to their proximity. Burned structures with adjacent unburned structures were selected and their characteristics logged with an app designed to assess how well a structure abides by the current FireSmart™ guidelines. Additional comments and characteristics were recorded to get a better understanding of additional influence of characteristics that the current standards might not capture.

The assessment involves collecting data regarding the following characteristics of the structure and the property:

- Address,
- GPS coordinates,
- Roof type, design, and condition,
- Gutter material, build, and condition,
- Eaves, soffit, and vent construction and condition,
- Siding type and condition,
- Extent and height of non-combustible materials at the base of walls,
- Window construction and condition,
- Location and characteristics of overhangs,
- Door construction and seal condition,
- Fence construction and location,
- Deck construction, condition, and location,
- Any combustible items or attachments to the structure,
- Combustibles in the immediate zone (0 m - 1.5 m) from the structure,
- Combustibles in the intermediate zone (1.5 m – 10 m),
- Combustibles in the extended zone (10 m – 30 m),
- Topography and other influencing factors,
- Characteristics of detached accessory structures, and
- Comments on items not covered in the previous sections.

Structure characteristics from all assessments were collated into tabular format. Due to the high variation from structure-to-structure, the characteristics needed to be combined into more broad categories to ensure large enough sample sizes per subgroup. The proportions of characteristics for burned and unburned structures for individual areas were then analysed using the Chi-Square test or Fisher's exact test if the number of samples per group dropped to approximately five or lower. For characteristics where significant differences were present between groups additional pairwise comparisons were completed using Bonferroni adjusted p-values to control for false positives. The same methods were used to determine significant differences for distance between vehicles and distance between wildland fuels and trailers. When significant differences were present pairwise comparisons were also completed. Statistical analyses were completed in R using various packages.

4.2.2 Structure survival within neighbourhood blocks

Due to resource constraints, it was not possible to do detailed field assessments on all impacted burned and unburned structures. However, due to the evidence of prolific structure-to-structure ignition within the affected areas of the townsite it became evident that additional data were necessary to describe the vulnerabilities of exposed neighbourhoods and burned clusters of structures. The threshold for a structure to resist ignition from direct flame contact and radiant heat emanating from an already burning structure beside it is much higher than from embers. Therefore, many of the vulnerabilities that would have been easier to identify if just one structure was burned in isolation are more difficult to determine since the structure that ignited the cluster is unknown.

These analyses focused on the survival and destruction of residential dwellings in the southern portion of the Jasper townsite and aimed to assess how structure destruction was affected by roof combustibility, structure arrangement, and woody vegetation within the structure ignition zone. Structure susceptibility is influenced by many aspects of construction, which could not be quantified in this analysis. However, consideration of roof combustibility is particularly pertinent for this case study as observations from firefighters present at the site indicate that structures with combustible roofs were among the first to ignite. Furthermore, roofs are the surface of a structure that typically experiences the greatest exposure to embers (Quarles et al., 2010) and is an important structural feature in FireSmart™ assessments (https://firesmartcanada.ca/).

Rapid damage assessment data, collected by the Municipality of Jasper, were used to identify destroyed and surviving structures. The dataset was validated and corrected where necessary through field assessments and manual interpretation of high-resolution satellite imagery. Information on roof combustibility was derived from pre-fire assessments of roof type and condition that were provided by the Municipality of Jasper. In these assessments, roofs were classed as combustible (e.g., wood shakes) or ignition resistant (e.g., asphalt in good condition). The roof combustibility dataset and the building footprints contained in the rapid damage assessment were assumed to be accurate and current. Although best efforts were made to validate and correct these datasets where possible, they could potentially be a source of error in the analyses.

Information on structure spacing (i.e., distance to nearest neighbour) was derived for every structure using building footprints in the rapid damage assessment dataset. Distance to the

closest structure was used as a proxy for a structures potential to ignite or be ignited by a neighbouring structure. Woody vegetation cover in the intermediate structure-ignition zone, defined using a 10 m radius surrounding every structure, was quantified using manual interpretation of the most recent imagery available in Google Earth (Summer 2023 or Summer 2022). A regular grid of points with a 7.5 m spacing was placed across the collective structure ignition zones of residential dwellings and commercial and institutional structures within each neighbourhood of south Jasper. A point intercept sampling method was implemented, whereby the fuel cover class intercepted by each point was recorded. Four primary classes were focused on: woody vegetation, herbaceous vegetation, bare areas, and structures. The proportion of points that were classed as woody vegetation was calculated at the relevant scale of structure grouping (i.e., block or cluster, see descriptions below). Metrics summarising potential exposure of structures to wildfire were also derived for each structure. These included:

i. distance to nearest burned neighbour (closest and closest upwind) both within and outside a neighbourhood,
ii. upwind distance to nearest patch of crown fire (>50% crown consumption) greater than 1 ha, and
iii. distance to nearest patch of burned wildland vegetation greater than 1 ha.

Neighbourhood scale assessment of burned structures was the initial focus of this analysis, due to the strong inter-dependence of destruction/survival of structures within a neighbourhood. Neighbourhood blocks were designated by placing a 20 m buffer around structure footprints, dissolving these polygons, then dividing them into blocks using a layer of roads (Collins et al., 2024) (Figure 1a). The 20 m buffer was used as structures located within 40 m of a burned structure have an elevated likelihood of being burned (Price et al., 2021). Roads were used to separate groups of structures into neighbourhood blocks, as they provide substantial fuel breaks and access for firefighters, which can reduce the probability of fire spread between structures. Structures were assigned to a neighbourhood block, and attributes were summarised at the block level. Median structure spacing and woody vegetation cover, and the proportion of structures with combustible roofs, were calculated for each block. The number of surviving and destroyed structures per block were tallied and used as the response variable in the analysis. Blocks with four or more structures were considered in the analysis. A generalised linear model with a binomial response was used to assess the effect that structure spacing, combustible roofs, and woody vegetation cover had on the proportion of structures destroyed within neighbourhood blocks located in the southern part of the Jasper townsite. Predictor variables were evaluated using tests of statistical significance ($P < 0.05$) and plots of their effect size and uncertainty (i.e., 95% confidence intervals).

Structure loss was highly clustered within neighbourhoods, a pattern that is consistent with the structure-to-structure propagation of fire during urban conflagrations. Comparison of clusters of destroyed and surviving structures was used to better understand what factors facilitated or inhibited structure-to-structure fire spread. In this analysis, groups of 4 or more destroyed (or surviving) structures were considered as a cluster (Figure 1b). This included instances where partial or complete destruction (or survival) of structures occurred within a neighbourhood. Metrics of exposure, woody vegetation cover, structure spacing, and combustible roofs were summarised for each cluster, as described above. Pairwise comparisons were used to evaluate if

there were significant differences in exposure and the vulnerability of clusters of destroyed and surviving structures. Linear regression was used for the analysis of continuous variables and beta regression was used for proportional variables (i.e., combustible roofs, woody vegetation cover). Log transformations were applied to some continuous variables for statistical analysis to meet the assumption of homoskedasticity. Violin plots were used to visualise differences in the distribution of data between clusters.

Analysis was conducted at the scale of individual residential dwellings to identify thresholds in structure spacing that may facilitate or inhibit structure-to-structure fire spread. Critical spacing distances were determined by examining the relationship between the probability of structure destruction and the distance to burned neighbours. Generalised linear mixed models with a binomial distribution were used to model these relationships. Pairs of structures that were each others closest burned neighbour were randomly subset to remove duplicate distances from the dataset. Distance to burned neighbour was fitted as a fixed effect and the neighbourhood block identifier was fitted as a random effect to account for structures being clustered within blocks. Preliminary analysis examined both the distance to nearest burned neighbour and the nearest burned neighbour located upwind, with the former explaining substantially more variation in structure loss. Therefore, we only present results for the analysis examining distance to nearest burned neighbour. Model predictions were used to identify distances where exposure to burned neighbours was likely to result in destruction of a target structure.

Statistical analyses were completed in R. The ‘glmmTMB’ package was used to fit the generalised linear mixed models (Brooks et al., 2017) and the ‘betareg’ package was used for beta regression (Cribari-Neto and Zeileis, 2010). The ‘emmeans’ package was used for pairwise comparisons (Lenth, 2025). Violin plots were produced using the ‘vioplot’ package (Alder et al., 2024).

Figure 1: Examples of a) neighbourhood blocks (black polygons), and b) clusters of destroyed (salmon polygons) and surviving (blue polygon) structures.

4.2.3 Case studies

Unique case studies were also present surrounding the town in the campgrounds and resorts/lodges affected by the wildfire (Figure 2). Assessments were conducted on burned/unburned pairs and/or summaries were created for the following areas:

- Lake Edith Cottage District,
- Jasper Park Lodge,
- Alpine Village Resort Jasper,
- Tekarra Lodge,
- Beckers Chalets,
- Whistlers and Wapiti campgrounds,
- Pine Bungalows, and
- Jasper House Bungalows.

A similar methodology was utilized for the case study areas to characterize wildfire spread into and through them as well as comparing characteristics of the burned and unburned structures. The analysis was often easier in these locations due to less structure-to-structure ignition and the properties that burned were built and maintained to similar standards of those that did not burn. This provided better isolation of differences due to exposure and less assumptions were needed to determine the characteristics of the burned structures.

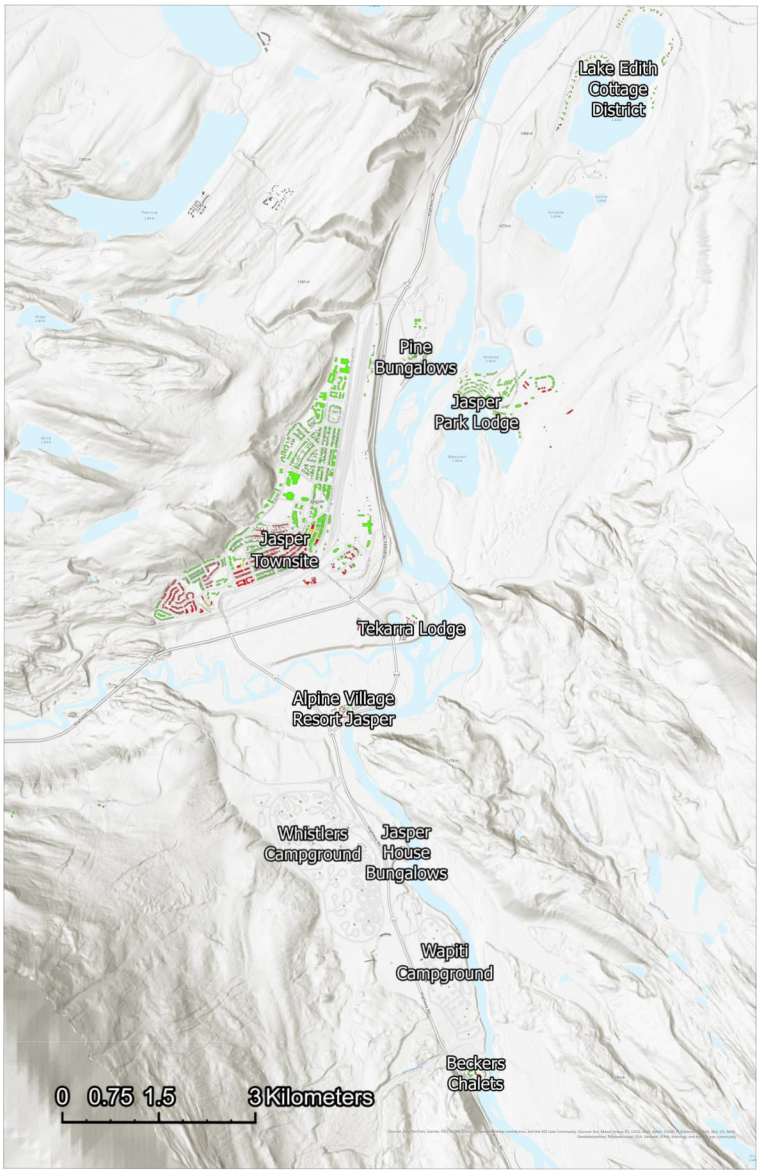

Figure 2: Locations of the case study areas.

4.3 Trailer and vehicle locations

The Jasper townsite and the Whistlers, Wapiti, and Wabasso campgrounds provided a unique dataset of vehicles and trailers in locations with varying exposure to burning wildland area and structures. This allowed for the collection of data regarding structure-vehicle, structure-trailer, and wildland-vehicle ignition trends. It is commonly thought that these items around a structure may increase the vulnerability of that structure to ignition. Therefore, the dataset in Jasper that contained vehicles with varying distances from burned structures and wildland fuels could help better understand the relative risk these items pose to a structure. As a result, locations and

descriptions were collected for all trailers and vehicles within the affected areas of the townsite and the campgrounds.

The vehicle data were collected from the townsite using position tracking cameras mounted to the top of a truck. As the truck was slowly driven through the affected areas of town, images were captured every second and coordinates were stored with the images EXIF data. The images were processed into a time-lapse movie with a coordinate overlay. The movie was watched and the vehicles surroundings paired with the coordinate overlay allowed for their locations to be transcribed into a shape file for further processing. Vehicles were classified as burned if they had experienced full self sustained combustion, damaged if there was visible heat damage on the vehicle, and unburned if there was no easily visible damage observed in the images. The images taken from the truck while driving through town could not always see all sides of the vehicle, therefore some of the vehicles that are identified as unburned may have been partially damaged. In addition to the truck collected imagery, video was captured of the townsite using a remotely piloted aircraft system (RPAS) which allowed for further refinement of vehicle locations in areas not easily visible from the roads.

