The Bulkley Morice Wildfire Resilience Project

KNOWLEDGE REPORT

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Definitions

This section[1] presents a glossary of key fire-related terminology utilized in this report, as well as terms frequently encountered in the fields of wildland-fire science and management.

While we have made an effort to use standard terms throughout, we acknowledge that alternative definitions and terminology may exist in different jurisdictions and within the broader literature. Therefore, the definitions provided here apply specifically to the context of this report.

Age class is an interval into which the age range of trees, forests, stands, or forest types is divided for classification. Forest inventories commonly group trees into 20-year age classes.

Anchor Point is an advantageous location, usually a barrier to fire spread, from which to start or finish construction of a control line. It is usually a secure, strategic location, such as a road, river, or ridgeline, that serves as a stable starting or ending point for control lines during wildfire suppression efforts.

Biogeoclimatic ecosystem classification (BEC) system is a multi-scaled, ecosystem-based classification system that groups ecologically similar sites based on climate, soils, and vegetation; it is widely used as a framework for resource management and scientific research in British Columbia. Three examples of biogeoclimatic zones in the project area are:

- ESSF Engelmann Spruce–Subalpine Fir (Biogeoclimatic Zone)
- SBS Sub-Boreal Spruce (Biogeoclimatic Zone)
- ICH Interior Cedar Hemlock (Biogeoclimatic Zone)

Buildup Index is a numeric rating that represents the total amount of fuel available for combustion in a wildfire. It is a component of the Canadian Forest Fire Weather Index (FWI) System and is calculated using the Duff Moisture Code (DMC) and the Drought Code (DC).

Burn Severity refers to the effects of fire on the environment, typically focusing on the loss of vegetation above ground and below ground, but also including soil impacts. It is a consequence of a fire's intensity and the pre-fire ecosystem condition[2]. Fire severity is generally synonymous with burn severity, but some authors use fire severity to refer to the broader changes caused by a fire to the overall ecosystem.

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[1] Definitions are sourced from The Canadian Interagency Forest Fire Centre, the B.C. Ministry of Forests, B.C. Wildfire and The B.C. Forest Practices Board, SIR 56

[2] https://www.nwfirescience.org/sites/default/files/publications/Fire%20Severity.pdf

Canadian Fire Behaviour Prediction (FBP) system is a component of the Canadian Forest Fire Danger Rating System (CFFDRS). It provides a systematic method for assessing wildland fire behaviour. The FBP System uses mathematical equations to relate fire characteristics to factors like wind, fuel moisture, and topography, and is used to predict fire behaviour.

Canadian Forest Fire Danger Rating System (CFFDRS) is a comprehensive, science-based system used across Canada to assess wildland fire danger and predict fire behaviour. It uses a hybrid system of empirical and physics-based equations to assess wildland fire danger and estimate likely fire behaviour. It is the principal source of fire information for all wildland fire management agencies in Canada.

Canadian Forest Fire Weather Index (FWI) System is a subsystem of the CFFDRS. The components of the FWI System provide numerical ratings of relative fire potential in a standard fuel type (e.g., a mature pine stand) on level terrain, based solely on consecutive observations of four fire weather elements measured daily at noon (1200 hours local standard time or 1300 hours daylight saving time) at a suitable fire weather station; the elements are dry bulb temperature, relative humidity, wind speed, and precipitation. The system provides a uniform method of rating fire danger across Canada.

Canopy Base Height (CBH) describes the average height from the ground to the bottom of the canopy. Specifically, it is the lowest height in a stand at which there is sufficient forest canopy fuel to propagate fire vertically into the canopy. This definition incorporates ladder fuels such as lichen, dead branches, and small trees. CBH is equivalent to the fuel strata gap (FSG) in the absence of appreciable ladder fuels when the surface fuel height is minimal.

Canopy Bulk Density (CBD) describes the density of available canopy fuel in a stand. It is defined as the mass of available canopy fuel per canopy volume unit, typically measured as kg/m^3. CBD estimates are used to determine the threshold spread rate or surface wind speed to determine the likelihood of active canopy (or crown) fire.

Climate-limited fire regime is a fire regime characterized by infrequent, severe wildfires occurring in areas where there is typically enough fuel, but moisture levels are too high to support frequent fires. These areas often have abundant vegetation but also experience periods of drought that can trigger large, intense blazes.

Coarse Woody Debris (CWD) refers to dead, woody material on the forest floor, typically logs, stumps, and large branches, with a diameter greater than a specified threshold.

Composite Burn Index (CBI) is a standardized field-based method for assessing the severity of fire impacts on vegetation and soil in a specific area. It provides a quantitative measure of burn severity by evaluating the effects of fire across different vegetation strata and soil, offering a comprehensive view of fire damage.

Community Wildfire Resilience Plan (CWRP) is a comprehensive strategy designed to help communities prepare for, respond to, and recover from wildfires. It is a framework for wildfire risk reduction within a specific community, outlining actions to mitigate wildfire hazards and enhance community resilience.

Control Line refers to constructed or natural fire barriers and treated fire perimeters used to control a fire.

Critical Surface Fire Intensity refers to the threshold level of heat output (measured in kilowatts per meter, kW/m) of a surface fire at which it can ignite the lower branches of trees, potentially leading to the development of a crown fire. This value is crucial in wildfire management, as it helps determine the conditions under which a fire may transition from a more manageable surface fire to a more dangerous crown fire.

Cultural fire holds different meanings for different Indigenous communities, but it is often defined as the controlled application of fire on the landscape to achieve specific cultural objectives.

Drought Code (DC) measures the moisture content of deep, compact organic layers in the forest, indicating the potential for smouldering fires in deep duff and large logs. It is a component of the Fire Weather Index (FWI) system used to assess wildfire danger.

Duff Moisture Code (DMC) is a numerical index used in fire weather forecasting to represent the average moisture content of deep, compact organic layers. It is a component of the Canadian Forest Fire Weather Index (FWI) System.

Fine fuels are fuels that ignite readily and are consumed rapidly by fire (e.g. cured grass, fallen leaves, needles, small twigs). Dead, fine fuels also dry very quickly.

Fire cycle is the number of years required to burn over an area equal to the entire area of interest.

Fire frequency refers to the average number of fires per unit of time, often expressed as its inverse (the **fire return interval).**

Fire guard is a type of fuel break in which fuel is entirely removed, often constructed using a crawler tractor equipped with a blade or manually.

Fire Hazard abatement is legally required in B.C. for industrial activities such as timber harvesting. It is the process of reducing or eliminating conditions that could cause or spread a fire. It involves taking proactive measures to minimize the potential intensity and spread rate of a fire. This includes removing or modifying flammable materials (fuel) and addressing other factors that contribute to fire spread.

Fire intensity refers to the amount of energy or heat released by a wildfire (measured in kW/m) at a specific point in time, usually at the fire front (head fire intensity).

Fire Rank is a classification system used to describe the behaviour of a wildfire. It ranges from Rank 1 to Rank 6 as follows:

- R1 - a smouldering ground fire with no visible flames.
- R2 - a low vigour surface fire with visible open flames.
- R3 - a moderately vigorous surface fire.
- R4 - a highly vigorous surface fire with torching or passive crown fire.
- R5 - an extremely vigorous surface fire or active crown fire that moves from tree to tree.
- R6 – a blow up or conflagration, extreme crown and aggressive fire behaviour.

Fire regime describes the spatio-temporal patterns of fire, its intensity, type and severity in a particular area or ecosystem, and spans decades or centuries.[3]

Fire refugia are landscape elements within a wildfire perimeter or landscape that remain unburned or experience minimal fire effects, providing critical refuge for plants and animals during and after a fire event. Fire refugia are a characteristic of the fire regime of an area.

Fire severity refers to the effects of fire on the environment typically focusing on the loss of vegetation above ground and below ground but also including soil impacts. It is a consequence of a fire's intensity and the pre-fire ecosystem condition. Fire severity is generally synonymous with burn severity, but some authors use fire severity to refer to the broader changes caused by a fire to the overall ecosystem.[4]

Forest Landscape Planning (FLP) is a new forest management approach in British Columbia that establishes objectives and direction for forest resource values at a landscape and stand level, including biodiversity and ecosystem resilience. It replaces the older Forest Stewardship Plans and is designed to address forest management challenges, guide forestry activities, and promote sustainable practices within defined areas.

Fuel break means (a) a barrier or a change in fuel type or condition, or (b) a strip of land that has been modified or cleared to prevent fire spread.

Fuel strata gap (FSG) is the distance from the lower limit of the crown fuel stratum that can sustain vertical fire propagation to the top of the surface fuel layer. FSG is equivalent to canopy-

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[3] Brown, James K., ed. 2000. Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

[4] https://www.nwfirescience.org/sites/default/files/publications/Fire%20Severity.pdf

base height (CBH) in the absence of appreciable ladder fuels when the surface fuel height is minimal.

Fuel-limited fire regime is one where fire spread and intensity are primarily controlled by the availability and characteristics of combustible material (fuel), rather than by weather conditions or other factors.

Fuel management encompasses various techniques (treatments) to manipulate and/or reduce living or dead forest fuels for forest management and other land-use objectives (e.g., hazard reduction, silvicultural purposes, wildlife habitat improvement).

Fuel hazard means the potential fire behaviour, without regard to the state of weather or topography, based on the physical fuel characteristics, including fuel arrangement, moisture condition, fuel load, condition of herbaceous vegetation and the presence of ladder fuel.

Head Fire Intensity (HFI) is the predicted intensity, or energy output, of the fire at the front or head of the fire, measured in Kilowatts per metre (kW/m). The Canadian Forest Fire Danger Rating System uses these values to help predict and categorize fire behaviour based on factors such as fuel type and wind conditions.

Ladder fuels provide vertical continuity between the surface fuels and canopy fuels in a forest stand, contributing to the ease of torching and crowning (e.g., tall shrubs, small-sized trees, bark flakes, tree lichens).

Landscape, with respect to wildfire, refers to an area large enough to encompass the spatial scale that wildfire operates at, considering the fire regime, vegetation mosaics, topography and climate patterns, human communities, and governance systems.

Lop and scatter is when slash is cut into smaller pieces and scattered, so coarse woody debris lies flatter on the forest floor.

Planned ignition is a tactic used to control an advancing fire by "burning off" fuel between the fire's edge and control lines. Skilled and experienced firefighters coordinate operations. They use fire weather information to ensure public safety.

Prescribed fire (burning) is the knowledgeable and controlled application of fire to a specific land area to accomplish predetermined forest management or other land use objectives. These fires are managed to minimize smoke emissions and maximize the benefits to the site.

Shaded fuel breaks are strategically implemented treatments designed to modify fire behaviour, facilitating wildfire suppression efforts. These treatments reduce surface fuels, increase the height to the base of live crowns through ladder fuel removal, and decrease crown bulk density by thinning the canopy.

Spotting refers to a fire producing firebrands, carried by the surface wind, a fire whirl, and/or a convection column, that fall beyond the main fire perimeter and result in spot fires.

Values-at-Risk is the specific or collective set of natural resources and man-made improvements/developments that have measurable or intrinsic worth and that could be destroyed or otherwise altered by fire in any given area.

Wildfires are any naturally caused or unplanned human-caused fires that burn in and consume natural fuels, such as forests, brush, tundra, and grass. Also include escaped prescribed fires.

Wildland Fire is any fire burning in and consuming natural fuels: forest, brush, tundra, grass, etc. Includes wildfires and prescribed fires.

Wildland Urban Interface (WUI) is the area where human development (structures and infrastructure) meets or intermingles with undeveloped wildland vegetation.

1.0 Introduction

About the Project

This report serves as a foundational document supporting the Bulkley Morice Wildfire Resilience Project. The report documents existing knowledge about fire regimes, wildland fire, and potential wildfire mitigation strategies, while identifying knowledge gaps. This foundational understanding will inform the development of modelling and decision-support tools used by the project to support planning and creating effective management strategies.

The project aims to address the increasing risk of wildfires affecting communities and ecosystems in the Bulkley Morice area. The project is based on the premise that addressing the wildfire problem requires landscape-level and tactical planning to inform management. Planning should be founded on a comprehensive understanding of the area's fire regime and ecology, employing the most current scientific research while also incorporating local and Indigenous knowledge.

The project design utilizes an integrated social-ecological approach, acknowledging the interdependence between community well-being and ecosystem health. Collaborative relationships among stakeholders are essential. We will seek collaboration with governments, community groups, and land managers to enhance understanding of wildfire resilience and reduce vulnerability to wildfires. The project aims to integrate scientific, local and Indigenous sources of knowledge, offering multiple engagement opportunities for local land managers and community stakeholders. It will focus on creating a toolkit and offering engagement and outreach services, ensuring that outcomes can influence emerging planning initiatives and policy development. For instance, project outputs can be directly linked to the Bulkley Morice Forest Landscape Plan. This integrated approach can foster the development of sustainable and effective fire management practices.

This initiative is a place-based project and is part of the SPARK (Select Pilots Achieving Resilience with Key Indicators) Program, a component of the Gordon and Betty Moore Foundation's Wildfire Resilience Initiative (WRI). Overall, the WRI aims to promote healthy ecosystems and resilient communities by reducing ecosystem vulnerability through improved stewardship and decreasing the risk of fire disasters. For more information about the project, please visit the project website at https://bvcentre.ca/wildfire-resilience/.

Report Purpose

The purpose of the Knowledge Report is to establish a comprehensive understanding of what is known and what remains unclear about wildfire in the Bulkley Morice area. This report investigates the existing literature and knowledge of wildfires and their management, with a particular focus on their relevance to the Bulkley Morice area. The report does not attempt to include all knowledge about wildfire that applies broadly across different ecosystems and does not replace program- or ministry-specific guidance or other sources that researchers or wildfire experts may have access to. Instead, it tries to cover key wildfire concepts for a broad audience, including land managers, practitioners, policymakers and decision-makers who may or may not be familiar with wildfire and then links those broad principles to the specific ecosystems in this region.

The starting point for developing this report is the recognition that there are gaps in understanding wildfire and wildfire management in the project area, which hinder effective wildfire management. At the same time, there is a significant amount of scientific knowledge about fire regimes and fuel management in other regions, such as the dry forests of southern British Columbia (B.C.) and the western United States (U.S.), while relatively little is understood about the sub-boreal forests typical of the project area. It remains uncertain how well the science and management principles from these other regions can be adapted to our specific area.

The report examines our understanding of wildfire and what we know about mitigation and management. We begin by exploring principles of wildfire resilience and present an overview of the roles of fire, disturbance regimes, and fire history. We examine the ecological effects of wildland fire, emphasizing the effect of burn severity on fire resistance, recovery, and resilience. At a foundational level, we discuss the role and importance of Indigenous fire stewardship.

Building on this foundation, we analyze the role of management and outline fuel management principles and practices that are relevant to the study area. We assess current forestry practices and explore opportunities to integrate fuel management strategies. On a landscape scale, we summarize principles of landscape fire management, describe methods for designing fuel treatments, and highlight key components for creating fuel breaks within the Bulkley Morice landscape.

Developing this report is an iterative process, where this version of the Knowledge Report serves as a first draft for review and feedback, and to advance the dialogue and our collective understanding of wildfire in the project area. What we learn in the review period will inform a final report to be completed in 2027. Any reader who wishes to provide additional sources of information or has questions or comments on the draft can submit them at any time to BuMoWildfire@bvcentre.ca.

Audience

The intended audience is land managers, practitioners, policymakers, decision-makers and policy influencers who work in the fields of forest and wildfire management. It encompasses all governments, including Indigenous governments, local municipal governments, and the provincial government, as well as key stakeholders who play a crucial role in implementing strategies and actions on the ground. Outcomes from the project may inform Indigenous stewardship plans, community wildfire resilience plans (CWRPs), WUI Wildfire Risk Reduction Plans (WRRP), fire management plans (including suppression), and landscape-scale forest management plans (FLPs).

Best Available Information

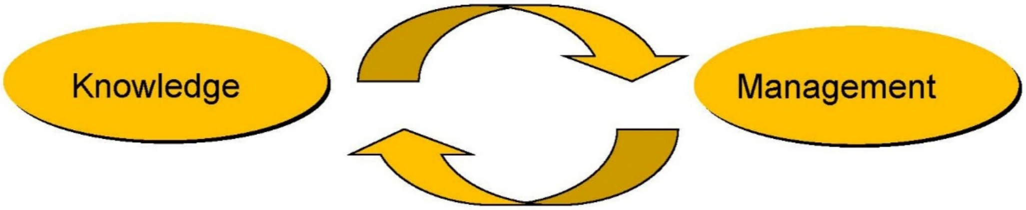
This report provides a comprehensive review of the current literature on wildfire and the empirical data that supports it. Our approach aims to integrate scientific, Indigenous and local knowledge—and acknowledge that much work remains to be done in this regard. We hope to continue this process through partnerships with Indigenous knowledge holders from the plan area communities and to present a more comprehensive analysis in future report iterations.

This report identifies knowledge gaps and proposes opportunities for further research and adaptive management to enhance our understanding of the system and to inform fuel management approaches in the region. The project scope does not include undertaking new primary research; instead, it draws from our current knowledge and aims for continuous review and improvement throughout the project, culminating in a final report in 2027.

Knowledge Informs Decision Making

For this project, we have adopted a theory-of-change model grounded in evidence-based assumptions, logically linked through a series of "if…then" statements. It is believed that better knowledge of the system leads to better solutions. If land managers are informed and have adequate decision-support tools, then it could lead to better plans and policies.

The project is not the decision-maker; rather, it enables better decisions through improved knowledge. This means that we avoid making prescriptive statements about what needs to happen. Setting clear objectives is the role of decision-makers who know and balance the values of the communities.



Project Area

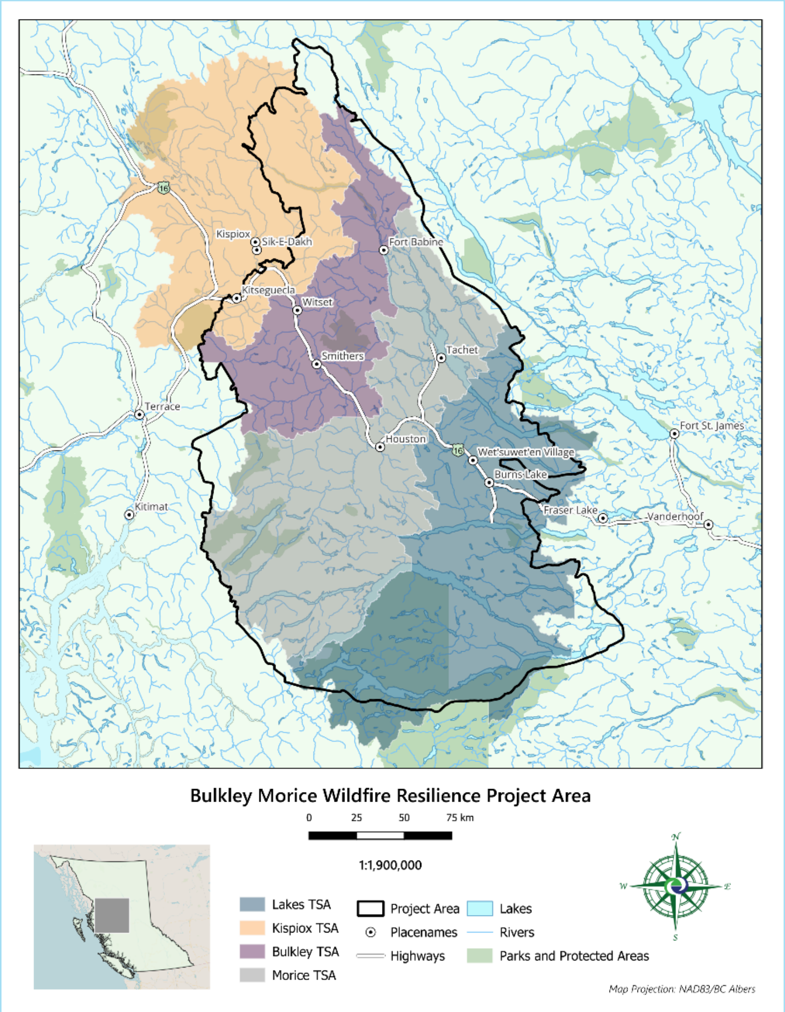


Figure 1.1. Study area map showing the administrative boundaries of the Bulkley and Morice Timber Supply Areas (TSAs). The study area includes the territories of the Wet'suwet'en, Gitxsan, Lake Babine, and Cheslatta Indigenous Nations.

The study area (4.392 million hectares), located in the sub-boreal forests of northwestern British Columbia, represents a transition from wetter coastal forests to drier interior forests (Figure 1.1). The study area includes the Bulkley (736,000 ha) and Morice (1.5M ha) Timber Supply Areas (TSA), as well as a surrounding buffer area to account for the influence of the adjacent landscape and ecological effects. The study area encompasses the territories of the Wet'suwet'en, Gitxsan, Lake Babine, and Cheslatta Indigenous Nations. Indigenous fire stewardship and cultural burning were common practices throughout the study area before European settlement.

The sub-boreal forests of the area comprise a distinct cultural and ecological region extending along the northern interior of northwest B.C., bounded on the western side by the coastal mountain ranges (Meidinger & Pojar 1991). It is characterized by a cool and moist climate with a mix of rugged and steep mountainous topography, high-elevation plateaus, and deep glacial-fluvial valleys. The region supports the headwaters of some of the world's most productive salmon rivers, a diversity of conifer and deciduous species, and mosaics of productive forests in riparian areas, along with lower-productivity wetland ecosystems in subdued terrain (Pojar et al. 1994).

Higher elevations support subalpine forests and non-forested alpine tundra (Meidinger & Pojar 1991). Steep moisture and temperature gradients exist between subzones, resulting in contrasting microclimates on windward and leeward mountain slopes and distinct plant and animal assemblages. Lower elevations are referred to as the sub-boreal spruce (SBS) biogeoclimatic zone and are comprised of lodgepole pine (*Pinus contorta*), hybrid white spruce (*Picea engelmannii x glauca*) and a mix of broadleaf species, including black cottonwood (*Populus trichocarpa*)*,* willow (*Salix spp*.), and trembling aspen (*Populus tremuloides)* (Meidinger & Pojar 1991). Drier south-facing slopes also support drought-tolerant species such as Rocky Mountain juniper (*Juniperus scopulorum)* (Heussler et al. 1991).

Climate varies considerably across the sub-boreal zone, with mean summer temperatures of around 18.5 °C (July) and mean winter temperatures of around -3.5 °C (January) and mean annual precipitation ranging from 600 to 800 mm at higher elevation sites (Government of Canada Climate Normals 1981-2010). Precipitation accumulates as snow in the winter (23%) and rain (77%) during the remainder of the year, sometimes with weeks of no rain in the summer months because of persistent high-pressure ridges that form over higher elevation plateaus (Government of Canada Climate Normals 1981-2010). In July and August, high-pressure ridges promote periods of hotter and drier weather, increasing the probability of lightning ignitions.

Modern land use in the region began in the 19th century, following the European settlement and the construction of the railway in 1912, which led to the development of forestry, agriculture, and mining.

Fire suppression was introduced in a significant way in the mid-20th century. At the same time, resource development, particularly commercial forestry, expanded and became the prevailing disturbance to the forest land base, creating different forest assemblages via reforestation. The region currently supports a significant forest industry and has recently faced changes due to a severe beetle epidemic and increased wildfire activity, which have impacted the structure and composition of its forests.

Wildfire Context

While wildfires are a necessary and beneficial process in many ecosystems, they also pose significant challenges at both the community and ecological levels. Since 2017, the Bulkley Morice area and B.C. as a whole have seen an increase in wildfires, with some events representing extremes in historical measures of area burned (Daniels et al. 2025, Jain et al. 2024).

Climate change is contributing to warmer and drier summers, as well as longer fire seasons—conditions that facilitate the ignition and spread of wildfires. Equally important are the forest conditions themselves. Over the past century, land use and settlement patterns have changed, compounded by fire exclusion policies in fire-dependent landscapes. These factors are believed to have contributed to an increase in dry and dead vegetation, as well as denser forests. This change has the potential to affect wildfire behaviour, making it more intense compared to the conditions experienced in the 20th century. Understanding these dynamics can help us develop strategies for managing and mitigating wildfire risks in the future.

As we face the challenges posed by recurring and complex wildfire seasons, the application of better planning, landscape fire modelling, the role of prescribed fire, Indigenous-led cultural burning and managed wildfire are all tools to help reduce wildfire risk while enhancing the health and resilience of human and ecological communities.

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2.0 Resilience and Wildfire Risk

By Kevin Kriese

Background

This chapter summarizes how resilience principles and theory are being applied to the Bulkley Morice Wildfire Resilience Project.

Resilience theory in natural resource management often draws on ecological resilience theory, where resilience refers to an ecosystem's ability to absorb disturbance and reorganize while maintaining its essential structure and function. A related field of resilience theory is community disaster resilience, which shifts the focus from only responding to disasters to helping communities prevent, respond to, and mitigate the harms caused by disasters. This form of resilience thinking is embodied in the Sendai Framework for Disaster Risk Management, which was formally adopted in B.C. through the *Emergency and Disaster Management Act*. In this project, we draw from the socio-ecological resilience theory that explicitly acknowledges and manages the interconnected and interdependent nature of people and ecosystems[5].

Wildfire resilience is a specific subset of socio-ecological resilience and uses assessment tools and practices that draw from both ecological resilience and disaster risk management. Wildfire resilience can be thought of as a necessary, but not sufficient, condition for socio-ecological resilience [6].

Wildfire Resilience Defined

The project's definition of ‘wildfire resilience’ draws from both ecological and community disaster resilience:

"Wildfire resilience is the ability of a system (both ecosystems and connected communities) to react to perturbations, internal failures, and environmental events by absorbing the disturbance and/or reorganizing to maintain its functions, whether the changes are gradual or abrupt or both, and to include the capacity of ecosystems, people, and communities to adapt, persist, develop, or even transform into new development pathways in the face of dynamic change."

Definition source: Developed by Ken Allen, Centre for Law, Energy and the Environment, University of California Berkeley and the Gordon and Betty Moore Foundation Wildfire Resilience Initiative.

For the Bulkley Morice project, this definition means that the project will examine how wildfires affect ecosystems, as well as human communities, and their interactions. The community and ecological dimensions each make distinct contributions to understanding the effects of wildfire on the social-ecological system. This definition of resilience requires that communities decide what values and services they most care about, both today and in the future: “Resilience is in

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[5] See: Understanding Resilience: How to Persist and Evolve with Change

[6] For example, community disaster resilience will consider resilience to earthquakes or other natural disasters, while ecological resilience will consider the effects of other disturbances, such as insects.

the eyes of the beholder". This project is designed to inform decisions by governments, including provincial and Indigenous, who will determine what values they wish to see managed and maintained, but the general framework of resilience can help them make more informed decisions.

To keep this project tractable, it will not examine the full suite of elements of socio-ecological resilience that would be of interest to a community (for example, resilience to other risks like floods is out of scope). However, it is hoped that our work on wildfire resilience will inform and support broader social-ecological assessments.

Mechanisms of Resilience

Burton (2025) defines five different mechanisms that can be used to promote overall resilience depending on the context. These definitions are drawn from ecological resilience, but the underlying principles can be applied to both community and ecosystems.

Recovery: where the ecosystem returns to its original state following the disturbance. For example, a spring fire in a grassland where the vegetation quickly regrows after the fire.

Resistance: where the ecosystem prevents or absorbs the disturbance. E.g. where a particular forest type does not burn and is skipped by a wildfire, such as a forested wetland.

Adjustment: where the disturbance results in a minor change to forest structure or composition. For example, a wildfire removes conifer species from a mixed aspen/conifer forest.

Reconfiguration: where a major change in forest structure or composition post-wildfire occurs. An example is the transition from a conifer forest to a broadleaf forest.

Transformation: where there are changes in the identity of the system. For example, a shift from a forested ecosystem to an open meadow following a high-severity fire at high elevations.

These five mechanisms go beyond what has been termed "basic resilience" (Walker et al., 2004)[7] and reflect the understanding that simply returning ecosystems or communities to pre-existing conditions may not be possible or prudent. These mechanisms are not absolute and can be thought of as a continuum, where the way they operate depends on the scale being considered.

In wildfire management, the historical approach could be described as "resistance" to wildfire, where the dominant response was to suppress wildfires. One of the main changes with embracing resilience thinking is the shift away from resistance – excluding fires altogether – to explicitly accepting the important ecological role of wildfire and allowing some fires to burn

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[7] Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. P. (2004). Resilience, adaptability and transformation in social-ecological systems. Ecology and Society, 9(2)

when the consequences are acceptable and where the system (either ecosystem or community) can recover, adjust, reconfigure, or transform, while continuing to provide key services both from an ecological and community perspective.

When examining community protection from wildfire, the dominant approach has been ***resistance to wildfire***, which involves suppressing all fires to protect communities. Protecting lives and communities, and resisting *the damage* from wildfires, remains a valid approach; communities should prevent damage wherever possible, rather than rebuilding after property is destroyed. A deeper understanding of how communities can resist damage expands the focus to include the vulnerability of communities through the design, construction and maintenance of buildings and their surroundings. This represents a shift toward strategies, collectively referred to as "FireSmart," that enable communities to "live with fire" while avoiding the damage caused by wildfires.

> *A resilient community is one that suffers fewer losses and recovers more quickly after a risk takes place* (Chuvieko 2023).

As the science of resilience evolves, there is a growing understanding of how ecosystems are shifting in response to climate change. More recent climate-driven frameworks for resilience incorporate an explicit understanding that some places will undergo shifts in composition or structure, and that resilience principles can be utilized to guide or manage these adjustments, reconfigurations or transformations. This is an important distinction from earlier approaches to resilience, which primarily focus on restoring the system to its pre-disturbance state.

In summary, a wildfire resilience framework requires examining how wildfire affects both ecosystems and communities. There are many different pathways to resilience. In the past, a dominant approach was resistance to wildfires to reduce risk to communities. That evolved to include “basic” resilience where the system bounces back to a pre-existing state. Resilience is now understood to also include broader mechanisms where either communities or ecosystems will reconfigure or transform to new states.

Ecological Dimension of Wildfire Resilience

Gilson et al. (2019) summarize the general approach for applying socio-ecological resilience principles to the management of the ecological dimension of wildfire. A central element is developing an understanding of the fire regime of the ecosystem under consideration. It is common practice to assess the historical fire regime of an area in order to compare current forest composition and patterns with those of a reference period, thereby developing a functional understanding of the ecological processes and structures that link climate, vegetation, fire, and human management. The authors conclude: "In summary, paleoecological and historical information helps clarify long-term ecosystem dynamics, including fire, and helps define conservation and management objectives based on disturbance history and ecological function." However, managing for resilience is more than restoring previous conditions; it also requires an understanding of processes and considering the adaptive capacity of an ecosystem to respond to future conditions (Johnstone et al. 2016, Falk 2017). Management strategies thus require not only information about vegetation and fire history, but also a mechanistic understanding of the specific climate-fire vegetation interactions that have led to current landscape conditions.

In the past, it was common to refer to the natural range of variability when looking at ecological resilience. It is widely recognized that this framing of “natural” systems overlooks the existence of complex stewardship systems of Indigenous management that interacted with and maintained many ecosystems. The role of Indigenous fire stewardship is explained in Chapter 6. For this project, we do not use the term “natural” but instead refer to the historical condition of the ecosystem, recognizing that Indigenous stewardship shaped many ecosystems.

Applying these concepts to wildfire management, managers can analyze a projected future fire regime and compare it to the current regime, evaluating how desired attributes of a wildfire-resilient forest can be implemented. Further, a set of climate futures can be modelled to gain insights into future potential states of an ecosystem, highlighting the adaptive forest landscape management strategies that could be invoked to maintain a wildfire-resilient landscape.

The fire regime for the Bulkley Morice is described in Chapter 3: Fire Ecology. This information will be made available to planning tables and stakeholders in the area to inform their assessments of the state of ecosystems in the region and to inform planning and management processes in identifying potential strategies to improve wildfire resilience.

Through the development of a landscape fire model, the project aims to project how changes in management strategies could influence key aspects of the fire regime, such as area burned, fire size, or fire severity. In addition, the project will develop indicators of wildfire resilience that can be assessed and projected at the landscape level.

Community Dimension of Wildfire Resilience

Wildfire risk reduction is a common approach to promoting community wildfire resilience and is adopted globally, including by the United Nations and the province of British Columbia. In wildfire risk reduction, the goal is to reduce wildfire-related losses to important human assets or ecological services. Therefore, the goal is to promote resistance to losses, enabling communities themselves to be resilient.

There are several definitions and approaches for assessing and managing wildfire risk. The province uses the following definition:

> “**Risk from wildfire:** The exposure to the chance of loss from wildfire. For example: there is a 25% chance that a value at risk will be destroyed by a wildfire sometime in the next 50 years. Risk can also be calculated by multiplying damage (or loss) by uncertainty.”

This definition is similar to the well-known concept that 'Risk = Probability × Consequence', which is used in ISO and CSA standards for risk assessments[8].

A somewhat different framework breaks wildfire risk into Hazard and Vulnerability and then subdivides each into sub-components. This framework is shown in Figure 2.1.1.

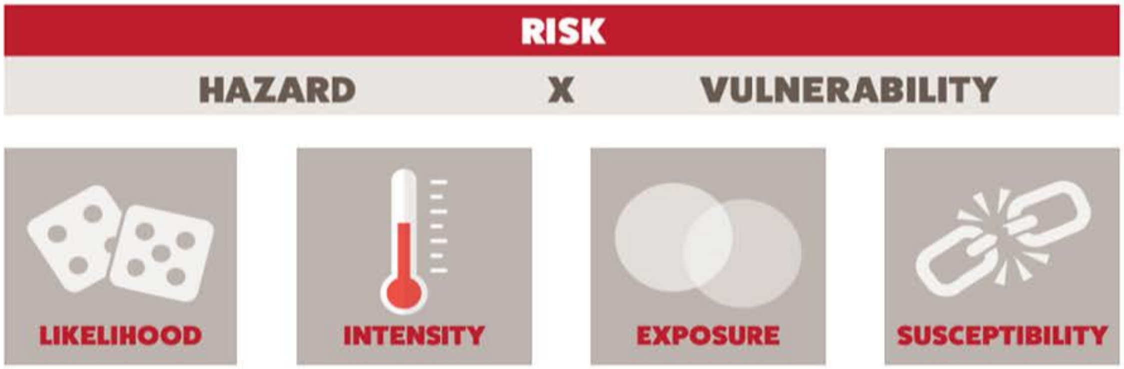

Figure 2.1. A community's wildfire risk is the combination of likelihood and intensity, together called "hazard", and exposure and susceptibility, together called "vulnerability". Source: WildfireRisk.org.