Distance from the vehicle to the nearest burning structure was determined using a near analysis in ArcGIS Pro. Only vehicles within 100 m of a burning structure were included in the analysis as there were no vehicles burned outside of that distance. Vehicles were put into distance bins with an equal number of samples and a Chi-Square test was completed to determine the presence of significant differences. This was followed by pairwise multiple comparisons to determine significant differences between distance bins and a logistic regression to determine the probability of a vehicle burning with increasing distance from a burning structure.

Trailer data were collected in the campgrounds using an app that records the cameras direction and location. Pictures were taken of each trailer to document the campsite characteristics, trailer characteristics, and adjacent burned wildland fuels. The image locations were used in conjunction with satellite imagery to triangulate exact trailer locations and characteristics were transcribed into an attribute table to conduct further processing. Statistical analysis like what was used for the townsite vehicles was completed on the campground trailer dataset, although the sample size was not large enough for a logistic regression analysis. Analysis focused on determining correlation between trailer survival and the nearest patch of crown fire (greater than approximately 10 m x 10 m), the nearest 1 ha patch of fire upwind with at least 25% canopy consumption, and the nearest 1 ha patch of crown fire upwind with at least 50% canopy consumption. These distinctions were chosen to hopefully determine influence of flame and radiant heat vs ember ignitions of the trailers themselves.

5 RESULTS AND DISCUSSION

5.1 How the fire entered and spread within the Jasper townsite

Ignition sequence and fire spread leading up to the townsite was complex, with many events occurring simultaneously. To assist with orientation, Figure 3 can be used to determine where ignitions and spread occurred. Initial ignitions in the Jasper townsite were reported at approximately 17:45. Through reports from firefighters at the scene, the initial influx of embers occurred when the wildfires' convective column collapsed, causing the embers that were previously being lifted into the atmosphere to be dropped down inside the town. At this point the visibility started to deteriorate, and ignitions began occurring in the southern half of town.

One of the first ignitions reported by firefighters occurred on the rooftop of a structure at the back end of Brewster Crescent, followed by ignitions up on the benchlands north of town and the rooftop of the Maligne Lodge. At this time the head of the fire was around the Miette River south of town. After this point in time the firefighters report a rapidly evolving scenario and there was difficulty determining exactly when and where defensive actions took place for each structure. The firefighters reported many ignitions were occurring on rooftops in the commercial area of town, as well as other areas.

As the head of the fire crossed the Miette River, intensity and associated canopy consumption remained high (Figure 4). The fire spread direction was predominantly north with small variations to the east and west as indicated by the blue arrows in Figure 4. Potential for ember transport into town remained high as the fire passed the river and burned through the area south of Highway 16. After the fire jumped Highway 16 west of Connaught Drive it encountered a change in fuel type where the understory became dominated by deciduous trees and shrubs (Figure 5 and Figure 6). This change in fuel significantly limited the potential for ember production, especially on the far west extent of the fire, leading up to the Stone Mountain neighbourhood (Figure 7 and Figure 8).

Once the fire jumped the fuel break of Highway 16 between Connaught Drive and Hazel Ave it did not build up to the same intensity again before encountering another break in fuels, the railroad and Sleepy Hollow Road. The head fire intensity, canopy consumption, and wind gusts meant the forest was likely still capable of producing embers in this area that could land within the townsite. The area also experienced significant blowdown where many trees were knocked over or tops snapped off (Figure 9). Surface fire intensity remained high with almost complete consumption of the organic layer in most areas.

As the fire burned through the area east of Hazel Ave the many fuel breaks and discontinuous fuels seemed to limit the spread rate of the surface fire, leading to less surface and canopy consumption in this area (Figure 10). Furthermore, the area likely burned later than the southwest and central portion due to the fire spread containing a more easterly component.

As the fire progressed closer to town, firefighters reported needing personal protective equipment to have adequate protection from the periodic ember transport caused by the wind

gusts. The fire jumped the railway between Connaught Drive and Hazel Ave to two fuel patches on either side of a rock pile. Due to the low surface fuels, thinned and pruned trees the canopy consumption in these areas was minimal, though surface fire with flame heights of up to 2 m was observed. Ember production through these two areas was minimal compared to the area south of the track.

All structure ignitions north of the railway and Connaught drive were caused by wildfire embers and not direct flame or radiant heat. There was sufficient distance to eliminate potential for ignition due to direct flame contact or radiant heat in the transition to the urban area. However, there was evidence of potential pockets of forested areas threatening structures if defensive actions had not taken place along the cabin creek ravine. There was evidence that the northwest structure in the Patricia Place neighbourhood ignited due to a spot fire that started in the ravine and burned up to the northwest corner of the structure. Other than this location the other ignitions were started due to embers from the wildland or urban area as there were unburned green sections or large fuel free zones at the WUI of the other areas. Once the embers from the wildland started the urban conflagration, ignition of new structures was due to structure-to-structure radiant heat and flame progression or embers from upwind structures combined with wildland embers.

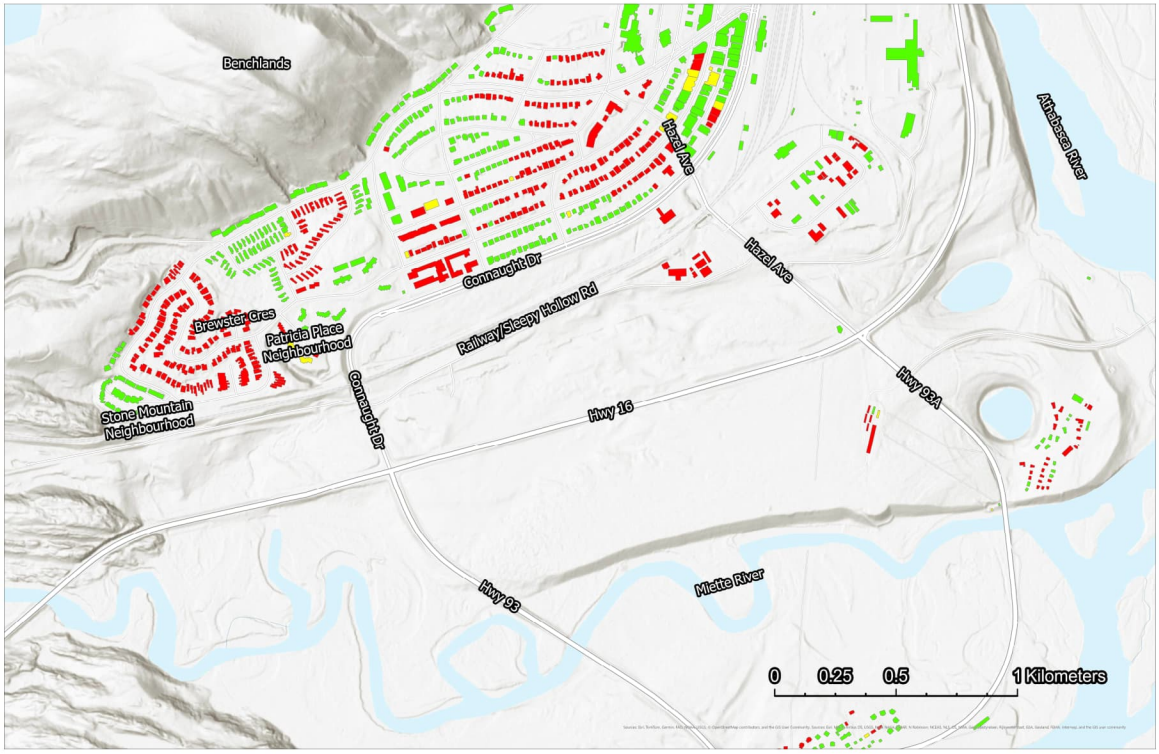

Figure 3: Jasper townsite location names for reference.

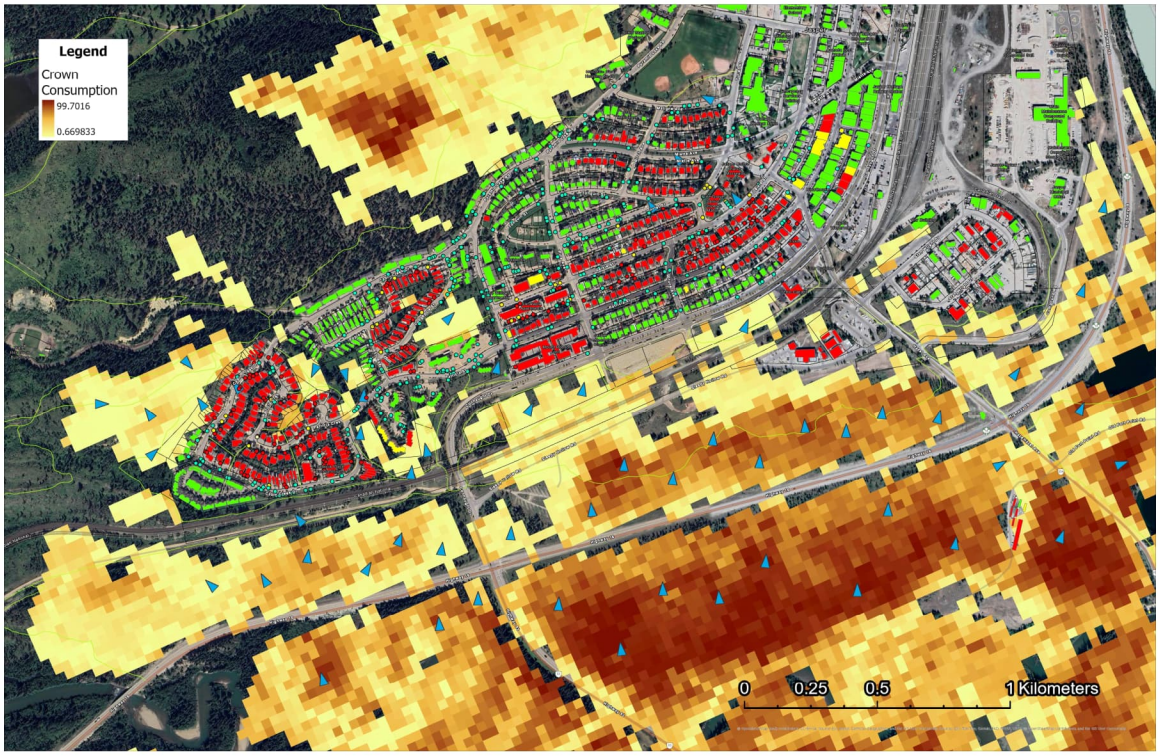

Figure 4: Jasper townsite. The degree of canopy consumption is shown with the coloured pixels while fire spread direction is shown with the blue arrows. The structures that are green have no easily visible fire damage, yellow have visible fire damage, and red are destroyed. Vehicle locations and condition represented by round dots following the same colour scheme as the structures.

Figure 5: Forest area surrounding the most southwest portion of the Jasper townsite.

Figure 6: View looking south of the forest area surrounding the most southwest portion of the Jasper townsite.

Figure 7: View looking northwest at the post-fire consumption of the wildland fuels leading up to the southwest side of Jasper townsite.

Figure 8: View looking southwest at the post-fire consumption of the wildland fuels approaching the southwest portion of the Jasper townsite.

Figure 9: View looking north at the post-fire consumption of the wildland fuels leading up to the central portion of the Jasper townsite.

Figure 10: View looking northeast at the post-fire consumption of the wildland fuels surrounding the northeast portion of the Jasper townsite.

5.2 Townsite vehicle survival

Previous post-fire and ignition research has indicated that vehicles and recreational units pose an ignition risk to the structures they are adjacent to. The typical rationale is that they are composed of rubbers and plastics which are combustible and once they achieve self sustaining combustion emit large amounts of energy. However, it is difficult to validate the assumptions in a wildfire context with a large and variable dataset. Many vehicles were left in large parking lots that surround the industrial area of town. These vehicles were left out of the dataset to compare similar exposure conditions. Furthermore, the type and number of vehicles in those parking lots could not be verified with appropriate accuracy. However, for the main analysis items such as ATVs, utility trailers, cargo trailers, motorhomes, other wheeled vehicles, and recreational units were included.

Figure 11 shows that as the distance between a burning structure and a vehicle increased the proportion of vehicles burned decreased rapidly ($P < 0.001$). After the 8.4 to <9.7 m bin, the differences between bins no longer passes statistical significance ($P > 0.05$). Only one vehicle burned at a distance greater than 13 m from the nearest burning structure. To follow up the multiple comparison analysis that was completed on the distance bins a logistic regression was created to allow for approximation of the proportion of vehicles that will burn at a specified distance from a burning structure (Figure 12). The logistic regression model values can be seen in Table 2 along with the equation to determine vehicle survival relative to distance from the structure. Given the strong correlation between distance from a burning structure and the loss of a vehicle while considering the hundreds of vehicles that did not burn unless they were very close to a burned structure, it is safe to assume that the burning structures most likely caused the ignition of the vehicles. Automotive tires are often identified as a weak point of vehicles and a potential source for their ignition. However, research on tire flammability suggests that they may

be difficult to ignite depending on their orientation, ignition location, and ignition source (Gratkowski, 2014).