This framework is used by the USFS and by some Canadian researchers[9]. The United Nations Office for Disaster Risk Reduction uses a variation on this where Risk is defined as the combination of 'hazard × exposure × vulnerability'.

The "Hazard × Vulnerability" framework divides risk into discrete elements, enabling researchers or managers to address specific risk factors. This method is well-suited to the Bulkley Morice area because it translates more cleanly onto the kinds of decisions communities and agencies need to make—whether to reduce ignitions, modify fuels, harden structures, or change land-use patterns. Specifically, the drivers of hazard relate to land and forest management, while the drivers of vulnerability relate to community land use. This project is adopting the more complex framework (Hazard × Vulnerability) described in Figure 2.1[10]

The initial stages of the project are dedicated to analyzing wildfire hazard in forested landscapes and evaluating the impact of various management strategies on mitigating hazard. In

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[8] CSA-ISO 31000-10.

[9] Erni, Sandy, Xianli Wang, Tom Swystun, et al. "Mapping Wildfire Hazard, Vulnerability, and Risk to Canadian Communities." International Journal of Disaster Risk Reduction 101 (February 2024): 104221. https://doi.org/10.1016/j.ijdrr.2023.104221.

[10] However, the two different approaches are not opposed. The probability of a wildfire causing damage is the probability of a wildfire occurring multiplied by the asset's exposure to the wildfire. The consequences of a wildfire include the intensity of the wildfire and the asset's susceptibility to damage.

subsequent years, the project intends to assess community vulnerability by modelling the built environment.

Over the long term, managers would benefit from evaluations of wildfire risk to ecosystem services such as water. Although this project does not intend to conduct such assessments directly, it establishes foundational elements—such as hazard assessment—that will facilitate future studies on wildfire risk for additional values of interest.

How is Wildfire Hazard Defined?

Wildfire hazard is the physical conditions that make a location susceptible to damaging wildfires.

It is a combination of:

Fuel: The amount and type of live and dead vegetation available to burn

Weather: The weather conditions in the area

Topography: Primarily the slope and aspect of the area.

Ignition potential: The likelihood of an ignition occurring

Concept to Practice: Developing Knowledge to Support Wildfire Resilience in the Bulkley Morice

Managing for resilience encompasses numerous frameworks and conceptual models, depending on the context in which it is applied. For wildfire, resilience needs to embrace both the ecological and community dimensions. With a changing climate, simply returning ecosystems or communities to their pre-existing states may not be appropriate or even possible. Managers need to understand how climate change will affect our ecosystems and communities and consider whether it is possible or desirable to manage for historical conditions, as well as the degree to which adjustment or managed transformation to new states will be needed.

Applying wildfire resilience concepts to B.C.'s forests is complex. Many ideas are new to the region and require collaboration with local decision-makers to be relevant. Data limitations may restrict how thoroughly these concepts can be implemented.

The knowledge, assessment tools and reports being developed in this project are designed to support the resilience framework outlined here. This will involve complementary assessments of the community dimension (wildfire risk) and the ecological dimension (fire regime).

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3.0 Fire Ecology

By Phil Burton

Introduction

Landscape-level planning for wildfire resilience requires understanding how climate, vegetation, humans, and fire interact with one another. Fires shape vegetation composition, structure and spatial patterns, while vegetation in turn influences fire susceptibility in a region. Climate change, land use conversion, and resource management (human drivers) complicate the fire-vegetation dynamic and hinder generalization about the predictability of fire-vegetation interdependence. Examining historical patterns of fire and vegetation response can provide a starting point for understanding the underlying disturbance regimes and how they continue to evolve.

The occurrence and behaviour of individual fires depend on the ignition source, fuels, topography, and weather, factors that vary geographically and over time. In the long run, the factors influencing past, present, and future fires are reflected in disturbance regimes shaped by regional climate, terrain, vegetation, and human activity.

This chapter provides background information on the historical, contemporary, and potential role of fire in the Bulkley Morice study area. The current knowledge on the disturbance regimes and fire history of the study area is introduced here, and the drivers of and constraints on fire behaviour are discussed in Chapter 4. Chapter 5 examines the ecological effects of wildland fire, emphasizing the effect of burn severity on fire resistance, recovery, and broader resilience. Comments on knowledge gaps are included throughout, and potential indicators and analyses are suggested to inform wildfire planning.

Disturbance Regimes

A disturbance regime is that combination of disturbance agents, including fires, storms, insect outbreaks, and human activities, along with disturbance attributes such as frequency, event size, severity, seasonality, and selectivity, that characterize a landscape or region (White & Pickett 1985). Variability in the occurrence and severity of disturbances can be more important than historical averages because variability generates habitat diversity that supports high levels of biological diversity (Kelly et al. 2020). Although we are primarily interested in fire, all disturbances have legacy effects that may interact with each other in a manner that can dampen or amplify subsequent disturbances (Buma 2015, Burton et al. 2020). Influenced by climate, vegetation, and the human footprint, disturbance regimes shift over time, making it difficult to describe a "natural" or "characteristic" disturbance regime (Turner & Seidl 2023). A region's pre-industrial disturbance regime historically generated a landscape mosaic that promoted and sustained its characteristic biodiversity. It has been suggested that the resulting patchy mosaic confers resistance to the spread of disturbance, providing a template for sustainable and resilient forest management (Spies & Turner 1999, Bergeron et al. 2002, Drever et al. 2006).

Over millions of years, wildfires have played a significant role in driving natural selection and the evolution of species, as well as their survival traits, in various regions worldwide. Changes in the frequency and severity of fires have led to the decline of certain species while allowing others to thrive (Davis 1969, Hill & Field 2001, Doherty et al. 2024). Climate, fire, and humans serve as selective agents in the environment, determining which species combinations can persist and flourish in specific locations within a landscape or region. Ecosystems, ecoregions, and biomes vary across the planet, each characterized by a distinct combination of species that maintain a co-existence with the climate and the occurrence of fires.

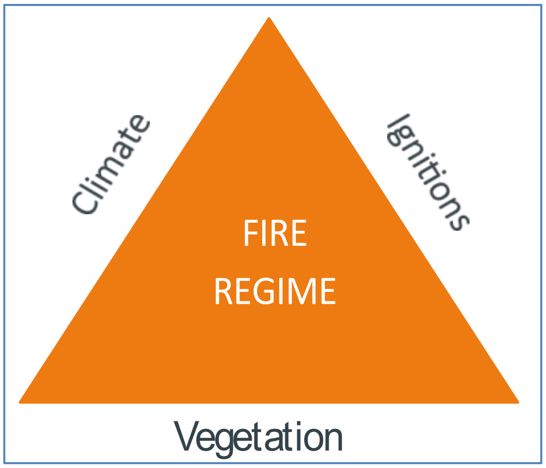

Figure 3.1. The fire regime triangle.

The combined interrelationship of climate, ignitions, and vegetation collectively constitutes the drivers of the fire regime (Figure 3.1). Because vegetation often depends on fire as well as climate, the overall fire regime ultimately reflects the prevailing regional climate. Consequently, fire regimes can be expected to exhibit bioclimatic zonation.

Those interrelationships can be summarized as follows:

- The frequency and severity of droughts are determined by precipitation and temperature and are influenced by how well soil and organic matter retain water, balanced against the drying power of the air as determined by temperature, humidity and wind.
- The frequency and density of ignitions are determined by the frequency of lightning, the frequency and depth of droughts, and by human influence.
- Vegetation characteristics, including physical structure and chemistry such as resin content, as well as post-disturbance recovery, determine ignition and spread.

There are multiple dimensions to the fire regime and many attributes that can be used to describe and quantify it. Those attributes of the fire regime that lend themselves to comparison among regions or over time are those related to the frequency and area of wildfires, and their associated spatiotemporal patterns, such as the frequency distribution and patchiness of burn severity. See the following text box for some definitions and the Fire Effects Information System glossary[11] for additional details.

Fire Regime Terminology

Both fire occurrence and burn area describe fire activity on landscapes over time. Fire frequency, or the average number of fires per unit time, is often expressed as its inverse, fire return interval (FRI, in years). FRI can refer to individual points, such as burn scars on trees or larger areas like forest management units. Typically, fire frequency is higher (and FRI is shorter) for larger areas, which are more likely to experience fire within a defined perimeter.

Mean annual area burned (AAB) estimates the average area burned each year and can be expressed in absolute (hectares per year) or proportional terms (percentage per year). AAB expressed in proportional terms is useful for regional comparisons but may overestimate actual forest burned, as it can include unburned patches within mapped wildfire perimeters. The fire cycle, or the number of years needed to burn an area equivalent to the reference area, is the inverse of AAB (100/AAB).

The fire cycle is not the same as FRI, despite both being measured in years, except under unrealistic assumptions (Reed 2006). Furthermore, a fire cycle does not mean all forests in a reference area will burn in that time, as some areas may experience multiple fires, or reburns, while others may remain unburned. In many forest types, approximately 37% of the area can consist of stands older than the fire cycle (Van Wagner, 1978; Bergeron et al., 2002).

A fire regime describes the characteristic role of fire over hundreds of square kilometres and decades or centuries (Figure 3.2a). The sequence of fire triangles shown can be described as a hierarchical, nested system of controlling factors that vary in scale over time and space, with each category reflecting the net result of the lower categories while being constrained by factors at the higher level (Figure 3.2b). Because the fire regime is a feature of a landscape or region, its characterization requires information from a broad area that encompasses decades of information on the occurrence and severity of disturbance. In the case of the last several decades of wildland fires, that information typically comes in the form of mapped fire perimeters or from dense networks of dendrochronological (tree-ring) sampling designed to document the extent and frequency of past fires from burn scars found on surviving trees and the age of shade-intolerant tree cohorts that establish after fire.

If we extend the analogy of describing climate as an overview of long-term annual weather conditions, a timespan of at least 30 years is needed to characterize a fire regime. Longer periods are desirable for incorporating the growth of long-lived trees and successional turnovers in forests. Longer periods, however, incorporate more significant variability in climatic conditions, whether due to natural shifts or the unidirectional trend of human-caused climate change. The change in fire regime over time also reflects trends in the human population and land use. Like climate and terrain, a region's

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[11] https://www.fs.usda.gov/database/feis/glossary.html

historic fire regime can be considered an environmental characteristic that determines a region's contemporary vegetation and fire behaviour.

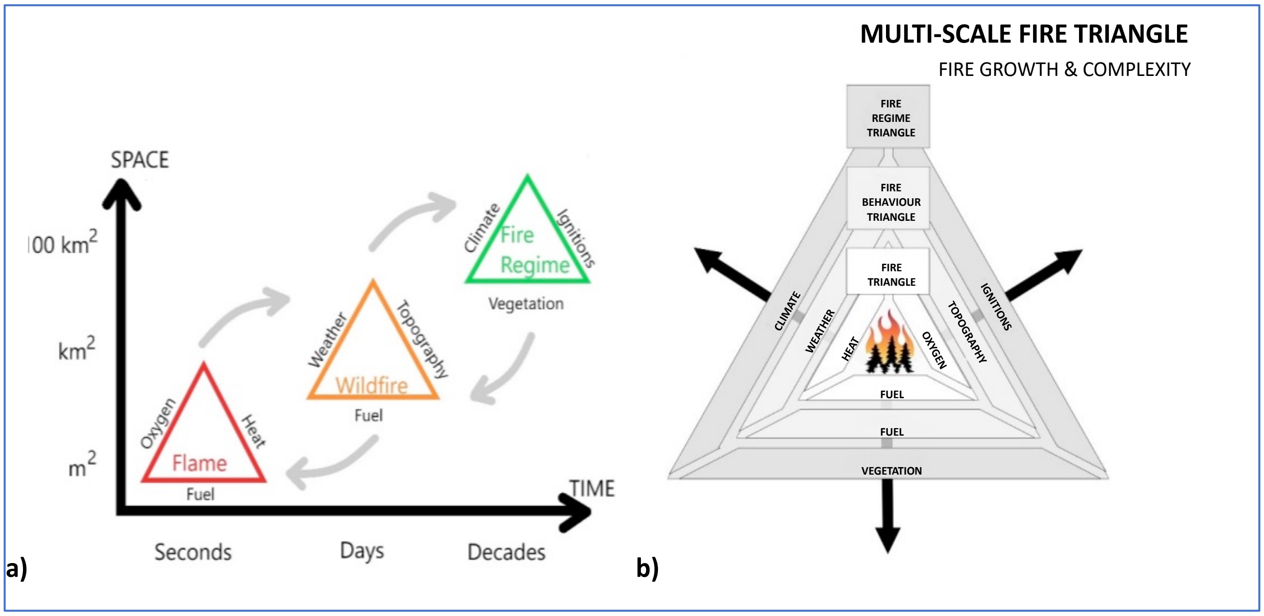

Figure 3.2a. The hierarchy of fire triangles in space and time. b. The nested nature of fire triangles that drive wildfire growth and complexity[12]*.*

It is worth considering which axis of the fire regime triangle is most limiting or important to a landscape's fire regime. Public service announcements to prevent forest fires imply that wildfire incidence and the modern fire regime are driven by, or at least have a strong relationship to, the frequency of unintended human ignitions. However, this is only partly true as human ignitions across B.C. were responsible for a minority (39%) of fire starts from 2006 to 2020 (Coogan et al. 2022). Some parts of Canada are known to be especially prone to lightning ignitions, such as northeastern Alberta and southeastern B.C. (Aftergood & Flannigan 2022).

Fuel-reduction treatments are based on the assumption that they reduce fire intensity and the incidence of uncontrollable wildfires. They can also imply a belief that forest fuels have accumulated to levels above historic norms, or that fires are strongly fuel limited. This may be true for much of the low- and medium-elevations in the western USA and southern B.C., where hot weather reliably dries fuels sufficiently every summer for ignitions to start frequent fires (Littell et al. 2009). However, boreal, subalpine, and perhaps sub-boreal forests do not experience suitable fuel-drying conditions so regularly, meaning that forest fires occur there

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[12] Graphic (a) from https://en.wikipedia.org/wiki/Fire_triangle; graphic (b) from https://www.usgs.gov/media/images/multi-scale-fire-triangle-fire-growth-and-complexity-simplified

mostly during occasional events of extreme fire-weather (Bessie & Johnson 1995, Macias Fauria & Johnson 2008).

The relative influence of fuel versus climate has been characterized as bottom-up or top-down control of the fire regime in the wildfire literature, with important implications for fire suppression and fuel treatment policies. Understanding the relative importance of fire regime drivers, particularly their variability by region and over time, can help managers develop sensible long-term fire stewardship strategies. Yet the weather of individual years inevitably exceeds "normal" conditions sometimes, and it is indisputable that the climate is warming. This makes an understanding of current and historical fire regimes of strategic importance, but of limited utility in tactical responses to individual fire seasons.

Natural Disturbance Type (NDT)

In British Columbia, natural disturbance types (NDTs) are classifications used to describe the frequency and severity of naturally occurring events that affect forest ecosystems. These disturbances, such as fire, windstorms, insects, and disease, shape forest structure, composition, and succession.

Features such as typical stand ages, stand age-class structure, and the presence, abundance and age of charcoal and burn scars allowed ecologists to distinguish between disturbance-maintained and disturbance-regenerated ecosystems. Whereas mature trees often survive frequent surface fires in disturbance-maintained (NDT4) ecosystems, the other NDTs are characterized by less frequent but more severe wildfires or insect outbreaks that appear to kill most trees, after which regeneration initiates the development of new forest stands in patches of various sizes.

In our study area, the lower-elevation, dry cool SBSdk subzone and the moist cold SBSmc subzone, which dominates much of the upland plateaus, are both described as NDT3 landscapes and are thought to experience “frequent” stand-initiating events, with a mean or median disturbance return interval of approximately 125 years. Higher elevation and wetter forests within and around our region, specifically those in the ESSFmc, ESSFmk, ESSFwv, ICHmc, and CWHws subzones, are described as NDT2 landscapes. These landscapes are characterized by “infrequent” stand-initiating events, which have a return interval of approximately 200 years (Anonymous 1995).

Fire Regimes of West-Central British Columbia

) —lies on the boundary of the Montane Cordillera and Boreal Cordillera ecoregions and is dominated by Sub-Boreal Spruce (SBS) and Engelmann Spruce – Subalpine Fir (ESSF) biogeoclimatic zones. Ecoregions capture major shifts in physiography, while biogeoclimatic subzones capture significant shifts in vegetation patterns associated with climate, particularly along sharp elevation gradients. The following discussion, with supporting data summarized in Appendix 3.1, provides a chronological itemization of the growth in understanding disturbance regimes in our study area. The period from which each study drew data, and whether that included the massive mountain pine beetle outbreak (approximately 1999 to 2015, affecting more than 18 million hectares in the B.C. interior) or the extensive wildfires that followed (2017 to 2024, which collectively burned more than 7.5 million hectares), strongly influenced the fire regime attributes reported.

One of the first efforts to characterize and map the disturbance regimes of British Columbia was led by B.C. Ministry of Forests (MoF) fire ecologist John Parminter, and is reflected in the Biodiversity Guidebook released in support of B.C.'s Forest Practices Code (Anonymous 1995). It utilized the expert opinion of ecologists, informed by their experience with thousands of vegetation plots sampled around the province over the previous two decades (MacKenzie & Meidinger 2018), to assign each biogeoclimatic unit (at the subzone or variant level) to one of five "natural disturbance types" (NDTs, see box on Page 27).

Doug Steventon, a MoF wildlife habitat ecologist, made some of the first attempts to quantify the disturbance regime in our study area. He used the mapped forest inventory to describe historic rates of stand initiation by working backwards from estimated stand ages (Steventon 1997, 2002). His approach was based on several assumptions: a) that the vegetation resource inventory (VRI) estimates of stand age are accurate; b) that most stands are even-aged and had regenerated after stand-replacing disturbances; c) that natural disturbances should leave a negative exponential distribution of stand ages; and d) that burning was age-insensitive, meaning that some stands re-burned before some older stands had burned for the first time. Recognizing the limitations of forest inventory data, that tree ages do not always equate to the time since stand-replacing fire, and a large degree of statistical uncertainty, he was still able to identify clear distinctions between high disturbance rate subzones (SBSdk and SBPSmc), moderate disturbance rate subzones (SBSmc and ESSFmc), and low disturbance rate subzones (ESSFmk and ESSFwv). His estimates of the annual area burned (AAB), and the fire cycle derived from the AAB for each subzone are presented in Table A3.1 and are illustrated in Figure 3.3.

Wong et al. (2003) compiled the results of disturbance analyses available up to that date to provide more substantiated evidence for describing disturbance regimes around the province, again organized by biogeoclimatic unit. In addition to the referenced forest inventory analysis by D. Steventon to determine fire cycles, they noted that historical wildfires in the SBSmc and ESSFmc were documented to include a wide range of unburned patches (1 to 245 hectares) within mapped fire perimeters (Wong et al. 2003, p. 26). Furthermore, cyclical defoliation caused by the western hemlock looper and the 2-year-cycle budworm is typical of the ESSFmc zone, with the budworm occurring at estimated intervals of 24 to 39 years. This phenomenon is relatively synchronized across north-central British Columbia (Wong et al. 2003, p. 13). The authors concluded that disturbance rates were highly variable in the past but were much lower in the ESSF and ICH (Interior Cedar-Hemlock) zones in pre-settlement times than in the 20th century (Wong et al. 2003, p. 15). That report also reviews several methods for determining disturbance return intervals, each with its assumptions and limitations.

Kirsten Campbell (2006) further explored the disturbance history of the SBSdk (centered around Francois Lake and dominating lower elevations in the Bulkley Valley) during different past periods and organized the results by current forest cover type. Campbell's analysis used mapped fires and aerial overview surveys of moderate and severe mountain pine beetle (MPB) outbreaks from 1904 to 2004, noting that the mapping of both fires and MPB outbreaks was incomplete before the 1950s. While fires predominated in the first half of the 20th century, beetle outbreaks and logging prevailed in the second half. Campbell (2006) concludes that fires were responsible for 59% of the 0.67%/yr of the area disturbed by all causes before 1954, but only 1% of the 0.7%/yr of the area disturbed between 1954 and 2004. The more recent era, up to 2004, was dominated by MPB (55% of the disturbed area) and logging (44% of the disturbed area). With no tabulated data presented explicitly for the area burned in the different strata (e.g., upland or wetland, or by current forest cover type) as a subset of the overall disturbance rate, it is difficult to ascertain the actual role of fire, except in a general sense. However, if one applies the 59% pre-1954 disturbance rate attributed to fire, the estimated burn rate was 0.75%/yr for upland forest and 0.43%/yr for upland scrub. It is also estimated that stands currently dominated by broadleaf tree species (mostly trembling aspen) had average disturbance intervals (presumably with little logging or insect mortality) of 82 years before 1954, compared to an estimated 352 years post-1953. Although trembling aspen is considered an early-seral species throughout most of its range, aspen stands can persist – largely through vegetative suckering -- in situations where conifer seed sources are absent or fire recurs frequently (Perala 1990, Cumming et al. 2020). The marked decline in the role of fire reported by Campbell (2006) is likely attributable to a period of wetter climate, the cessation of cultural burning, and vigorous fire suppression that began around mid-century.

Boulanger et al. (2012) prepared the first empirically classified fire regime maps for western Canada using point data for all documented fires greater than 1 hectare in size from 1980 to 1999. When divided into 40 km cells, much of the north- and west-central B.C. plateau country was classified as having a homogeneous fire regime (HFR 4). This classification indicated similar levels for all fire attributes recorded, with a burn rate of 0.043% area burned per year. Notably, 76% of these fires were ignited by human activity. The mean fire size in HFR 4 during that period was 37 hectares, with human-caused fires starting on an average date of June 20, compared with natural fires beginning around July 25 on average. Reanalysis examining only large fires (over 200 hectares) over a broader period mapped our region as part of HFR zone P when divided on a 60 km scale. However, it reported a comparable burn rate of 0.04% per year (Boulanger et al. 2014).

Burton and Boulanger (2018) subsequently focused on B.C. at a finer scale and over a more extended period, considering insect outbreaks and fires to empirically map both homogeneous fire regimes and more general homogeneous disturbance regimes (HDRs). They used mapped polygons of wildfires (all those greater than 1 hectare) and moderate-to-severe insect outbreaks in the 1956 to 1996 period to empirically identify and map distinctive combinations of fire and insects across B.C. on a 20 km grid. Homogeneous fire regimes were classified and mapped based on ignition date, final size, and annual area burned; homogeneous disturbance regimes were classified and mapped based on the area affected by fire, insect defoliators, and bark beetles. The two HFR zones relevant to our study area are HFR 5 (encompassing the Bulkley and Skeena River valleys, surrounding slopes and much of the Lakes area) and HFR 17 (most upland areas, especially the Nadina). HFR 5 is characterized by more frequent, earlier, and smaller fires than found in the higher and more remote HFR 17.

These statistics (see Table A3.1), including a burn rate of only 0.069% per year, reflect a largely domesticated landscape with very effective wildfire control and sharply contrast with estimates of the pre-industrial fire regime. The combined fire and insect HDR that covers most of our study area is HDR 24, characterized by an overall areal disturbance rate of 0.134% per year, with equal contributions from fire and bark beetles, and a lesser role for defoliating insects. Those attributes indicate more fire activity but much less insect activity than some adjacent zones, such as those immediately to the northeast. Note that the Burton and Boulanger (2018) analysis did not extend to the period of the most recent mountain pine beetle outbreak and did not evaluate interactions between fire and other disturbances, such as insect outbreaks or wind damage.

Erni et al. (2020) refined the Canada-wide fire regime mapping first undertaken by Boulanger et al. (2012, 2014), using fires greater than 50 hectares in size from 1970 to 2016. This work identified 15 broad fire regime types (FRTs) and 60 fire regime units (FRUs). Rather than treating ignition date as a continuous variable, fires were categorized into spring fires (started before June 22) or summer fires (started after June 21), with lightning vs human ignition being another classification variable. Within the broad FRT 12 covering our area, the average burn rate was 0.113% of the area burned per year, implying a fire cycle of approximately 883 years, based on the 46-year study period. More specifically, our area is primarily dominated by FRU 47, with a mean burn rate of 0.131%, with 59% of the fires starting in summer and 66% human-caused. FRU 57 occurs at higher elevations, where the fire frequency is less than half that in FRU 47, but with a similar burn rate (0.124% area burned per year), indicating larger fires. Notably, 85% of these fires start in summer, and only 22% are human-caused.

Ministry of Water, Land and Resource Stewardship landscape ecologist Doug Lewis prepared an update to the Erni et al. (2020) fire regime analysis, incorporating fires through the 2022 fire season and better reflecting the latest biogeoclimatic mapping used for fine-scale mapping of fire regime units (Lewis 2023). Although FRU boundaries in our region have not changed since the classification by Erni et al. (2020), the many recent fires have resulted in a higher overall burn rate in both low to medium-elevation areas (FRU 47, 0.304% per year) and the adjacent subalpine forests (FRU 57, 0.197% per year). When considering fires over the past six years, it is apparent that spring and human-caused fires now play a reduced role in our region.

Daust and Price (2025) conducted a roll-back of the 2010 forest inventory to estimate the period of origin for all stands by biogeoclimatic unit within the Sub-Boreal Spruce zone. Using the same methods as Steventon (2002) and focusing on 20-year age classes, their analysis selected 1930 as the breakpoint between historic and contemporary fire regimes. Contrasts in the fire cycle between those two epochs are remarkable in their magnitude and consistency across the B.C. Central Interior. In our study area, Daust & Price (2025) estimate that fire cycles have increased from 63 to 307 years in the SBSdk (or burn rates of 1.587% per year and 0.326% per year, respectively) and from 105 to 596 years in the SBSmc (0.952% per year shifting to 0.168% per year). Similar trends were observed in the less abundant SBSwk (a fire-cycle shift from 114 to 613 years) and SBSdw (a shift from 59 to 422 years).

Burton (2025) summarized the mapped disturbances specific to the Bulkley Morice study area, including fires, forest health surveys (which included data on wind, flood, and landslide events), and logging. In the 1972-2024 interval for which data on all disturbance agents were available, fire disturbed slightly less area than logging: 708,168 ha (16.1% of the study area) compared to 728,630 ha (16.6%), respectively. The area disturbed by moderate to very severe damage from insects and fungal pathogens was much greater than either fire or logging. However, annual surveys reported areas experiencing ongoing attacks, not just new outbreak events, making comparisons with fire difficult. The areal contribution of other agents of forest damage was relatively minor and is discussed further below. In terms of the ongoing effects of fire, it is worth noting that post-burn (delayed) tree mortality – presumably within mapped wildfire perimeters -- was documented for a total of 133,882 ha (3.05% of the study area) since 2012. Focusing on the full period of recorded fires, Burton (2025) observed moderate burn rates (0.54%/yr) from 1919 to 1932, followed by a lull in fires from 1933 to 2003 (during which the average burn rate was only 0.03%/yr), which was subsequently replaced by a higher burn rate of 0.73%/yr since then. Summarized by BEC zones or by the D. Lewis BEC groups, results confirmed the patterns detected by earlier studies: higher burn rates of approximately 0.51-0.95%/yr in the SBPS (Sub-Boreal Pine-Spruce) and the drier SBS subzones, intermediate burn rates of 0.34%/yr in the SBSmc, and lower burn rates of 0.16-0.21%/yr in the subalpine ESSF forests (see Appendix 3.1).

Some recent studies have described the disturbance history of more localized segments within the Bulkley Morice study area. Maltman et al. (2024) characterized the contemporary disturbance regimes (1985-2019) of the ranges occupied by all individual B.C. caribou herds. Their findings were based on the mapped impacts of wildfire, logging, and non-stand-replacing disturbances, including insect outbreaks. All three caribou herds in our study area primarily utilize subalpine ESSF forests and adjacent BAFA (Boreal Altai Fescue Alpine) areas, with occasional use of surrounding mid-elevation SBS forest, and SBPS forest in the case of Tweedsmuir caribou. In the northeast corner of the study area, vegetation within the range of the Takla caribou herd experienced a burn rate of only 0.018% per year. Similarly, the Telkwa caribou herd, located at the western edge of our study area, experienced a burn rate of only 0.021% per year. In contrast, the wider-ranging Tweedsmuir caribou herd, located in the southern quarter of our study area, experienced a much greater burn rate of 0.597% per year, plus an additional 0.37% per year due to other natural disturbances, such as the mountain pine beetle. Logging activities took place at a similar level (0.31-0.41% per year) within the ranges of all three herds.

Hoffman et al. (2025) conducted dendrochronological studies in part of the range of the Tweedsmuir caribou herd, focusing on evidence for fire at both culturally utilized (lakeside) and less utilized (upland) sites around Tesla Lake, at the intersection of the SBSmc, ESSFmc, and ESSFmk subzones. If one treats the authors' FRI determinations as equivalent to fire cycles, they imply AAB values of 11.1% per year of cultural burning at locations regularly visited by Indigenous people before 1957, compared with 1.83% per year at upland sites that were burned by a combination of natural and cultural fires. In contrast to the modern seasonality of fire ignitions, cultural fires recorded in this study (at higher elevations for black huckleberry and whitebark pine nut productivity) historically burned in late summer and early fall, as opposed to lower-elevation sites that burned more frequently in the spring and early summer (Hoffman et al. 2025). The high burn rates documented in this study indicate the degree to which contemporary fire regime classifications underestimate the extent of cultural burning, and therefore overall burn rates across much of the study area prior to European settlement (see Chapter 6: Indigenous Fire Stewardship).

Some Consistent Intra-Regional Differences and Temporal Trends of Fire Regimes

As previously discussed, fire regimes can be characterized by various attributes, including frequency, seasonality, and burn severity. The fire return interval at any given point may be most important to the ecology and fire resilience of a forest stand and can be determined from dendrochronological analysis of burn scars; however, such sampling is rare. Fire frequency per unit area (e.g., fire starts per 100,000 hectares) can be obtained from mapped fire records; however, it is challenging to visualize, and reliable mapping of burn perimeters is a relatively recent development (post-1950s). “Burn rate,” or more correctly, standardized annual area burned (AAB) as the average proportion of the reference area burned per year, is probably the most consistently calculated descriptor of the fire regime. However, the recency of reliable spatial mapping again limits its use. This provides an opportunity to compare estimates prepared using different data and approaches, as well as for different time windows (Figure 3.3). On the other

Even though estimates of standardized AAB are highly uncertain and vary with the method of analysis used, it is clear from all available information that most of the Bulkley Morice study area can be described by three fairly distinct disturbance regime zones, which feature moderate, long, and longer fire cycles along climatic gradients (Figure 3.3, Panels a, b, and c, respectively). Also noteworthy in all three disturbance-regime zones is the transition to much lower burn frequency sometime in the mid-twentieth century. The data indicate that the most notable changes have occurred in dry forests or areas with evidence of past cultural burning (as shown in Figure 3a), compared to moist forests or locations with less cultural burning (illustrated in Figure 3b), followed by the lowest overall rates and least proportional change in the subalpine forests (depicted in Figure 3c) characterized by colder and moister conditions. These modern reductions in the role of fire are believed to have had widespread implications for forest age class structure, carbon storage, wildlife habitat, and fuel accumulation.

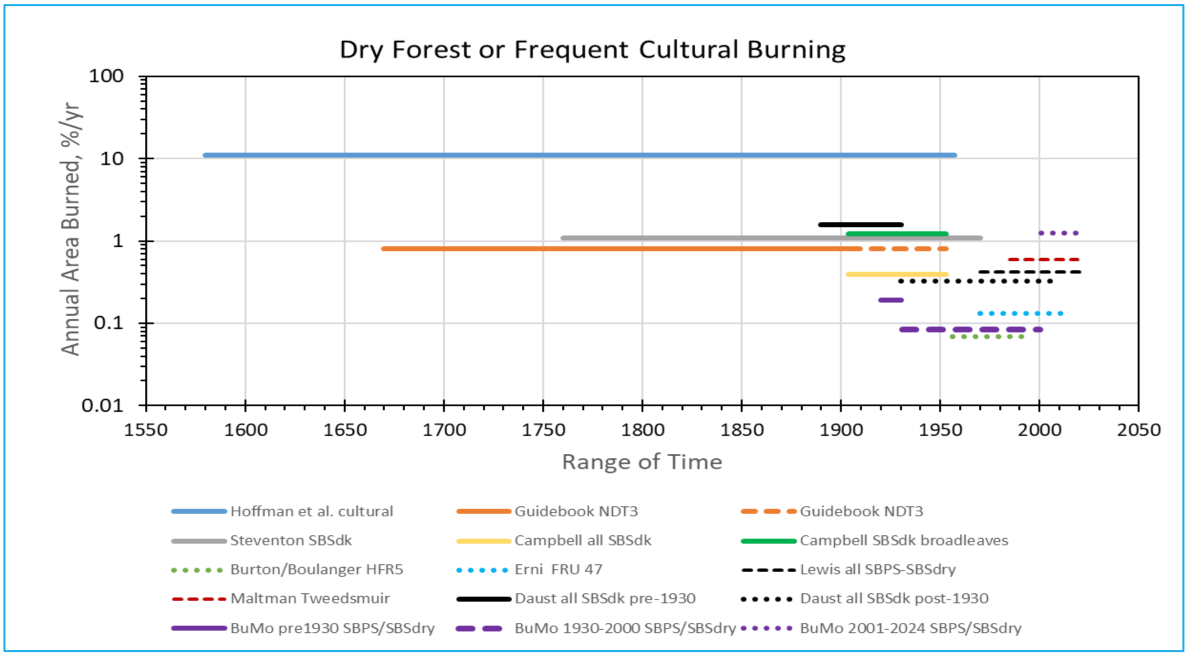
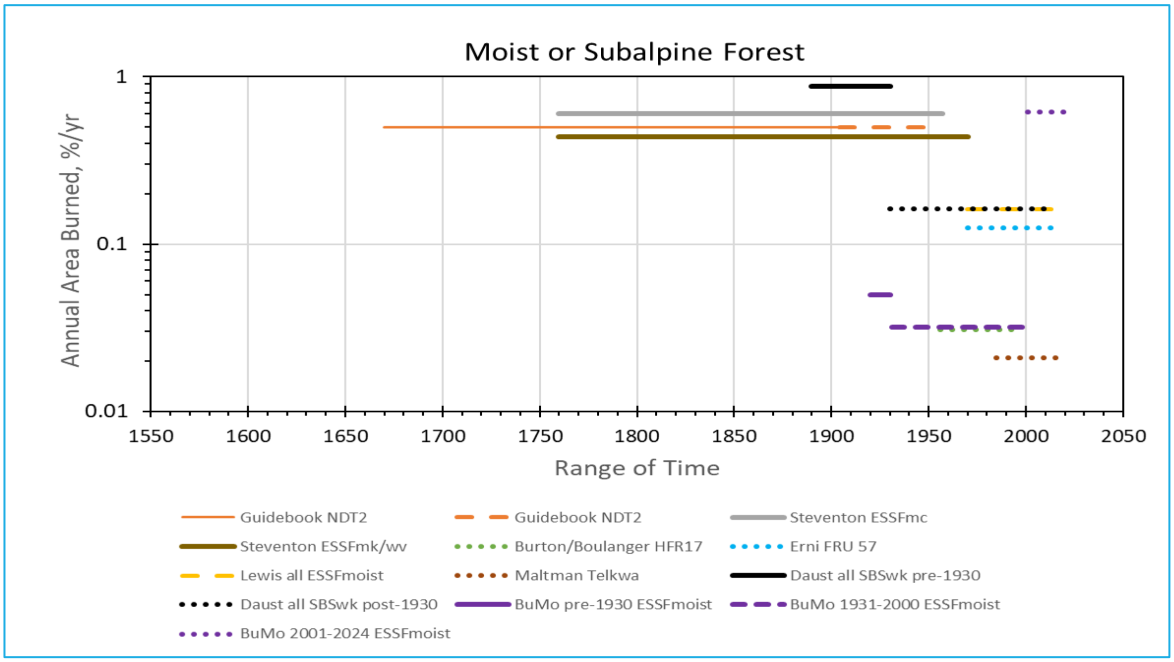
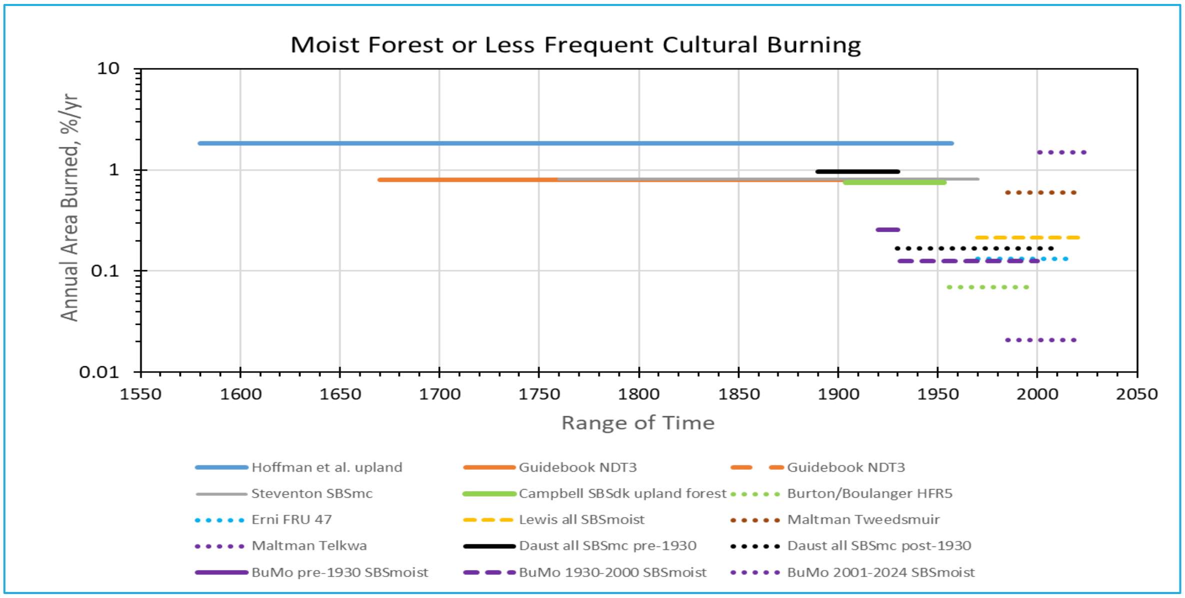


Figure 3.3. Panel a. Graphical portrayal of available estimates of burn rate for three disturbance regime zones in the Bulkley Morice study area over different time periods; note the different logarithmic scale in each panel. The length of each line denotes the time period to which the data refers but is not meant to imply a constant burn rate. BuMo values refer to the Burton (2025) analysis across the Bulkley Morice study area using the Lewis (2023) groupings of biogeoclimatic units.



Panel b.



Panel c.

Controlled burning, one aspect of fire stewardship practiced by Indigenous Peoples, was an important component of the disturbance regime in pre-colonial times, making it desirable to estimate its overall contribution and place-specific footprint. Based on numerous ethnographic and empirical sources (see Chapter 6: Indigenous Fire Stewardship), it is apparent that cultural burns were conducted frequently around village and camping sites, as well as along travel corridors, and were employed less regularly in upland and less-frequented locations (Gottesfeld 1994, Hoffman et al. 2025). Frequent burning and deep soils are suspected of having maintained low-elevation areas of west-central B.C. in grassland and open woodland, especially in locations today dominated by trembling aspen (Pojar et al. 1984).

With those observations in mind, it is worth examining Whitford and Craig's (1918) map of forest resources and land suitable for agriculture, one of the first comprehensive maps of B.C. vegetation. With land suitable for cultivation and grazing consisting mainly of grassland and open forest, it is estimated that only 7.35% of the entire Bulkley Morice study area met those criteria over a century ago. Most of that land was in the SBSdk (51%), followed by the SBSmc (32%). As a proportion of the area in each biogeoclimatic unit, land likely to have a history of cultural burning (inferred by supposed suitability for agriculture) was more critical in the SBSdw and the ICHmc than in the SBSmc (Figure 3.4).

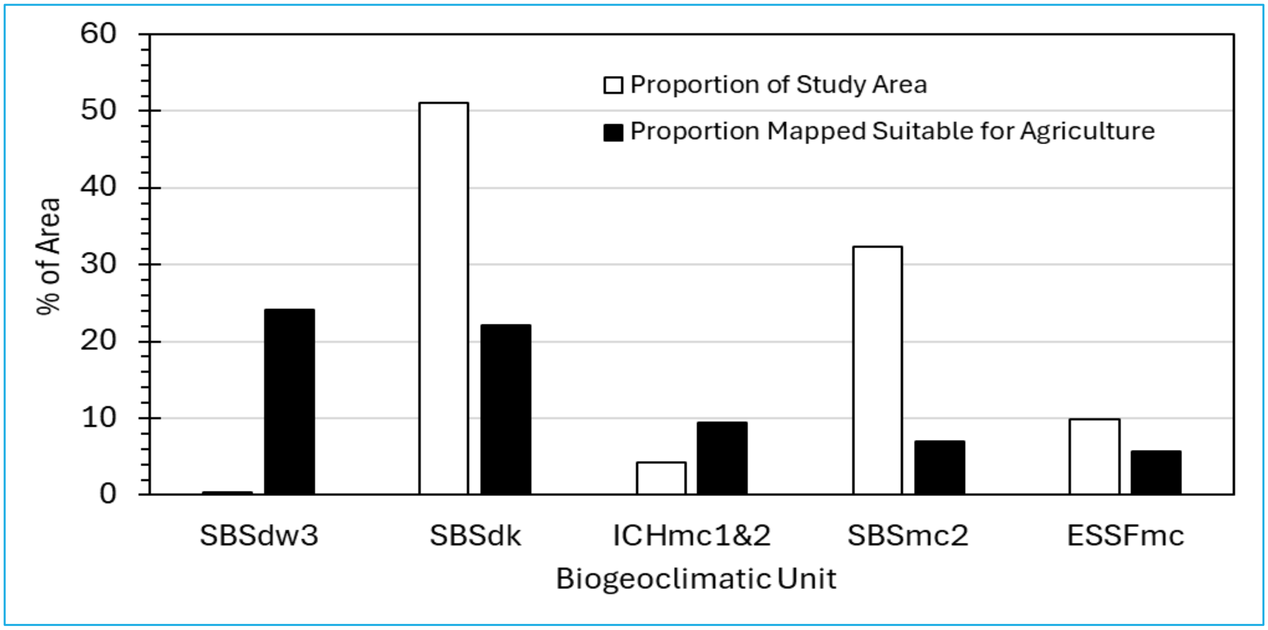


Figure 3.4. Land mapped as suitable for agricultural purposes at a scale of 1:1,598,680 by Whitford and Craig (1918), georeferenced and overlaid on biogeoclimatic units of the Bulkley Morice study area. It is hypothesized that the proportions mapped as suitable for agriculture are indicative of relative levels of cultural burning in the pre-settlement era.

Disturbance Considerations Other than Fire

A region's natural disturbance regime is not just its fire regime. In the Bulkley Morice, it is generally accepted that most forest stands originated after fire or have a history of fire, as charred wood and charcoal are pervasive on or in the forest floor throughout our region. However, with a recent history of bark beetle outbreaks in the B.C. Central Interior, it is apparent that even-aged stands can also originate after widespread insect outbreaks. Furthermore, interactions between fire and other disturbances can play a significant (if episodic) role in governing regional disturbance regimes. When bark beetles or windstorms leave a concentration of dead vegetation and woody material that is elevated and easily dried, wildfires may follow with greater frequency, intensity, or extreme behaviour than when burning in undisturbed forests (Hicke et al. 2012, Perrakis et al. 2014, Woo et al. 2024). These additional disturbance agents and disturbance interactions are difficult to document, but must be considered when focusing on fire.

Many disturbances that are not stand-replacing and typically affect individual trees or small groups of trees can be described under the umbrella concept of gap dynamics. Canopy gaps are generated when trees die from drought, snow press, endemic levels of insect attack, fungal rusts and root diseases. Tree species differ in their susceptibility to these stressors and mortality agents, with important differences also associated with tree and stand age. Estimating a "natural" level of non-fire disturbances and gap dynamics is difficult because they were only sporadically documented in the past, and the influence of so many of those mortality agents is increasing in a warming climate (Woods et al. 2010).

Other disturbance agents documented in the Bulkley Morice since about 2000:

The areal contribution of agents other than fire, insects, and logging have been relatively minor: direct effects of drought affected 10,723 ha (0.24% of the study area) since 2006, floods 8,208 ha (0.19%) since 2001, mammal damage 4,018 ha (0.09%) since 1975, wind 2935 ha (0.07%) since 1988, and landslides 885 ha (0.02%) since 2002.

Nevertheless, single disturbance events can be important: for example, a severe windstorm (possibly a derecho) damaged approximately 1000 ha in the Morice-Lakes area in 2005 and was subsequently subject to extensive timber salvage work. Tomentosus root rot in old spruce forest and numerous rusts in pine plantations are important agents of mortality, but have not been consistently tabulated or mapped on a per-unit-area basis, making the calculation of their footprint or disturbance interval difficult. Some of this information could be summarized from spatialized data mapped annually from the aerial overview surveys of forest health (data available from https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health/aerial-overview-surveys/data-files).

Bartemucci et al. (2002) conducted transect surveys to assess the extent of persistent and disturbance-related gaps in old forest (mapped as >140 years of age) found in the SBSmc2, the ESSFmc, and ICHmc2. While the specific causes of death in trees generating "developmental" or treefall gaps were not identified, it was found that these gaps occupy an average 36.5% of the area in old-growth SBSmc2 stands, 66% of ESSFmc stand area, and 32% of ICHmc2 stands, with mean gap sizes of 173, 196, and 148 m^2, respectively.

The authors noted that light levels are generally high in these old forests, with large areas kept open -- especially in the ESSF -- due to dense shrub growth and soil limitations. Consequently, gaps do not necessarily lead to tree regeneration (Bartemucci et al. 2002). While these surveys highlight the importance of intermediate, within-stand disturbances, it is difficult to infer a rate of gap formation and tree death or treefall without detailed dendrochronological reconstruction. This study reaffirmed previous observations regarding the gappy nature and importance of root rot, windthrow, and bark beetles in old sub-boreal spruce stands (Kneeshaw & Burton 1997). In contrast, an earlier survey of primary ICHmc forest in the Kispiox Valley found natural gaps make up only 7% of the forest (Coates & Burton 1997). Bartemucci et al. (2002) suggest that very old forests in our study area have one-third to two-thirds open canopies, but reliable regeneration was only found in the ICH. In terms of both the prevalence of persistent gaps and tree recruitment in gaps, SBS forests can be considered intermediate between those of the ICH and the ESSF. If this gap-filled canopy structure is found in most old forests in our region, they should exhibit greater resistance to crown fire spread. This hypothesis can be evaluated retrospectively by assessing large fires that have occurred over the last decade to determine whether age-class 7/8/9 forests (those more than 140 years old) burn less frequently, with lower severity, or have served to stop wildfire spread.

Knowledge gaps, limitations and weaknesses

There are several gaps, limitations, and weaknesses in the available information on the disturbance regimes of the Bulkley Morice study area. Fully understanding the landscape prior to Euro-Canadian settlement, particularly the role of Indigenous fire stewardship, is challenging; this makes it difficult to provide a reliable historical benchmark to describe the pre-colonial era. Another weakness in existing tabulations and classifications of disturbance regimes in B.C. and elsewhere is that they typically have not addressed the issue of variability in disturbance severity. This information can now be compiled using satellite-based fire severity mapping (e.g., Burton et al. 2008). With reliable Landsat imagery now freely available back to 1984, we can analyze how low-severity (largely surface), moderate-severity, and high-severity (stand-replacing) fires have been distributed in our study area, or how the ratio of moderate/high severity to unburned/low severity wildfires differ over space or time. Nonetheless, satellite-based estimates of burn severity undoubtedly underestimate the role of surface fires under living forest canopies and are again constrained to recent decades. Dendrochronological analysis of burn scars can overcome those weaknesses but is limited to a relatively few point-based sampling locations, with very little of such work having been done in the many forest types found across the Bulkley Morice study area.

As shown in Figure 3.3, the ecosystems of the Bulkley Morice experienced pronounced deviations from the historical disturbance regime during the second half of the 20th century. This indicates a landscape in which the existing climate-vegetation-fire balance has been altered, a condition sometimes characterized as a "fire deficit" (Parisien et al. 2020). We can infer that a large loss of balance is associated with a shift from many small, cool fires and infrequent large high-severity fires to a few small, cool fires and more large, high-severity fires. Planning and management for resilient landscapes also requires an appreciation of ecosystem responses and recovery patterns following prescribed and unintended fire. The issues of fire severity, ecosystem impacts, and recovery from fire are addressed in Chapter 5: Fire Effects, which discusses fire effects, which are closely dependent on fire behaviour (Chapter 4: Wildfire Behaviour).

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Appendix 3.1 – Data Characterizing the Bulkley Morice Fire Regime

Table A3.1. Alternative descriptors of the recent fire regime for portions of the Bulkley Morice study area, emphasizing burn rate and implied fire cycle.

Source	Stratum	Period	AAB, %/yr	Fire Cycle, yrs	Mean Size, ha	Median Size, ha	Season	Cause	Caveats
Anonymous 1995	SBSdk, SBSmc	pre-settlement	0.80	125*	300 - 10,000		all	all	expert opinion,
(Biodiversity Guidebook)	ESSFmc, ESSFwv,		0.50	200*	20 - 1000				inferred from
	ESSFmk, ICHmc, CWHws								vegetation plots
Steventon 2002	SBSdk	1760-1970	1.09	92		626	all	all	assumes an
	SBSmc		0.81	124		681			untruncated
	ESSFmc		0.60	166		517			neg. exponential
	ESSFmk		0.42	237		408			distribution of
	ESSFwv		0.45	220		392			stand ages
Campbell 2006	all SBSdk	1904-1953	0.3953	253					multipliers of
(SBSdk only)	all SBSdk	1954-2004	0.007	14286		<==ignore this period for breakdow			59% pre'54 and
	upland forest	1904-1953	0.746	134		by strata (too few fires)			1% post-'53 to
	upland scrub		0.43	233					estimate fire,
currently dominated by:	lodgepole pine	1904-1953	0.61	165					but not true for
	interior spruce		0.60	167					each partition;
	black spruce		0.78	128					illogical to treat
	subalpine fir		0.63	160					a veg type as a
	broadleaves		1.22	82					landscape with its
	shrubs		0.40	250					own dist. regime
Boulanger et al. 2012	HFR4, human cause	1980-1999	0.033	3030	37	3	June 20 ave	76% human	gridded to 40 km
	HFR4, natural cause		0.010	10000	(all fires)	(all fires)	July 25 ave.	24% natural	point fire data
Boulanger et al. 2014	HFR P	1959-1999	0.04	2500			all	all	gridded to 60 km
									only fires >200 ha
Burton & Boulanger 2018	HFR 5	1956-1996	0.069	1449	17	3.2	June 25 ave.	all	combined human
	HFR 17 (higher elev.)	1956-1996	0.031	3226	81	6.4	July 31 ave.	all	and lightning fires
Erni et al. 2020	FRU 47	1970-2016	0.1313	762			58% summer	66% human	only fires >50 ha
	FRU 57 (higher elev.)		0.1244	804			85% summer	22% human	spring/summer
Lewis 2023	FRU 47	1970-2022	0.304	329			71% summer	31% human	as for Enri et al.
	FRU 57 (higher elev.)		0.197	508			86% summer	10% human	(only fires >50 ha)
"BEC Groups"==>	SBPS-SBS Dry		0.418	239			73% summer	3% human	
	SBS Moist		0.214	467			74% summer	29% human	
	ESSF Moist		0.161	621			88% summer	16% human	
				*more properly fire return interval (FRI), not fire cycle					

Table A1, continued

Source	Stratum	Period	AAB, %/yr	Fire Cycle, yrs	Mean Size, ha	Median Size, ha	Season	Cause	Caveats
Maltman et al. 2024	Tweedsmuir caribou herd range	1985-2019	0.597	167	104		all	all	plus 0.37% non-stand replacing (including MPB) and 0.31%/yr logging disturbance
	Telkwa caribou herd range		0.021	4857	(across all 9 northern herds of the Southern				plus 0.07% other, & 0.41%/yr logging
	Takla caribou herd range		0.018	5667	[values calculated from their Fig. 2]				plus 0.21% other, & 0.38%/yr logging
Burton 2025	BAFA	1920-2024	0.0038	26316		12.1	all	all	years with no data
(Bulkley-Morice	CWH	overall	0.0019	52632		13.6			interpretted as
study area only)	ESSF		0.1605	623		99.0			missing, not used
	ICH		0.0700	1429		16.8			in burn rate
	MH		0.0107	9346		169			calculation
	SBPS		0.9501	105		2145			(very small areas
	SBS		0.1619	618		45.5			for BAFA, CWH, MH)
	SBPS/SBS-dry		0.5122	195		39.0	all	all	
	SBS-moist		0.3393	295		74.8			
	ESSF-moist		0.2123	471		134			
Hoffman et al. 2025	cultural sites, lakeside	1580-1957	11.11	9*			late summer / early fall	human	SBSmc2, ESSFmc, ESSFmk ca. 1000m
	no cultural sign, upland		1.83	55*			mid-summer / early fall	natural & human	upland sites to 1500m elevation
Daust & Price 2025	all SBSdk	1890-1930	1.5873	63			all	all	rollbacks of VRI
		1930-2010	0.3257	307					stand ages, like
	all SBSmc	1890-1930	0.9524	105					Steventon 2002;
		1930-2010	0.1678	596					assumes all stands
	all SBSwk	1890-1930	0.8772	114					even-aged fire
		1930-2010	0.1631	613					w/ fire random

4.0 Wildfire Behaviour

By Phil Burton and Larry McCulloch, with input from Brad Martin and Dr. Kira Hoffman.

Introduction

Fire behaviour describes how fuel (primarily vegetation and other biomass) ignites, how flames grow, and how a fire spreads (CIFFC 2022). This behaviour is influenced by the interplay of three factors: fuel, weather, and topography (Figure 4.1). Recent weather conditions—such as precipitation, temperature, and wind—affect the moisture content of potential fuels. Additionally, the landscape, including slope and sunlight exposure, also influences how well moisture is retained.

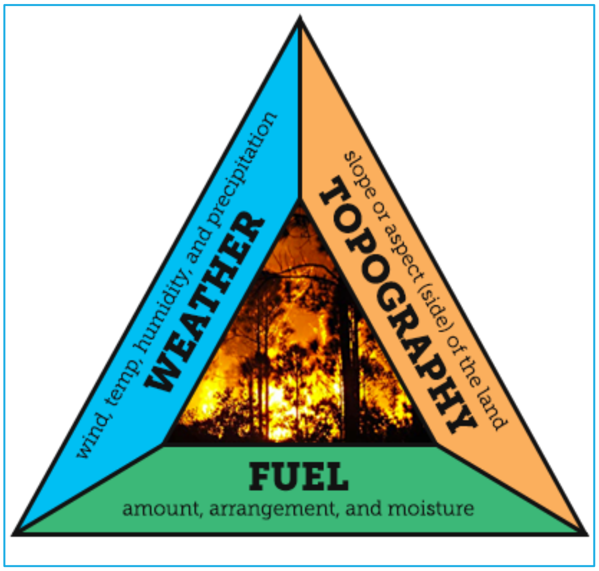


Figure 4.1. The fire "behaviour triangle" emphasizes the co-dependence of fire behaviour attributes on the interaction of fuels (living and dead vegetation), weather and topography. *https://learn.weatherstem.com/modules/learn/lessons/121/12.html*

During a fire, the fuel characteristics, weather conditions, and topography determine how hot and fast the fire burns. Fire behaviour and fire management are based on these relationships. Depending on their location, plants, their parts, and dead plant material dry out at different rates. They also have different chemical compositions and arrangements. As a result, the type and structure of vegetation influence how easily fires start, how long they last, and how intense they become.

Ultimately, the characteristics of fire behaviour—such as flame height, intensity, fuel consumption, spread rate, fire duration, and spotting—determine the effects of the fire.

A forest's ecological composition and structure strongly influence fuel load, fuel configuration, microclimate, and overall susceptibility to fire (e.g. Thomas et al. 2016, see Figure 4.2).

Some tree species, like conifers, have foliage that is more flammable than that of others, reflecting a combination of low moisture content and the presence of flammable secondary compounds (e.g., terpenes, oils, resins). Conversely, broadleaf foliage and new conifer foliage are higher in moisture content than old conifer foliage (Agee et al. 2002). Other highly flammable species include certain shrubs, such as junipers, and invasive plants such as cheatgrass. Forest stands can also differ in the vertical and horizontal continuity of fuels, with stands having low-hanging branches, such as those found in black spruce and subalpine fir, being more prone to crown fires.

Forest stands can vary considerably in their canopy bulk density (fuel density per m^3), and consequently, in the intensity of wildfires they can support. Canopy bulk density varies with tree densities, crown diameter, and the length of their live crowns, which vary among tree species and with stand development history. The horizontal continuity of fuels, in terms of stand density and the presence, density and position (elevation above the forest floor) of fallen tree boles, can influence the potential for fire spread. Many of those traits change throughout stand development and succession, with a large quantity of dead woody fuels found for a few decades after a previous disturbance, such as a bark beetle outbreak or fire. Those fuels gradually deteriorate and are eventually replaced by more fallen trees during stand self-thinning, a process that becomes increasingly prevalent after canopy closure during stand development.

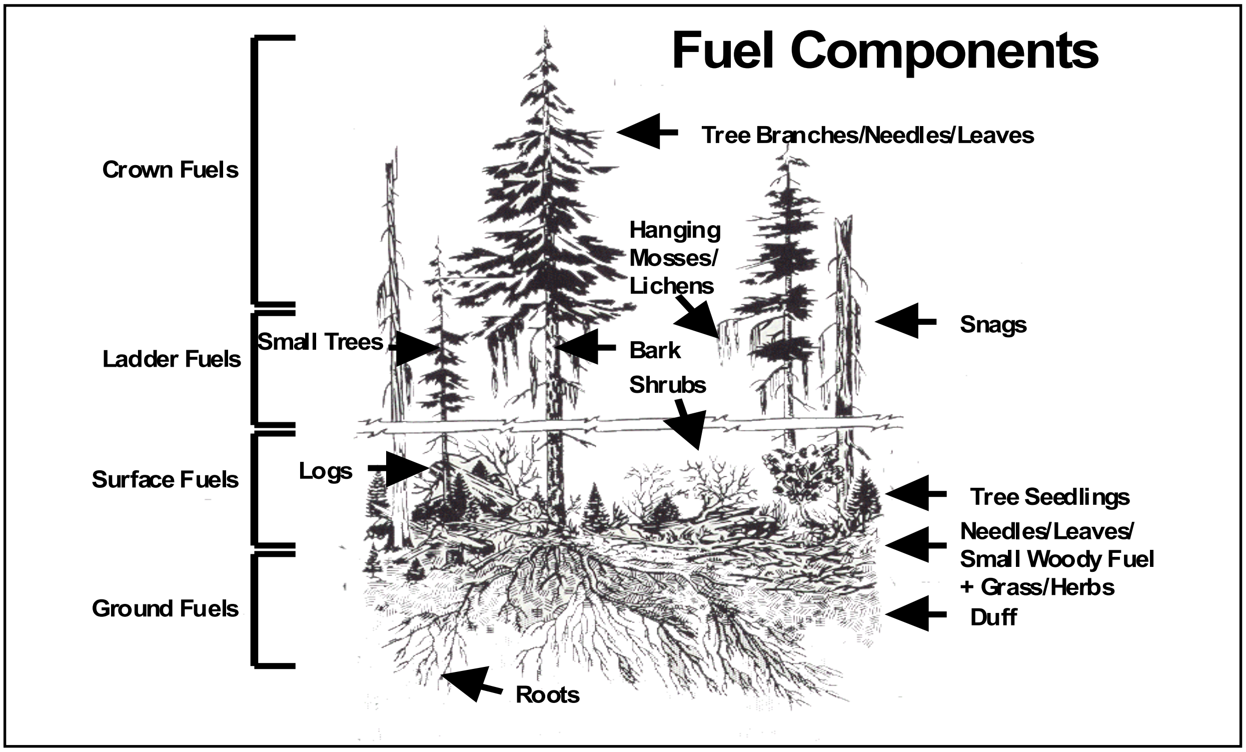


Figure 4.2. Fuel attributes (density, moisture content, vertical and horizontal continuity) can vary considerably with forest stand composition and structure (from Salis 2008).

The gappy structure of old-growth forests, or forests that have been continuously managed with fire, often results in uneven fuel distribution and irregular wind effects, meaning that fire behaviour can differ markedly from that in uniform mature or juvenile forest stands. Additionally, thick layers of forest floor debris that develop over time and under cool, wet conditions can support more long-lasting smouldering fires.

Types of Fuel

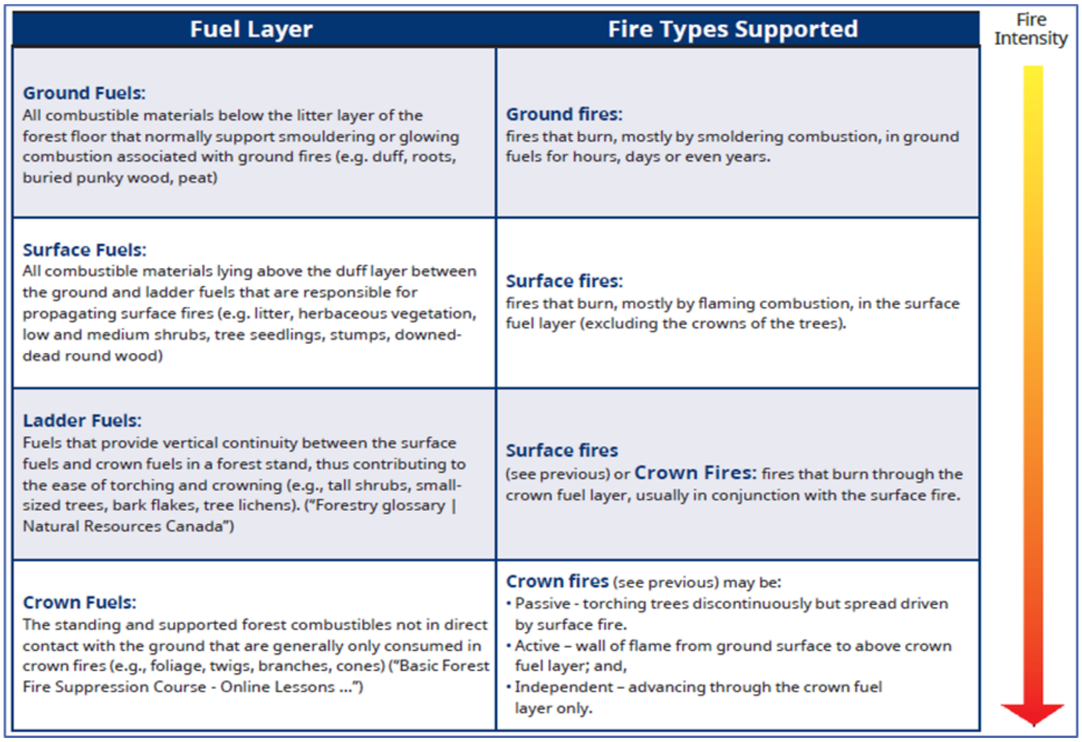
Wildland fires burn four types of forest fuels, based on their vertical distribution within a forest profile: crown fuels, ladder fuels, surface fuels and ground fuels (Figure 4.3). Grass and woody fuels are often categorized into live and dead (or cured in the case of dried grass) components. In the Canadian Forest Fire Danger Rating System (CFFDRS), dead surface fuels and ground fuels are used to calculate a fire weather index based on drying rates. Those three fuel categories are:

- **fine fuels**, consisting of the top 1 to 2 cm of surface litter (dry grasses, dead needles, twigs and dead woody material under 7 cm in diameter that dries out in 2 to 3 days);
- **the duff layer**, consisting of dead organic matter in the forest floor beneath the litter layer, nominally to a depth of about 7 cm, that dries out in about 12 days; and
- **the deep, compact organic layers** or peat deposits nominally at a depth of 18 cm, plus large dead woody material (≥7 cm in diameter) that dries out in about 52 days (Van Wagner 1987).

In addition, the moisture content of conifer foliage is estimated and is used in some fire behaviour predictions (FCFDG 1992), such as for crown fire initiation.

The time lag for fuel moisture to come into equilibrium with the environment is also used in the U.S., and this classification system is sometimes used in Canada as well. The U.S. Forest Service describes four time-lag categories (NWCG 2025):

- **1-hour fuels**, which consist of litter, herbaceous matter, and woody material <6.4 mm in diameter;
- **10-hour fuels**, which include 0.6-2.5 cm diameter woody material and subsurface litter and duff <1.9 cm below ground;
- **100-hour fuels**, which include 2.5-7.6 cm diameter woody material and organic matter 1.9-10 cm below ground;
- and **1000-hour fuels**, which consist of wood >7.6 cm in diameter and organic matter >10 cm below ground.



Fuel Layer	Fire Types Supported
Ground Fuels: All combustible materials below the litter layer of the forest floor that normally support smouldering or glowing combustion associated with ground fires (e.g. duff, roots, buried punky wood, peat)	**Ground fires:** fires that burn, mostly by smoldering combustion, in ground fuels for hours, days or even years.
Surface Fuels: All combustible materials lying above the duff layer between the ground and ladder fuels that are responsible for propagating surface fires (e.g. litter, herbaceous vegetation, low and medium shrubs, tree seedlings, stumps, downed-dead round wood)	**Surface fires:** fires that burn, mostly by flaming combustion, in the surface fuel layer (excluding the crowns of the trees).
Ladder Fuels: Fuels that provide vertical continuity between the surface fuels and crown fuels in a forest stand, thus contributing to the ease of torching and crowning (e.g., tall shrubs, small-sized trees, bark flakes, tree lichens). ("Forestry glossary | Natural Resources Canada")	**Surface fires** (see previous) or **Crown Fires:** fires that burn through the crown fuel layer, usually in conjunction with the surface fire.
Crown Fuels: The standing and supported forest combustibles not in direct contact with the ground that are generally only consumed in crown fires (e.g., foliage, twigs, branches, cones) ("Basic Forest Fire Suppression Course - Online Lessons ...")	**Crown fires** (see previous) may be: • Passive - torching trees discontinuously but spread driven by surface fire. • Active – wall of flame from ground surface to above crown fuel layer; and, • Independent – advancing through the crown fuel layer only.

Figure 4.3. Summary of fuel layer (from BCWS 2024a).