Analysis including only the ignited vehicles was completed to determine if wind direction and the associated exposure from adjacent burning structures influenced vehicle ignition (Figure 13). At the closer distances there is no influence of directionality but as distance increases some trends for direction start to emerge. Once the distance to the nearest burning structure reached approximately 6.6 m a trend for directionality emerged where vehicles had the nearest burning structure upwind. A smaller proportion of vehicles at the greater distances have the nearest burned structure downwind.

A large portion of the dataset includes vehicles in laneways that were perpendicular to wind direction while the structures were burning. It is possible that at farther distances it is necessary to have more burning structures surrounding the vehicle to pass the threshold for ignition. The farther vehicles typically had rows of houses upwind of them that burned. It is difficult to determine if these trends are due to the orientation of the streets where vehicles were exposed or wind influence as some of the areas with significant structure and vehicle loss happened to run perpendicular to the wind direction or a combination of factors.

Lastly since all wheeled vehicles and trailers were included in the initial analysis they were further divided to see if any recreational vehicle or trailer types were more susceptible to ignition at farther distances from a burning structure (Figure 14). Once divided, sample sizes for each group became small (0 to 4) except for the motor vehicle group. Still, none of the subgroup recreational vehicles or trailers ignited at distances greater than 8.4 m from a burning structure within the townsite.

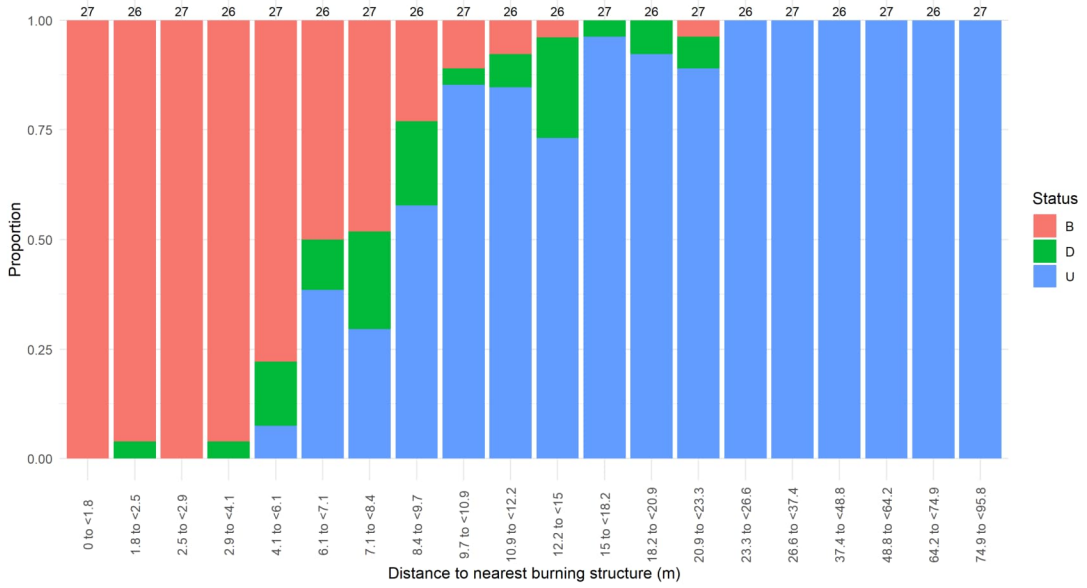

Figure 11: Motor vehicle status in the Jasper townsite relative to distance from the nearest burning structure. B stands for burned, D for damaged, U for unburned. The numbers at the top of each bar represent the number of vehicles in each distance bin. Vehicles with a distance greater than 100 m were not included in the analysis as none of them burned.

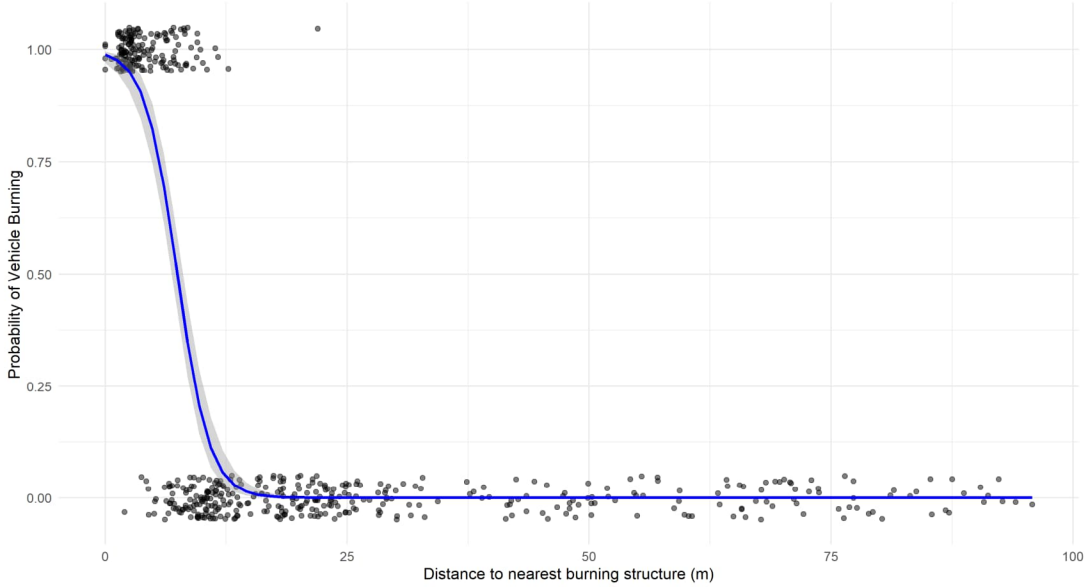

Figure 12: The probability of a vehicle burning relative to its distance from the nearest burning structure. The blue line shows the predicted probability obtained from the logistic regression model. The grey shading shows the 95% confidence interval. The points show the raw data used to fit the regression model and represent a value of 1 (burned) or 0 (unburned). They are distributed around their respective lines to show relative point density. Vehicles with a distance greater than 100 m were not included in the analysis as none of them burned.

Table 2: Vehicle survival logistic regression model values.

Logistic regression terms	**Estimate**	**Std error**	**Statistic**	**P value**
B_o	4.436561	0.486697	9.115659	7.82E-20
Distance = B_1	-0.59599	0.061988	-9.61455	6.94E-22
Equation:	$P(Distance) = e^{Bo+B1(Distance)}/1+ e^{Bo+B1(Distance)}$			

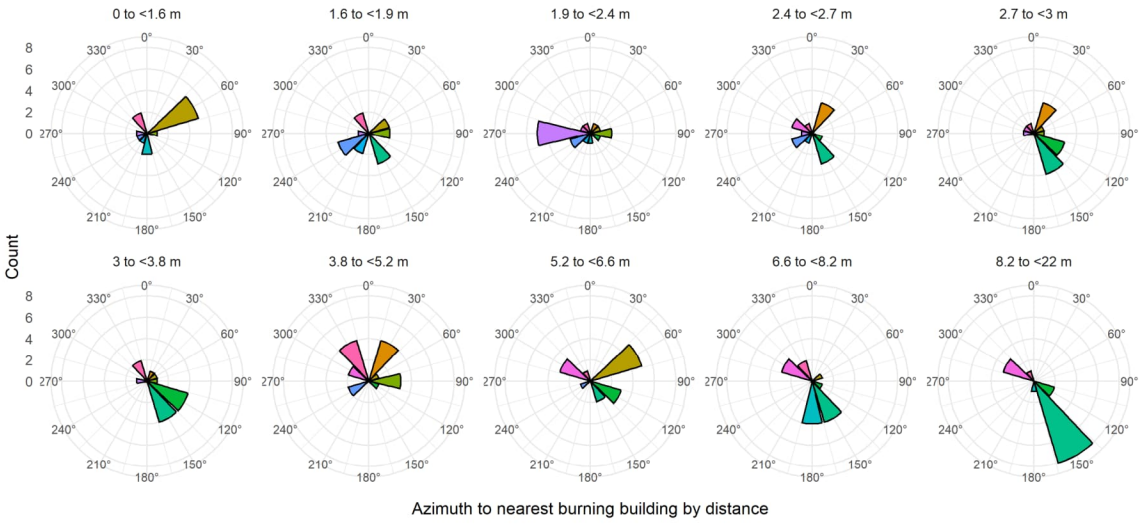

Figure 13: A subset of the burned vehicles split into equal sample size distance bins with the corresponding azimuth to the nearest burning structure. The length o the cone represents the number of vehicles and the colour represents azimuth bin to the nearest burning building.

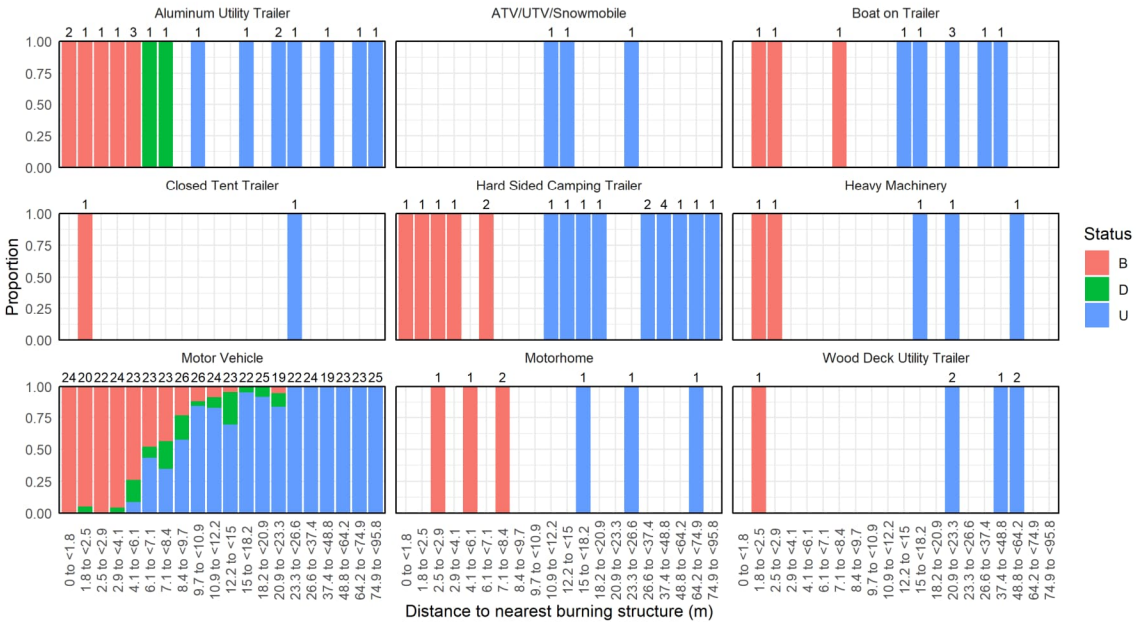

Figure 14: This figure shows all the motor vehicles split up by their main sub-types. With “motor vehicle” in this figure representing regular cars, trucks, and other motorized vehicles commonly found on roadways. B stands for burned, D for damaged, U for unburned. The numbers at the top of each bar represent the number of vehicles in each distance bin. Vehicles with a distance greater than 100 m were not included in the analysis as none of them burned.

5.3 General characteristics of burned and unburned structures

5.3.1 Paired structure assessments

Paired burned and unburned structures were assessed in the townsite to determine any differences that could lead to the ignition of one and not the other. Structures were put into groupings of burned or unburned structures and their proportions of individual characteristics were compared between groups. Due to similarities between the burned and adjacent unburned structures, we did not find any statistically significant differences in the characteristics of burned and unburned structures, regardless of whether individual or composite characteristics were assessed. Due to the number of structure-to-structure ignitions reported by firefighters and the burn patterns within the town it is unlikely that the structure on the edge of a burned cluster was where the ignition initiated in that cluster.

There was widespread evidence of heavy machinery use and other suppression efforts to limit the spread of fire from burning structures to other neighbouring structures. These efforts targeted burning structures adjacent to unburned structures, as well as burning structures surrounded by burned structures to eliminate potential ember sources. This made it difficult to determine when and where suppression took place relative to the burned structure and adjacent unburned structure targeted in the paired assessments. It was difficult for firefighters to recall exactly where and when suppression efforts took place as the environment did not allow for such observations to be easily collected or documented. All personnel were focused on eliminating spread and stopping additional ignitions, not on documenting where and when they occurred.

Accounts from firefighters did help to determine the initial ignitions in town and general progression of the events. For properties that were impacted through ignitions that seemed to either be self extinguished or put out by firefighters, the ignitions took place primarily in the following locations:

- Spruce or other conifer hedges (Figure 15),
- Dry grass leading up to the structure,
- Dry grass or other items that then ignited fences or other combustibles, and
- Mulch beds on the property or around the foundation of the main structure.

In addition, firefighters that were interviewed frequently mentioned rooftops as the initial ignition location of the structure. Multiple observations from different areas of town indicated that the roof material would catch fire, starting a chain reaction of structure-to-structure ignition. With the accounts of roofing material and structure-to-structure ignition taken into consideration further analysis was completed to identify factors that contributed to the urban conflagration that occurred across the southern part of the Jasper townsite.

Figure 15: Dense spruce hedge surrounding a property.