Most conifer forests have a pronounced duff layer, consisting of partially and fully decomposed organic materials just below the litter layer or the living moss. The surface layer consists of fallen leaves, twigs and cones, along with any living and dead herbaceous and woody vegetation, including downed woody material, shrubs and tree seedlings. Depending on the species composition and structure of a forest, there may or may not be a fuel strata gap between the surface and crown layers (Figure 4.4). Specifically, the fuel strata gap is the distance between the average height of understory fuels to the average height of the overstory

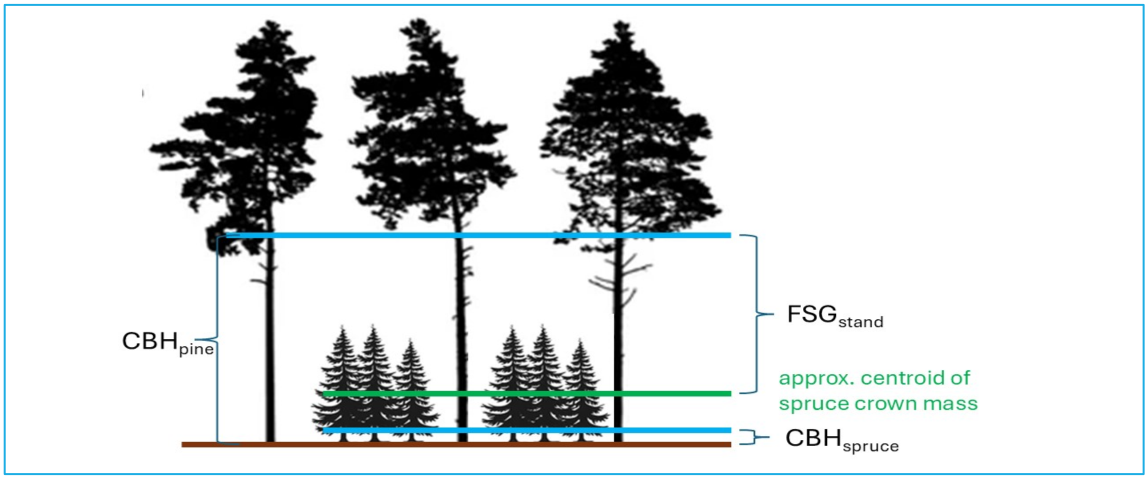


Figure 4.4. Diagram illustrating the difference between crown base height (CBH), which can vary among species within a stand, and the fuel strata gap (FSG), which is an overall stand attribute. FSG is equivalent to the overstory CBH when there is no understory.

green crown base. The larger the gap, the less likely that a surface fire will transition into a crown fire (BCWS 2020). For example, black spruce, subalpine fir, and western redcedar often have branches that reach the forest floor, leaving no gap. On the other hand, if such trees are rare in a stand, their low-hanging branches (along with dead branches, flakey bark, and living or dead saplings, and suspended deadwood found throughout the stand) can be considered ladder fuels that span the fuel strata gap. Where a stand is relatively dense and homogeneous, the natural pruning of lower branches through self-shading, especially in shade-intolerant species such as pines, will typically leave a pronounced fuel strata gap (Jain et al. 2020). Where there is minimal advance regeneration or shrub growth in such stands, the crown base height (also known as the height to live crown), largely determines the energy required for a surface fire to transition into a crown fire (discussed further below).

The Canadian Fire Behaviour Prediction (FBP) system further classifies vegetation and surface fuel loading into 16 fuel types based on stand composition, tree crown characteristics and typical fuel arrangement (FCFDG 1992): C1 to C7 (coniferous fuel types), M1 to M4 (deciduous and mixed-wood fuel types), S1 to S3 (slash fuel types), and O1a and O1b (open and grassy fuel types); see Appendix 4.1 for details.

Although updated relatively recently (Wotton et al. 2009, Perrakis et al. 2023), the FBP system is based on a few well-instrumented and well-documented experimental burns and wildfire observations, primarily in eastern and boreal forests. Various assumptions and analogies have been employed to translate the diversity of B.C. forests into that limited set of FBP fuel types. For example, many open conifer forests in northern B.C., such as those found one or two decades after a bark beetle attack, are classified as the C-7 fuel type, which is calibrated for open ponderosa pine and Douglas-fir forests, despite the absence of those tree species (Perrakis et al. 2018). Structured evaluations elsewhere in the province suggest much further work is needed to translate or devise B.C. fuel types, or that a different approach (e.g., based strictly on stand structure attributes) to B.C. fuel type characterization is needed (Baron et al. 2024).

Types of Wildfire

As shown in Figure 4.3, three general types of wildfires are recognized: ground fires, surface fires, including those in ladder fuels, and crown fires. Fires generally start in the fine dead plant material or dry vegetation, which may include moss, lichen, grass, or other short plants, found in the surface layer. Fires can spread along the forest floor, where fire burning in fallen dead woody material and other fuels can sometimes generate sufficient flame length and heat to ignite tree crowns, but can also support long-lasting flaming, glowing, and smouldering combustion in large woody material on the forest floor. Ladder fuels can facilitate and accelerate a surface fire becoming a crown fire by providing a direct pathway for flames to travel into crown fuels. Fires in the forest canopy can be most intense where a dense and well-spaced biomass accumulation is well aerated. While not supporting intense fires, ground fuels (duff, roots, peat, and buried wood) can smoulder for extended periods without flames ever appearing. Ground fires are usually associated with deeper duff horizons and peat deposits that develop in areas that are usually wet, such as bogs or muskeg, or where there are dead or diseased trees with a root structure that allows surface fire to travel down the roots beneath the soil surface.

A surface fire consumes understory fuels such as moss, litter, grass, leaves, small shrubs, regenerating conifers, and fallen trees and branches. It does not burn into the tree canopy. Surface fires can vary in intensity from smouldering wood coals with no visible flames to high-intensity flames reaching several metres in height. However, they do not involve the larger tree crowns. Depending on fuel loads, their arrangement, wind speeds and slope, surface fires can be intense and difficult to control. Ladder fuels are a component of surface fuels and include vegetation, such as small trees, shrubs, and low-hanging branches, that can carry flames from a surface fire into the tree canopy. The flaky or shaggy bark of some trees can also act as ladder fuel.

The wildfire rank system

Another set of wildfire descriptors, especially important with regard to fire suppression efforts and public safety, is the wildfire rank system.

Rank 1 fires are ground fires, and Rank 2 and 3 fires are primarily surface fires. Rank 4 wildfires are typically intermittent crown fires, but Rank 5 and 6 fires are all-consuming crown fires, with Rank 6 wildfires being particularly explosive and unpredictable (BCWS 2024b).

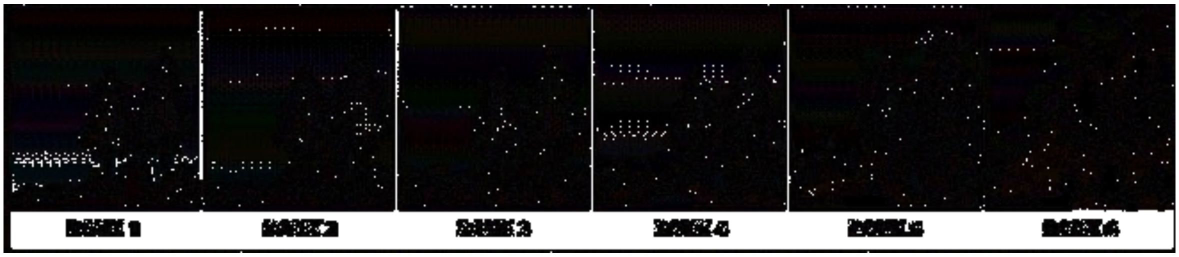


Figure 4.5. Graphic portrayal of differences in wildfire ranks (from BCWS 2024b).

The transition from a surface fire to a crown fire can occur where the crown base height is low, very high radiant heat is generated, or ladder fuels carry the fire upward. Crown fires exhibit extreme wildfire behaviour that limits ground suppression opportunities and has the potential to severely impact values and communities. Passive or intermittent crown fire occurs when fire ignites individual or small groups of tree crowns, a phenomenon known as candling or torching.

However, it does not spread continuously through the canopy and primarily remains connected to surface fuels, with occasional bursts into the canopy.

Active crown fires occur when flames spread from the crowns of trees to other trees while still relying on the intensity of underlying surface fire. These types of fires spread more quickly and generate longer flame lengths compared to surface fires. They are also more effective at creating spot fires, which are ignited by wind-driven embers that launch ahead of the main fire front. The winds that carry these burning embers, which often consist of large pieces of bark, twigs, or cones from tall trees, are usually a combination of surface winds fueling the fire and convective updrafts created by the fire's heat.

On some occasions, independent crown fires can develop without any understorey surface fire; however, these typically last only brief periods. For example, lightning strikes may ignite the crown of a single tree or a small group of trees, but not spread much further, leaving a canopy gap in the forest. One of the goals of fuel treatment strategies is to prevent surface fires from escalating into crown fires or to encourage crown fires to transition back to surface fires. This can help moderate fire behaviour and reduce its intensity. Fuel reduction treatments (see Chapter 7: Stand-Level Fuel Management) often aim to achieve conditions that would maintain fire intensities below 2,000 kW/m, a level at which ground suppression efforts (including heavy equipment) are generally effective in controlling the fire (BCWS 2021).

Drivers Of Wildfire Behaviour

The 2023 wildfire season in B.C. and across Canada resulted in an unprecedented amount of forest area being burned (Daniels et al. 2025, Jain et al. 2024). Notably, five of the six largest B.C. provincewide levels of area burned since reliable records began in 1950 occurred in the last decade (CWFIS 2024, BCWS 2025). Novel conditions are influencing the weather (including precipitation and wind patterns as well as temperature) and/or vegetation (fuel) components of the fire behaviour triangle, while topography remains unchanged. Additionally, unusual and dangerous fire spread events have become more common. For example, the Lower East Adams Lake and Bush Creek East fires (north of Chase and northeast of Kamloops) merged, spreading 20 kilometres in just 12 hours. Similarly, the Patry Creek fire spread over 30 kilometres in a single day on September 1, 2024, prompting evacuations north of Fort Nelson (Daniels et al. 2025). This raises the question: *What is driving the current increase in wildfire activity and behaviour?*

At the stand level, several factors affect how fire behaves. These factors include the amount of fuel available, the forest's structure, the types of tree species present, any damage to forest health, local wind and weather patterns, and the landscape's topography. However, these factors do not explain the record wildfires that occurred in Canada in 2023 under varied local conditions.

At the landscape level, Daniels et al. (2025) identify two leading causes: 1. Fire weather conditions that include extended periods of drought, high temperatures, low humidity, and strong winds, which reached levels higher than 95 percent of observations for those variables over the past decades in parts of British Columbia during May, June, and September; 2. Landscapes that have become more flammable and at risk due to a century of fire suppression, the exclusion of Indigenous fire management practices, industrial land use, population growth, and increased human activities, such as recreational uses and construction of roads and residential areas in forests.

Other factors include a legacy of the mountain pine beetle epidemic, which affected approximately 18.3 million hectares from 1999 to 2015, with varying proportions of dead lodgepole pine contributing to amplified fire behaviour and effects at the stand level (Perrakis et al. 2014, Talucci et al. 2022, Woo et al. 2024). Against this backdrop of extreme fire weather and millions of hectares of susceptible fuel, the last two decades of targeted fuel reduction efforts have been both minuscule in area and relatively ineffective under such conditions. Urza et al. (2023), in a landscape-scale study of fuel treatment effectiveness, noted that a common theme from their case study data was that fuel treatment effectiveness declined during periods of extreme fire weather. Barnett et al. (2016) concluded that western U.S. wildfires encroached on only 6.8% of fuel-reduction treatments over the following 14 years, with most requiring re-treatment by that time.

Van Wagner (1977) identified **critical factors for initiating a crown fire**. Summarized here, they include:

1) a well-fueled flaming surface fire;

2) a crown base height low enough to be reached by surface or ladder-fuel flames, or that can be ignited by the radiant heat of the surface fire; and

3) sufficient canopy continuity or wind to drive flames to new fuel as burned fuel is consumed.

One of the most critical thresholds in wildfire behaviour is the transition from a surface fire to a crown fire. Conifer tree crowns can constitute a well-aerated fuel mass rich in waxes, resins, volatile compounds and other flammable secondary compounds. That combination of fuel structure and chemistry readily supports the "torching" or "candling" of individual trees. Especially when aided by wind, crown-to-crown ignition can follow rapidly in a closed canopy conifer forest. Unlike surface fires or a passive crown fire with occasional torching, ground crews and equipment cannot directly control an active crown fire (Table 4.1). The ability of different forest stands to meet the criteria to support an active crown fire may explain differences in fire behaviour and severity across the landscape. These factors can sometimes be managed through techniques such as surface fuel removals, pruning, and stand thinning, which can reduce the likelihood and intensity of crown fires (Agee & Skinner 2005, BCWS 2021, 2024a), as further elaborated upon in Chapter 7.

Fire intensity is a key consideration in understanding, predicting, and moderating wildfire behaviour. The combination of average live crown length and stand density determines how much elevated, well-aerated biomass (expressed as canopy bulk density) is available. Once ignited, wildfire intensity is a multiplicative product of canopy biomass (fuel available) and the rate of spread, which is typically driven by wind and thus reflects the rate at which fuel is oxygenated. That intensity and the associated heat generated, often measured as kW per metre of fire front, then determines the ease with which an active crown fire can be sustained, what level (rank) of fire behaviour is exhibited, and, to a large extent, what level of control is possible.

Table 4.1. Wildfire rank characteristics (based on BCWS 2024b).

Rank	Description	Flames	Smoke	Flame Front	Spotting	Rate of Spread
1	smouldering ground fire	no open flame	white	none	none	slow, creeping
2	low-vigour surface fire	visible open flame	grey	unorganized, inconsistent	none	slow
3	moderately vigorous surface fire	occasional candling	grey	organized (surface)	rare	moderate
4	highly vigorous surface fire with torching; intermittent crown fire	into and occasionally above the forest canopy	grey to black	organized surface flame front	short-range	moderate to fast (on the ground)
5	extremely vigorous surface fire; active crown fire	throughout and above the forest canopy	black to copper	organized crown fire front	moderate to long-range; independent spot fire growth	moderate to fast (on ground and in canopy)
6	conflagration or blow up; extreme, aggressive fire behaviour	all encompassing, possible fireballs and whirls	black and copper	organized crown fire front, plus expansion through spot fires	long-range spotting; independent spot fire growth	fast, unpredictable

Predicting Wildfire Behaviour

The Fire Weather Index (FWI) system.

Meteorological attributes of the FWI system are gathered from the nearest weather station or temporary fire weather stations.

The **duff moisture code** (DMC) and **drought code** (DC) are combined to generate a **buildup index** (BUI) indicative of overall drought-driven susceptibility. The **fine fuel moisture code** (FFMC) is used in conjunction with wind speed to generate an **initial spread index** (ISI), a key indicator of ignition potential.

Another ancillary attribute that can be predicted from FWI components is **foliar moisture content** (FMC), as calibrated for generic conifer foliage (Van Wagner 1974, Lawson and Armitage 2008).

The BUI and ISI are then used to calculate the fire weather index (FWI), which estimates fire intensity that would develop under those conditions.

Most operational aspects of wildfire management conducted in Canada over the last three to five decades – including risk and hazard assessment, risk reduction activities such as fuel treatments, and fire suppression efforts – are based on the Canadian Forest Fire Danger Rating System (CFFDRS, Stocks et al. 1989).

The CFFDRS currently has two main component subsystems, the Canadian Forest Fire Weather Index (FWI) system and the Canadian Fire Behaviour Prediction (FBP). The FWI system estimates the moisture content of fuels based on recent and medium-term rainfall, as well as the cumulative effects of drying associated with air temperature, relative humidity, and wind.

Fire Metrics of the Canadian Forest Service Fire Behaviour Prediction (FBP) system

Total Fuel Consumption (TFC) is a prediction of biomass consumption (in kg/m^2) by a fire, both on the forest floor (which is first estimated separately) and in the forest canopy. Those fuel consumption predictions are based on **foliar moisture content** (FMC) and rate of spread (ROS).

Head Fire Intensity (HFI) is the predicted energy output at the head of a fire. Measured in kilowatts per metre of fire front (kW/m), HFI indicates the difficulty in controlling a fire and is based on the ROS and TFC.

Crown Fraction Burned (CFB) is the proportion of tree crowns predicted to be consumed by the fire, and is based on buildup index (BUI), FMC, and ROS. Fire type is generally indicated by CFB, with CFB < 10% denoting a predominantly surface fire, CFB > 90% a continuous crown fire, and intermediate values representing an intermittent crown fire (Kirsch 1996, Wotton et al. 2009). After a fire has been extinguished, CFB is an attribute that can be easily verified by aerial inspection or remote sensing.

The FWI informs the daily severity rating (DSR) of low, moderate, high, very high or extreme fire danger, based on regional thresholds, which is widely communicated to the public (Natural Resources Canada n.d.).

Those daily indices are indicative of wildfire susceptibility, but hourly changes in temperature, relative humidity, precipitation, and wind can greatly influence fire behaviour.

Collectively, the BUI, ISI, and FWI codes, along with wind speed, predict different aspects of fire behaviour, which are used in conjunction with fuel type (vegetation) classification and geographic considerations in the FBP system. Predictions from the FBP system consist of quantitative estimates of potential head fire spread rate, fuel consumption, and fire intensity, along with fire behaviour descriptions including crown fraction burned and potential fire type (Kirsch 1996, Wotton et al. 2009). The rate of spread (ROS) is the predicted speed of fire growth (in metres per minute) at the head of the fire, taking into account both crowning and spotting behaviour. Secondary outputs include spread distances and fire intensities for flank and backing fires, as well as head fire behaviour (Figure 4.6).

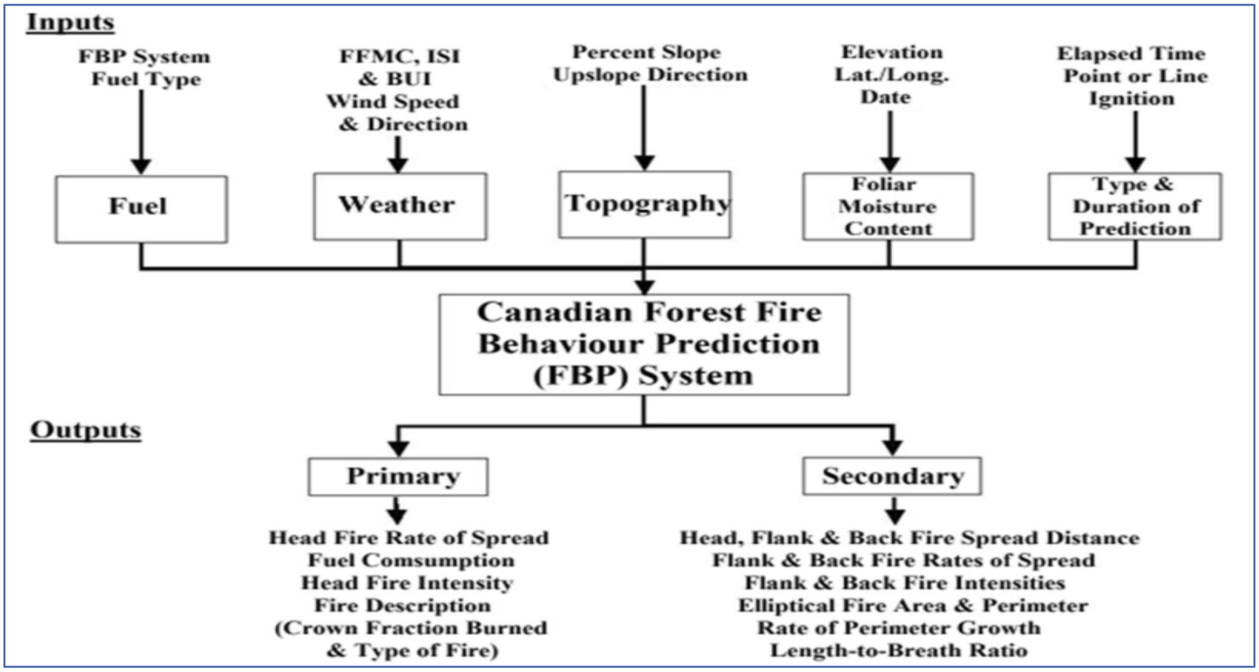


Figure 4.6. Structure of the CFFDRS Fire Behaviour Prediction system (Wang et al. 2017).

At the national or provincial level, FWI and its component indices, which are indicative of fire susceptibility and behaviour, are gridded (interpolated) and presented on maps daily. This information is publicly available for all of Canada[13] and for overall fire danger in B.C.[14] .

The thresholds defining fire danger classes vary among Canadian jurisdictions, based on the cumulative frequency by which different levels have historically been observed (Stocks et al. 1989). Should ignition occur, certain aspects of fire behaviour can be anticipated under each danger class. Based on satellite-based classifications of fuel types (Beaudoin et al. 2014), these fire weather index values are then used to create nationwide maps[15].

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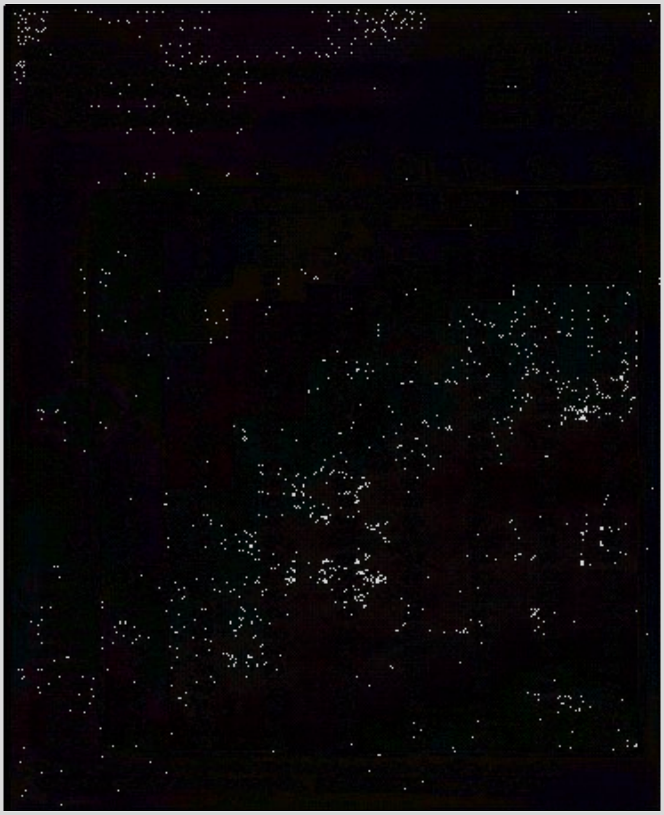
[13] https://cwfis.cfs.nrcan.gc.ca/maps/fw?type=fwi

[14] https://www2.gov.B.C..ca/gov/content/safety/wildfire-status/prepare/weather-fire-danger/fire-danger

[15] https://cwfis.cfs.nrcan.gc.ca/maps/fb

Red Book look-up table for C2 fuel type



Equilibrium rate of spread and fire intensity class for the C-2 (boreal spruce) fuel type as a function of Initial Spread Index (ISI) and Buildup Index (BUI).

In practice, fire managers can use published look-up tables or digital apps on smartphones or tablets to make localized FBP predictions. Use of look-up tables in Taylor et al. (1996), popularly referred to as “The Red Book,” has been standard practice for many years.

The resulting information is used by fire personnel to plan fire management activities, such as direct or indirect attack, and to determine when and where to establish control lines. Supplementary tables and equations predict the probability of sustained ignition in selected fuel types based on ISI, BUI, and DC (Taylor et al. 1996).

The fundamental relationships used in the FBP system are based on continuous theoretical functions and empirical regressions, so the look-up table approach is a simplification.

There are now several digital decision-support systems and simulation models of fire spread or growth that share the same underlying features describing the physics of fire behaviour. For example, the Government of B.C. has developed the FBP-GO app[16] for use on iOS or Android devices that is based on the open-source R script implementation of the combined FWI and FBP systems.

Focusing on the head fire rate of spread, such models assume wind-driven fire growth, resulting in a more-or-less elliptical wildfire perimeter (Weber 2001). As noted above, wind effects can be accentuated or dampened by slope, with upslope fuels being preheated by the fire front. In reality, wind directions and speeds can change markedly between day and night as well as from hour to hour, greatly limiting the predictability of the rate and direction of fire growth. Models differ in the degree to which they aim to predict fire intensity and fire residence time, with

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[16] https://psu.nrs.gov.B.C..ca/fbp-go

smouldering combustion (Watts & Kobziar 2013), and spot fires and their effects being especially challenging (Martin & Hillen 2016).

Early simulation models of wildfire spread include those created by Rothermel (1972) and the BEHAVE model, developed by the US Forest Service (Andrews 1986), which continues to evolve in its components and applications (Andrews 2014). The FARSITE model was subsequently devised to use the output of BEHAVE and the Canadian FBP system to predict and map projected fire intensity and spread (Finney & Ryan 1995). It has application in a wide range of ecosystems (e.g., Salis 2008). In addition to FBP-GO, more complex, spatially explicit fire growth models currently used in Canada include Prometheus (Tymstra et al. 2010), PFAS (Anderson 2010) and Cell2Fire (Pais et al. 2021).

A clear advantage of computerized geospatial models of wildfire behaviour is that they can incorporate mapped variations in vegetation (fuel) and topography, as well as gridded interpolations of fire weather. FARSITE and Prometheus are largely deterministic, but fire behaviour modelling increasingly incorporates random or stochastic behaviour as computing power increases (e.g., Anderson et al. 2007, Anderson 2010, Boychuk et al. 2009). Such stochastic or “Monte Carlo” approaches allow estimation of probabilities over multiple (hundreds or thousands of) simulations with key drivers selected from known or random distributions of input variables. Some platforms, such as BURN-P3, which takes output from multiple runs of Prometheus or Cell2Fire with varying levels for input variables, can be used to map the relative susceptibility to wildfire across an existing map of vegetation and terrain (Parisien et al. 2005). Spatially explicit landscape dynamics models such as SELES (Fall & Fall 2001) and LANDIS (Mladenoff 2004) simulate both disturbance and succession and so have also been used to model fire growth and spread. Such models incorporate many of the features of specialized fire models and can potentially incorporate internal variability in fire behaviour and effects (Sturtevant et al. 2009). Fire growth and behaviour modelling continue to be an area of rapid research and development, with the increasing use of satellite resources for fuel characterization and near-real-time fire activity incorporation (e.g., Anderson et al. 2009). Despite all efforts to date, there is recognition that wildfire behaviour often defies prediction, and much more work needs to be done (Alexander & Cruz 2013).

Knowledge Gaps and Work Needed

The above discussion is a cursory overview of the science underpinning our understanding and prediction of wildfire behaviour in forests. It can also be said that there is an "art" to interpreting what is happening and going to happen in forest fires, based on years of experience, cultural knowledge, and difficult-to-articulate hunches about what any given fire “wants to do.” Furthermore, much of the science and art of wildfire behaviour focuses on the stand level and individual fires, at a time when we are often faced with multiple fires across a region during suitable fire weather, and the footprint of multiple recent fires in many landscapes. A great deal of work needs to be done to develop our understanding of the landscape ecology of fire behaviour.

As we look ahead, a critical question for the Bulkley Morice area is to understand the extent to which the current fire regime and wildfire behaviour are driven by climate factors (top-down), and by fuel conditions (bottom-up). Additionally, we need to examine how landscape fuels reflect land-use and land-management practices. The relative importance of these top-down and bottom-up drivers likely varies by season, year, place, and with the specifics of forest composition and structure. We may think we have more certainty about fuels than about weather, but vegetation inventories are incomplete and prone to error, too. They can become rapidly outdated in the face of insect outbreaks and industrial activity. In the face of uncertainty surrounding such issues, the fundamental drivers of fire behaviour need to be considered under current and future conditions.

We must begin from first principles, re-evaluating our strategies for landscape and fuel management to devise new solutions. The modelling of current and future fire risk and behaviour will have to incorporate multiple scenarios of climate change and land management, with large degrees of randomness in all inputs and recognition that predictions inevitably include very wide confidence limits.

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Appendix 4.1 – Canadian Fuel Type Classifications

In Canada, forest fuels are classified according to the Canadian Forest Fire Behaviour Prediction System as follows (Forestry Canada Fire Danger Group 1992):

Coniferous Fuel Types

- **C1 - Spruce-Lichen Woodland**: Open stands of black spruce with a ground cover dominated by lichens. It is highly flammable due to low moisture content.
- **C2 - Boreal Spruce**: Dense stands of black or white spruce. These have a continuous layer of needles and dead material that can contribute to intense surface fires.
- **C3 - Mature Jack or Lodgepole Pine**: Stands dominated by mature jack pine or lodgepole pine. It tends to produce intense fires with crown fire potential due to the continuous canopy.
- **C4 - Immature Jack or Lodgepole Pine**: Younger, more densely packed jack or lodgepole pine stands. These can be very flammable due to the tight arrangement of smaller trees.
- **C5 - Red and White Pine**: Mature red and white pine stands with a less continuous canopy and understory. Surface fires are common, with a lower likelihood of crown fires.
- **C6 - Conifer Plantation**: Plantations of conifers like spruce, pine, or fir. Their uniform structure can lead to predictable fire behavior, often intense due to the density.
- **C7 - Ponderosa Pine-Douglas Fir**: More open stands of these species with grass or shrubs underneath, which can lead to surface fires and occasional crown fires.

Deciduous and Mixedwood Fuel Types

- **D1 - Leafless Aspen**: Deciduous stands, primarily aspen, without leaves (typically during spring or fall). Fire spread is usually limited due to the absence of continuous fine fuels.
- **D2 - Green Aspen:** Deciduous stands with leaves present, where the moisture content in the leaves generally limits fire spread.
- **M1/M2 - Boreal Mixedwood (Leafless/Green):** Stands with a mix of coniferous and deciduous trees. M1 is used when deciduous trees are leafless (more flammable), and M2 when they are in leaf (less flammable).
- **M3/M4 - Dead Balsam Fir Mixedwood (Leafless/Green):** These stands include a significant component of dead balsam fir, which increases the risk of intense fires. M3 is for leafless conditions, and M4 for green.

Slash Fuel Types

- **S1 - Jack or Lodgepole Pine Slash**: Residual debris (slash) left after harvesting or natural disturbance in pine stands. These fuels can be very dry and flammable.
- **S2 - White Spruce-Balsam Slash**: Slash from white spruce or balsam fir, which can ignite easily and burn intensely.
- **S3 - Coastal Cedar-Hemlock-Douglas Fir Slash:** Debris from coastal logging of cedar, hemlock, or Douglas fir, with moderate to high flammability.

Open and Grassy Fuel Types

- **O1a - Grass (Standing)**: Dry, cured grass in open areas. These can carry fast-moving fires, especially in windy conditions.
- **O1b - Grass (Matted)**: Cured grass that is more matted down, resulting in a slower but still potentially fast-spreading fire.

5.0 Fire Effects

By Phil Burton

Introduction

Fire effects encompass a broad suite of physical, biological, and ecological changes to resources, assets, and values caused by fire, whether immediate or long-term, and whether detrimental, beneficial, or benign (CIFFC 2022). Media reports and headlines worldwide understandably emphasize the detrimental effects of uncontrolled wildfires on human lives, infrastructure, and property. Those effects range from the inconvenience of evacuations in the face of threatening wildfires and the health effects of prolonged smoke inhalation to human mortalities and the destruction of homes, businesses, other private property (such as vehicles and industrial equipment) and infrastructure.

Attention is also paid to the immediate impacts on wildlife and their habitats, with burned conifer forests often characterized as "destroyed timber" (e.g., Lindenmayer et al. 2023). Economic impacts can only be estimated. For example, the 2023 fire season in British Columbia (B.C.) cost $817 million in fire suppression and $720 million in insured losses (Daniels et al. 2025). The indirect costs, such as lost wages, destruction of public timber and damage to physical and mental health due to smoke and the trauma of evacuations, are unknown, but could be as much as 20 times higher than the direct costs (Labbé 2025). In the long run, the knock-on ecological effects may be even more substantive than the direct, short-term human impacts, because wildfires affect ecosystem services such as carbon budgets, watershed hydrology, forest composition, timber supply and the risk of future disturbances for decades to come.

The negative impacts of wildfires on humans, experienced intermittently and dramatically across North America in the 20th century, led to the establishment of wildfire suppression agencies and policies in all jurisdictions (Pyne 1982). Many decades of suppressing both wildfires and Indigenous fire stewardship, including cultural burning, perhaps in combination with runs of relatively cool wet weather, have created a "wildfire paradox". While small fires have been successfully controlled, fuel accumulation may now be contributing to larger fires or higher-severity fires (Ingalsbee 2017, Fernandes et al. 2020). The wildfire paradox is one potential explanation for a "fire deficit" that has been found to prevail across much of Canada (Parisien et al. 2020). However, this is debated in the context of closed-canopy boreal conifer forests (Johnson et al. 2001). Hai et al. (2023) conducted a systematic review of research on the effects of wildfire suppression on wildfire regimes. They concluded that while fire suppression controlled burned areas across all ecosystems, the evidence for the wildfire paradox was mixed, with some studies finding it and others providing opposing findings. They concluded that the wildfire paradox is more likely to occur in fuel-limited systems (such as the dry forests of western North America) and is less likely to occur in climate-limited systems in humid climates, including some parts of the boreal forests. Such a fire deficit is more substantiated in low-elevation forests of the USA and southern B.C. (Parks et al. 2015, 2025). While there has undoubtedly been a mid-20th-century decline in the footprint of wildfires in the Bulkley Morice study area (see Figure 3.3), it remains uncertain whether fuel accumulations substantially contribute to the increased risk of fire across this region. Nonetheless, it is clear that any exploration of "fire effects" should also consider "fire suppression effects."