5.3.2 Structure survival within neighbourhood blocks

On average, approximately 42% of structures were destroyed within neighbourhood blocks across the southern part of the Jasper townsite, though there was considerable variation in impacts, which ranged from complete destruction (i.e., 100% loss) to no structure loss. The generalised linear model indicated that variation in the proportion of structures destroyed within a block was significantly correlated with the proportion of combustible roofs ($P < 0.001$), woody vegetation cover within the intermediate zone of structures ($P < 0.001$) and spacing between structures ($P = 0.013$). The proportion of combustible roofs had a strong influence on structure loss rates (Figure 16b). On average, loss rates were ~3 to 4 times greater in neighbourhood blocks that had a relatively high proportion of combustible roofs (e.g., >10%) than those with no combustible roofs (Figure 16b). Woody vegetation cover also had a strong effect on structure loss rate, with 2 to 4 times greater losses being associated with neighbourhood blocks that had relatively high (e.g., >20%) vs low (<10%) woody vegetation cover (Figure 16c). Distance to neighbouring structures had a moderate effect on structure loss rates, with proportionally fewer structures being destroyed as spacing between structures increased (Figure 16a). Examination of model residuals revealed that there was one outlier neighbourhood located between Lodge Pole Ave and Poplar Ave, where every structure was destroyed. Structures in this neighbourhood were predominantly mobile homes with ignition resistant roofing, but many other features that made the structures vulnerable to ignition (e.g., combustible siding, combustible decks). Removal of this outlier did not cause any meaningful change to the model.

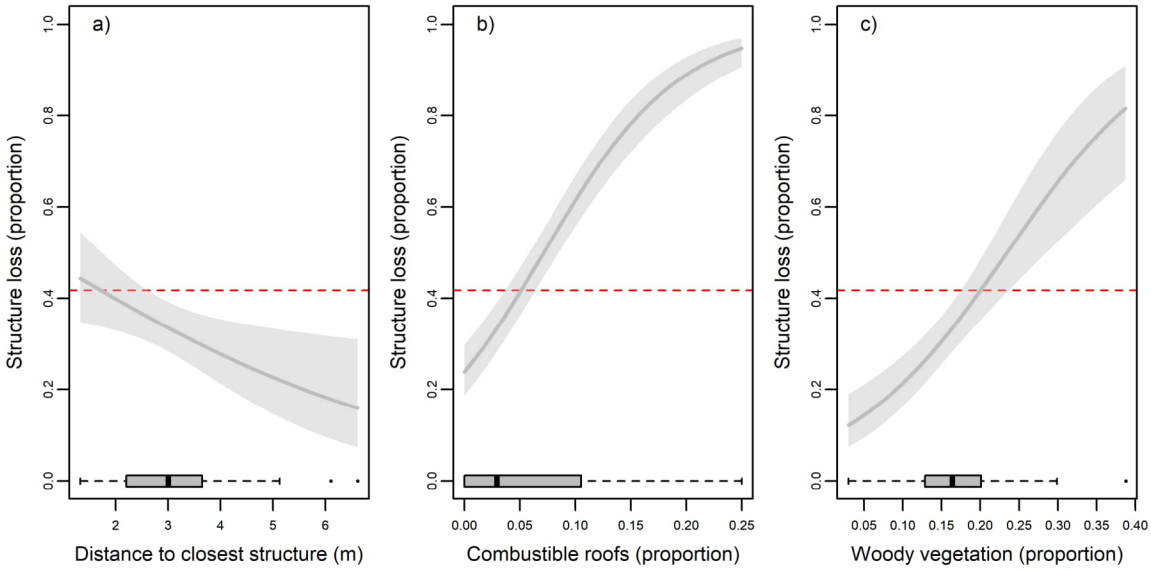

Figure 16: The modelled response of the proportion of structures destroyed within a block to (a) distance to closest structure, (b) proportion of combustible roofs within a block, and (c) proportion of the intermediate structure ignition zone that is covered by woody vegetation. Bold grey lines show the mean predicted proportion and the shaded grey areas show the 95% confidence intervals. The red dashed line shows the average rate of loss across the sampled population. Horizontal boxplots show the distribution of observations for each predictor variable. The boxplots show the median (black bar), upper and lower quartiles (grey box), 1.5x the interquartile range (whiskers), and outlying observations (points). Predictions were made with other predictors being held at their median value.

Pairwise assessments revealed some important differences between destroyed and surviving clusters of structures. For the exposure metrics, significant differences in the proximity to burned structures located upwind in neighbouring blocks were recorded for destroyed and surviving clusters, but there was no difference in metrics summarising the exposure to wildland fire (i.e., proximity to crown fire, proximity to burned wildland) (Figure 17a-c). The median distance to the closest burned structure located upwind was substantially smaller for destroyed clusters (median = 34 m) than surviving clusters (median = 134 m; Figure 17a). For the vulnerability metrics, significant differences were observed in the proportion of combustible roofs and woody vegetation cover in the intermediate SIZ, but not structure spacing (Figure 17d-f). Destroyed clusters had proportionally more combustible roofs than surviving clusters (Figure 17e). Three quarters of the destroyed clusters contained at least one combustible roof compared to 20% of surviving clusters. Woody vegetation cover in the intermediate structure ignition zone was generally greater in the destroyed clusters. Although there were small differences in median woody cover, there were substantial differences in the distribution of values: three quarters of destroyed clusters had woody cover greater than 15.3% whereas three quarters of surviving clusters had woody cover less than 16.7% (Figure 17f).

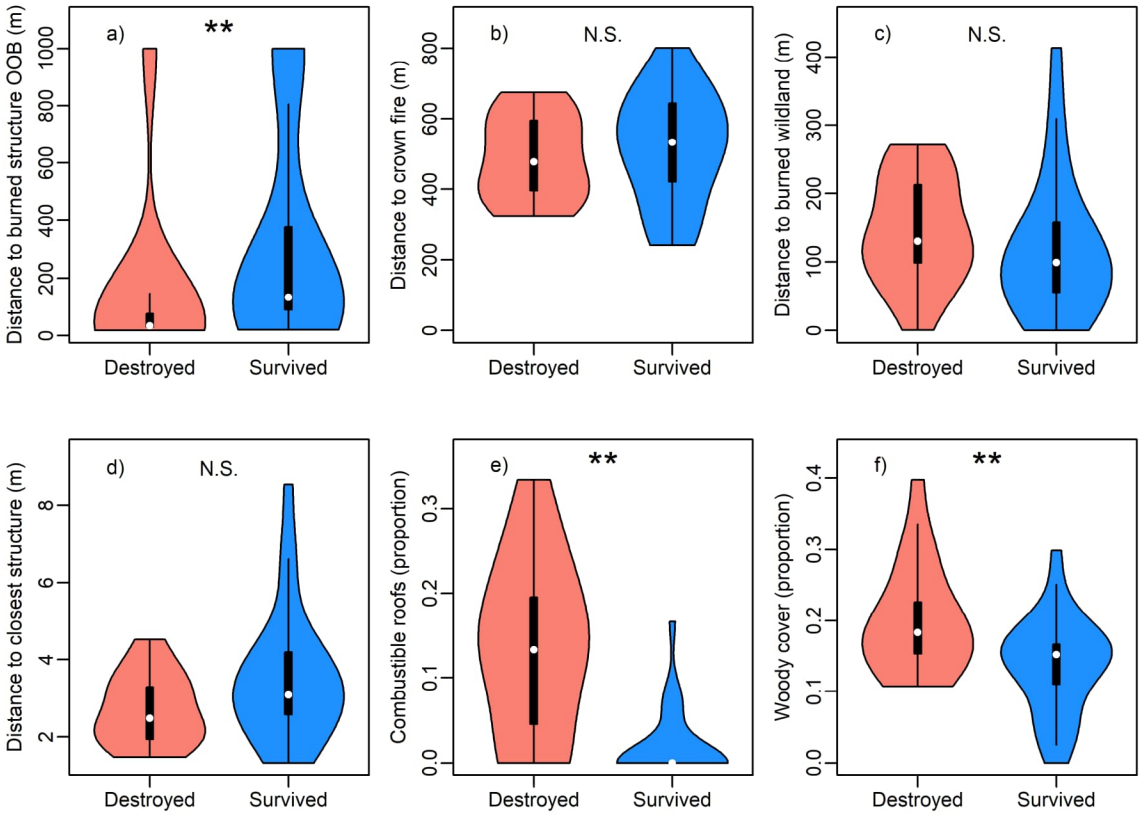

Figure 17: Characteristics of destroyed and surviving clusters of structures. The panels show violin plots for (a) distance to closest burned structure located upwind and outside of the block (OOB) containing the cluster, (b) upwind distance to the closest patch (>1 ha) of crown fire, (c) distance to the closest patch (>1 ha) of burned wildland vegetation, (d) distance to closest structure within the block containing the cluster of structures, (e) the proportion of structures in the cluster that had combustible roofs, and (f) the cover of woody vegetation within the intermediate structure ignition zone of structures in the cluster. Violin plots show the distribution of the data (mirrored vertical histograms) with embedded boxplots. The boxplots show the median (white point), upper and lower quartiles (black box), and 1.5x the interquartile range (whiskers). Symbols at the top of each panel show the results of the statistical comparison between destroyed and surviving clusters: *** (p-value < 0.001); ** (p-value < 0.01 – 0.001); * (p-value < 0.05– 0.01), and N.S. (p-value ≥0.05).

Densely developed neighbourhoods with small gaps between structures (e.g., < 5 m) are more vulnerable to urban conflagrations than those with adequate spacing (e.g., >20 m) and defensible space (Calkin et al., 2023; Knapp et al., 2021). Structure spacing across the residential areas in the southern part of the Jasper townsite was likely favourable for structure-to-structure fire propagation, with 90% of primary structures being within 5.4 m of a neighbouring structure. We tested this further by modelling the influence of proximity to burned neighbouring structures on the likelihood of destruction for individual structures, as opposed to the differences between clusters of structures as shown in Figure 17. The probability that a structure was destroyed was highly correlated with distance to the closest burned structure ($P < 0.001$). Buildings that were located within 5 m of a burned structure were very likely to be destroyed (Probability > 0.8), whereas those greater than ~20 m had a very low likelihood of destruction (Figure 18). This finding

highlights that housing arrangement within neighbourhoods of the Jasper townsite were favourable for structure-to-structure fire propagation. It is important to note that burning structures produce an elliptical field of exposure that is orientated with the prevailing winds (Purnomo et al., 2024). Therefore, critical separation distances for structure-to-structure spread will be dependent on the arrangement of structures relative to wind direction (Hedayati et al., 2024). In our analysis of structure spacing, we could not differentiate between downwind, crosswind, and upwind exposure sources. Therefore, we may underestimate critical separation distances when exposure occurs from burning structures located upwind, and overestimate distances for crosswind and upwind exposure.

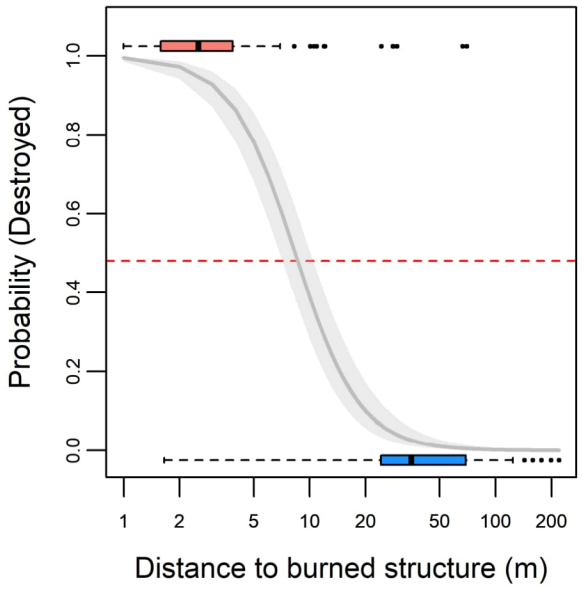

Figure 18: The modelled response of the probability of structure destruction in relation to distance to closest burned structure. Bold lines show the mean predicted probability and the shaded areas show the 95% confidence intervals. The red dashed line shows the average rate of loss across the sampled population. Horizontal boxplots show the distribution of observations for distance to burned neighbour for structures that were destroyed (salmon) or survived (blue). The boxplots show the median (black bar), upper and lower quartiles (grey box), 1.5x the interquartile range (whiskers), and outlying observations (points).

The results for the block and cluster scale analyses are consistent with contemporary understanding of the urban fire disaster sequence (Calkin et al., 2023). To summarise, initiation of urban fires can occur when extreme wildfire conditions overwhelm wildfire suppression, exposing structures to wildfire through flame contact, radiant heat, and embers. In communities with many vulnerable structures (e.g., combustible roofs) and little defensible space between structures, the number of ignited buildings can quickly exceed available suppression resources. Burning structures become an ignition source and fire can spread rapidly from structure-to-structure, culminating in an urban conflagration (Calkin et al., 2023). The positive correlation between combustible roofs and neighbourhood scale losses reported above suggest that these vulnerable structures contributed to the initiation and spread of fire within neighbourhoods of the Jasper townsite. The vulnerability of structures with combustible roofs is widely recognised

(Papathoma-Köhle et al., 2022; FireSmart™, 2023) as is their potential contribution to the development of urban conflagrations (Calkin et al., 2023). Furthermore, across the Jasper townsite, building spacing was generally insufficient to inhibit structure-to-structure spread, and this appears to have been exacerbated in neighbourhoods with higher (e.g., >20%) woody vegetation cover in the intermediate structure ignition zone (i.e., within 10 m of the structure). The maintenance of defensible space (i.e., areas of low fuel hazard) around structures increases their survival rates during WUI fires (e.g., Collins et al., 2024; Syphard et al., 2014) and is an important step towards limiting fire growth in urban settings (Calkin et al., 2023).

5.4 Commercially zoned structure ignitions

In the commercially zoned area north of Hazel Ave there were five ignitions that resulted in visible damage to the structures. All five of these ignitions were initiated by embers on the roof of the structures in the wood shake roofing material. One of the more destructive ignitions shown in Figure 19 resulted in the consumption of the entire upper portion of the roofing material and as the fire progressed, it started to burn down into the upper floor of the structure. Interestingly, the steeper section of the wood shake roofing material avoided ignition, potentially due to increased ability of the steep slope to shed any embers before they could smoulder into a sustained ignition.

Figure 19: Wood shake roofing ignited by embers in the commercial area of Jasper townsite.

5.5 Observations and analysis of Lake Edith Cottage District

5.5.1 Fire spread into and through area

As the fire approached Lake Edith from the south it first encountered Lake Annette (Figure 20). The fire burned intensely up the east side of Lake Annette and based on the spread direction there it is possible that embers were lofted over the lake to start spot fires on the northern side. There was intermittent surface burning on the northern side of Lake Annette with spread in random directions indicating that there was not a strong pull or prevailing wind in the low intensity areas between Lake Annette and Lake Edith.

There is a berm/ridge paralleling the west side of Lake Edith approximately 250 m west of the road. The fire burned intensely along the west side of that ridge. On the east side of the ridge up to the structures on the southwest side of Lake Edith, there was low intensity surface fire with little canopy consumption in most areas. There were two areas of high intensity burning between the two lakes. The first one was just north of the Lake Annette shoreline and west of the open grassland area. The other area was close to the shore near the southwest corner of Lake Edith.

The area near the southwest corner of the lake was approximately 1 ha and experienced full canopy consumption only 100 m from the first structure on the southwest side of Lake Edith. Given the spread and wind direction, this area likely sent a significant ember shower towards the two structures that were burned. As the fire progressed up the east side of Lake Edith it encountered lower density fuels resulting in less canopy consumption and a lower intensity surface fire. The low-density fuels paired with the high intensity fire burning farther to the east seemed to have a pulling effect and most of the spread directions were away from the structures on the east side of the lake. However, there was a change in wind direction to the north, when paired with continuous fuels of sparse conifers mixed with long grass, allowed for fire to spread into the intermediate and immediate zones of the structures that were lost on the east side of the lake.

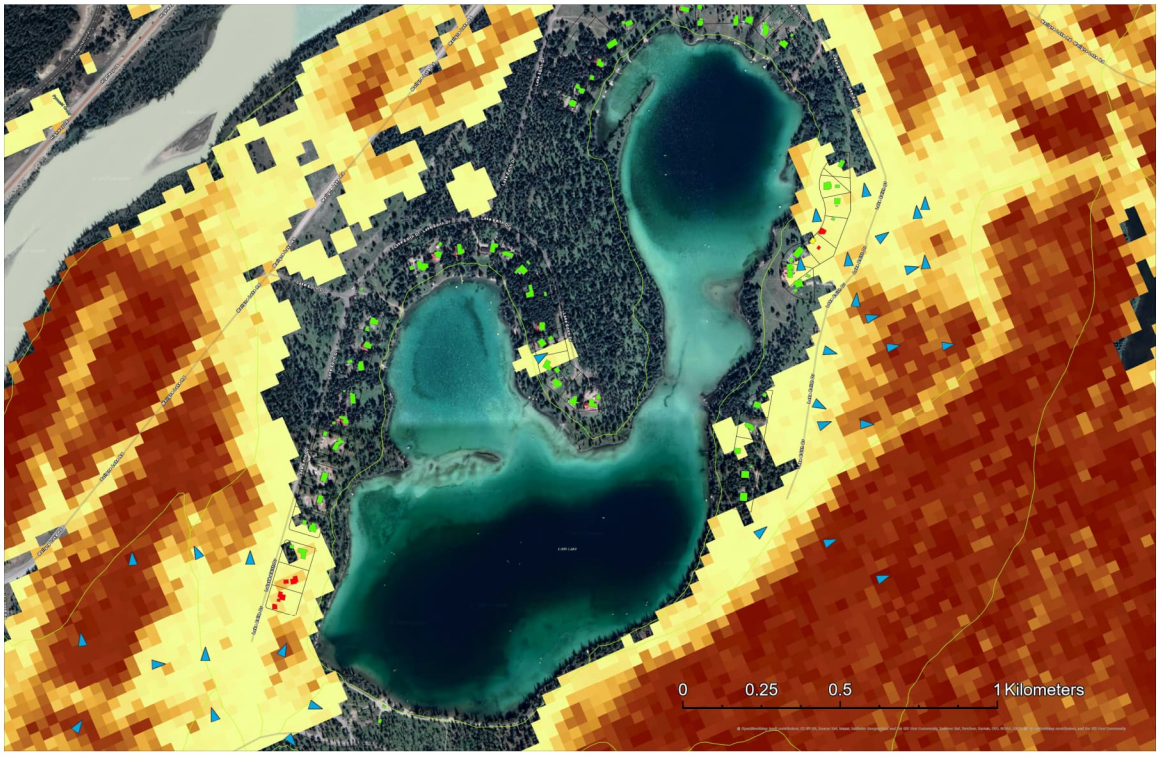

Figure 20: Lake Edith Cottage District. The degree of canopy consumption is shown with the coloured pixels while fire spread direction is shown with the blue arrows. The structures that are green have no easily visible fire damage, yellow have visible fire damage, and red are destroyed.

5.5.2 Burned and unburned structure characteristics

The first and second primary structures on Lake Edith Drive burned in the fire. The third primary structure did not burn. Some of the vulnerabilities present on these structures include:

- Grass right up to the foundation paired with wooden siding close to the surface,
- Large, burned conifers near the garages and one was snapped in half due to high winds,
- The garages were surrounded by dense conifers and had combustible fences attached, and
- Potential for structure-to-structure ignition from garages to main structures.

The third primary structure did not burn but still had fire damage to the raised garden beds with evidence of hose and sprinkler use in the area. The structure had combustible siding but there was a non-combustible vertical surface around much of the structure and the horizontal surface was raked clean of debris and did not have much fuel to ignite. It is possible that this structure was exposed to less embers than the other structures as there were fewer spot fires on this property when compared to the areas of the burned properties that were outside of where the burning structures would have had influence. There were single pane windows on the side of the structure that the fire would have approached from. Around the deck was well maintained but there were large accumulations of needles under the deck.

On the northeast side of the lake many of the structures surrounding those that burned were clean and free of fuels and debris around the base of the structure. One of the unburned structures had an ember ignition in two pieces of pergola roof joist that were bolted together. The ember got caught in the gap between them and burned away part of the joist. When the burning piece fell off the rest seemed to self extinguish. One of the structures was not exposed on its backside (Figure 21). Had it been exposed in this area instead of the front where spot fires had lit in the sparse grass it may have succumbed to the fire. The deck had tightly packed spruce seedlings surrounded by tall grass underneath it. The garage on this property was surrounded by conifers and other materials and ended up burning in the fire.

The neighbouring structure that burned had continuous fuel pathways from the roadside to it that were also burned. The structure likely had the following risk factors:

- Wood siding with long dead grass up to it,
- Continuous wildland fuel pathways in the immediate, intermediate and extended zones,
- Some of the conifers still had ladder fuels and low limbs, and
- A large deck on the backside of the structure with grass leading up to it and wood under it.

Figure 21: Dense seedlings and saplings around deck area of an unburned structure.

5.6 Observations and analysis at Jasper Park Lodge

5.6.1 Fire spread into and through area

The fire approached the Jasper Park Lodge property from the south with fire spread directions predominantly to the northeast. There was full canopy consumption leading up to the south side of the golf course and Beauvert Lake with embers likely lofted over portions of the lake to get to the spotting locations within the property. As the spot fires burned through the available fuel on the property they remained low intensity, likely due to the prevalence of well watered lawns and

firefighters on the property during impingement. The conifer patches between the golf greens experienced full canopy consumption in most areas with some mixed wood areas at the transition zones experiencing lower canopy consumption (Figure 22).

As the fire spread north of the golf course towards the structures in Thornton Village, on the northeast side of the property, the sparse canopy, pruning of lower branches, and minimal ladder fuel seemed to limit canopy consumption in this area. However, indicators of surface fire with average flame heights of 1-2 m and up to 4 m in some locations were still observed. Lower surface fire intensity was observed as the fire got closer to the southern structures in Thornton Village and jumped the road that leads to the golf course (Figure 23 and Figure 24).

There were multiple pieces of evidence for extreme winds around the property including downed trees along the lakeshore (Figure 25) and a large spruce tree snapped in half on the golf course. The wind damage was potentially exacerbated due to fuel free areas such as the lake and clearings around the golf course allowing for greater wind speed to develop near the surface.

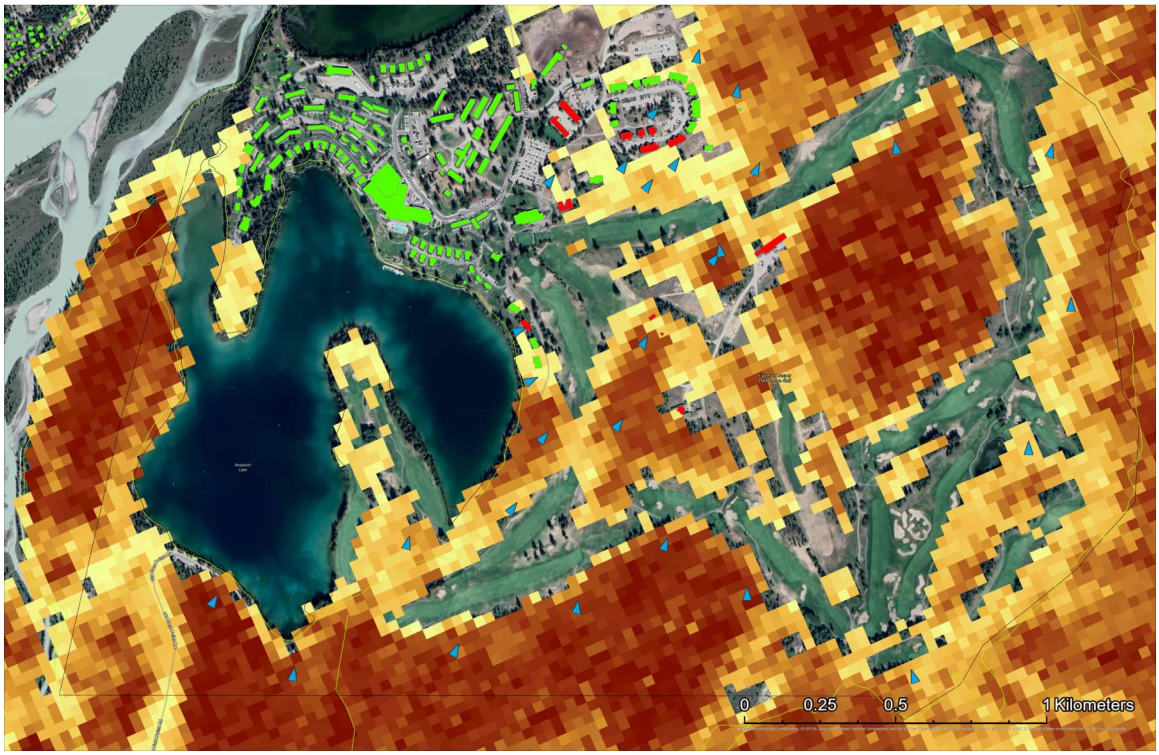

Figure 22: Jasper Park Lodge. The degree of canopy consumption is shown with the coloured pixels while fire spread direction is shown with the blue arrows. The structures that are green have no easily visible fire damage, yellow have visible fire damage, and red are destroyed.

Figure 23: Fire spread into the affected area of Thornton Village looking east.

Figure 24: Fire spread into affected area of Thornton Village looking northwest.

Figure 25: View looking east of the burned structure just northeast of Beauvert Lake at Jasper Park Lodge.

5.6.2 Burned and unburned structure characteristics

Assessments were completed on three areas of impacted structures with adjacent unburned structures. Several other areas in the golf course and maintenance areas experienced structure loss but did not have a suitable unburned pair nearby. The three assessment areas were the burned Mulligan Cabin and adjacent unburned structure to the east, the burned lakeshore structure and adjacent unburned structures, and Thornton Village. Embers landed in other areas of the property but did not result in ignition due to self extinguishment or actions of the firefighters.

The Mulligan Cabin (Figure 26) was burned and possessed the following vulnerabilities that were absent on its unburned pair:

- Coarse mulch beds surrounding the base of the structure on the 3 sides facing the fire,
- Deck frame made of horizontal logs embedded in the deep coarse mulch bed,
- Juniper or other flakey bark shrubs present on the sides of the structure, and
- Fir tree in coarse bark mulch against the structure.