It has been argued that allowing or prescribing small, cool, controlled fires, which reduce susceptible fuel loads, constitute "good fire" (i.e., are beneficial) while large, hot, uncontrollable fires are "bad fire" (are detrimental) (Pyne 2016). The underlying premise in such categorical and explicitly value-laden labels is that the effects of beneficial fire include reduced fuel susceptibility to future fires and provide ecological benefits. In contrast, detrimental fire results in the destruction of sensitive biodiversity, loss of human life or property, or the long-term degradation of other forest values (e.g., soil health and productivity, hydrological regulation). From an ecological perspective, beneficial fire is desirable (or at least acceptable) for species and ecosystems with an evolutionary history of adaptation to fire, as is the case for boreal and sub-boreal forests. Conversely, extensive and severe fires in “fire-naïve” habitats such as rainforests can be ecologically devastating, with very long-lived consequences and limited prospects for ecological recovery (Kaufmann et al. 2005, Berlinck & Batista 2020).

Ecology of fire effects

Ecologists are interested in the differential effects of fire on various plant, animal, fungal, and microbial species, as well as on ecological processes such as carbon sequestration and hydrological regulation. Central to understanding these and related effects are several important considerations:

- The effects of fire can vary considerably with fire severity.
- The long-term effects of fire can differ markedly from those evident soon after a fire.
- There are cumulative and cascading effects of recurrent fires at the same location, and fires interact with other stressors such as drought, storms, and insect outbreaks (Buma 2015, Burton et al. 2020).
- Although ecosystem services are undeniably impacted by fire, determining what is beneficial or detrimental fire is inherently a human value judgement, depending heavily on context.

Let us first review the concept of fire severity, then address its effects on species and plant communities, followed by a brief exploration of its effects on ecosystems and ecological processes, including trajectories of post-fire recovery. This section does not explicitly address the effects of fire on human health, cultural heritage, infrastructure, or communities.

Burn severity

Burn severity is one feature determining wildfire resilience (vegetation survival and recovery). Burn or fire severity differs from fire intensity in that severity refers to the degree of impact, not just the energy released by a fire. An intense fire does not necessarily have severe impacts, such as when a hot, wind-driven fire moves rapidly through a stand but consumes relatively little biomass. Conversely, a low-intensity smouldering fire that lingers in a stand can consume more biomass and have a more severe effect on the ecosystem than a high-intensity flaming front. Burn severity typically refers to the level of mortality and biomass consumption caused by a fire (Keeley 2009). It is often evaluated separately and cumulatively for the tree layer, understory vegetation, and forest floor, which can be aggregated based on field survey plots to generate the Composite Burn Index (CBI) (Key & Benson 2006), as well as through satellite-based estimates of changes in biomass. Plant mortality immediately after a fire is rarely a sufficient measure of burn severity, in part because some species of trees and many understory plants can appear dead but are subsequently able to resprout from regenerative tissue that has survived the fire; conversely, some trees may remain green after a fire, but die from their injuries over the next year or two.

Although clearly varying along a continuum, and often differing among canopy, understory, and soil layers, the following descriptions provide useful reference conditions for the categorization of burn severity in forests (NWFSC 2015):

- **Low severity**: fire has a limited effect on overstory trees (e.g., <30% mortality), understory vegetation, and soils.
- **Moderate severity**: fire produces variable, moderate effects on overstory trees, averaging 30-80% of the vegetation killed, and moderate soil exposure.
- **High severity**: fire results in a high amount of overstory tree mortality (e.g., >80%) and extensive mineral soil exposure.

Damage to the forest floor is frequently evaluated in terms of the depth of burn, measured by the absolute depth and proportion of duff (forest floor litter, fermentation and humus (LFH) layers) consumed by a fire. Especially where fires have burned through to mineral soil, the depth of burn is an important measure of long-term environmental impact, as soil organic matter helps retain and release the nutrients and moisture needed for plant growth. Any consumption of the forest floor also compromises the ability of rhizomes and seeds to sprout after the fire. The percent cover of exposed soil can also indicate vulnerability to water erosion and sediment mobilization on slopes. Consequently, many practitioners measure vegetation burn severity and soil burn severity separately (Keeley 2009).

Conceptually, the overall consumption of organic fuels or the net severity of a fire reflects peak fire intensity, fire residence time, including the duration of glowing and smouldering combustion, as well as soil and plant dryness (Keeley 2009). In practice, researchers have found that burn severity varies with fire weather and fire behaviour, topographic and geographic considerations (e.g., Whitman et al. 2018), and pre-fire fuel (vegetation) characteristics such as species composition, stand age, tree density and size (Lee et al. 2024, Povak et al. 2025).

Fire behaviour specialists often estimate surface and overstory fuel consumption in their assessments and predictions of wildfire behaviour. For example, in the Fire Behaviour Prediction (FBP) component of the Canadian Forest Fire Danger Rating System (CFFDRS), surface fuel consumption has been empirically calibrated as a function of fuel moisture indicators for different fuel (vegetation) types, and crown fuel consumption is the product of crown fuel load and crown fraction burned (FCFDG 1992). Quantitative measurements of actual fuel consumption in kg/m^2, including both pre- and post-fire measurements (Trowbridge et al. 1989), are superior descriptors of burn severity than using post-fire ground plot estimates only. Such empirical data on burn severity can be compared to predictions. They can help improve fuel consumption predictors, such as the Build-Up Index (BUI) and the overall FBP system (refer to Chapter 4: Wildfire Behaviour) (Wotton 2009, Wotton et al. 2009).

The CBI methodology (Appendix 5.1) is a widely utilized field-based approach for assessing burn severity and validating satellite-based assessments. However, it often entails many subjective estimates. This methodology encompasses aspects of ecosystem recovery, extending beyond the immediate fire effects. Experts have suggested developing alternative quantitative methods for measuring burn severity (Morgan et al. 2014, Han et al. 2021). Keeley (2009) cautions against conflating ecosystem responses, such as post-fire sprouting, with the direct effects of fire. Conversely, combined metrics such as the CBI may provide a better indication of resilience to fire—which implies a certain degree of recovery potential and adaptability, rather than mere resistance—than measurements solely based on biomass consumption. Field assessment methods often prioritize attributes of burn severity, including separate estimates for scorch height and char height, changes in live canopy cover, the proportion of fire-killed trees or fire-killed basal area, and quantitative assessments of surface char and burn depth (Saberi et al. 2022). Meanwhile, remote sensing specialists continue to assess the effectiveness of various sensor wave bands and combinations for fire severity mapping, understanding that each has distinct strengths and weaknesses in detecting plant pigments like chlorophyll, as well as the moisture content of vegetation and soils, and the reflectance from soil and charred substrates (Kurbanov et al. 2022).

Fire severity varies considerably within the perimeter of many forest fires, leaving not only unburned islands of green trees (Andison & McCreary 2014), but large areas in partially burned canopies, moderately burned understories, and severely burned areas in which all aboveground vegetation has been consumed or turned to charcoal (e.g. Burton et al. 2008, Whitman et al.

2018). Even forests characterized by high-severity or stand-replacing fire regimes exhibit complex patterns of tree survival and variable burn severity (Andison & McCreary 2014, Collins et al. 2017). Such variability has long been considered diagnostic of mixed-severity fire regimes as found throughout much of the US West and southern B.C. However, it is probably much more prevalent in boreal, sub-boreal, and subalpine forests than previously thought (e.g., Figure 5.1).

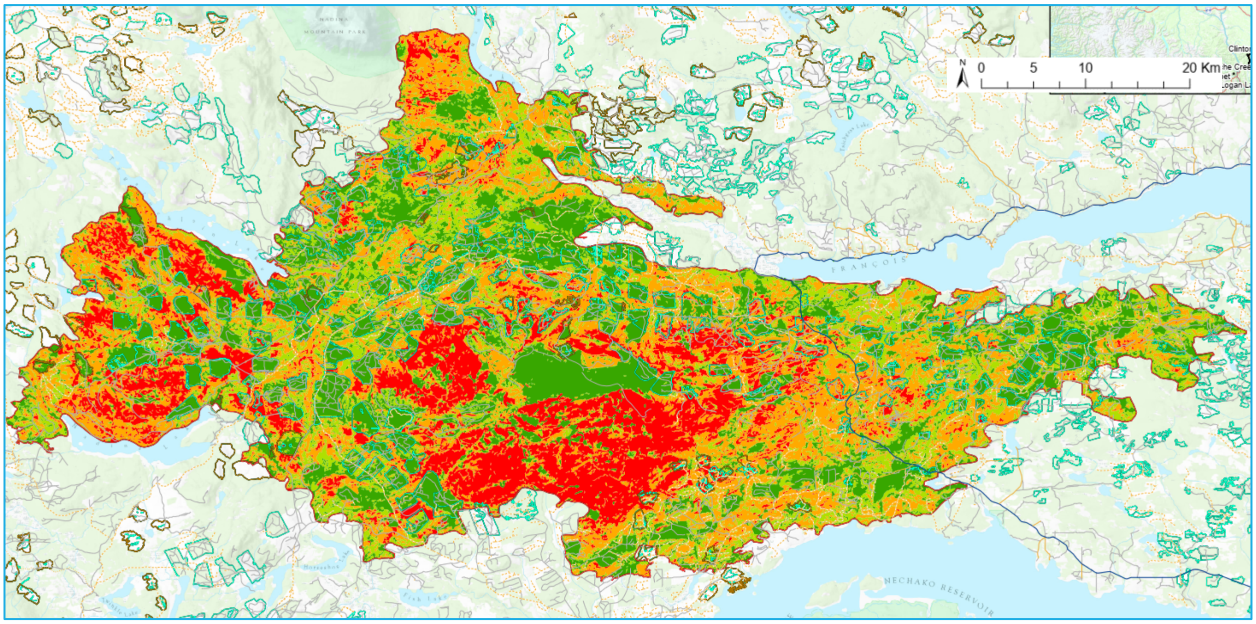

Figure 5.1. Burn severity distribution as mapped by the Province of B.C. for the 88,063 ha Nadina Lake Fire, which burned from July 31 to August 31 in 2018. This was one of the largest recent wildfires in the Bulkley Morice study area. Map showing the spatial distribution of burn severity classes as mapped by satellite using standard BARC categories of dNBR: dark green = unburned, light green = low severity, orange = medium severity, and red = high severity.

The variability in burn severity can be mapped using satellite imagery, where the difference between post-burn and pre-burn greenness is calculated on a georeferenced pixel-by-pixel basis (Hall et al. 2008, Kurbanov et al. 2022). All such indices are continuous metrics, which are helpful for research purposes. They are often mapped as colour-themed portrayals of unburned, low-severity, moderate-severity, and high-severity burn areas. Ideally, the differenced normalized burn ratio (dNBR) or relativized burn ratio (RBR) thresholds for each burn severity class should be calibrated for each vegetation type (Hall et al. 2008). However, many government mapping programs, including those in B.C.[17], currently utilize a standard set of Burned Area Reflectance Classification (BARC) categories (Clark et al., 2003).

Because satellites primarily detect the reflectance of light from the overstory or topmost vegetation of forest ecosystems, they typically do a poor job of detecting the extent of low-severity fires that burn primarily in the understory. This means that closed-canopy forests

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[17] https://catalogue.data.gov.B.C..ca/dataset/fire-burn-severity-historical

subject to low-severity fire can be incorrectly mapped as unburned, and mapped fire perimeters can be inaccurate. Perhaps comparisons with ground-based measurements of burn severity in closed-canopy conifer forests should primarily consider the overstory component of multi-criteria scorecards as used in the CBI methodology, but this is rarely done.

Another issue is the timing of the post-fire satellite imagery. Should imagery be taken as soon after the fire as possible to document immediate effects, or later to allow for delayed mortality and potential recovery as a better indicator of net ecological impact and resilience? Such decisions can result in marked differences in the perception of fire severity, depending on the balance of delayed mortality and regrowth (e.g., Figure 5.2). Due to phenological changes throughout the year, long-lasting wildfires that burn into the fall (or even persist over winter) require post-fire imagery to be taken under cloud-free conditions in the following year and as close as possible to the pre-fire imagery date. With delayed mortality, post-fire recovery, and phenological shifts playing a role in most ecosystems, such considerations can amplify or cancel errors in the accurate determination of burn severity and certainly limit the precision with which measurements such as dNBR or RBR can be relied upon. In all such assessments, Keeley (2009) warns that indices derived from remotely sensed data should be considered indicators, not direct measures, of burn severity.

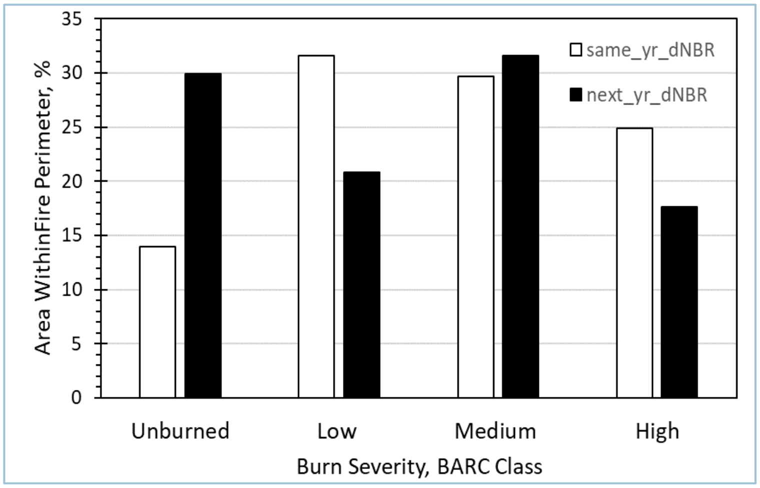

Figure 5.2. Differences in portrayals of the relative abundance of burn severity classes in the 2018 Nadina Lake wildfire, depending on the delay in post-fire satellite imagery used for dNBR calculation. Same-year mapping was based on post-fire satellite data from 2018-09-22 (Clason et al., in review), compared to the archived version of data (as mapped in Figure 5.1), which is publicly available and is based on post-fire imagery from 2019-09-02.

Mixed-severity and moderate-severity fires, occurring at moderate intervals and in medium-sized patches, are generally found to maximize species richness and other measures of biodiversity, supporting the intermediate disturbance hypothesis (He et al. 2019, Kelly et al. 2020). In contrast, high-severity fires can have several negative effects, including nutrient loss, habitat alteration, increased carbon emissions, and a greater potential for soil

Measuring burn severity remotely

The most common measures used are the differenced normalized burn ratio (dNBR) or similar relativized indices (e.g., relativized burn ratio, RBR, or relative differenced normalized burn ratio (RdNBR)) for which the post-fire and pre-fire signals are either divided by or subtracted from each other.

Relativized indices are expected to be more sensitive to differences in pre-fire conditions, such as the presence of bare rock, grassland, and other non-forested cover.

erosion. These fires are also less amenable to control when they pose threats to infrastructure or public safety. Even low-intensity fires can have long-term impacts on sites with shallow or sandy soils. Severely impacted soils, regardless of canopy damage, can seriously deplete soil carbon and nutrients, resulting in compromised forest productivity for decades (Page-Dumroese & Jurgensen 2006).

High-severity fires, defined by the ratio of high-severity to low- and moderate- burns within a wildfire perimeter, may indicate negative impacts in our study area. But this requires careful examination of the fire history, for high-severity fires may be an integral part of a region's disturbance regime, to which organisms are adapted. We could create a matrix to show wildfire impacts on various ecosystem services as classified in the Millennium Ecosystem Assessment (Reid et al. 2005), including provisioning services (such as the production of edible berries), supporting services (e.g., providing habitat for biodiversity), regulating services (e.g., water purification), and cultural services (e.g. supporting recreation). This matrix would categorize impacts by fire severity (high, medium, low) and consider the effects of fire deficits. This process is complex, as high-severity fires tend to reburn less often (Tortorelli et al., 2024) and leave behind more charcoal and black carbon, which can store carbon for centuries. However, a significant amount of organic matter is also released as carbon dioxide during burning (DeLuca & Aplet, 2008).

Species responses, recovery, and succession

The survival and recovery of different species after fires illustrate the resilience of a forest ecosystem to fire. Rowe (1983) described a five-category fire adaptation classification system for plants (see text box). In general, post-fire plant communities transition over many decades from being dominated by resisters to incorporating endurers, evaders, and eventually avoiders. Detailed information on the ecology, reproduction, and response to fire of most B.C. plant species can be found in the US Forest Service's "Fire Effects Information System (FEIS)[18]".

Animal response strategies to wildfires are complex. While some can flee, many cannot escape severe, fast-moving fires. Not only do fire avoidance, tolerance and habitat preferences vary among species, but also with life stage and fire timing (Stillman et al. 2019). For example, wildfires in spring and early summer can harm bird eggs and young wildlife. Generally, burrowing and flying animals, as well as medium to large mammals, tend to fare better, although mortality rates for vertebrates during wildfires range from 1% to 9% globally (Jolly et al. 2022). Certain species, such as longhorn beetles, actively colonize burned trees, followed by other specialists, like the black-backed woodpecker. Many fungi survive mild fires, but if all trees are destroyed, mycorrhizal fungi that depend on them usually do not survive. Soil fungi can

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[18] https://www.feis-crs.org/feis/

recover in decades, while some bacterial and fungal species (e.g., morels) thrive in post-fire habitats (Whitman et al. 2019).

The relative abundance of species with various fire adaptation strategies influences the persistence of pre-fire biotic communities and the shifts in composition during ecosystem recovery. In mixed-severity fire regimes, it's common to find a combination of these strategies within wildfire perimeters. In many boreal and sub-boreal forests, dominated by endurers and evaders, post-fire plant community composition often closely resembles pre-fire conditions, indicating limited succession. Boreal ecosystem recovery nonetheless shows a transition from early colonizers like fireweed and bluejoint reedgrass to shrubby plants such as raspberry and willows, eventually leading to tree dominance. This transition is followed by a long phase in which shade-loving bryophytes, lichens, and specialized plants and fungi re-establish as the forest matures.

Summary of plant species representing five fire adaptation strategies (from Rowe 1983)

Fire Resisters: This includes mature Douglas-fir and old pines, which have thick bark that insulates the cambium from high surface fire temperatures, allowing them to survive. However, they can perish if the crown is consumed by fire.
Fire Avoiders: This includes thin-barked species susceptible to damage from surface fires and are easily killed by a hot surface fire, such as subalpine fir. Fire-sensitive plants like twinflower and mosses rely on off-site seed or spore dispersal for re-establishment after a fire.
Fire Endurers: Many plants, including shrubs like Sitka alder and black huckleberry, may lose their above-ground parts to fire but can survive if belowground buds are intact, allowing for regrowth after low- to moderate-severity fires.
Fire Evaders: This includes species that retain viable seeds capable of germinating after a fire. For instance, some tree species have serotinous cones, like lodgepole pine, or semi-serotinous cones, like black spruce. These cones remain closed and protect the seeds from all but the most intense fires. Once the fire occurs, the cones open up, releasing the seeds to germinate on the newly exposed forest floor.
Fire Invaders: This includes species such as paper birch and fireweed that can only recolonize post-fire areas by seed dispersal from unburned locations. They can disperse over long distances, prefer to germinate and establish on exposed mineral soil, and thrive in open conditions.

Edwards et al. (2015) studied post-fire vegetation dynamics in a lodgepole pine stand affected by mountain pine beetle, located at the Carrot Lake experimental burn site south of Vanderhoof, B.C. Their research, conducted in the moist cold subzone (SBSmc3) of the Sub-Boreal Spruce biogeoclimatic zone, involved using prescribed fire as a treatment. They compared plant cover by species over five years to pre-fire conditions, noting varied burn severity similar to a mixed-severity wildfire. The study found that species representing all five fire adaptation strategies persisted. A notable trend was the loss of seedlings and saplings of the fire-avoiding subalpine fir and red-stemmed feathermoss in moderate- and high-severity burn plots. However, lodgepole pine, an evader with serotinous cones, showed high seedling densities proportional to burn severity, along with increased cover of black huckleberry and dwarf blueberry, important to foragers. Conversely, soapberry, culturally significant to Indigenous people, had not recovered to pre-burn levels after five years (Figure 5.3). Other trends included increased growth of fireweed, heart-leaved arnica, and common yarrow. After five years, understory plant cover had returned to half of its pre-fire conditions, but species richness had risen by 40% compared to the pre-fire condition. Similar changes were observed in unburned plots affected by mountain pine beetle mortality, although less significantly, without those invader species that rely on mineral soil exposure.

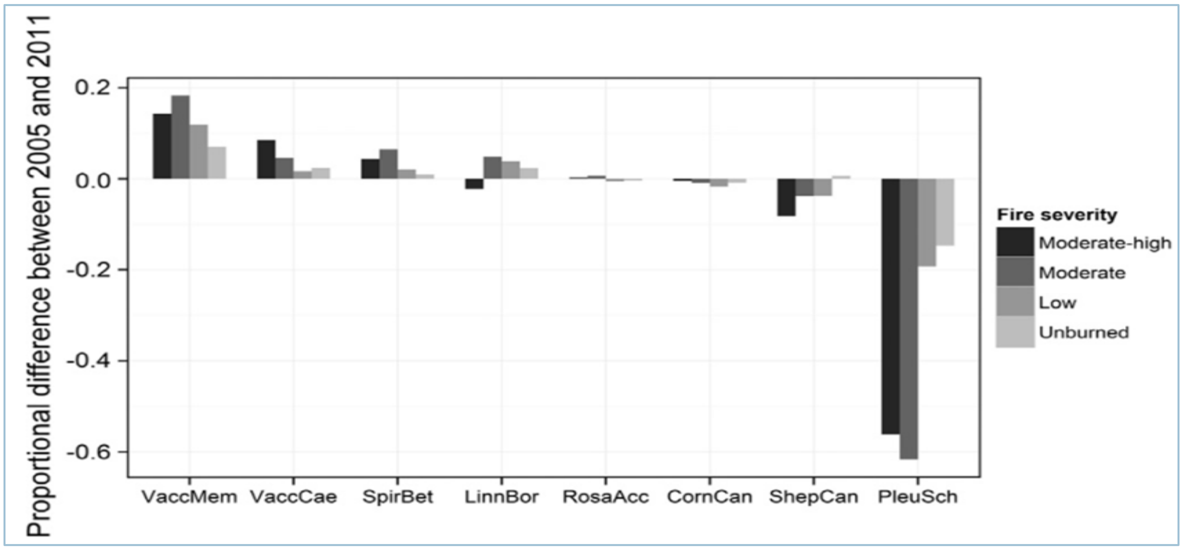

Figure 5.3. Proportional change in the cover of eight understory species present in all burn severity classes in 2005, and in 2011 after the 2006 Carrot Lake experimental burn, SBSmc3, south of Vanderhoof, B.C. Species from left to right are Vaccinium membranaceum (black huckleberry), V. caespitosum (dwarf blueberry), Spiraea betulafolia (birch-leaved spirea), Linnaea borealis (twinflower), Rosa acicularis (prickly rose), Cornus canadensis (bunchberry), Shepherdia canadensis (soapberry), and Pleurozium schreberi (red-stemmed feathermoss). (from Edwards et al. 2015).

Results from the SBSmc at Carrot Lake were mirrored in the SBPSmc after natural and prescribed fires. Following a severe 2006 wildfire near Vantine Creek, Haughian et al. (2008) recorded only trace ground lichens on xeric sites but noted an increase in kinnikinnick cover from year 1 to year 2. Other recovering or invading species included fireweed, bunchberry, bluejoint reedgrass, twinflower, prickly rose, and others. Year-over-year cover buildup generally exceeded that on more mesic sites. Similarly, a 2009 prescribed burn near Laidman Lake eliminated red-stemmed feather moss and ground lichens, with vascular plants recovering nearly to pre-fire levels seven years later (Cichowski et al. 2022).

Post-fire development and ecological succession depend on factors like pre-fire composition, burn severity, soil moisture, and proximity to seed sources (Figure 5.4). These factors influence the speed of species regeneration, density, and the progression toward forest cover. Even with initial growth, it takes decades for forest floor organic matter to reach pre-fire levels, affecting nutrient cycling, carbon retention, and water regulation—ecosystem services that recover slowly after fire and are often overlooked. Clason et al. (2022) sampled 75 planted or unplanted stands in 21 wildfires across or near the Bulkley Morice study area. They determined that after approximately 60 years, there was little difference in the carbon stocks under those alternative management strategies, although unplanted stands had more carbon in large woody material while planted stands had more wood in tree boles.

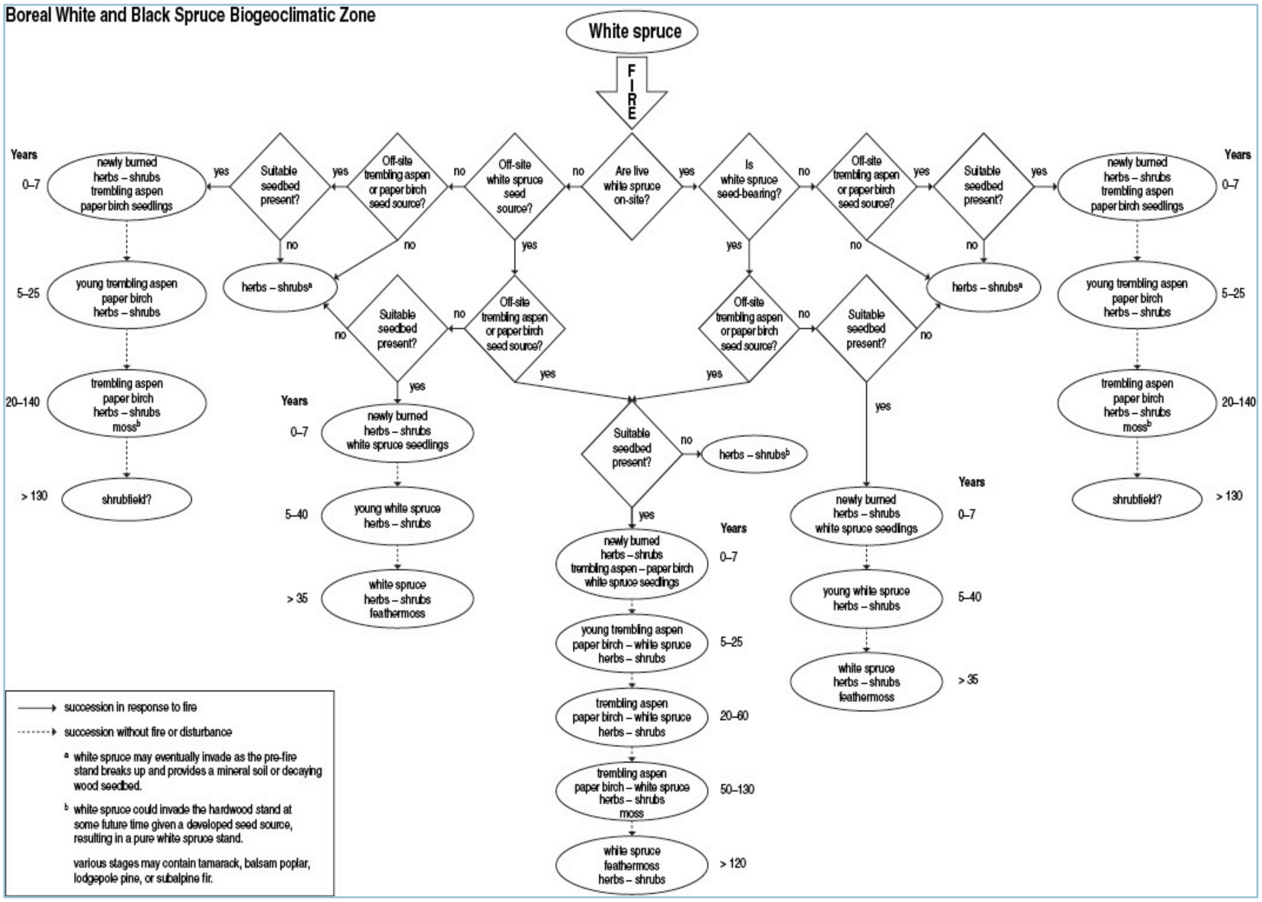

Figure 5.4. Multiple trajectories of post-fire stand development inferred following fire in white spruce stands in northeastern British Columbia (from Parminter 1983).

Physical structure and fuel loads

From the perspective of ecological resilience and conservation biology, it is essential to evaluate what is left behind after a fire, not just what is consumed. Elements such as standing snags, fallen logs, clusters of surviving vegetation, seed banks, tree roots, charcoal and charred duff, and even topsoil constitute "biological legacies". These are physical remnants or evidence of past biological activity that provide continuity between pre- and post-disturbance ecosystems, and that can play a crucial role in facilitating ecological recovery (Franklin et al. 2000).

The amount and form of post-fire legacies are influenced not only by the severity of the fire, but also by factors such as past fire history (e.g., short-interval fire events), site productivity and individual species traits. In a study sampling disturbed SBSmc and ESSFmc stands in the Bulkley Morice study area, Lloyd et al. (2008) found that wildfire left more standing snags and fewer fallen logs than windstorms, and fewer surviving green trees than beetle-attacked stands. Arrayed along axes of disturbance levels to soil, understory, and canopy layers, wildfires stand out as having more soil and understory disturbance than exhibited by windthrow or bark beetles (Figure 5.5). Lloyd et al. (2008) concluded that most snags fell within 10 years after fire, contributing to a growing volume of large woody material (LWM). In assessments of six fire-damaged stands in the SBS biogeoclimatic zone, Manning & Deans (2010) concluded that only 4% of fire-impacted trees were considered "dangerous" under B.C.'s Wildlife-Danger Tree Assessment (WDTA) criteria, primarily due to compromised root systems. This determination suggests that tree planting and other ecological restoration activities could be safely conducted in burned stands without snags first being knocked down, although pre-planting surveys and caution are warranted.

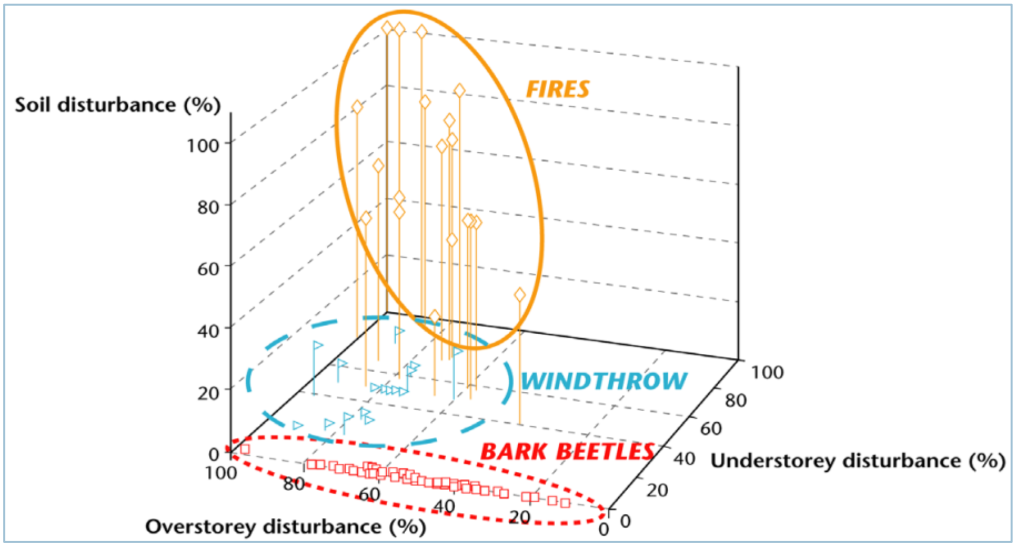

Figure 5.5. Levels of overstory, understory, and soil disturbance severity measured after various natural disturbances in the SBSmc subzone, Bulkley and Nadina Forest Districts (from Burton 2008). Note differences in residual overstory structure (horizontal axis).

Fuel load dynamics follow a similar pattern as conceptualized for LWM during post-disturbance stand development (Spies 1994, Clark et al. 1998). High levels of fallen woody material prevail in the first several decades as fire-killed trees collapse, then decline as that wood decomposes and becomes soft and heavily saturated, until new trees grow and die as a function of stand self-thinning and later gap dynamics due to root rots, stem rusts, wind, insect damage and other intermediate disturbances. The abundance, moisture content (often associated with decay state), position and connectivity of that woody material can play a large role in determining the subsequent susceptibility of a stand to a future wildfire.

While post-disturbance studies of stand development and succession emphasize species composition and growth rates, fuel succession is a less-studied aspect. It can involve numerous attributes and categories that are not easily derived from standard inventories or growth and yield models used in forestry. For example, Davis et al. (2009) identified transitions among 18 understory fuel types (3 grass, 2 grass-shrub, 4 shrub, 7 timber litter, and 2 timber understory complexes) in three California national parks. No such detailed breakdown, analysis, or post-fire modelling of surface fuel succession has been done for the Bulkley Morice study area, although Clark et al. (1998) provide a post-fire chronosequence overview of the abundance of standing snags and fallen large woody material volumes for the SBSmc subzone (Figure 5.6).

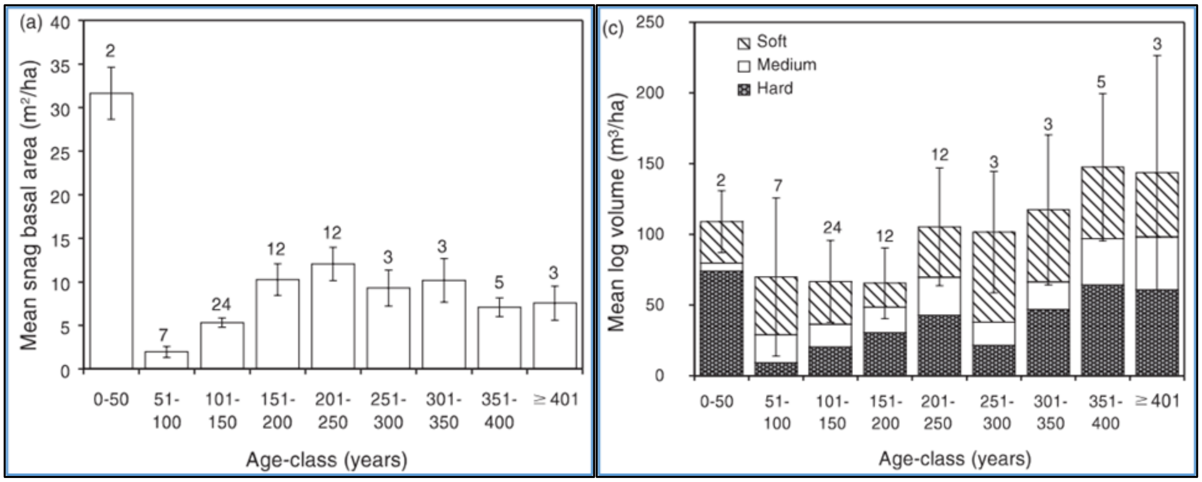

Figure 5.6. Means and standard errors of standing snag basal areas (m²/ha) and large woody material volumes (m³/ha) across a range of post-fire age classes sampled in SBSmc2 around Smithers and Houston, B.C. The number of stands sampled is provided above each bar (from Clark et al. 1998). Such data can serve as a proxy for more detailed studies of fuel accumulation during post-fire stand development.