There was some low intensity surface fire through grass near the edge of the golf course that resulted in consumption of some of the log fence. This was the closest evidence of spot fire spread, and it is likely that embers ignited in one of the vulnerabilities around the base of the structure. Furthermore, firefighter accounts place the initial ignition location low on the back side of the structure where the deck was. When it was observed, the deck was fully engaged with flames coming up over the roof.

The burned structure along the lakeshore was built identically to the surviving structures on either side of it, providing valuable data describing what the structure looked like before it burned. Several vulnerabilities present on the burned and adjacent unburned structures were:

- Coarse mulch bed with a fence in and over it that was attached to the structure on the windward side where embers likely came from (Figure 27),
- Mulch beds on either side with wood siding contacting the mulch in some places (Figure 28), and
- 2x6 and 2x8 wooden planter boxes with debris inside them on windward side balconies and on the ground on the leeward side of the structure.

It is important to note that ignition in these vulnerabilities is not certain and that randomness of where the embers fall paired with other variables influence whether the embers' landing location will result in the burning of the structure. Furthermore, several ignitions were noted in these vulnerabilities on the adjacent structures, however likely due to self extinguishment or firefighter actions they did not result in loss of the structure. Firefighters reported not being able to access this area safely during impingement due to downed trees and fire intensity. All four of the identical structures along the lake had three sprinklers setup on their roofs, with one on each end and one in the middle. The first two structures and the last two structures were on separate pumps that were getting water from the lake. During the extreme wind gusts, it is possible that the second pairs' (structures 3 and 4 when starting count from the southern most structure along the lake) water supply became compromised due to fallen trees. When it was safe for the firefighters to return to the area it was noted that the sprinklers on the 4th structure were not operating optimally.

The last assessment area at the Jasper Park Lodge focused on the structures in Thornton Village. There was little evidence left of pre-fire vulnerabilities surrounding the affected structures due to the use of heavy machinery to ensure extinguishment. Vulnerabilities were identified by locating areas and items on the remaining structures that had ignited but did not propagate to consume the structure. These could have either been self extinguished or extinguished by firefighters. The remaining structures were built similarly to those that burned (Figure 29) and were used to assist in the identification of vulnerabilities that could have been present on the burned structures. Some of the vulnerabilities include:

- Straw mats,
- Combustible items placed around the wooden staircases (Figure 30),
- Combustible shrubs and a large spruce planted up against the front of one of the burned structures,
- Organic debris buildup around the base of the structures (Figure 31),
- Wooden decking material (Figure 32), and
- Approximately 2 x 2 m gable vents to the attics where embers could potentially enter.

It is possible, especially for the southeast burned structure in Thornton Village, which had continuity of wildland fuels up to its southwest corner, that direct flame or radiant heat ignited the structure. However, it is likely that one of the vulnerabilities on or immediately next to the structure were ignited from wildfire embers. Accounts from firefighters at the lodge during impingement indicate that the fire spread through the top of most of the burned Thornton Village structures. However, it cannot be confirmed that the ignition did not start lower on the structure, such as on the large front wooden deck, and then moved quickly upwards. Additionally, the firefighters reported seeing embers from adjacent burning structures lofting into the large vents

at the top of the walls on the ends of the structures. As a result, they focused some of their efforts towards soaking the vents on the immediately adjacent unburned structures to with the intention to reduce the chance of additional ignitions. There was likely structure-to-structure ignition given the wind direction as the fire spread through the area.

Firefighters also reported ignitions on and around structures on the northwest peninsula of Beauvert Lake. Firefighters were able to extinguish all ignitions in this area and no structures were lost. Ignition locations were commonly reported in:

- Gutters with debris, and
- Mulch beds.

The ignitions in the Jasper Park Lodge areas that were assessed were largely caused by embers from the surrounding wildfire in vulnerabilities located on and around the structure.

Figure 26: Pre-fire image from the Jasper Park Lodge website showing the now burned Mulligan Cabin.

Figure 27: Vulnerability (mulch bed with fence attached to structure) present on the burned structure on the shore of Beauvert Lake.

Figure 28: Vulnerability (mulch under combustible siding) that was also present on the burned structure on the shore of Beauvert Lake. Photo of identical adjacent unburned structure to show likely state before burning.

Figure 29: Thornton Village structure characteristics example.

Figure 30: Extinguished ignition pathway on a surviving Thornton Village structure.

Figure 31: Ignited organic matter buildup around a surviving structure in Thornton Village.

Figure 32: Burning of a surviving structures deck in Thornton Village. Ignition likely started from an ember in the tight crack between the ends of the deck boards where the most mass loss has taken place.

5.7 Observations and analysis at Alpine Village Resort Jasper

5.7.1 Fire spread into and through the area

Ignitions occurred in the area due to wildfire embers that were lofted across the Athabasca River and the west side of Highway 93 (Figure 33). Tree and crown density on the southwest side of the property was more sparse than other areas to the north. However, the presence of significant ladder fuels throughout, feathermoss surface layer, and conifers with limbs to the forest floor allowed the fire to spread rapidly through the area with intermittent canopy consumption.

Spot fires developed randomly throughout the dense manicured spruce trees on the property (Figure 34), with unburned ones surviving right next to those that experienced full consumption. This effect was likely due to the prevailing winds and heat fluxes being pushed away from the surviving tree. This was also witnessed in several places in the wildland throughout the fire area (Figure 35). There were other spruce trees observed in isolation that had the bottom third fully consumed, the middle third charred, and the top third unaffected with angles of char pointing in the spread direction. The winds were likely strong enough that the top half of the tree was able to self extinguish as there was no evidence of firefighting activities in these areas.

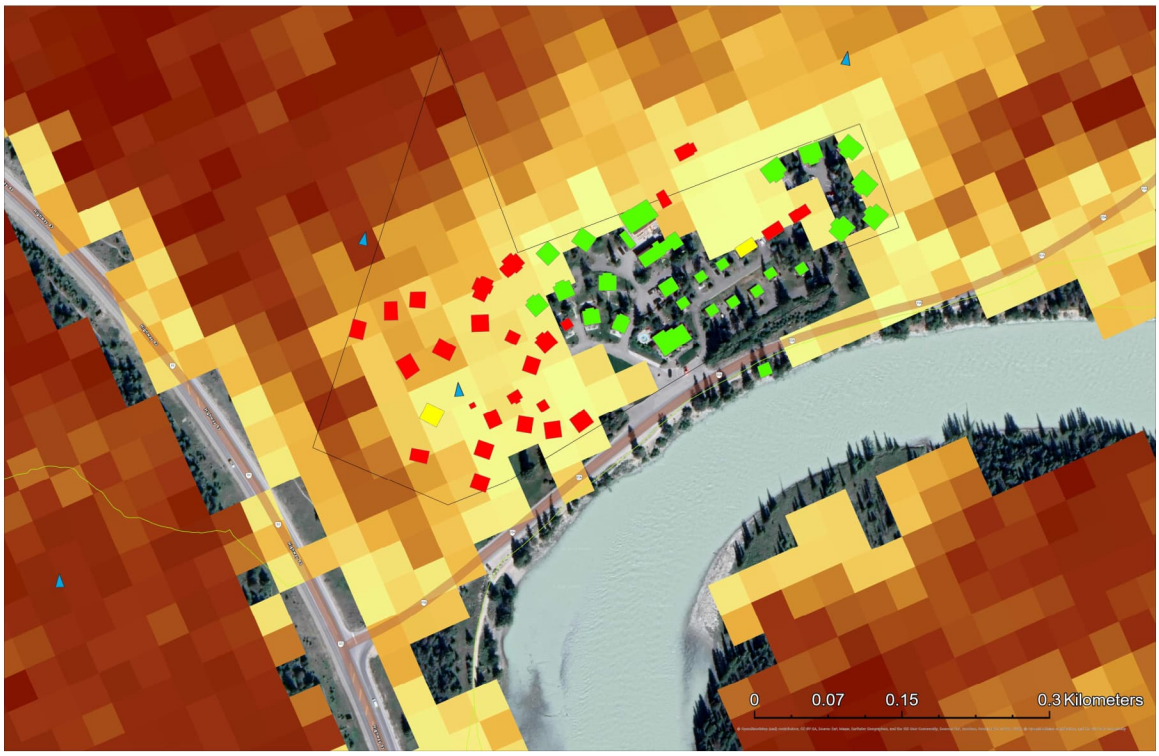

Figure 33: Alpine Village Resort Jasper. The degree of canopy consumption is shown with the coloured pixels while fire spread direction is shown with the blue arrows. The structures that are green have no easily visible fire damage, yellow have visible fire damage, and red are destroyed.

Figure 34: Full consumption of a manicured spruce next to an unburned tree of similar characteristics.

Figure 35: Example in the wildland showing consumption of trees between two unburned trees.

5.7.2 Burned and unburned structure characteristics

Only one structure was left standing in the southwest corner of the property (Figure 36). This structure assessment was paired with the burned structure immediately to the south of it. The structure that burned had similar build characteristics to the one that was unburned; however, it had continuous wildland fuels leading up to 3 of its 4 walls (Figure 37). The burned structure would have been exposed to direct flame contact from the intermittent crown fire that led right up to it. The intermittent to continuous crown fire persisted past the burned structure towards the unburned structure.

The unburned structure was showered with embers produced by the wildfire and neighbouring structures as evident from the numerous melting marks in the composite deck material and the ash marks on the walls facing the fire. However, the structure appeared to survive due to its build characteristics and differences in its exposure to the wildland fuels. Green grass and a roadway created a fuel break on the south side of the structure that extended around to its northeast side (Figure 37 and Figure 38). The structure had angled windowsills, composite decking with non-combustible post to ground mating surfaces and was far enough away from the smaller wildland fuels to its south to avoid direct flame contact. The structure did get slightly darkened on the wood fascia of the roof from the radiant heat, but it did not ignite the structure. Aside from the green grass at the front, the structure was free of any combustibles for more than 2 m surrounding the base of the structure, with much of the structure being surrounded by gravel.

The other burned structures had similar vulnerabilities to the burned pair such as:

- Continuous pathways of wildland fuels that burned up to the structure,
- Dense conifers growing around and over the structures, and
- Dense pruned spruce bushes on the front with mulch or needle litter under them with the branches touching the ground.

Figure 36: Surviving structure surrounded by burned structures:

Figure 37: Burned pair to the unburned structure on the southwest side of the property.

Figure 38: Close view of the side of the unburned structure showing the direction fire approached from.

5.8 Observations and analysis at Tekarra Lodge

5.8.1 Fire spread into and through area

The fire jumped the Miette and Athabasca rivers from the south of Tekarra Lodge. The property was impacted by spot fires that developed from the head of the fire. Intense surface fire with almost complete surface consumption developed quickly in the forested area between Highway 93A and the southern cluster of structures on the property. There were enough surface fuels to

promote 1-2 m flame heights through this area but with little canopy consumption due to the lack of ladder fuels. Spot fires ignited and began burning some of the southernmost structures and up the east side of the property. Surface consumption up the east side remained high with flame heights of 1-3 m. Once the fire made it to the denser wildland fuels near the northeast side of the property, the fire intensity increased, resulting in almost complete surface and canopy consumption. Surface and canopy consumption remained high on the northwest side of the property with a predominantly north spread direction. However, once it reached the northwest corner of the property there was a change in wind direction to the northeast leading the fire right into the structures in that area. This change in wind direction could potentially be due to burning structures or the high intensity crown fire on the east side of the property.

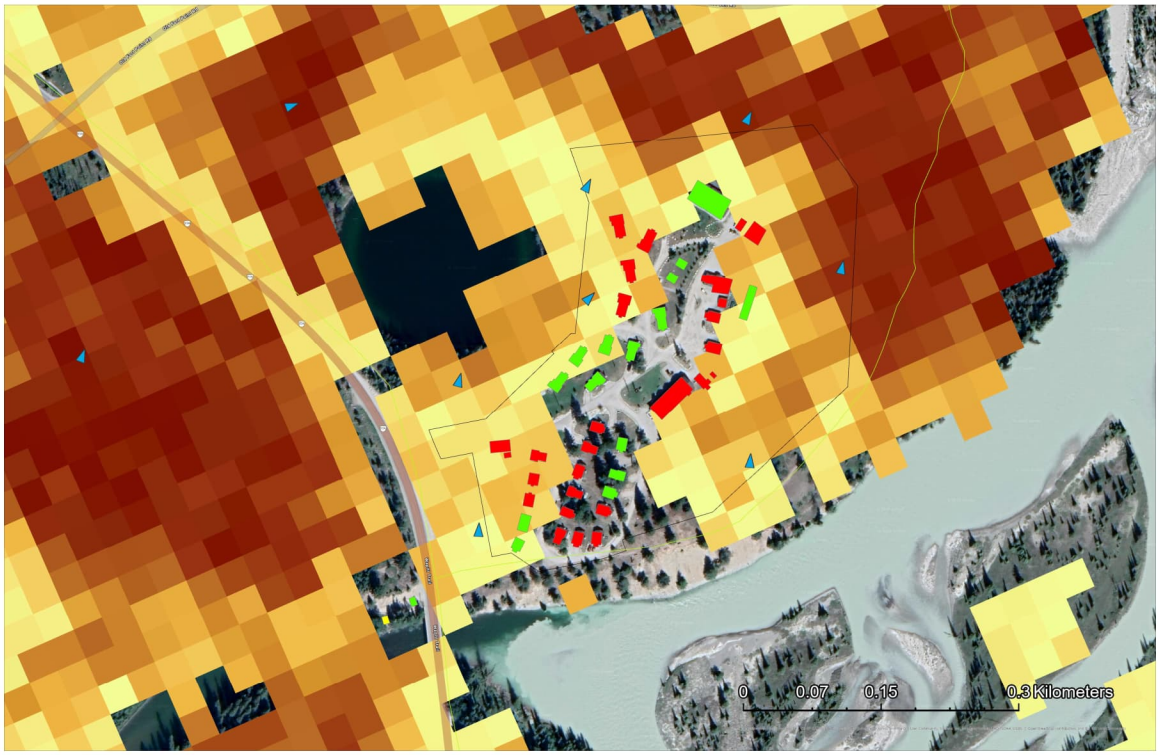

Figure 39: Tekarra Lodge. The degree of canopy consumption is shown with the coloured pixels while fire spread direction is shown with the blue arrows. The structures that are green have no easily visible fire damage, yellow have visible fire damage, and red are destroyed.

5.8.2 Burned and unburned structure characteristics

Most of the structures at the lodge were constructed in a similar way. They had asphalt shingles, partial gutters, wood siding down to the ground in most cases, and wooden decks that were open underneath them. The burned structures that were assessed had adjacent unburned structures with identical builds and orientation but different exposures to wildland fuels. The structures that burned in the southern portion of the property were situated under large conifer trees which had caused a deep build up of organic material such as needles, cones, and grass (Figure 40) which often extended to underneath the low lying wood decks that were attached to the structures and up to the siding. The unburned structures in the southern portion of the property largely still had

these vulnerabilities but the spot fires did not progress up to their foundation nor were they impacted enough by the other structures burning nearby to ignite.

The structures in the northwest corner of the property were assessed as they had suitable pairs adjacent to them that were built similarly but had different exposure and home ignition zone characteristics.

Common traits of the burned structures in the northwest include:

- Decks with wildland fuel and accumulation of litter around and under them on the west side of the structures,
- Continuity of burned wildland fuels up to the west side of the structures (Figure 41, Figure 42, and Figure 43),
- Combustible siding and features that extend to ground level, and
- Indicators that initial ignition and mass loss of the structure occurred on the western walls that were directly exposed to burning wildland fuels. Fridges within these structures fell towards the wildland fuels, suggesting that the western wall and floor gave way before other parts of the structure.

There was a large propane tank in the forested area west of the burned structures, however it was unburned and still slowly venting propane when the assessments were completed. Therefore, it does not appear to have influenced the burning of the structures.

Common traits of the unburned structures include:

- Green grass up to the base of the structure,
- Presence of roads between the structures and adjacent wildland fuels, providing a complete fuel break,
- Minimal combustible fuel leading up to the base of the low-lying decks,
- Larger non-combustible foundation distances between the ground and combustible siding, and
- The fire on the other side of the road was moving parallel to them and not towards them.

After the wildland fuels burned up to the structures or embers ignited vulnerabilities surrounding them, structure-to-structure ignition likely occurred on the property in areas where structures were near one another.

Figure 40: Image from Tekarra Lodge Facebook page showing pre-fire fuel conditions around the southwest side of the property.

Figure 41: Looking south from the northwest side of Tekarra Lodge. The burned structures were built similarly to the two seen in the background.

Figure 42: Continuity of wildland fuels on the west side of the burned structures in the northwest portion of Tekarra Lodge.

Figure 43: Larger scale view of the wildland fuels leading up to burned structures in Tekarra lodge.

5.9 Observations and analysis at Beckers Chalets

5.9.1 Fire spread into area

Beckers Chalets was exposed to wildfire embers produced from the south on both sides of the Athabasca River. No direct flame or radiant heat damage occurred on the structures around the periphery of the property and the vegetation remained green and unaffected. Before the fire arrived, some sprinklers were setup to assist in protection but the highway, topography on the west side of the highway, and the river likely mitigated most of the direct fire exposure from the area outside of the property. There was minimal evidence of wildfire embers igniting any spot fires within the property as most of the surface was covered by well maintained green grass. Many of the trees on the property were limbed to at least 0.5 to 1 m, above an area with minimal surface fuels, and spaced at distances that would reduce crown fire spread.

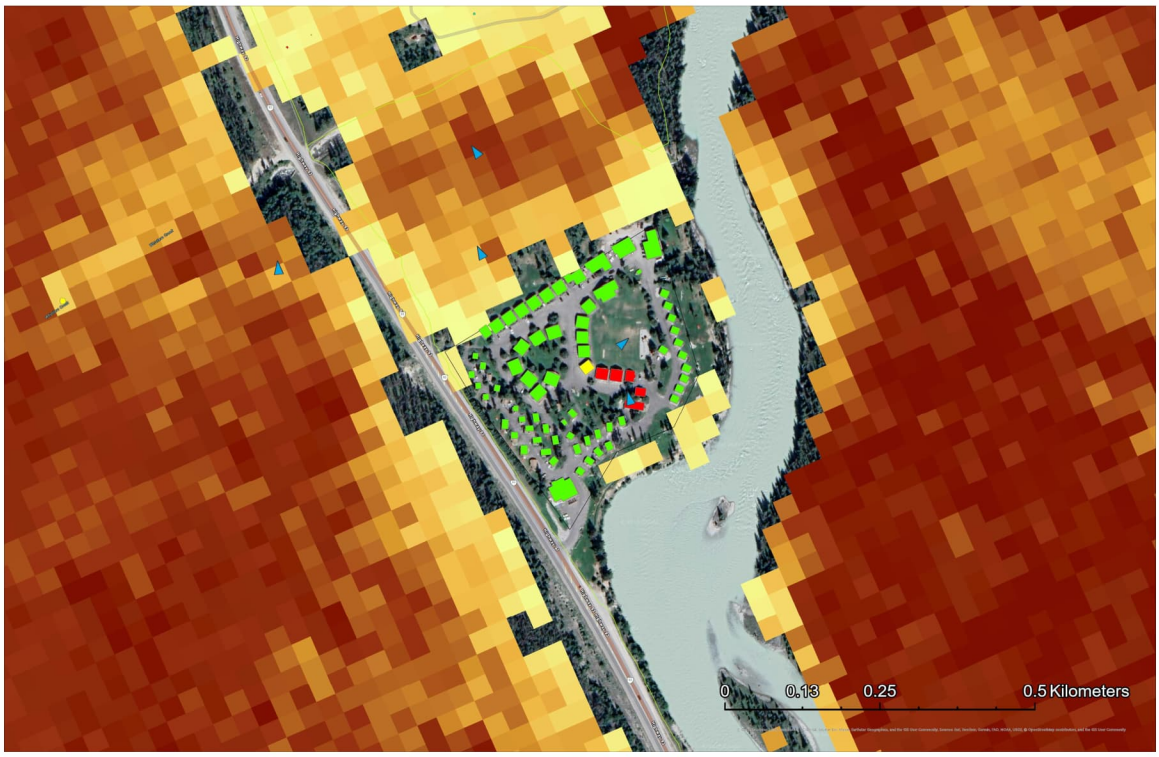

Figure 44: Beckers Chalets. The degree of canopy consumption is shown with the coloured pixels while fire spread direction is shown with the blue arrows. The structures that are green have no easily visible fire damage, yellow have visible fire damage, and red are destroyed.

5.9.2 Burned and unburned structure characteristics

Many of the structures were constructed similarly with asphalt shingles, wood siding, and sufficient vertical clearance of the foundation above the surface (Figure 45). However, many of the structures had vulnerabilities such as densely pruned spruce shrubs up against their fronts with coarse bark mulch underneath them. Considering the spread direction indicators

surrounding the ignited structures, the first structure to ignite was likely the most southern burned structure. This structure had several vulnerabilities around it such as bark mulch and dense conifers. Once ignited, flames and radiant heat emanating from the structure likely impacted neighbouring structures to the north. Charring on the road north of the first two burning structures indicated that flames and radiant heat contributed to the ignition of the farthest east structure of the three burned structures located on the north side of the road. The farthest east structure in that group had conifers with mulch under them that were likely ignited by the structures to the south.

Once the farthest east structure on the north side of the road ignited, there was likely structure-to-structure ignition occurring as the fire made its was through each subsequent structure to the west. During the time it took the fire to progress through those structures, the fire on the east side of the river was likely starting to exhibit a pulling effect on the air in Beckers Chalets. This was observed through changes in the azimuths of the heat affected grass on the north side of the burned structures. Once the fire reached the farthest west burned structure north of the road there was wind pushing the heat and flames to the northeast. The change in wind direction combined with increased spacing and change in structure orientation likely led to the damaged structure (yellow coloured structure in Figure 46) surviving.

The damaged structure was still exposed to significant embers from the adjacent burning structure as seen in Figure 47, but it did not ignite the mulch fuel underneath the window. The wall facing the adjacent burning structure was blackened by radiant heat, but it was not sufficient to break or displace the windows. However, the outside panes were cracked while remaining in position and the plastic window frame had sagged enough to open air gaps in both the top and bottom storey windows. The charring on the exposed side of the damaged structure decreased substantially as the distance between them increased from 5 m to 14 m due to their relative angling.

Factors likely contributing to structure loss included:

- Combustible material such as mulch and organic litter around the base of the structures,
- Coniferous vegetation surrounding structures, and
- Close distance between structures leading to structure-to-structure propagation.

Figure 45: Picture from Beckers Chalets Facebook page showing an elevated view of the property pre-fire.

Figure 46: Structure with visible damage (yellow structure on the area map) adjacent to the burned structures.

Figure 47: Mulch bed beneath window of structure with visible damage adjacent to the burned structures.

5.10 Observations and analysis in the Whistlers and Wapiti campgrounds

5.10.1 Fire spread into and progression through area

The fire spread directions surrounding Wapiti campground indicate that wildfire embers were likely lofted into the area from the south and west side of Highway 93. The intense fire burning on the opposite side of the Athabasca River could have pulled air towards it to give an easterly component to the winds. Numerous spot fires were distributed throughout the campground with some growing larger before they encountered roads or pathways. In addition, there were likely spot fires caused by fuels within the campground through torching and canopy consumption driven by the high winds. General progression through the campground was in the north-northeast direction (Figure 48).

Similar trends can be seen in the southwest portion of the Whistlers campground which experienced wildfire ember exposure from the south and south-southwest directions. In the northwest half of the campground conifer fuels were more continuous, with many of the conifer patches experiencing intermittent to full crown fire with complete canopy consumption. Embers produced from these sections likely drove the spot fire production through the northern half of the campground as the fire outside the campground had spread directions that were parallel with the exterior road around the campgrounds western side. Spread directions through the northern half of the campground shifted direction to the north-northwest.

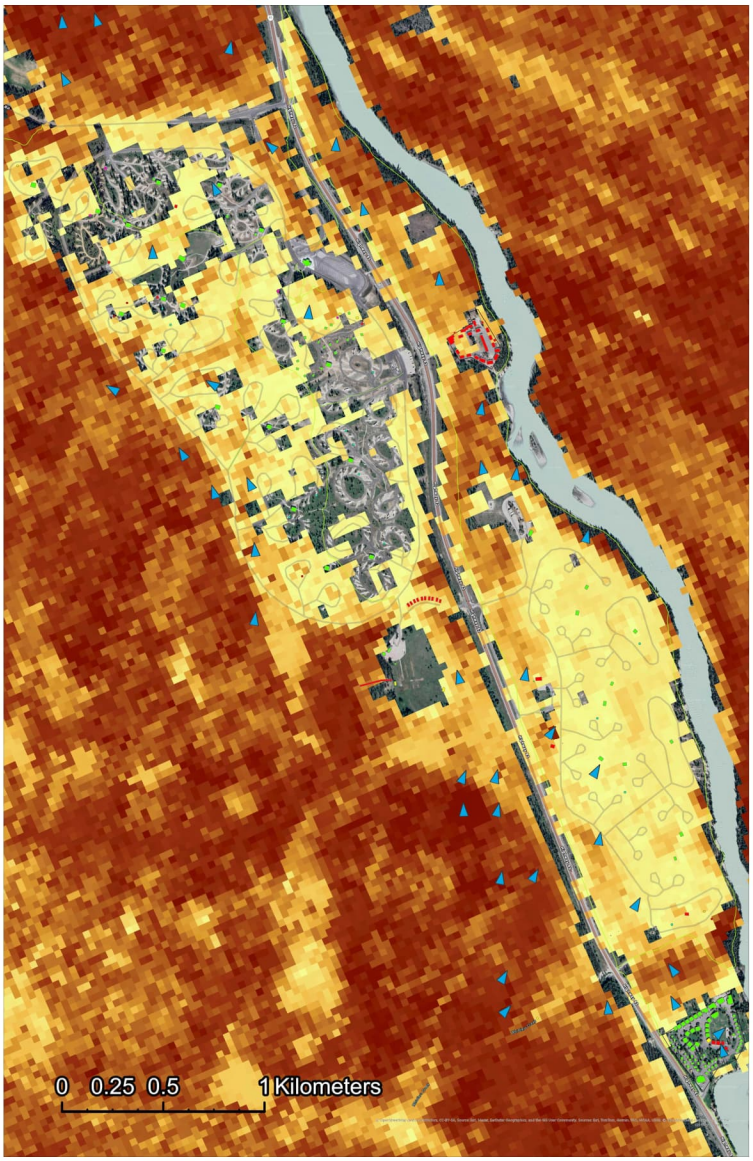

Figure 48: Whistlers and Wapiti Campgrounds. The degree of canopy consumption is shown with the coloured pixels while fire spread direction is shown with the blue arrows. The structures that are green have no easily visible fire damage, yellow have visible fire damage, and red are destroyed. Dots for trailer locations follow the same colour convention as the structures.