The big picture: fire effects at the landscape level

The above discussion has emphasized fire effects, particularly as they relate to burn severity and its measurement, at the stand or microsite level, with a focus on differential species responses. Collectively, differences in site characteristics, such as soil depth, slope steepness and aspect, water-shedding or water-receiving slope positions, and stand composition and stand structure, can result in differences in burn severity (e.g., Lentile et al. 2006, Schwilk & Caprio 2011, Whitman et al. 2018). Combined with differences in weather during large fires, it is not unusual to observe large variations in burn severity and in the abundance and types of biological legacies left behind after

Pyrodiversity

Pyrodiversity refers to the variety of fire regimes as described by the patterns of fire behaviour, frequency, intensity, and seasonality across a landscape or region. Just as biodiversity refers to the variety of life forms in an ecosystem, pyrodiversity examines the different types of fire dynamics that shape and maintain ecosystems.

wildfires. This is one manner in which fires, especially large ones, are important generators of habitat diversity (Burton et al. 2008, Tingley et al. 2016). It has been suggested that a diversity of fires and fire regimes –"pyrodiversity"– promotes biological diversity (Kelly & Brotons 2017; Steel et al. 2024). However, empirical evidence is mixed, depending on scale, ecosystem, and measured attributes (Jones & Tingley 2022). Prescribed and cultural burns, as supplements to climate-mediated lightning ignitions under very dry conditions, may be especially important drivers of plant and habitat diversity (Greenwood et al. 2024, Hoffman et al. 2025).

Where wildfires are an important natural disturbance agent, fire events leave their footprint scattered across a landscape. These fire events can create even-aged forest stands or result in multi-aged stand structures. This mosaic of patches, each characterized by different times since the last fire, adds another level of ecological diversity at the landscape level (Forman 1995, Spies & Turner 1999). Large, severe wildfires can homogenize compositional and structural differences in forest vegetation, resetting large areas and initiating a new, more or less even-aged forest (Cansler & McKenzie 2014, Harvey et al. 2022). In contrast, large fires can also sometimes accentuate and perpetuate pre-fire differences, as when wetter sites, such as those found along riparian corridors, avoid burning or burn with less severity (Dwire & Kauffman, 2003). In other cases, severe fires happening in short succession can result in a transition to grassland or scrub, creating even more diversity at the landscape scale.

In B.C.'s Sub-Boreal Spruce zone, wildfires tend to be larger but more irregular in shape (resulting in a greater edge density) than clearcuts (DeLong & Tanner 1996). Those features have important implications for wildlife. For example, moose thrive on resprouting willow and red-osier dogwood that appear a few years after wildfire and persist until conifers crowd them out. Still, they also require proximity to dense living conifers for escape and thermal cover. That combination of open foraging habitat and closed conifer habitat is better where disturbance boundaries are sinuous, undisturbed patches are abundant, and edge habitat prevails. Caribou, on the other hand, may do better in extensive open burns if severe fire promotes ground lichens free from vascular plant and moss competition, but it takes a long time for those ground lichens to recover (Coxson & Marsh 2001). If appropriate post-fire ages and associated forage are not found in a landscape, such animals may experience elevated mortality, or they may be forced to migrate to other landscapes.

The overall extent of wildfires in a watershed also has a pronounced effect on its hydrology, which is especially important should there be episodes of high precipitation soon after a fire. A combination of reduced rainfall interception, reduced forest floor absorption (due to both forest floor consumption and the generation of hydrophobic surfaces), and reduced transpiration can result in elevated levels of overland flow, sediment transport, and soil saturation. Those effects are eventually expressed as high streamflow, flooding, and soil slips or landslides, with undesirable consequences to ecosystem values downslope and downstream (Rust et al. 2018, Hancock & Wlodarczyk 2025).

The mosaic of wildfire footprints on a landscape can also be considered a differential filter, or a maze of fuel susceptibility for future wildfires. Modifying living vegetation and dead fuels through fires of different severities, coupled with varying forest recovery rates and fuel succession, results in a complex spatiotemporal array of wildfire vulnerability.

Of particular interest is the period during which burned forest remains resistant to reburning, which varies not only with the severity of the initial fire but also with forest type and fire weather (Buma et al. 2020, Whitman et al. 2024). A visual assessment of recent wildfire patterns in central B.C. suggests that burns less than 5-10 years old often stop or slow the advance of more recent fires (Figure 5.7). On the other hand, all but the most severe wildfires leave unburned deadwood that will support a subsequent fire, especially once dead trees start falling (Brown et.al 2003).

Figure 5.7. Perimeters of wildfires from 2010 through 2023 in central British Columbia.

Reburn potential and prediction are areas of active research (e.g., Solander et al., 2023). Findings will greatly influence the degree to which maintaining a landscape of many small fires (a fine-grained disturbance pattern) can deter the development of large catastrophic fires that generate a coarse-grained landscape pattern (Spies & Turner 1999). Such questions can be explored under various scenarios of fuel types, fire weather, fire severity, and spatially targeted fuel treatments in dynamic landscape simulation models (Fall & Fall 2001, Sturtevant et al. 2009, Perera et al. 2015, Pritchard et al. 2023), an exercise yet to be done for the Bulkley Morice study area.

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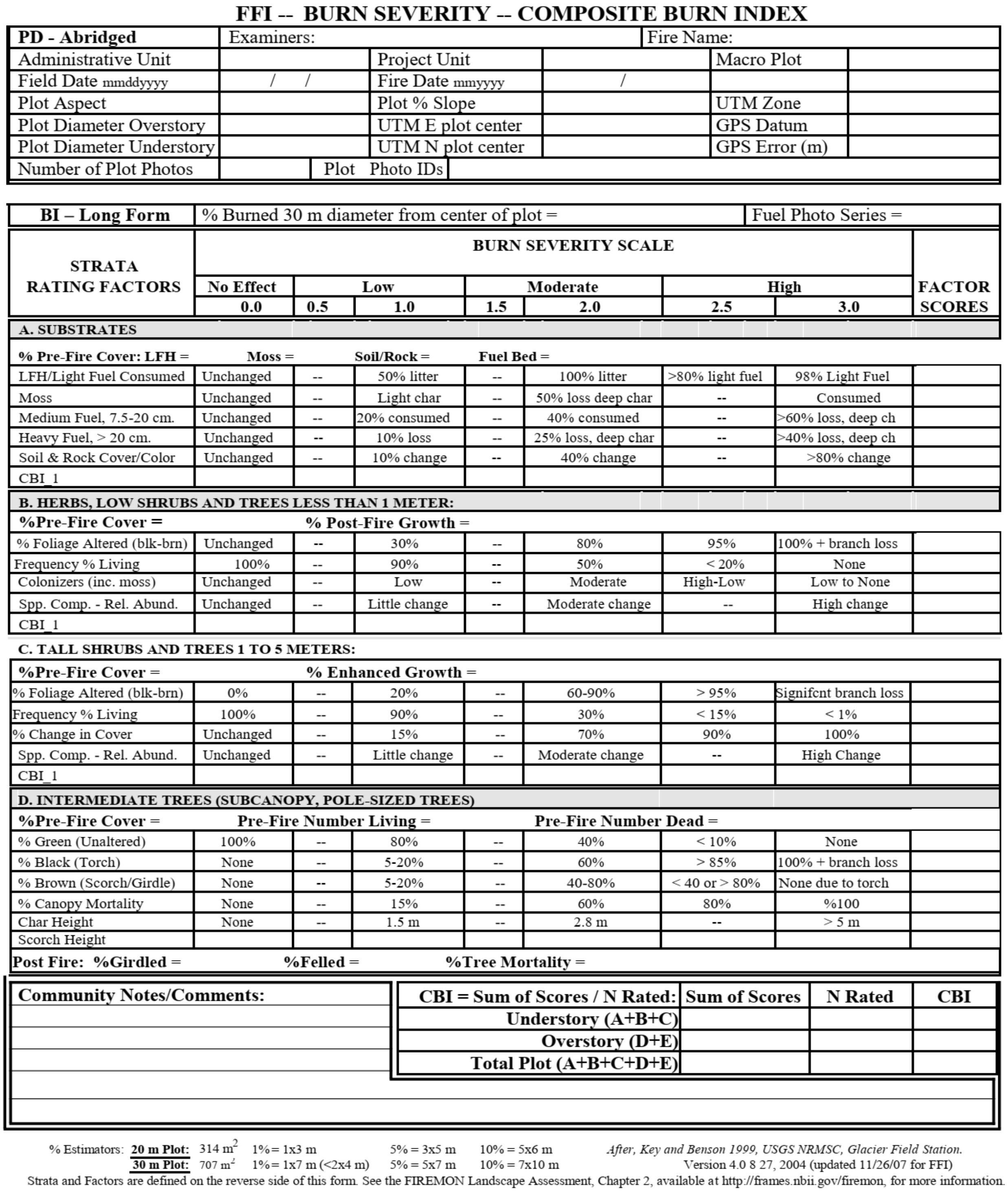
Appendix 5.1

A modified worksheet (with subcanopy and canopy tree layers combined) and instructions for ground-based assessments of burn severity and calculation of a Composite Burn Index (CBI) score (from Key & Benson 2006).



FFI -- BURN SEVERITY -- COMPOSITE BURN INDEX

PD - Abridged	Examiners:			Fire Name:	
Administrative Unit		Project Unit		Macro Plot	
Field Date mmddyyyy	/ /	Fire Date mmyyyy	/		
Plot Aspect		Plot % Slope		UTM Zone	
Plot Diameter Overstory		UTM E plot center		GPS Datum	
Plot Diameter Understory		UTM N plot center		GPS Error (m)	
Number of Plot Photos		Plot Photo IDs			

BI – Long Form	% Burned 30 m diameter from center of plot =	Fuel Photo Series =

STRATA RATING FACTORS	**BURN SEVERITY SCALE**							**FACTOR SCORES**
	No Effect	**Low**		**Moderate**		**High**		
	0.0	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	
A. SUBSTRATES								
% Pre-Fire Cover: LFH = Moss = Soil/Rock = Fuel Bed =								
LFH/Light Fuel Consumed	Unchanged	--	50% litter	--	100% litter	>80% light fuel	98% Light Fuel	
Moss	Unchanged	--	Light char	--	50% loss deep char	--	Consumed	
Medium Fuel, 7.5-20 cm.	Unchanged	--	20% consumed	--	40% consumed	--	>60% loss, deep ch	
Heavy Fuel, > 20 cm.	Unchanged	--	10% loss	--	25% loss, deep char	--	>40% loss, deep ch	
Soil & Rock Cover/Color	Unchanged	--	10% change	--	40% change	--	>80% change	
CBI_1								
B. HERBS, LOW SHRUBS AND TREES LESS THAN 1 METER:								
%Pre-Fire Cover = % Post-Fire Growth =								
% Foliage Altered (blk-brn)	Unchanged	--	30%	--	80%	95%	100% + branch loss	
Frequency % Living	100%	--	90%	--	50%	< 20%	None	
Colonizers (inc. moss)	Unchanged	--	Low	--	Moderate	High-Low	Low to None	
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High change	
CBI_1								
C. TALL SHRUBS AND TREES 1 TO 5 METERS:								
%Pre-Fire Cover = % Enhanced Growth =								
% Foliage Altered (blk-brn)	0%	--	20%	--	60-90%	> 95%	Signifcnt branch loss	
Frequency % Living	100%	--	90%	--	30%	< 15%	< 1%	
% Change in Cover	Unchanged	--	15%	--	70%	90%	100%	
Spp. Comp. - Rel. Abund.	Unchanged	--	Little change	--	Moderate change	--	High Change	
CBI_1								
D. INTERMEDIATE TREES (SUBCANOPY, POLE-SIZED TREES)								
%Pre-Fire Cover = Pre-Fire Number Living = Pre-Fire Number Dead =								
% Green (Unaltered)	100%	--	80%	--	40%	< 10%	None	
% Black (Torch)	None	--	5-20%	--	60%	> 85%	100% + branch loss	
% Brown (Scorch/Girdle)	None	--	5-20%	--	40-80%	< 40 or > 80%	None due to torch	
% Canopy Mortality	None	--	15%	--	60%	80%	%100	
Char Height	None	--	1.5 m	--	2.8 m	--	> 5 m	
Scorch Height								
Post Fire: %Girdled = %Felled = %Tree Mortality =								

Community Notes/Comments:

CBI = Sum of Scores / N Rated:	**Sum of Scores**	**N Rated**	**CBI**
Understory (A+B+C)			
Overstory (D+E)			
Total Plot (A+B+C+D+E)			

% Estimators: **20 m Plot:** 314 m^2 1%= 1x3 m 5% = 3x5 m 10% = 5x6 m *After, Key and Benson 1999, USGS NRMSC, Glacier Field Station.*

30 m Plot: 707 m^2 1%= 1x7 m (<2x4 m) 5% = 5x7 m 10% = 7x10 m Version 4.0 8 27, 2004 (updated 11/26/07 for FFI)

Strata and Factors are defined on the reverse side of this form. See the FIREMON Landscape Assessment, Chapter 2, available at http://frames.nbii.gov/firemon, for more information.

STRATA

Substrates—Inert surface materials of soil, duff, litter, and downed woody fuels. **Herbs, Low Shrubs and Trees—**All grasses + forbs, and shrubs + small trees <1 m. **Tall Shrub and Trees—**Shrubs and trees 1–5 m tall. **Intermediate Trees (pole -size, subcanopy)—**Trees between tall shrubs/trees and upper canopy, approximately 10–25 cm diameter, and 8–20 m tall. May be stratified heights and extend to upper canopy, but crowns receive little direct sunlight. Size is relative to upper canopy and varies by community. If this size is upper canopy, count as intermediate trees. **Big Trees (mature, dominant and co-dominant, upper canopy)—**Larger than intermediate trees, occupy upper canopy, receive direct sunlight; tallest may extend above average big- tree level. **Understory—**Substrates, herbs/low shrubs+trees, tall shrubs+trees. **Overstory—**Intermediate and big trees. **Total Plot, or Overall—**All strata of the plot combined.

GENERAL

Pre-fire exposed soil/rock is considered unburned if there is no sign of overlying substrates or vegetation that burned. Avoid sites with >50% exposed pre-fire soil/rock, see guidelines. **Rehab Site—**Mulch or other does not count, estimate as if that was not present. Planted, growing vegetation can be tallied where appropriate, but not as new colonizers. A specific factor may not be rated if is not relevant, shows inconsequential presence or insignificant indication of severity (write in N/A for not applicable), or when effects are unclear and cannot be reasonably judged (write in UC for uncertain). **Percent Plot Area Burned—**Record the percent surface area (burned substrates and low-growing plants) showing any impact from fire for the 30-m diameter plot, and for the nested 20-m plot, if that is used for the understory. **Prefire Variables—**Report cover (percent area), depth (inches) and density (number of trees) plot- wide as if before fire. Consider burned evidence + unburned areas within plot or nearby; reasonable approximation of prefire conditions. If too difficult to estimate, write in UC for uncertain. **Enhanced Growth Factors—**100 percent + percent productivity above that, judged to be fire- enhanced; regard amount of green biomass in terms of cover, volume and density. If plots show about the same or less productivity than before fire, then enter as not applicable (N/A). If plot shows enhanced growth, then enter the percent productivity that is augmented by fire, with 100 percent being the same postfire productivity as prefire (for example, 200 percent represents double the estimated prefire productivity); write in UC if uncertain.

SUBSTRATE RATING FACTORS (Do not count litter or fuels built up after fire.)

Litter/Light Fuel—Relative amount consumed of leaves, needles, and <7.5-cm diameter wood on the ground at time of fire. Not new litter-fall. Count litter/light fuel even if it occurs under living plants. **Duff condition—**Relative amount consumed and charring of decomposed organic material lying below the litter. Not fine root mass. Count duff even if it occurs under living plants. **Medium Fuel—**Consumption of down woody fuel between 7.6–20 cm. **Large Fuel—**Loss and charcoal from down woody fuel >20 cm diameter. Base both classes on change to fuel load. Omit or join as one if either fuel class < 5 percent plot cover, see text. Include stumps in appropriate size class, if relevant. **Soil Cover/Color—**New exposed soil and color change; lightening at moderate to high, ~10 percent red at high severity— overlook ash. Consider soil or rock surface *not* covered by litter, duff or low herbaceous cover less than about 30 cm. If such occurs under taller shrubs and trees, count it.

HERBS, LOW SHRUBS AND TREES LESS THAN 1 METER RATING FACTORS

Percent Foliage Altered—Only low shrubs and trees (<1 m, prefire live or dead cover that are newly brown, black or consumed. Ignore resprout. **Frequency Percent Living—**Percent of prefire vegetation that is still alive after fire, based on number plot-wide; survivorship, not cover, not new seedlings. Include unburned as well as burned, resprouting perennial herbs, low shrubs and trees 1 m pot-wide. Include all green vegetation as well as burned plants that have not had enough time to resprout but remain viable. Burned plants may need to be examined for viable growth points. Do not include new plants from seed or suckers. **Colonizers—**Potential dominance 2–3 years postfire of new (native or exotic) plants from seed; includes herbs and tree seedlings, plus aspen or other tree-to-shrub suckers, and nonvascular plants (for example, thistle, fireweed, pokeweed, ferns, moss, fungi, seedlings of lodgepole pine, slash pine, western larch, many weedy spp.). Rate only if spp. response to fire is known. **Species Composition/Relative Abundance—**Change in spp. and/or relative abundance of spp. anticipated 2–3 years postfire. How much does postfire spp. composition resemble prefire stratum? Consider presence of new or absence of old spp., plus how dominance is spread across spp.

TALL SHRUBS AND TREES 1 TO 5 METERS RATING FACTORS

Percent Foliage Altered—Percent prefire live-or-dead crown volume (leaves, stems) newly brown, black or consumed. Ignore new resprout; it does *not* lessen the amount of prefire foliage altered. **Frequency Percent Living—**Percent of prefire tall shrubs/trees that are still alive after fire. This is a measure of survivorship based on numbers of individuals. Include unburned as well as burned but viable tall shrubs/trees 1–5 m tall plot wide; examine growth points for viability if needed. Do not include new plants from seed or suckers. Account for potential mortality that could occur up to 2 years postfire. **Percent Change in Cover—**Overall *decrease* in cover of tall shrubs/trees between 1 and 5 m, relative to the area occupied by those plants before fire. Count resprouting from plants that burned, plus the unburned plants as cover that lessens the amount of decrease in cover. Do not include suckers or plants newly germinating from seeds. **Species Composition/Relative Abundance** Change in spp. composition and/or relative abundance of spp. Anticipated 2 to 3 years postfire.

INTERMEDIATE AND BIG TREE RATING FACTORS (COMBINED)

Percent Unaltered (green)—Percent prefire live-or- dead crown volume unaltered by fire. Include new resprout from burned mcrowns, not from bases. **Percent Black (torch) —**Percent prefire live-or-dead crown volume that actually caught fire (black or consumed stems, leaves). May or may not be viable postfire; resprout from black crowns does not lessen percent black. At high severity, consumption of fine branching is evident. Include deciduous blackened crowns. **Percent Brown (scorch)—**Percent prefire live crown volume affected by scorch or girdle without direct flame contact. Brown is due to proximal heating, where foliage did not catch fire. Includes delayed mortality, insect damage, and brown foliage that has fallen to ground. **Percent Canopy Mortality —**Percent prefire live canopy volume made up by trees killed directly or indirectly by fire within 1–2 years. Proportion of a plot's total once-living canopy lost to dead trees (include insect/disease kill) in relation to total prefire canopy volume. **Char Height—**Mean char height from ground flames averaged over all trees. The mean is halfway between upper and lower heights on a tree. Include unburned (char height = 0) and burned trees ***only*** when char height is discernable. Do ***not*** include black from crown fire; enter N/A for most crown fire burns.

RECORD FOR EACH OVERSTORY STRATUM, BUT DO NOT COUNT IN CBI SCORES

Percent Girdled (at root or lower bole)—Percent of trees effectively killed by heat through the lower bark, sufficient to kill cambium around lower boles or buttress roots. Include trees either dead or likely to die within 1–2 years. Do not include trees killed by torch or scorch to crown. May or may not char through bark and into the wood; may have loose sloughing bark in 1–2 years. **Percent Felled (downed)—**Percent live-or-dead trees, that were standing before fire but now are on the ground. Usually from wind throw after fire, they exhibit fresh up-turned root masses, and different charring patterns than trees that were down when fire occurred. **Percent Tree Mortality —**Percent of once living trees on the plot that were killed by the fire, based on number of trees. Suspected insect and disease effects also may be included, if such contributed to killing whole trees relatively soon after fire (for example, within 1–2 years).

RATING ADVICE

Factors that are not applicable or cannot be resolved in a plot are not rated; they are omitted from that plot's composite ratings. Moreover, if there is much uncertainty about how a specific factor should be rated, or whether it is even relevant to the plot, then that factor should be left unranked. Only the number of rated factors is used to compute averages. If a factor is not rated, enter not applicable (N/A) or uncertain (UC) on the CBI data form. Do not just leave the field blank; such factors are not part of the CBI average, but one wants to know whether these factors were actually assessed and it was decided not to rate them, or just accidentally overlooked and skipped. Zeros, on the other hand, are valid entries and do get averaged into composite scores. Zeros should be used when a rating factor is applicable and exhibits an unburned condition. A zero represents no detected change in an observable factor.

6.0 Indigenous Fire Stewardship

By Dr. Kira Hoffman

Introduction

This section reviews Indigenous fire stewardship in the sub-boreal forests typical of the Bulkley Morice area and similar ecosystems. The aim is to highlight the significant role that Indigenous cultural burning plays in promoting community, cultural, and ecological resilience. This introduction will serve as a foundation for further engagement and Indigenous-led and co-led approaches to better understand historic fire. This section is also part of a larger review of Indigenous fire stewardship in sub-boreal and temperate ecosystems (with co-authors Elder Darlene Vegh, Hanamuxw (Don Ryan) and Chelsey Geralda Armstrong - manuscript in review).

Humans have played a major role in altering their surrounding environments, specifically the distribution of plant and animal communities, using fire, cultivation, and widespread trade across former geographic barriers (Bowman et al. 2011, Huffman 2013, Ryan et al. 2013, Turner et al. 2014). Understanding the historical pattern of human impacts on vegetation is critical to interpreting the ecological basis of current species distributions and landscape patterns (Keeley 2002, Marlon et al. 2008, Pausas et al. 2009). Indigenous Peoples of North America have a long history of intensive utilization of plant resources, altering the distribution of forests, woodlands and meadows through Indigenous fire stewardship (Turner et al. 2013, Christianson et al. 2022, Copes Gerbitz et al. 2023, Lake et al. 2021, Margolis & Guiterman 2022). However, scientific depictions and records of fire stewardship often depict post-contact practices, while oral histories and ethnographic accounts of pre-contact fire management remain scarce (Lepofsky & Lertzman 2008, Turner 2014, Hoffman et al. 2017, Copes-Gerbitz et al. 2022).

Supporting the return of Indigenous-led fire stewardship and recognizing Indigenous food systems and fire as a tool for resource management can help communities rebuild intergenerational knowledge exchange and mitigate the impacts of increasingly severe wildfires (Daniels et al. 2024, Mulverhill et al. 2024, Christianson et al. 2024). Indigenous fire and plant management systems require a profound understanding of complex relationships, ecological processes, and resilience, as well as a deep respect for the natural world (Turner 2014, Lake & Christianson 2021). Cultural burning is one aspect of Indigenous fire stewardship, used to create diverse habitat types and increase the abundance of select species in a given area (Lake et al. 2021, Hoffman et al. 2022). Active fire suppression throughout the 20th century, together with the banning of cultural fire, contributed to the loss of pyrodiversity in B.C., and has also resulted in larger and more severe wildfires (Steel et al. 2023, Parisien et al. 2023, Jain et al. 2024). Forest management practices that are not co-created or informed by Indigenous fire stewardship are limited by an incomplete understanding of forest health, structure, and function (Hoffman, Copes Gerbitz et al. 2024). Furthermore, forest practices perpetuate colonial ideologies, management practices, and systems.

The physical evidence of Indigenous fire stewardship in sub-boreal forests of northwest B.C. has been largely erased through industrial forestry, agriculture, wildfire and land settlement (Hoffman et al. 2025), and several sites that were historically maintained with fire have been farmed (Lepofsky et al. 2017). In addition, many settlements have been established on flat riparian habitats that once supported root and forest gardens, which were actively maintained with fire (Deur 2002a, Turner et al. 2013, Armstrong et al. 2021, 2024). Oral histories have suffered loss through forced relocation onto reserves and direct impacts of colonization, such as the banning of cultural practices, assimilation through residential school systems, disease, racism and many ongoing impacts (Hoffman et al. 2022).

Stewardship practices such as cultural burning often have a light footprint (are lower- or mixed in severity) (Lepofsky et al. 2005) so evidence for cultural burning is not always apparent in archaeological records (Lepofsky & Lertzman 2008). Therefore, landscape patterns such as patch mosaics, evidenced through post-fire cohorts and fire-scarred trees, and ethnographic accounts through oral histories, provide the basis of our current understanding of fire as a tool for resource management (Hoffman et al. 2022). Other lines of evidence include plants found outside of their natural ranges (Smith 2011, Armstrong et al. 2021, 2024), purposeful selection of specific genetic traits (Lepofsky & Lertzman 2008), and paleoecological evidence such as pollen and charcoal residues (Hoffman et al. 2016, Whitlock & Knox 2002). To gain an understanding of Indigenous fire stewardship, research must be collaborative and led by Nations with support from researchers who can respectfully gather and share knowledge (Hatch et al. 2023, Hoffman, Copes, Gerbitz et al. 2024).

In boreal forests, some researchers contend that Indigenous use of fire had dramatic and widespread impacts on the landscape (Keeley 2002, Pyne 2004), while others suggest that fire effects were minimal and only occurred in concentrated settlement areas (Vale 2002, Lightfoot et al. 2013). Fire (wild and controlled) was an important process across scales from local to landscape level, with small-scale uses not limited to fires for heating, cooking, tanning hides, and drying and smoking foods (Boyd 1999). Within sub-boreal forests, cultural burning varied largely across ecosystems and served multiple purposes, depending on the species of interest, climate and First Nation/community (Main Johnson 1994, Trusler & Johnson 2008, Johnson 2013, Hoffman et al. 2025). Several burning techniques were synchronous across large geographic areas and forest types. These were utilized to keep weedy, uneconomical plants at bay (Boyd 1986), to run game (Turner 1999), to communicate (Turner et al. 2013) and to keep insects and pests away (Peacock & Turner 2000). The most common use of cultural fire was to create open landscapes, which increased the productivity of food and medicinal plants and provided forage for wildlife (Table 6.1).

Early colonial and anthropological accounts depicted Northwest Coast and Northern Interior Indigenous Peoples as primarily reliant on marine/freshwater resources, as well as large terrestrial game (Deur 2002a), and underestimated the role of plants in their everyday diets (Turner & Peacock 2005). However, Indigenous Peoples employed complex methods of plant management prior to European contact (Lepofsky & Lertzman 2008, Turner 2014, Armstrong et al. 2024). Ethnographic accounts from Indigenous Peoples living in interior forests indicate that they have been enhancing plant production systems and increasing the quality and quantity of food, materials and medicines since time immemorial (Tait 1903, Suttles 1974, Turner 1975, Armstrong 2022).

When first visiting village sites on the Central Coast and North Coast as well as interior river valleys of British Columbia, early explorers observed an abundance of salmon and an unfamiliar, seemingly inhospitable climate for plant cultivation (Turner & Deur 2005). Across B.C., colonists depicted an empty and “pristine” landscape that, despite its perfection, was perceived as unused because it contained no western versions of agriculture (Turner 1975, Suttles 2005, Beckwith 2004, Turner et al. 2014). These early accounts, and the work of anthropologists who did not understand fire stewardship practices, led to the popular hypothesis that Indigenous Peoples in B.C. were sedentary "Fisherfolk" or complex hunter-gatherers who did not cultivate plants or work the land (Sauer 1952, Anderson 1969, Moseley 1974). This theory was perpetuated because gardens were tended seasonally (Lepofsky et al. 2005, Armstrong 2022), resources were distributed widely (Turner et al. 2013), and plant enhancement was distinct from European preconceived notions of plant cultivation (Turner 1991, Turner 1999).

Fortunately, Indigenous-led and collaborative research has demonstrated complex systems of plant and animal management through burning (Gottesfeld 1994, Turner 1999), transplanting (Armstrong et al. 2021), pruning (Johnson 2013) and selective harvesting (Peacock & Turner 2000, Armstrong et al. 2021, Hoffman et al. 2025). Indigenous scientific research estimates that approximately 300 plant species in the territories now known as British Columbia were regularly harvested for food, medicines and materials (Turner & Deur 2005, Turner et al. 2014, Armstrong 2022). Approximately 100 of those plant species were food-specific and gathered in large quantities using several techniques common across Nations. At least 50 of these plants were enhanced through controlled, cyclical burning (Turner & Peacock 2005, Johnson 2013). The widespread and in-depth knowledge of plant resources suggests a long history of tending and stewarding lands through the use of fire (Table 6.1).

Due to active fire exclusion (including fire suppression and the forced removal of Indigenous Peoples from their lands) beginning at the start of the 20th century, it is challenging to determine the role that lightning-ignited fires played across ecosystems (Brown & Hebda 2002, Lepofsky et al. 2005). In many ecosystems, Indigenous Peoples greatly accelerated the fire regime (increased fire activity) (Brooks et al. 2021), thereby increasing species turnover, establishing fire-adapted species, and utilizing lightning-ignited fires to support their food systems on a larger scale (Hoffman et al. 2025). Although causal mechanisms for fire ignition have likely shifted throughout the Holocene (Brown & Hebda 2002, Hoffman et al. 2016), lightning fires alone do not explain the vegetation patterns visible in sub-boreal forests today (Burrows 2002, Parisien et al. 2023).

Sub-Boreal Forests

Sub-boreal forests comprise a distinct cultural and ecological region extending along the northern interior of northwest B.C., bounded on the western side by the coastal mountain ranges (Meidinger & Pojar 1991). The region supports the headwaters of some of the world's most productive salmon rivers, a diversity of conifer and deciduous species, and a mosaic of productive riparian areas, along with lower-productivity wetland ecosystems in subdued terrain (Pojar et al. 1994). Due to the patchy and heterogeneous landscape, tremendous variation exists between habitats, and culturally important plants and animals are unevenly distributed throughout the region (Gottesfeld 1994, Trusler & Johnson 2008, Hoffman et al. 2025). This presented a challenge for Indigenous Peoples who had to migrate long distances between essential resource sites (Turner 1999, Johnson 2013).

Although sub-boreal forests are productive ecosystems, most plant biomass is contained within conifer species, and many plants have limited growth under dense forest canopies (Turner & Deur 2005, Talucci & Krawchuk 2014). The inner cambium of some conifers, such as lodgepole pine (*Pinus contorta)* and hemlock (*Tsuga heterophylla*), was harvested regularly for consumption. Edible herbaceous plants are not found in great abundance in closed-canopy forests (Turner et al. 2014). Many important food and medicinal plant species, such as berries, are limited to more open forest types, including meadows, parklands, early successional forests, and clearings (Turner 1991, Lepofsky et al. 2005, Hoffman et al. 2025). Indigenous Peoples maintained and seeded selected annual and perennial plants in open forest structure with cultural fire to ensure reliable and productive food sources (Keeley 2002, Anderson 2006, Lewis et al. 2018, Armstrong et al. 2018, Copes-Gerbitz et al. 2022, Hoffman et al. 2022, Christianson et al. 2022, Dickson-Hoyle et al. 2023). There was also a vibrant trade system of plants and animals woven into lakes, rivers and trails across territories.

Patterns of Indigenous Fire Stewardship

Indigenous Peoples inhabiting sub-boreal forests are culturally and linguistically distinct from coastal Peoples (Turner & Deur 2005, Armstrong 2022). However, they actively trade and travel between territories and possess highly developed techniques for berry patch burning, specifically for black huckleberry (*Vaccinium membranaceum*) (Gottesfeld 1994b, Main Johnson 1994, Johnson 2013).

Cultural burning was a cyclical practice that occurred on a variety of spatial and temporal scales (Blackburn & Anderson 1993, Gottesfeld 1992, 1994, Main Johnson 2001, Trusler & Johnson 2008, Hoffman et al. 2025). Fire was a high-intensity plant management technique that required the input of several people and was a form of community-level resource management (Turner et al. 2005, Copes-Gerbitz et al. 2022). The landscapes of sub-boreal forests are heterogeneous, with complex topography, climate, and ecology that limit the safe and effective use of fire (Daniels et al. 2024). Despite this, several methods of cultural burning are widespread and synchronous across ecosystems (Turner 1999, Turner et al. 2014), with similar patterns of how fire was conducted to achieve similar outcomes apparent across Nations (Turner & Deur 2005, Christianson 2015, Armstrong et al. 2021, Hoffman et al. 2025). Cross-cultural similarities in fire use result from both simultaneous invention and knowledge transmission between Nations (Turner et al. 2014, Johnson et al. 2013).

Table 6.1. Cultural uses of fire for plant and animal management in sub-boreal forests and/or similar ecosystems. References: Gottesfeld 1992, Main Johnson 1994, Turner 1999, Williams 2002, Trusler and Johnson 2008, Lepofsky & Lertzman 2008, Johnson 2013, Turner et al. 2014, Armstrong 2022, Hoffman et al. 2025.

Management type	Burning Season	Direct fire effects	Indirect fire effects	Fire severity	Genus or Species	Habitat type
Run/hunt game, birds	Late summer/ fall	Corral game, force into open meadows, corridors or waterways	Increase grass fodder, create more accessible hunting areas and predictable locations	Low and Moderate	Deer (*Odocoileus* spp.), moose (*Alces alces*) caribou (*Rangifer tarandus*), rabbit (*Sylvilagus spp.*), geese (*Branta* spp.), ducks (*Anas* spp.)	Widespread (from valley bottom to alpine)
Honey/sap collection	Late summer	Smoke out wasps to collect larvae, collect sap	Clear brush around trees	Low	Yellow jackets (Vespula pensylvanica), Lodgepole pine	Drier forests, south-facing aspects
Burn herbaceous perennial species	Spring/ late summer/ fall	Kill pests, insects	Increase productivity, reduce competition, create straight growth for basketry, maintain open meadows decrease the effects of wildfire	Low	Lilies (*Lilium* spp.*)*, asters (*Asteraceae spp.),* wild onion (*Allium* spp.) stinging nettle (*Urtica dioica*), strawberry (*Fragaria* spp.), graminoid spp.	Widespread (from valley bottom to alpine)
Burn woody perennial species	Late summer/ spring/fall	Rid of disease dwarf mistletoe (*Arceuthobium americanum*), fell trees for house construction, canoes, firewood, winter lichen fires	Increase berry/seed production, enhance vegetative growth, reduce competition, increase forest openings	Moderate	Berries (*Vaccinium* spp., *Rubus* spp.), hazelnut (*Corylus cornuta*), cottonwood (*Populus balsamifera* spp.), willow (*Salix* spp.) birch (*Betula* spp.)	Widespread (from valley bottom to alpine)
Burn conifer species to promote pinenut production	Late summer/ fall	Increase the productivity of whitebark pinecones containing nutritious nuts	Support the abundance of black huckleberry as an understory plant	Moderate	White bark pine (*Pinus albicus*), Berries (*Vaccinium* spp.)	Nechacko Plateau, higher elevation montane sites (throughout SBS)
Spiritual	During ceremony (any season)	Increase rains during drought, bring back salmon, provide cover for salmon during late summer heat	Clear village sites, rid of pests, increase plant productivity, make safe travel corridors	Moderate	Several species	Widespread
Defense/economic	Anytime	Scorch earth, maintain open, safe corridors	Kept areas around village sites clear, decrease enemy hiding spots	High	Several species	Widespread
Warfare and signalling	Anytime	Declare war (burn valley bottoms), communicate, signal a kill	Replenish soils	Low, Moderate and High	Several species	Widespread

Table 6.1 summarizes examples of direct and indirect uses of fire for plants and animals that have been documented throughout the Pacific Northwest. Some uses of fire were regionally and culturally specific; other techniques, such as running game, were common among Nations and across large geographic areas (Turner et al. 2013). Although fire had several uses, it was most commonly utilized to manage plants or increase plant productivity in subsequent years (Turner et al. 2000). Burning occurred seasonally, annually, and at longer intervals, depending on the species and habitat of interest (Boyd 1999).

Groups of families, clans/house groups, and individuals would regularly return to resource sites, ensuring that their land was properly tended and monitored, and burned at the appropriate times (Johnson 1999, Turner and Peacock 2005, Hoffman et al. 2025). Many sites had combined management systems, focusing on two or more species simultaneously (Boyd 1999, Hoffman et al. 2022). These species would be managed concurrently or when focal species lay fallow (Turner et al. 2013). Cultural burning was complemented by pruning, mulching, partial rotation of plants and selective harvesting (Turner et al. 2014, Armstrong et al. 2021). Resource sites were distributed across large geographic areas, and families worked together, rotating fallow and actively managed plots to ensure reliable food sources (Peacock & Turner 2000). This type of resource management ensured that Indigenous Peoples maintained high levels of food security (Blackburn & Anderson 1993, Turner & Spalding 2013).

Cultural burning was both species-specific and site-dependent and based on several ecological considerations, including the direct and indirect effects of fire (Table 6.1). For example, species would be carefully pruned and burned to synchronize fruiting, allowing resources to be collected at specific and predictable times (Johnson 2013). Many plants were transplanted to concentrate production in a single area, which made containing fires and tending plots easier (Armstrong et al. 2024). The temperature of the fire was critical to stimulate, but not damage, underground roots and rhizomes (Gottesfeld 1994). Fires also had to be hot enough to volatize inorganic nutrients and recycle organic matter into the soil to increase available nutrients the following year (Ross 1999). Moisture and temperature levels in the soil were monitored to know the specific time to burn and the resulting plant impacts (Turner 1999). Many burns were carefully timed to ensure that incoming rain would support available nutrients in soils for uptake by plants (Hoffman et al. 2025). The basic ecological use of fire was to create repeated disturbances on the landscape, promoting a specific successional phase or to select for plant (and animal) communities (Turner & Deur 2005).

Cultural Burning Techniques

Cultural burning typically occurred in the early spring before an approaching storm with heavy dark clouds, when the ground was still wet (and sometimes even frozen) (Gottesfeld 1994, Johnson 2013), or in the late summer or fall, when fires could be more easily controlled due to incoming rains and cooling temperatures (Table 6.1) (Turner 1999, Turner & Peacock 2005). Seasonal indicators such as plant phenology and the arrival or departure of migrating species helped determine when to burn (Turner 1999, Lantz & Turner 2003, Suttles 2005). The Wet’suwet’en monitored their territory closely, observing the state of yintah “territory” elements. People were positioned in certain parts of the territory at specific times to monitor signs of change. This close relationship with their surrounding environment, meant they had a deep understanding of factors that controlled the intensity and spread of fire (Hoffman et al. 2022). This included an in-depth knowledge of fire behaviour and how it was affected by humidity, time of day, slope, aspect, and prevailing winds (Turner 1999). To control the spatial extent of fires, firebreaks (Boyd 1999), backfires (Barrett & Arno 1999), topographical features (Hoffman et al. 2025) and wetted conifer boughs were utilized to extinguish or direct fires (Lewis & Ferguson 1988). Knowledge of how frequently areas were burned, how long areas should lie fallow, and the ownership of plots or individual plants was passed on to the next generation of firekeepers (Turner 1999, Hoffman et al. 2022).

Cultural burning required an understanding of natural processes, community characteristics, forest and plant succession, and climate (Turner 1999). Fire created specific habitat types, such as open meadows and early-successional forests, to increase the productivity of roots, herbaceous shrubs, and woody plants (Turner & Deur 2005, Anderson 2006). Controlled, low-severity ground fires were also set to increase plant productivity in the following year (Boyd 1999) and to promote fire-follower species available in subsequent years (Turner & Peacock 2005). Although some shrub species were individually burned (such as berry-producing shrubs), the most common and well-documented fire practices were landscape-scale burns (Gottesfeld 1994). Stand-replacing fires, although less common, were a component of Indigenous fire stewardship in sub-boreal forests and were utilized to restore unhealthy forests, reduce the risk of wildfire to habitation sites, and convert forests into more productive lands for food, medicinal plants, and wildlife forage (Hoffman et al. 2025).

Mid-elevation meadows (>900 meters above sea level [m asl]) were important resource sites for hardy perennial species requiring ample light. Vaccinium species such as oval-leafed blueberry (*Vaccinium ovalifolium*) and black huckleberry were important berry plants (Table 6.1; Turner 1999, Turner & Peacock 2005, Hoffman et al. 2025). Although not as geographically widespread, other important high elevation berry species included raspberry (*Rubus idaeus*), blackcaps (*Rubus occidentalis*), and elderberry (*Sambucus racemosa)* (Robbins 1999, Turner 1999). Various berries were important in different regions, but in general, black huckleberry was the most prized. Black huckleberries are known to be high in carbohydrates, sugars and vitamin C (Kuhnlein & Turner 1991, Gottesfeld 1994, Johnson 2013).

Berry patches were most often located on south-facing, moderately sloping areas that were snow-free earlier in the year and received the most direct sunlight (Johnson 2013). Berry patches were strategically placed at high (800-1200 m asl), medium (600-800 m asl), and low elevation (300-600 m asl) sites to increase food security in the event of early frosts (Trusler & Johnson 2008). The timing of the late summer berry harvest coincided with the hunting and trapping of game, and seasonal camps were established to manage high-elevation resource sites (Gottesfeld 1994, Turner et al. 2013, Hoffman et al. 2025). Berry burning occurred in the late summer and early fall, as high-elevation sites could be covered in snow until midsummer (Lepofsky et al. 2003, Turner et al. 2011).

Because soils were thin in higher elevation areas, burning was less frequent, occurring on average every 7-12 years (Turner 1991, Peacock & Turner 2000). These resource sites were monitored to ensure they could continue to produce critical food sustenance and managed each year through pruning, which was less intensive than burning (Turner 1999, Johnson 2013). It took approximately 5-12 years for berry plants to reach peak productivity after a burn (Gottesfeld 1994, Johnson 2013). Berries were gathered in large quantities, dried in the sun and then placed on long racks above smouldering logs to create a raisin-like consistency (Norton 1979, Turner et al. 1999, Turner et al. 2014). After drying, berries were made into cakes before being transported back to winter village sites (Gottesfeld 1994, Lepofsky et al. 2005). It's estimated that each family required between 60 and 80 kilos of berries for the winter months (Hoffman et al. forthcoming).

Fire was rarely used for only one purpose, and what increased the abundance of one species would also increase the diversity and abundance of several others (Turner & Peacock 2005, Hoffman et al. 2022). For example, grasslands that were maintained by fire were also important for several fire-follower species such as bracken fern (*Pteridium aquilinum*), stinging nettle, fireweed (*Epilobium angustifolium*), trailing blackberry (*Rubus ursinus*), raspberry and nodding wild onion (*Allium cernuum)* (Norton 1979, Turner 1999, Hoffman et al. 2017).

Because lightning-ignited wildfires were relatively common in sub-boreal forests, cultural burning was used in conjunction with lightning ignitions to reduce fuel availability and decrease the intensity of wildfires that were harmful to cultivated plants and village sites (Turner 1999, Anderson 2005, Turner & Deur 2005, Hoffman et al. 2025). This was similar in many ways to fire practices in the dry, fire-adapted prairie landscapes of the interior west (Norton 1979, Blackburn & Anderson 1993, Boyd 1999). The large-scale and widespread use of fire in sub-boreal forests altered species composition by creating patch mosaics with an abundance of edges (Hoffman et al. 2025). Intermediate levels of fire disturbance increase plant and animal diversity in an area (Hagmann et al. 2023, Pickett 1985, Turner 2001).

Defining Natural and Cultural Fire Histories

It is important to note that prevailing concepts and understandings of natural (lightning-ignited) fire regimes are rooted in scientific perspectives on fire ecology and fire behaviour developed during a century of widespread natural and cultural fire suppression (Dickson-Hoyle et al. 2023). Scientific perceptions of fire regimes are largely independent of Indigenous applications of fire advanced through systems of knowledge spanning thousands of years (Hoffman et al. 2021). Scientific experiments and observations of the natural environment often span short periods, usually 2-5 years, with the longest records just over 100 years (Stewart 2002). In some locations, Indigenous Peoples used fire in a manner that mimicked the scale and intensity of natural fires or incorporated lightning ignitions into their fire stewardship practices (Hoffman et al. 2025). At other locations (especially wetter sites), cultural fire was distinct from natural fire regimes (Hoffman et al. 2017, Hoffman et al. 2021, Lake & Christianson 2021).

Many fire stewardship practices, such as the annual burning of grasslands, have a light footprint and leave very little long-term evidence on the landscape, so attempting to distinguish between natural, lightning-caused fires and cultural, purposeful fires can be challenging (Lepofsky et al. 2005, Trant et al. 2016, Hoffman et al. 2017). This is especially true when reconstructing fire histories on landscapes that appear and function differently today than they did before contact (Table 6.2). Changes in causal mechanisms and complex interactions between climate, vegetation, and Indigenous fire stewardship techniques throughout the Holocene period make it difficult to demonstrate that fires were an intentional form of resource management (Hebda 1995, Lepofsky & Lertzman 2008, Ryan et al. 2013). Fortunately, Indigenous fire science (including detailed ethnographic records, paleoecological evidence, historic fire reconstruction and cultural burning techniques still practiced today) can inform fire stewardship practices at the landscape scale.

Table 6.2References: Hoffman et al. 2025, Turner 1999, Turner et al. 2008, Armstrong et al. 2018, Gottesfeld 1994a, Gottesfeld 1994b, Johnson 2000, Trusler & Johnson 2008; Johnson et al. 2013, Armstrong 2022, Burrows 2002, Krawchuk et al. 2006, Kimmerer & Lake 2001; Greene et al. 2017, B.C. Biodiversity Guidebook 1995, Chavardès et al. 2021.

Fire characteristics	Natural Fire Histories	Cultural Fire Histories
Location	All aspects, but largely south-facing slopes, no specific landscape pattern. Often patterns of repeat ignitions (high-density lightning areas).	South-facing slopes, meadows, high-elevation sites, riparian sites and around village sites, valley bottoms.
Climate conditions/ seasonality	Large fires after periods of prolonged drought, mid and late summer after sustained high-pressure ridge development. Many fires were climate limited.	No necessary climate signal, but generally during dry and warm periods in early spring, late summer or fall. Not climate limited.
Regionally synchronous fires	Likely (multiple lightning ignitions)	Likely (multiple cultural ignitions and interaction with lightning-ignited fires).
Estimated fire return intervals	>100 years (SBS zone)	Annual (grasses and herbs), or at intervals of 5-12 years (berries/other shrubs) or 20-30 years (retain meadows/ keep at specific successional stage).
Fire severity	Currently characterized as stand-replacing (or initiated) crown fires. Emerging evidence suggests it was much more likely a mixed-severity fire regime with vigorous surface intermittent crown and crown fires.	Low- moderate- and high-severity, ground to crown fires with different management techniques relating directly to plant management and desire for open forest canopies and other desirable habitats.
Fire extent	Both patchy 10-500 ha and widespread >10,000 ha	Contained > 100m^2 and patchy (< 10 hectares), repeat burning along specific fire breaks/perimeters
Fuel consumed	Primarily conifer, broadleaf, and shrub (July-September)	Conifer, broadleaf, graminoid and forb species (March - May [spring]), conifer and shrub (August-October [summer and fall])
Forest age	Post-wildfire cohorts ranging from 100-200 years along with mixed-aged stands.	Old-growth forests (maintained with ground fire >150 yrs.), meadows surrounded by younger conifer and broadleaf stands and grasslands/ forest gardens in valley bottoms.

Cultural fire return intervals are often orders of magnitude shorter than lightning fire return intervals (Trant et al. 2016, Hoffman et al. 2017, Brookes et al. 2021, Hoffman et al. 2025). Low- and moderate-severity surface fires leave evidence in the form of fire-scarred trees, which are marked by scorching of the outer bark without killing the tree. Cultural burning primarily consumes lighter fuels (graminoid, moss, leaf and shrub species), with frequent low-severity fires emitting low amounts of ash and charcoal that is recorded in lake sediments or soil records (Lepofsky et al. 2005). In sub-boreal forests, lightning fires are usually mixed-severity fires that are low-, moderate- or high-severity and can be stand-replacing, consuming heavy fuels (conifer species) and leaving few living trees that retain fire scars (Table 6.2). Lightning-ignited fires can be recorded through the establishment of post-fire cohorts and large deposits of charcoal, leaving distinct charcoal peaks in lake sediment records (Whitlock & Larsen 2001). Other evidence that can be used to distinguish between lightning and cultural fire histories includes changes in vegetation patterns, such as encroachment of former meadows by conifers, retraction of species ranges, such as a loss of the broadleaf component, and the presence of fire-intolerant species (Lepofsky & Lertzman 2008, Steel et al. 2023).

Conclusions

The landscape-level practice and fire rotation interval of Indigenous fire stewardship in sub-boreal forests are likely much greater than what has been assumed based on western scientific methods and proxies alone. Although many oral traditions have been lost, Indigenous-led fire stewardship remains a practice specific to First Nations in sub-boreal forests, retaining a deep understanding of plant management and how fire can be used as a tool to manage healthy and productive landscapes. First Nations understand the intricacies of their local environments, remain connected to shifting plant phenology related to climate change, and are adapting to increased weather extremes (Hoffman et al. 2021). Sub-boreal forests continue to be affected by impactful wildfire seasons, and co-created fire management plans that are informed and Indigenous-led can help protect communities from destructive wildfires, support healthy ecosystems, and shift our management tactics from single to multiple values (Hoffman et al. 2025).

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7.0 Stand-Level Fuel Management

By Larry McCulloch, with input from Brad Martin

Introduction

The B.C. government provides guidance on fuel management practices specific to B.C. in the 2024 Fuel Management Practices Guide (B.C. Wildfire Service 2024a). In this section, we build on that framework with additional information from the literature and practical experience relevant to the Morice Bulkley project study area. We aim to provide information that will help wildfire managers and practitioners develop effective strategies and identify appropriate treatments, including areas of uncertainty. This section details our current knowledge of fuel management principles and practices. We also identify knowledge gaps that could inform adaptive management and where further research could be undertaken to optimize fuel management approaches for the unique conditions of the Bulkley Morice area.

This section is not about hazard abatement as defined in the B.C. *Wildfire Regulation*. The chapter on Forest Management Practices addresses how the *Wildfire Regulation* contributes to fuel management objectives. Related information about fuel types, types of fire, and fire behaviour is in Chapter 4: Wildfire Behaviour and Chapter 5: Fire Effects.

Fuel Management Defined

Fuel management is important at both the landscape and stand levels, playing a crucial role in preventing and mitigating the impacts of wildfires. It involves the planned manipulation of forest fuels, which include both living vegetation—such as trees, shrubs, herbs, grasses, and moss—and dead organic matter, such as deadwood, leaf litter, and duff. These materials can serve as potential fuel for wildfires—the B.C. Wildfire Service (2024a) states that the aim of managing fuels across the landscape is to create ecosystems that are resilient to wildfires and to foster communities that are adapted to living with wildfires.

Fuel Management and Fuel Treatment

Fuel treatment is a specific action to reduce flammable material (fuels) on the landscape, while fuel management is a broader, strategic approach encompassing various techniques to manipulate fuels and mitigate wildfire impacts. Fuel treatment is a tool used within the larger framework of fuel management.

Fuel treatment focuses on modifying the structure and composition of the forest to reduce fire intensity, prevent or slow the spread of fires, or reduce fire severity. Expected outcomes include reducing surface fire intensity and spread rate, preventing continuous crown fires and spotting, and supporting fire-fighting activities.

Stand-Level Principles

1. Reducing Surface Fire Intensity

Fuel treatment, particularly in the wildland-urban interface, aims to modify surface fuels to reduce surface fire intensity, which in turn reduces the likelihood of crown fire initiation and ember transport.

Altering surface fuels in conjunction with ladder fuels can reduce fire intensity, crown fire initiation, and ember transport, and promote a broader range of post-fire vegetation patterns, ultimately minimizing unwanted impacts to forest ecosystems or communities.

When fuels are removed through treatment, the fuel load (W) is reduced. Both the amount of fuel (W) and the rate of spread (R) need to be considered, however. Treatments that lead to more open conditions may lead to higher temperatures, more rapid drying, and greater opportunity for increased wind during the fire season, thus increasing R. Conversely, more open stand conditions may also contribute to higher snow capture, leading to a prolonged ground fuel moisture during snow melt in the spring compared to closed stands or clearcuts, particularly in low to moderate snow years (B.C. MoF 2025, Gillich 2023, Winkler 2001).

In fuel treatment, it is important to distinguish between fine surface fuels and larger woody fuels, also known as coarse woody debris (CWD). Fine fuels dry out quickly, are easy to ignite, and primarily influence the initial and equilibrium spread rates of fire; therefore, they are a critical part of the standards for fuel treatment. Fine fuels burn rapidly and can ignite larger fuels, significantly contributing to short-term fire intensity. However, they are generally considered less important for biodiversity objectives.

How is Fire Intensity Measured?

Fire intensity is defined by the equation $\mathbf{I = h*W*R}$

Where:
I is fire intensity in kW/m
h is the potential heat content of the fuel (kJ/kg)
W is the weight of fuel consumed (kg/m^2)
R is the rate of spread (m/second).

In contrast, larger woody fuels have a limited effect on the spread and intensity of the initial surface fire. Nevertheless, they can play a role in the development of larger fires and can lead to higher fire severity, particularly when vertical and horizontal continuity exists. Heavy accumulations of CWD can contribute to fire persistence, resistance to control, and longer residence times, as well as increase the likelihood of reburn and spotting; however, the exact extent of this influence remains uncertain (Brown et al., 2003). Although the priority of most fuel management treatments is reducing fine fuels, heavy accumulations of large and CWD, can prove challenging. Wildfire in these conditions leads to smouldering combustion which means longer residence time, potential for holdover fires as well as increased effort in control and mop-up operations. These conditions also mean more smoke, which is not desirable, particularly in the interface.

The duff layer is another important source of forest fuel to be considered during fire behaviour analysis and planning. The literature supporting the Canadian Forest Fire Danger Rating system indicates that calculating potential fire intensity should be based on both woody fuel consumption and forest floor consumption (Forestry Canada, 1992).

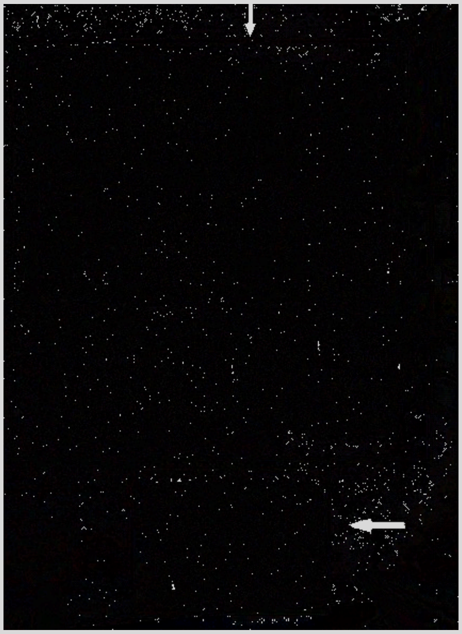
2. Prevention of Crown Fires and Spotting

Fuel treatment aims to reduce the availability of ladder and canopy fuels by reducing the number of large trees, increasing the fuel strata gap, and/or reducing canopy bulk density.

Crown fires are among the most destructive types of wildfire as they spread rapidly and contribute more readily to ember transport or spotting—the process by which embers are carried aloft by convection currents and ignite new fires beyond the fire front. Surface fires burning under a canopy have a lower risk of ember transport, as the canopy acts as a barrier and interferes with the development of an updraft (B.C. Wildfire Service, 2024a).

What counts?

Volume of fuel in the duff layers versus fine woody fuels after treatment at 10 sites in the Wetsinkwa Community Forest. Only the two trays at the bottom of the photographs are woody surface fuels



Source: Brad Martin, Fire Behaviour Analyst, MoF, pers. comm. 2024.

3. Support For Fire Response Efforts

Fuel treatments should reduce the rate of spread and fire intensity, improve sight lines, and reduce radiant heat, providing ground crews with more time and options for suppression activities, such as setting up sprinkler systems, constructing fire guards, and controlled burning.

Reducing the spread rate and intensity allows crews to get closer to the fire front and/or take direct action on flanks, and provides options for indirect tactics to keep fire behaviour manageable. Fuel treatments, such as thinning and large-scale fuel breaks, can also support air operations by reducing smoke, which can hinder operations, and by creating more open conditions that allow better penetration of water or fire retardant from air tankers or helicopters. Other safety and efficiency benefits of fuel management can include fewer danger trees, better footing, and faster extinguishment.

Direct-attack fire suppression efforts can only be maintained until a maximum fire intensity of about 4,000kW/m. The goal is to have all fuel managed areas well below 4,000 kW/m, ideally below 2,000 kW/m, as this will allow for direct fire suppression for crews (BC Wildfire Service, 2024a).

4. Fire Weather

Fire weather factors such as wind speed, air temperature, relative humidity, and rainfall play a crucial role in fire behaviour and the effectiveness of fuel treatments. Fuel treatment design must be explicit about the objectives and the circumstances (including weather) under which the treatment is expected to be effective.

Treatments are often designed to be effective under 90th percentile fire-weather conditions, subject to constraints resulting from policy, budget, other resource values, and the tools and equipment available. If fire weather conditions reach or exceed the 90th percentile, it could indicate a higher potential for challenging wildfire behaviour, and some or all treatments may be overwhelmed.

Whether or not 90th percentile conditions are conducive to high or extreme fire behaviour will depend on the type of fuel the fire is burning in. Fire behaviour is dependent on both fire weather and fuel. An example, provided in Table 7.1, shows that identical fire weather indices (90th percentile indices from the Ganokwa weather station (BCWS 90th Percentile Calculator[19])) result in much different behaviour in a boreal spruce fuel type than in a lodgepole pine fuel type. This example reveals that the potential for ground suppression to successfully contain the fire under 90th percentile fire weather in a C3 fuel type (lodgepole pine) would be substantially better than in a C2 fuel type (boreal spruce) because fire intensity and rate of spread in the pine type would be much lower and the fire would be on the surface rather than in the tree crowns.

90th percentile fire weather refers to weather conditions that are conducive to more aggressive fire behaviour than those observed on 90% of days within a given period (usually 10 years) for a particular location.

Table 7.1. Fire behaviour for two fuel types and identical fire weather. From: Field Guide to the Canadian FBP System (Taylor et al. 2018): FFMC=92, ISI=8, and BUI= 76.

Fuel type	**C2 (boreal spruce)**	**C3 (lodgepole pine)**
Fire Type	Intermittent crown fire (up to 90% crown fraction burned)	Surface Fire
Intensity Class	5 (4000 to 10,000 kW/m)	Class 3 (500 to 2000 kW/m)
Equilibrium ROS	10 m/min	3 m/min

This example highlights the importance of clearly defining treatment objectives and the specific fire weather conditions under which fuel treatments are expected to be effective. Fuel reduction treatments designed for 90th percentile fire-weather conditions may fail to achieve their suppression or protection goals if wildfire weather reaches the 95th percentile. If the risk tolerance is low—especially when the values at risk in a given location are particularly

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[19] https://wps-prod.apps.silver.devops.gov.B.C..ca/percentile-calculator

significant, or if a changing climate is anticipated to lead to more severe fire-weather in the future—the treatment may need to be adjusted for a higher percentile of fire weather conditions.

Designing Treatments[20]

Expected fuel conditions, W in the fire intensity equation, and weather conditions, R in the fire intensity equation, are both important considerations when designing fuel treatments.

This type of information can be used as input into several tools produced by the B.C. Wildfire Service[21] and the Canadian Forest Service, such as the Critical Surface Fire Intensity Worksheet to predict crown involvement, flame length, and desired crown base height.

(see also Chapter 4, Fire Behaviour).

Fuel Treatment Practices in the Literature

The literature typically describes two types of stand-level fuel treatments: mechanical reduction or modification and prescribed fire. Common combinations or variations of mechanical treatments discussed in the literature include thinning (with or without pruning, ladder fuel reduction, debris removal) and mastication. Prescribed fire and managed wildfire are also the subjects of many papers, and silviculture treatments, such as site preparation or stand establishment practices, also serve as fuel treatments. Each of these is described below, along with information on its efficacy and the circumstances in which it is used.

Thinning, Pruning, and Debris Removal

Treatment Description

Thinning is a common fuel treatment practice involving the selective removal of trees within a stand to reduce tree density and crown fuels (CBD). Thinning alone is unlikely to reduce surface fuels and is often combined with pruning, other forms of ladder-fuel reduction, and removal of post-thinning materials. Mechanical methods, such as mastication, are also used and are addressed separately below. Removal of materials can include harvesting merchantable logs or materials used in other commercial or domestic applications. Where markets exist, this approach is favoured to mitigate treatment costs and to reduce emissions from debris burning. Thinning from below (removing trees from the intermediate rather than dominant tree layers) is often prescribed when there is a desire to maintain crown closure.

Mechanical thinning operations may utilize a variety of equipment depending on the terrain, stand density, and project objectives. A feller-buncher/forwarder system is generally used to move both merchantable and unmerchantable materials. Cut-to-length systems, utilizing harvesters and forwarders, may be preferred in smaller-diameter stands or for non-commercial thinning, especially in sensitive soils. For steep terrain, winch-assist or cable-yarding systems have also been used. Thinning may also be performed by hand crews using chainsaws,

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[20] https://fireresearch.ca/conifer-pyrometrics/

especially in wildland-urban interface (WUI) zones, areas with sensitive soils, or areas with cultural significance. In such circumstances, felled materials are usually bucked and piled manually.

Pruning involves the manual or mechanical removal of lower branches on retained trees to reduce ladder fuels. This practice helps limit crown fire potential and is commonly done using pole handsaws or chainsaws. After thinning and pruning, residual debris, or slash—including limbs, tops, small-diameter trees, and some shrubs—must be managed to prevent fuel accumulation. Usually, this is accomplished by piling and burning with hand crews or machines such as grapple loaders or excavators with thumbs or rakes. These piles are then burned under controlled conditions during safe weather windows. In some cases, the slash may be chipped or lopped and the pieces scattered instead.

More detailed descriptions of these treatments are available in the Provincial 2024 Fuel Management Practices Guide by the Government of British Columbia, the 2024 BCWS Wildfire Risk Reduction Pile Construction and Burning Guidance document, the 2023 BCWS Fuel Management Prescription Guidance, and the B.C. FireSmart Guide[21] (for treatment around residences).

Thinning Treatment Efficacy

Much of the evidence for thinning efficacy in reducing fire severity is in Douglas-fir or Douglas-fir/ponderosa pine ecosystems common in the dry interior forests of southern B.C. These dry forest types are characterized by thick-barked conifer species that can withstand low-severity fires and have historically been considered open forest types. Comparatively, the sub-boreal forests of the Bulkley Morice are characterized by thin-barked tree species and closed canopies that historically experienced longer fire return intervals and stand-replacing fire events. Some ecosystems have higher fuel loading because of the mountain pine beetle outbreak. Note that although treatment principles in these drier ecosystems may be pertinent, caution must be exercised in assuming that changes in fire behaviour in the moist forests of the Bulkley Morice area will mirror those in the drier forest ecosystems that are typically fire-maintained.

Evidence from studies in the dry forest types of B.C. suggests that thinning, combined with the removal of surface debris, can significantly reduce fire intensity (FP Innovations 2024, Hvenegaard & Baxter 2023, B.C. Wildfire Service 2020). A recent review in the U.S. of over 40 case studies where wildfire burned into areas with previous forest treatments found evidence that thinning, coupled with prescribed burning or pile burning, can reduce future wildfire severity by more than 60 percent relative to untreated areas, and that thinning followed by prescribed burning was the most effective treatment combination. (Clark et. al. 2024).

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[21] https://firesmartB.C..ca/wp-content/uploads/2020/04/05.30.23_BeginsatHomeGuide_Web.pdf

Thin-barked species such as pine, spruce, and subalpine fir are more susceptible to damage from prescribed fire following thinning, which may make this treatment combination more challenging to implement in the Bulkley Morice compared to the drier forests of southern B.C.

Case study – Interior dry Douglas-fir ecosystem

Manwaring (2023), used harvest prescription data and other sources to approximate fuel conditions in an area south of Green Lake B.C. and ran this information through a fire effects model (B.C. CanFIRE - de Groot, W. 2022. B.C. CanFIRE-Excel v3.1.3 Model. Canadian Forest Service) to compare fuel treatment strategies to provide insight on building resilience in the wildland urban interface.

This area was an interior Douglas-fir ecosystem. Simulated treatments included keeping all aspen and less than 100 coniferous stems/ha, and 50% and 80% removal of coniferous species with no planting and with planting (aspen at 196 stems/ha). Results from this research show that there was a reduction of intensity class when examining climate change, slight decreases in final head fire intensities post-harvest, and a reduction in rates of spread with planting but that outcomes were dependent on the percentage of Douglas-fir removed. The author also noted that despite the statistical differences between the untreated and treated sites, the area still exhibited extreme fire behaviour with low fuel loads and continued to burn at intensity classes 4 to 6.

Factors Influencing the Success of Thinning Treatments

McCulloch (2020), in an assessment of fuel treatments that had interacted with wildfire across B.C., indicated that treatments involving thinning, debris removal, and ladder fuel reduction are affecting wildfire behaviour in positive ways and may be feasible at a larger scale. Some of the lessons learned in the 2020 study included:

- Small beneficial impacts were observed across a broad range of ecological conditions.
- Despite using short, thin (20 to 50m wide), linear strips, fire impacts such as scorch height, tree mortality, and crown involvement were still modified.
- Treatments positively affected fire behaviour in C3 (mature lodgepole pine), C4 (immature lodgepole pine), and C7 (ponderosa pine-Douglas fir) fuel types even in relatively high intensity fires (>2000 kW/m).
- Increasing crown base heights to as little as 2m had a positive impact when combined with thinning and debris removal.
- Thinning, with debris removal, did reduce tree mortality and crown involvement, but there was evidence that further gains can be made by reducing ladder and surface fuels.

Despite the observed changes in fire behaviour noted in the 2020 study, the author also concluded that treatments were not necessarily implemented in ideal locations and were usually too small to achieve broader fuel management objectives (see Chapter 10: Landscape Fire Management).