5.10.2 Burned and unburned structure characteristics

The only structures lost in the campground were the cook shelters and the staff cabins. The cook shelters were often beside the newer washroom structures and would have been exposed to similar wildfire ember and surface fire conditions. The paired cook shelters had similar vulnerabilities, but different exposure, as the fire did not spread near the unburned ones. The main vulnerability noted on the cook shelters was the high-density of spruce seedlings and saplings growing around the base of the structure and in some cases there were branches pulling up the metal siding (Figure 49 and Figure 50). The cook shelters had metal siding over plywood and were elevated on a concrete foundation. There was vertical separation of approximately 10

cm on both the outside and the inside of the structure before reaching combustible material. If a non-combustible perimeter was established around these shelters, they would likely be much more resistant to wildfire embers and low intensity surface fires.

The newly constructed washrooms have concrete sidewalks around their base, non-combustible siding, and metal roofing materials and none of them burned. Conversely the staff cabins located on the south end of the Whistlers campground all burned. Some of the vulnerabilities that were identified on the staff cabins were:

- Open foundation with sheets of wooden lattice to cover it,
- Footings for the trailer style structures were built with 2x4s in log cabin configuration,
- Cabins were close together and every other cabin was connected by a deck,
- Spacing between structures connected with a deck was approximately 5.5 m and distance between non-connected structures was 8-12 m, and
- Dead grass was present around the structures.

The area to the south, across the road from the cabins, experienced crown fire and over 50% canopy consumption. It is unlikely that this area had flames that reached the cabins, but they would have been exposed to large amounts of wildfire embers that were able to blow under the open foundations of these structures.

Figure 49: Burned cook shelter in Whistlers campground showing spruce seedlings and saplings growing up against structure.

Figure 50: Unburned cook shelter in Whistlers campground with similar spruce fuels growing near its base.

5.10.3 Recreational trailer survival in Whistlers, Wapiti, and Wabasso campgrounds

The trailers left in the Whistlers, Wapiti and Wabasso campgrounds provided a unique dataset for trailer exposure while they were setup in a camping configuration. This would mean that trailers were exposed to wildfire in more vulnerable states such as tent trailers with their beds out, awnings extended, and camping items placed around them. There were insufficient data to analyse individual styles of trailers as there were 31 trailers left in the campgrounds. Of those 31 trailers only 6 burned:

- 1 motorhome,
- 2 hard sided camping trailers, and
- 3 setup tent trailers.

A Chi-Square test was used to test for differences in trailer destruction with distance from fire. Only the nearest crown fire ($P < 0.001$) and nearest 1 ha patch of fire ($P = 0.0369$) had statistically significant differences in the distance bins for exposure. The 1 to <11 and 11 to <27 m distance bins for the nearest crown fire were significantly different than all other bins ($P < 0.05$) but were not significantly different from each other. For the nearest upwind fire only the 0-26.5 m distance bin was significantly different from the 147.6-349.9 m distance bin ($P = 0.0058$) (Figure 51).

All the trailers that burned were either exposed to direct flames or significant radiant heat and ember production due to crown fire within approximately 20 m of the trailer, with only one trailer burning at a distance >11 m to the nearest crown fire. There were several times where moderate intensity surface fires with intermittent crowning burned right past the trailers or caused multiple burn holes in the trailer's fabric (Figure 52 and Figure 53). However, they seemed to be resistant to this type of exposure both in the townsite and in the campgrounds.

One of the trailers was exposed to an extreme amount of heat with fully consumed mature conifers all around it. This trailer was the convenience/coffee stand usually positioned near the playground and amphitheatre. The trailer likely had some damage on the interior that could not be observed. However, the highly polished aluminum exterior seemed to reflect much of the radiant heat away from it instead of absorbing it. The plastic lights on the exterior experienced significant melting due to the heat and would likely not function anymore (Figure 54).

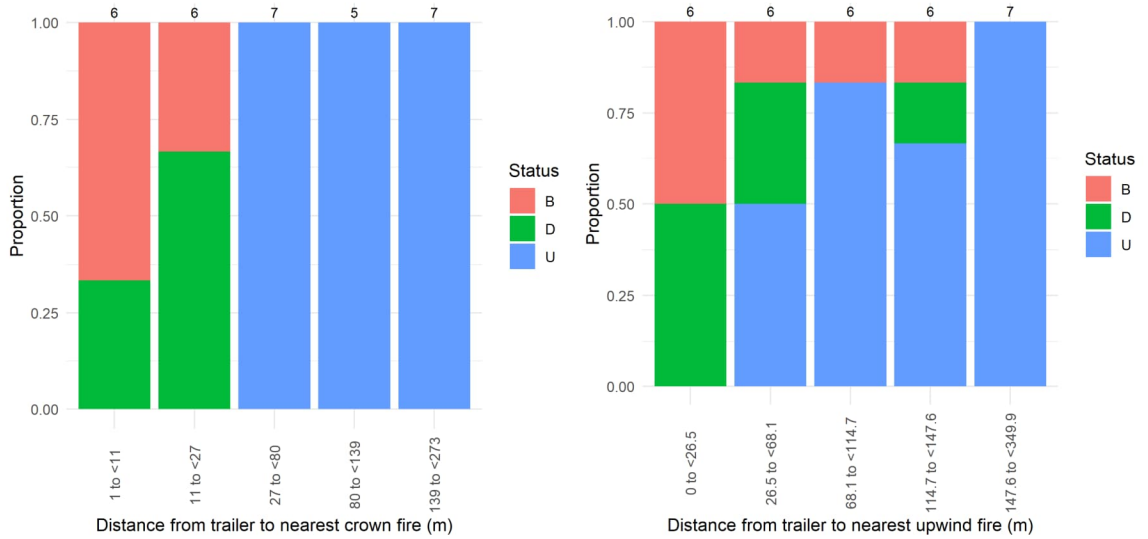

Figure 51: Trailer survival vs. distance to nearest crown fire and nearest upwind fire. B = burned. D = damaged. U = unburned. Numbers at the top of each bar represent the number of samples within that distance bin.

Figure 52: Surviving but damaged truck with hybrid hard and soft-sided camper with high intensity surface and intermittent crown fire leading up to and around it.

Figure 53: Hard sided trailer with moderate intensity surface fire surrounding it.

Figure 54: Minor damage to aluminum clad trailer that was surrounded by full canopy consumption crown fire in mature trees.

5.11 Observations and analysis at Pine Bungalows

5.11.1 Fire spread into and progression through area

The head of the fire did not spread into the Pine Bungalows area and wildfire embers likely entered the area from the east side of the Athabasca River (Figure 55). Once the embers landed within the property there was minimal surface fire spread, with many isolated spot fires. There was not enough surface fuel to carry the fire and not enough ladder fuels to carry any of the low intensity surface fire up into the canopy (Figure 56). Spots fires were able to consume isolated juniper bushes and the surrounding vegetation mostly in the area between the river side cabins and the river. A few of the larger spot fires (Figure 57) were not able to progress close enough to the cabins through the very sparse fuels to cause any damage. There were many unburned mulch pathways between the cabins and the river. They seemed to resist burning due to the compaction from repeated walking on them and the small particle size that allowed for more compaction.

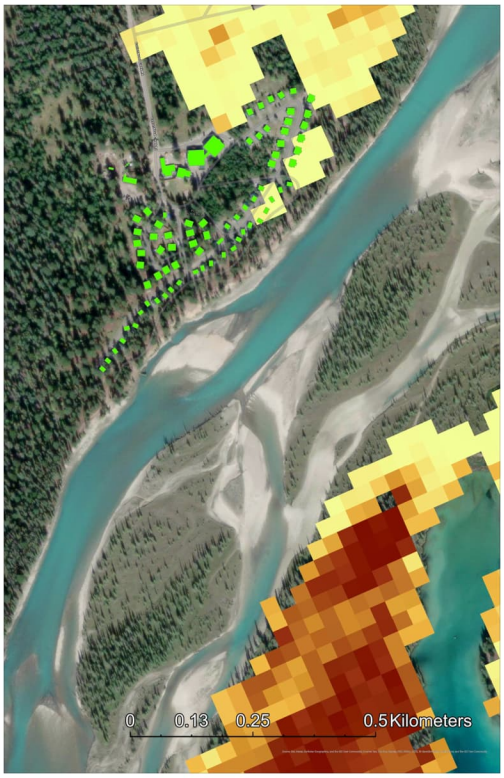

Figure 55: Pine Bungalows. The degree of canopy consumption is shown with the coloured pixels. The structures that are green have no easily visible fire damage.

Figure 56: Spot fires between the Pine Bungalows and the Athabasca River.

Figure 57: Spot fires near the Pine Bungalows along the Athabasca River

5.11.2 Unburned structure characteristics

None of the structures burned on the Pine Bungalows property. Structures were assessed for characteristics near the areas with the highest density and intensity of spot fire occurrence. The structures possessed metal roofs without gutters. Siding was wood with a non-combustible surface of larger rocks around the base of the structure. There was minimal vertical separation between the surface and the wood siding. However, many of the structures seemed to have overgrowth of live grass and herbaceous plants within the rock area surrounding the base of the

structure (Figure 58). Most of the plants were green and moist, potentially due to the absence of gutters on the structure, leading to increased moisture at the base of the structure for plant growth (Figure 59). Farther beyond this zone there was very sparse fuel that seemed to prevent spot fire progression up to the structures.

Figure 58: Fuel condition and load around the Pine Bungalows.

Figure 59: Typical fuel around the Pine Bungalows.

5.12 Observations and analysis at Jasper House Bungalows

5.12.1 Fire spread into area

The fire approached the Jasper House Bungalows property from the south with high fire intensity and canopy consumption over 80%. The south side of the property had wildland fuels within 10 m of the structures (Figure 60). Due to the intensity of the fire leading up to the property, the wildfire likely showered the structures with many embers before the head of the fire reached the structures on the south side of the property.

Figure 60: View of the Jasper House Bungalows property pre-fire. Only the maintenance structure on the top middle and main structure in the top left have asphalt shingles. The rest of the structures have wood shake roofs.

5.12.2 Burned structure characteristics

All structures burned on the property; therefore, general characteristics were collected instead of implementing the paired structure approach. Only two of the structures on the property had asphalt shingle roofing material and they were near sheds or other structures with wood shake roofing material. The foundation and immediate zone of the structures were clean and free of fuels (Figure 61). The risk factors for the structures were the log cabin construction and the wood shake roofing material. Ignitions on the roof material and structure-to-structure ignitions were likely large contributing factors to the loss of all structures on the property.

Figure 61: Picture from Jasper House Bungalows Facebook page showing the pre-fire condition and structure characteristics of the cabins.

6 CONCLUSIONS

The Municipality of Jasper and surrounding areas experienced a devastating wildfire that burned through the affected areas on July 24, 2024. Many structures were destroyed and the landscape of the National Park was drastically altered. The social and environmental impacts of the Jasper fire will be felt for many decades to come. Extreme and destructive events of this nature are becoming increasingly more common across North America (Higuera, et al. 2023). Learning from these events will be important for identifying and implementing actions that can increase the resilience of WUI communities to wildfire in the future. Key lessons learned from the Jasper Wildfire include:

- Severe winds and long-range spotting allow wildfire embers to enter urban areas from forests located far away from the wildland urban interface.
- Collapse of the convective column resulted in significant exposure to communities from wildfire embers. Predicting when and where these type of events will occur is beyond the scope of predictive tools that are used operationally (e.g., Burn P3). Quantifying and managing risk associated with column collapse is extremely challenging.
- Once wildfire embers cause ignitions in a community, structure vulnerability is a function of the location of that structure relative to its neighbours and the cumulative vulnerabilities of a cluster of structures that can support structure-to-structure spread.
- Wood shake roofing materials and their commonly associated structural characteristics increase the risk of ignition for a cluster and individual structures.
- After embers from the wildland caused many ignitions in the townsite, progression through the town was dominated by structure-to-structure ignition.
- Similar ignition pathways were observed in the case study areas surrounding the townsite but with a much higher proportion of ignitions caused by direct flame contact and radiant heat from the continuous wildland fuel pathways up to the affected structures.
- Common traits of burned or partially burned structures/properties included:
    - Combustible roofing material,
    - Proximity to another burned structure,
    - Continuous pathways of fuels up to the structure,

    - Combustible materials near and at the base of the structure such as mulch, trees, and shrubs,
    - Combustible material under and around decks, and
    - Long dead grass or other fuels leading to combustible vertical surfaces on the structure.
- During the Jasper Wildfire, motor vehicles and recreational units were not a risk to the ignition of the structures and contrarily the structures caused vehicle and recreational unit ignition.
- Future research would benefit from implementation of technology that allows firefighters to better document where and when defensive actions took place for each structure without increasing their task load.

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