Hudak et al. (2011) indicate that surface fuel loading increased in thinned-only treatment stands, which counteracted any potential effects of reducing ladder fuels, causing wildfire severity to remain mostly unaffected compared to the untreated stands. Mooney (2010) states that removal of surface and ladder fuels may play a more important role in changing fire behaviour than thinning of overstory canopy fuels and that extensive thinning does not reliably modify fire behaviour. Omi & Martinson (2009), in a meta-analysis of the literature on fuel treatment mitigation of wildfire fire intensity and severity, indicate that thinning treatments have demonstrated the most substantial reductions in wildfire severity, when there are substantial changes to canopy fuels (removing at least half), there is a shift in the diameter distribution towards larger trees, and thinning treatments are followed by broadcast burning. Safford et al. (2009), in a study of the effects of fuel treatments on fire severity in a mixed conifer forest in the Lake Tahoe Basin, indicate that thinning the forest canopy without strongly reducing surface fuels does not increase tree survival, although it may decrease some measures of fire severity.

In a study of stand-level fuel reduction treatments and fire behaviour in Canadian boreal conifer forests, Beverly et al. (2020) conclude that treatments are an important tool for mitigating fire behaviour in these forests. However, their long-term success depends on strategic application, maintenance, and integration with broader fire management strategies. Key points include:

- Fuel reduction treatments, particularly thinning and prescribed burning, can reduce fire intensity and spread in boreal coniferous forests.
- Thinning alone and thinning combined with prescribed burning were found to be the most effective ways to reduce the potential for extreme fire behaviour.
- Crown fire initiation and spread modelling frameworks can provide an intuitive and structured process for exploring the effects of fuel treatment on potential fire behaviour, but are encumbered by assumptions and subjective decisions about model inputs.
- Forest structure, fire weather conditions, and the time since the treatment influence the effectiveness of fuel treatments.
- Fuel treatments were generally effective at reducing modelled and observed fire behaviour and inhibiting crown fire development and spread under low to moderate fire weather conditions. However, fuel treatments in these fuel types will be ineffective when rates of spread and wind speeds are very high or extreme.

The authors highlight that boreal forests are fire-adapted ecosystems. While fuel reduction treatments can protect human infrastructure and mitigate immediate fire risks, natural fire cycles play a crucial role in maintaining ecological processes in these forests. Importantly, the authors conclude that at extreme fire weather, their effectiveness at moderating fire behaviour declines. The degree to which they are effective at extreme fire weather in the Bulkley Morice area forests remains questionable and untested.

Thinning Limitations

Thinning is generally intended to address crown fire spread by reducing canopy density and increasing the distance between trees. Thinning alone without mitigating surface fuel is unlikely to reduce surface fire intensity and may promote adverse effects in the understory.

Additionally, crowning and spread in closed stands (not thinned) when surface fire intensity is below the critical surface fire intensity threshold will be minimal even without treatment. Millikin et al. (2024) found, in a study of the impacts of thinning on microclimate near Whistler, B.C., that thinning led to warmer, drier, and windier fire environments, which could increase wind penetration and consequent fire spread rates, point ignition start potential, and potential crown involvement. They concluded that thinning alone cannot mitigate against wildfire severity under instances of extreme fire behaviour. Whether these findings are applicable in the Bulkley Morice ecosystems has not been well tested. Vanessa Foord (a B.C Ministry of Forests Research Climatologist) indicates, however, that preliminary findings from a study they are conducting on microclimate and wildfire risk in a number of stand types near Prince George and Smithers, B.C., confirms that open sites (as opposed to closed 30-year-old stands or mature forest) had higher soil surface temperatures, higher wind speeds, and lower relative humidity (RH) values (pers. comm. 2024). The author cautions that fuel treatments that open the canopy may create a drier environment which could increase fire weather indices. The degree to which this occurs in the Bulkley Morice study area is a knowledge gap.

Cochrane et al. (2012) stated that fuel treatments can either inhibit or enhance the rate at which fires pass through an area, depending on how the surface fuels have been altered. For example, in some forest types (e.g., ponderosa pine), the opening of the canopy through thinning operations may re-establish a grass understory that is exposed to sunlight and wind, and when cured, accelerates the passage of any fire that enters the site. It may be that a treatment can accelerate the spread rate, while reducing the possibility of crown fires and associated spotting. Mooney (2010) indicates that a disadvantage of fuel breaks is the potential for increased in-stand wind speeds and increased drying of surface fuels.

Beverly et al. (2020) suggest that under low-to-moderate fire weather conditions, fuel treatments —such as thinning and pruning, as in their example—will likely be successful in reducing fire behaviour. However, under high or extreme fire weather, the effects on boreal forest fuel types will not achieve the same reduction in fire intensity or rate of spread.

Thinning with Supplemental Treatment

Mechanical treatments alone can increase surface fuel loads in the form of branches and needles left on the forest floor as a result of the treatment. These leftover fuels can increase future fire severity if not reduced by prescribed fire or further treatment such as piling and burning.

By contrast, prescribed fire alone can consume surface fuels and kill small trees, but may not adequately reduce mature tree density, especially if trees have developed fire-resistant thick bark or if the fire burns with very low severity. Small trees that are killed in a prescribed burn can fall to the ground in later years, leading to a re-accumulation of surface fuel. The most effective treatments often involve multiple treatment activities, such as thinning followed by prescribed burning.

From a 2024 bulletin, from the USDA Rocky Mountain Research Station (Clark et al. 2024)

Research indicates that supplemental measures to thinning, such as the removal of surface and ladder fuels, are necessary to achieve substantial reductions in fire intensity (Pritchard et al. 2021, Hudak et al. 2011, Hayes et al. 2010, Mooney 2010).

Note that while evidence suggests some success with thinning treatments in dry interior forest types, it is important to note that these ecosystems differ from those in the Bulkley Morice area. Pete Laing (BCWS Superintendent of Fuel Management) suggests, for example, that in moister, cooler climates, it may be advantageous to maintain a relatively closed canopy to exploit environmental moisture, which could in turn lead to higher fuel moisture content (pers. comm. 2025).

Mastication

Treatment Description

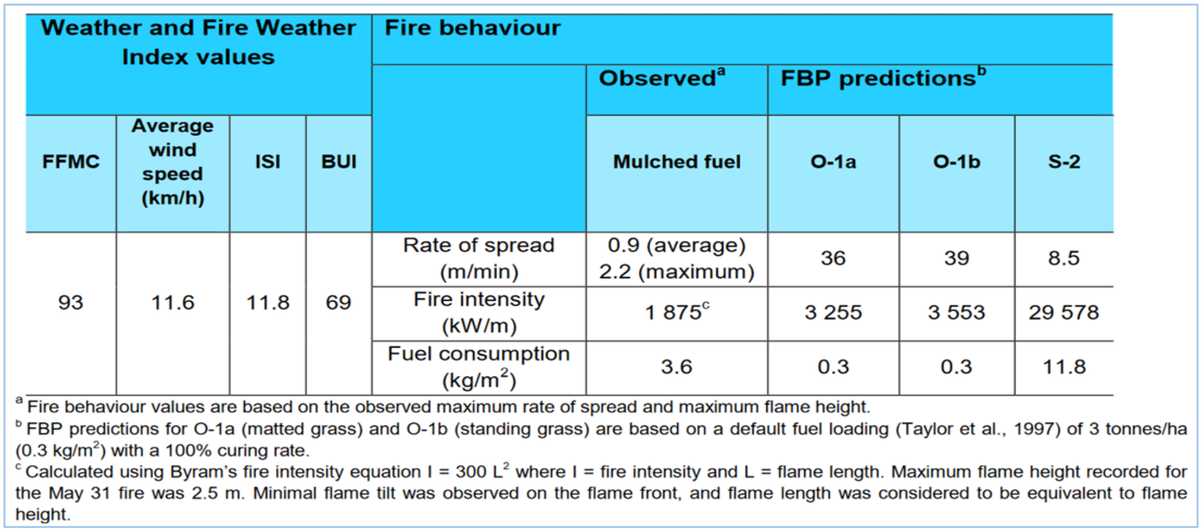
Mastication is a mechanical fuel treatment method in which vegetation is shredded and reduced to smaller particles. The treatment produces chips or mulch, terms that are often used interchangeably. The purpose of mastication is to break down ladder fuels and surface fuels such as shrubs and fine dead fuels, creating a less flammable, less continuous fuel bed. Masticated material can either be left in place, burned, buried, dispersed through the treatment area, or removed from the site. Various types of equipment are used, including stationary and mobile devices such as drum masticators, disc masticators, excavator-based masticators, and tractors with mulchers. As was the case with debris management for thinning treatments, it is possible that revenue could be generated on mastication projects, in this case, through the sale of the resulting mulch, fuel for boilers, or potential use in the pellet industry.

For detailed descriptions of the treatments, see the B.C. Wildfire Service (BCWS) 2024 Best Management Practices for Mastication as a Fuel Management Method in British Columbia. More information on mastication can also be found in a comprehensive literature review by Shifting Mosaics (2024), which describes the types of equipment used, operational limitations, chip and fuel bed characteristics, impacts on fire behaviour, complementary treatments, treatment longevity, utilization of chip products and markets, and environmental concerns.

Mastication Treatment Efficacy

The efficacy of mastication in the Bulkley Morice is not well tested; however, Shifting Mosaics (2024) report a variety of outcomes in B.C. in terms of fire intensity, rate of spread, and fuel consumption with mastication, depending on factors such as chip size, continuity, depth, moisture content, and fire weather at the time. An example of the potential difference in fire behaviour for a mulched fuel type compared to predicted outcomes for a grass fuel type (O1a and O1b) and a spruce slash fuel type (S-2) is shown in (Table 7.2).

Table 7.2. Observed fire behaviour (spread rate, intensity, and fuel consumption) with a mulch fuel bed compared to predicted behaviour for three fuel types where no mulch was involved (as reported by Shifting Mosaics, 2024 but sourced from Hvenegaard and Price, 2018).



Weather and Fire Weather Index values				Fire behaviour				
					Observed[a]	FBP predictions[b]		
FFMC	Average wind speed (km/h)	ISI	BUI		Mulched fuel	O-1a	O-1b	S-2
93	11.6	11.8	69	Rate of spread (m/min)	0.9 (average) 2.2 (maximum)	36	39	8.5
				Fire intensity (kW/m)	1 875[c]	3 255	3 553	29 578
				Fuel consumption (kg/m^2)	3.6	0.3	0.3	11.8

[a] Fire behaviour values are based on the observed maximum rate of spread and maximum flame height.

[b] FBP predictions for O-1a (matted grass) and O-1b (standing grass) are based on a default fuel loading (Taylor et al., 1997) of 3 tonnes/ha (0.3 kg/m^2) with a 100% curing rate.

[c] Calculated using Byram's fire intensity equation $I = 300 L^2$ where I = fire intensity and L = flame length. Maximum flame height recorded for the May 31 fire was 2.5 m. Minimal flame tilt was observed on the flame front, and flame length was considered to be equivalent to flame height.

The B.C. Wildfire Service (2024a, 2024b) reports that fire has been observed to move from the crown to the surface layer after mulching in some cases, with lower spread rates and reduced damage to trees. The removal of ladder fuels during mastication may also make the area more accessible for suppression actions.

The B.C. Wildfire Service recommends the following practices for mastication as a wildfire risk reduction tool:

- A maximum average depth of chipped material left on site of 7.5 cm.
- Masticated material should be dispersed with breaks in the horizontal continuity (unless burning is prescribed) and kept away from remaining tree stems.
- Dispersal of masticated material should not increase potential fire behaviour intensities above 2,000 kilowatts per metre (under fire weather conditions up to the 90th percentile).
- Masticated material should not be dispersed within 100 meters of residential structures or critical infrastructure.
- Prescribed fire can be an effective way to remove masticated matter from a treatment site. Reductions in fuel load from mastication, followed by prescribed fire, can be sustained for 10 to 20 years, particularly in conifer forests. As the time since mastication increases, masticated material becomes increasingly resistant to fire (2-5 years on moderately dry sites).
- Bolstering mastication treatment during suppression with retardant drops, sprinkler use, and planned ignitions should be considered.

Limitations

The B.C. Wildfire Service (2024a) indicates that mastication with all chips left on site and no post-treatment is not recommended and that dispersal of masticated woody material should only be considered after all other treatment alternatives have been explored and ruled out, including utilization, pile and burn, and off-site disposal. While mastication can reduce ladder fuels and improve access for firefighting crews, it is not without risks. Amongst these are short-term elevated fire risk during dry periods, masticated material can smoulder and burn for more extended periods (longer residence time) potentially releasing more smoke, large quantities of water may be required to extinguish smouldering fires, the fuel bed may ignite or reignite relatively easily if exposed to embers, and there may be adverse impacts in terms of ecological function such as disturbance, compaction, and/or hydrophobicity of soils, and on wildlife forage and habitat (B.C. Wildfire Service 2024a).

Prescribed Fire

Treatment Description

Prescribed fire, or controlled burning, whether through broadcast burning or the burning of debris piles or mulch, is a fuel treatment technique in which fire is intentionally applied under controlled conditions. Reducing fine fuels, duff, shrubs, and low vegetation, as well as large woody fuels through burning, changes fuel continuity and the fuel energy stored on the site, potentially reducing both fire intensity and burn severity (Reid 2010). Prescribed fire can be used at small scales for just a few piles or landscape-scale burns covering thousands of hectares. Burn operations can be as simple as just a few people with hand tools and drip torches, or much more complex burning with many ground personnel and air support, constructed fireguards, black lining, complex ground and/or aerial ignitions, bladders, sumps, and natural water sources with multiple hose lines and sprinklers, and a variety of water tenders and pump trucks, etc.

Prescribed fire is often viewed as a cost-effective option for managing fuel over large areas. However, it involves several regulatory requirements, such as obtaining authorizations and providing notifications, which can increase both the cost and complexity of the process, and it also carries the potential liability of unintentional damage to values outside the burn perimeter. Additionally, there is uncertainty in achieving the ideal weather conditions for conducting the burns. In B.C., prescribed fires are classified as resource management open fires under the *Wildfire Act*. To carry out a prescribed fire, practitioners must have an approved burn plan and comply with all regulatory requirements, although prescribed fire is generally not subject to the Open Burning Smoke Control Regulation.

For more detailed information and access to planning tools, visit the B.C.W.S.'s prescribed burning cultural and prescribed fire pages[22].

Prescribed Fire Treatment Efficacy

Prescribed fire, when properly implemented, reduces horizontal fuel continuity, which in turn disrupts the spread of surface fires, limits their intensity, and reduces the potential for spot fire

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[22] https://www2.gov.B.C..ca/gov/content/safety/wildfire-status/prevention/prescribed-burning

ignition (Reid 2010). Other authors believe that using a combination of thinning and prescribed fire is most effective at lowering crown fire initiation, spread, and severity (Hudak et al. 2011, Omi & Martinson 2009). Prescribed fire treatments may also be more cost-effective if conducted at scale (Forest Practices Board 2015, Cultural Burning and Prescribed Fire[23]). Formulating realistic fire behaviour objectives is critical and clearly articulating the environmental and wildfire thresholds where the treatment is likely to be successful will help ensure that it is used in the right circumstances.

Efficacy will vary as a function of the type, amount, size, spatial distribution and intensity of treatments, time since implementation, ecosystem type, topography, weather conditions at the time and geographic location of burning (Cochrane et al. 2012), which makes prescribed fire a fuel reduction tool that is more difficult to control (Fernandes & Bothelo 2003).

Limitations

Studies have shown that prescribed fire, when used in isolation, may not always be effective in significantly modifying fire behaviour. McCulloch (2020) evaluated prescribed fire treatments that had interacted with wildfire in the previous 10 years in B.C. and found that prescribed fire, as implemented in the past, was less effective than treatments that aimed to modify stand structure and surface fuels through thinning and debris disposal.

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[23] https://prescribedfire.ca/why-prescribed-fire/

Considerations regarding the effectiveness of prescribed fire as a mitigation treatment

- *Fire weather* – Although prescribed fire treatments may "cool" fire intensity, in extreme fire weather conditions (90th percentile or above), it is very difficult to achieve an intensity class less than 4 (<4000 kW/m).
- *Quality of treatment* – Incomplete, spotty, or low-surface-intensity broadcast burning may not reduce surface fuels enough to impact fire behaviour.
- *Time since treatment* - Data concerning how long broadcast burning might be effective in changing wildfire behaviour is scarce. McCulloch (2020) reported that burning that had occurred more than 20 years before the wildfire did not influence wildfire outcomes. It was also noted that, after about 20 years, there was good evidence that stand structure could be a more critical factor than broadcast burning in reducing wildfire impacts. Another investigation directly relevant to the Bulkley Morice area is a study by Clason et al. (2024) in which broadcast burning had a statistically significant effect in four of six sites that interacted with the 2018 wildfires.
- *Ecosystem condition* - Treatment is unlikely to be as effective or last as long in ecosystems where high levels of herbaceous species, grass, and tree litter are likely to develop quickly after treatment (mesic to fresh sites with limited shrub development).

Socioeconomic considerations:

- Socioeconomic constraints, such as smoke management concerns, public distrust and fear of fire escapes, liability and legal issues, regulatory barriers, treatment costs, and a lack of trained personnel, can prevent treatment.
- Conflicting land management objectives respecting biodiversity, habitat, or cultural heritage objectives.

Silviculture Treatments[24]

Treatment Description

While silviculture activities, other than prescribed fire, are not necessarily considered fuel treatments, tree species selection, stand establishment density, and site preparation can have an important impact on future fire behaviour. Clason et al. (2024) and McCulloch (2020) suggest that an effective approach to fire resilience in the Bulkley Morice may involve silviculture practices that influence post-harvest slash levels and stand structure.

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[24] This section overlaps with Chapter 8, the Forest Practices chapter. This section is intended to describe practices that can be employed where the primary purpose is fuel management, and that the same practices can also be used in harvesting, where timber management is the primary objective.

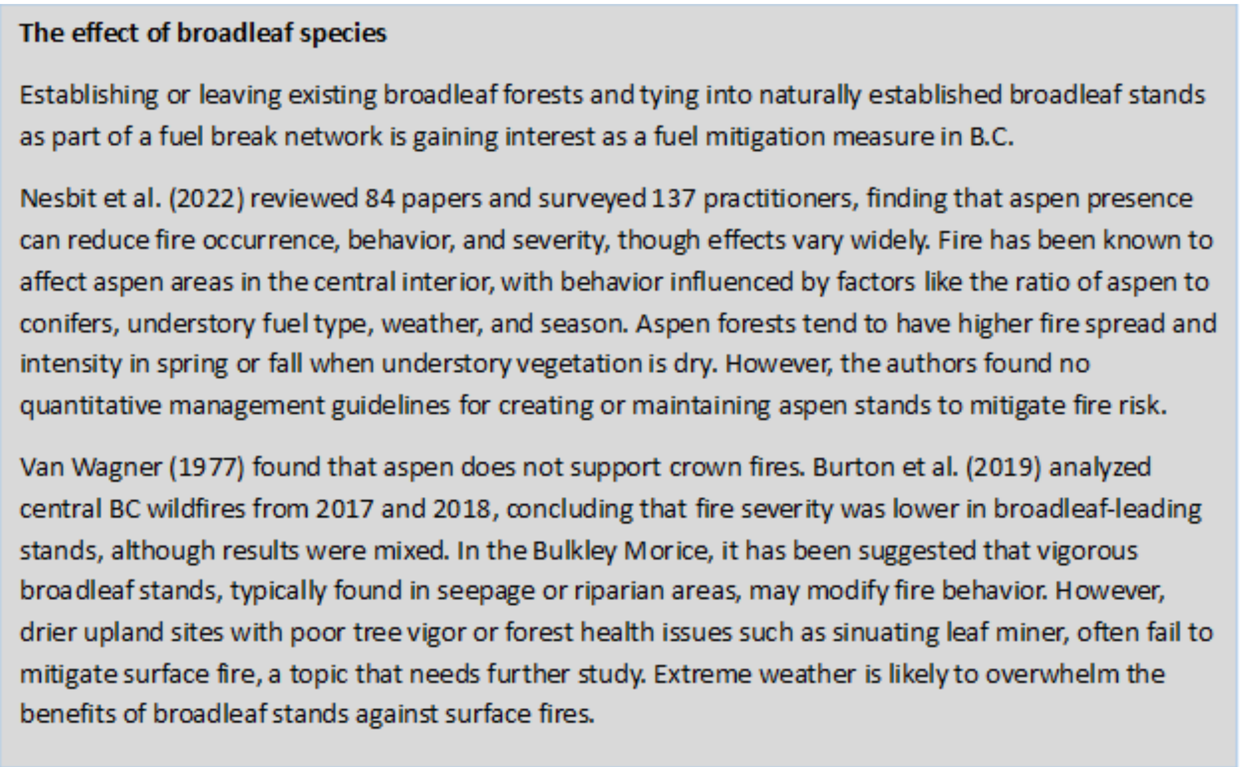
Silviculture site preparation treatments

Disc trenching - continuous linear mineral soil exposure and redistribution of slash

Ripping - mineral soil exposure in continuous lines or spots

Scarification - scraping or gouging the forest floor, exposing mineral soil and redistributing slash.

Silvicultural activities that impact the fuel amount or distribution include pre-reforestation site preparation, species selection, planting density and pattern, and post-establishment thinning and pruning. Treatments are typically applied where clear-cut logging has reduced or eliminated the risk of crown fire; however, they usually increase surface fire risk from the harvesting waste, which requires abatement. Treatments can create gaps in surface fuels that act as a barrier or slow the spread rate, depending on the orientation of the fire front relative to linear fuel gaps, wind, flame length, and the extent of spotting. From a fire management perspective, slash redistribution must not create concentrations or accumulations of fine fuels, which can result in spots that are predisposed to higher fire intensity and contribute to ember transport.



The effect of broadleaf species

Establishing or leaving existing broadleaf forests and tying into naturally established broadleaf stands as part of a fuel break network is gaining interest as a fuel mitigation measure in B.C.

Nesbit et al. (2022) reviewed 84 papers and surveyed 137 practitioners, finding that aspen presence can reduce fire occurrence, behavior, and severity, though effects vary widely. Fire has been known to affect aspen areas in the central interior, with behavior influenced by factors like the ratio of aspen to conifers, understory fuel type, weather, and season. Aspen forests tend to have higher fire spread and intensity in spring or fall when understory vegetation is dry. However, the authors found no quantitative management guidelines for creating or maintaining aspen stands to mitigate fire risk.

Van Wagner (1977) found that aspen does not support crown fires. Burton et al. (2019) analyzed central BC wildfires from 2017 and 2018, concluding that fire severity was lower in broadleaf-leading stands, although results were mixed. In the Bulkley Morice, it has been suggested that vigorous broadleaf stands, typically found in seepage or riparian areas, may modify fire behavior. However, drier upland sites with poor tree vigor or forest health issues such as sinuating leaf miner, often fail to mitigate surface fire, a topic that needs further study. Extreme weather is likely to overwhelm the benefits of broadleaf stands against surface fires.

Tree stocking levels in young stands, controlled through planting or thinning activities, can also influence fire behaviour. Several researchers have found that 20- to 40-year-old plantations are resistant to wildfire and act as an effective barrier because of a reduction in wind penetration into the stand and the surface fuel composition, arrangement, and amount do not carry fire well (Lewis pers. comm 2025, Clason et al. 2024, Jette et al. 2024, McCulloch 2020, Utzig 2019, Pritchard et al. 2014).

Kuntzemann et al. (in prep), for example, in a paper for predicting fire refugia in B.C., found that in much of the fire-prone NDT3 and NDT2 ecosystems in B.C., cutblocks aged 10-40 years are the most important variable explaining fire refugia. There are many examples of their efficacy in the Bulkley Morice. Burton et al. (2019) report that during post-fire surveys in the area, well-established, fully stocked plantations approximately 20 to 40 years of age were frequently observed to be skipped by fires. Conversely, the B.C. Ministry of Forests has also developed guidance for fire management stocking standards aimed at "reducing the likelihood of crown fire and fast-moving high intensity ground fire" by establishing lower stocking levels than might normally be required in some ecosystems (for example, in the IDFdk moving from a target of 1000 stems/ha to 400 stems/ha). This type of fire-management stocking standard, based on reduced stocking, originates in dry forests and is inconsistent with findings that increased stocking reduces the probability of burning in stands aged 10 to 40 years. Stands with reduced density wildfire stocking standards have not been tested against actual wildfires in the Bulkley Morice area. Defining effective stocking standards for these ecosystems is a critical knowledge gap.

Combining Treatments

The most effective fuel management strategies often involve a combination of thinning, burning, fuel redistribution treatments, and stocking standards. In summarizing an examination of 30 years of fuel treatment effects on wildfire severity across the Western U.S., a group of U.S. researchers found that the combination of prescribed burning and thinning was the most impactful treatment over time in reducing wildfire severity by an average of 72% (Moore 2024). Prescribed burning alone and thinning with pile burning were both effective treatments reducing fire severity by an average of 62%. Moore (2024) provides a conceptual illustration of the relative impact of combined treatments on fire severity (Figure 7.1).

In the Bulkley Morice, where fire behaviour is influenced by a combination of climate and fuels in multiple layers, these combined treatments are likely to be an effective strategy in wildfire management.

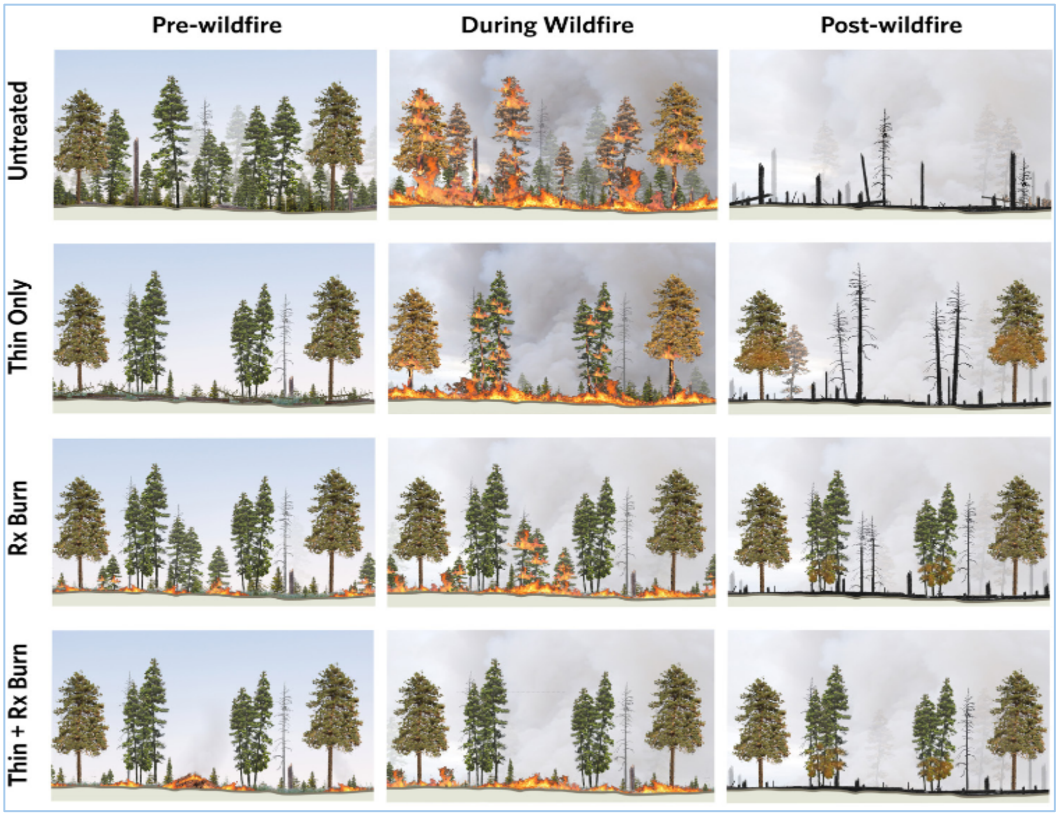


Figure 7.1. The conceptual illustration shows how different treatments can impact the severity of subsequent wildfires in the landscape. Areas that have received thinning and prescribed burn treatments fare better than areas left untreated or with only one treatment (Moore 2024).

Treatment Longevity

Recent treatments mitigate fire behaviour more effectively than older treatments, although there is some nuance, and the time required before retreatment depends on many factors. There are circumstances where some fuel treatments (e.g. thinning) may initially increase surface fuels and, over time, and as these degrade, the treatment might become more effective as long as ingrowth hasn't increased too much. Fuel treatments are not a single event, but rather an ongoing activity required to maintain their effectiveness (Utzig 2019). Jain et al. (2021), in a synthesis of 127 wildfire studies, mainly in the western U.S., noted that, for fuel break maintenance:

- Treatments are effective for a finite length of time
- The length of time needed before retreatment depends on the environment, fuels, and the rate of vegetation recovery.
- More recent treatments are more effective at mitigating fire behaviour and reducing fire severity.
- Treated areas with high surface fuels had more severe fire effects on soil and vegetation.

One way to think about treatment longevity is in terms of successional curves – the potential for an individual treatment to positively affect fire behaviour diminishes over time, and, given sufficient data, this can be expressed as a curve for different fuel types and fuel loading. Knowledge on the longevity of treatments in the Bulkley Morice is still evolving. Shannon Irvine (pers. comm. 2026), however, reports that BCWS has revisited all fuel treatment units in the NW Fire Centre/Skeena Region over the past few years to assess their maintenance requirements. They indicate that in the majority of the units, treatments were over 10 years old, and little or no maintenance was required at the time of assessment. As new treatments are completed in other fuel types, using different techniques, we will need to build on this knowledge and develop models of how treatment longevity changes over time across stands and landscapes.

Fuel Management Targets in the Literature

Treatment Shape, Size, and Frequency

Despite some modification of fire behaviour, there are no studies demonstrating that small-scale treatments significantly alter the spread or behaviour of a major fire (McCulloch 2020, Hayes et al. 2010). McCulloch (2020) found that small, thin, and irregular treatment areas, typical of many of the thinning fuel treatments in B.C. in the past, were less effective because wildfire would have more opportunity for spotting or to find a different path through another fuel type. Barnet et al. (2016) found that larger treatments that interacted with wildfire between 1999 and 2013 on U.S. Federal Lands were more effective at reducing fire impacts due to reduced edge effect and greater interior area. They emphasized the need to find innovative ways to treat larger areas. Other important considerations in treatment design include the treatment's relationship to values at risk, ease of maintenance, and the degree to which the treatment provides suppression personnel with effective and safe areas to operate from.

Some researchers suggest that, based on rates that fire can move in extreme fire weather conditions, 400 to 500 metres is probably a minimum target for fuel treatment width at the wildland-urban interface (Hayes et al. 2010, Safford et al. 2009). The Forest Practices Board (2023) indicated that targets for fuel break strategies vary and include narrow, right-of-way size less than 75 metres to large clearing widths (390 metres) for primary breaks.

Regarding targets for retreatment, Urza et al. (2023) indicate that the effectiveness of older treatments diminishes due to fuel regrowth and that, during periods of extreme fire weather, treatments are overwhelmed by the fire conditions. These authors suggest that the time required for retreatment depends on site productivity, plant species traits, initial fuel removal, and the potential for reburn in wildfires.

Mooney (2010) emphasizes the need for repeated treatments to maintain fuel conditions that reduce wildfire severity in Canada's boreal forests. Prichard and Kennedy (2014) found that, in productive ecosystems affected by the 2006 Tripod Complex fires, treatments may need to be repeated every 2–10 years due to flammable shrub and understory layers. Jain et al. (2021)

suggest treatments can be effective for 10-20 years, with dry forests maintaining effectiveness for 15-30 years and wetter types for about 10 years. They also note that wildfires can inhibit the spread of subsequent fires for only 6 years in dry areas, while in cooler, wetter areas, this effect can last 14-16 years.

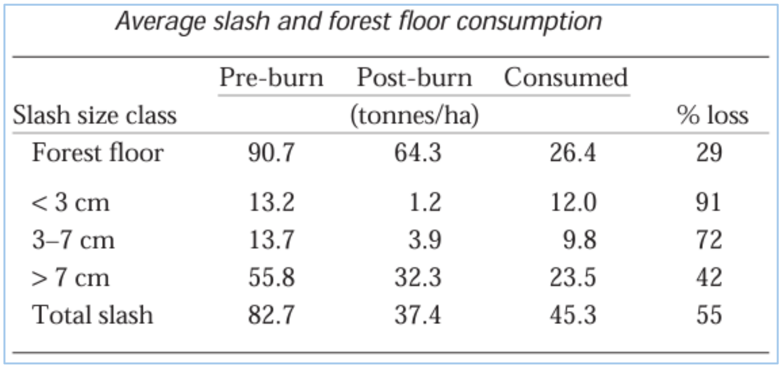
In a study of reburning after wildfires in the Western US, Buma et al. (2020) found that the likelihood of reburning decreases post-wildfire. However, this effect diminishes after 10 to 20 years, primarily due to the accumulation of fine fuel. Whiteman et al. (2024) studied Canadian boreal forests and noted a ~50% probability of fire spread in recently burned areas, suggesting that climate warming will likely increase fire spread beyond the capacity of these areas to resist. Most reviewed studies indicate that treatment effectiveness wanes within 5 to 15 years and becomes ineffective after 20 years (Utzig 2019), with limited information available for Bulkley Morice ecosystems.

In the context of establishing fire-resistant stands, after logging and abatement, there is also a question of timing and size. The question shifts from the frequency of treatment to determining the age at which young-stand resistance wanes and how much longer, beyond 40 years, the stand will remain fire-resistant. This is a knowledge gap. The effective width of these young stands is also uncertain, but it is likely a function of stand age (20 to 40+ years), slope, and crown closure, all of which have an effect on wind penetration into the stand. In recent wildfires in the Bulkley Morice, high-severity fire has not penetrated more than a few meters on many sites.

Residual Fuel Loading and Crown Spacing

Kranabetter & Macadam (1998) measured logging slash and forest-floor conditions on seven sites in Northwest B.C. They found that pre-broadcast burn slash loads varied from 48 to 109 t/ha and that fine fuels up to 7cm in diameter ranged from 11 to 57 t/ha (averaging 25 t/ha). Broadcast burning was found to reduce forest floor mass by an average of 29%, ranging from 14% to 39% across sites. On average, 55% of the total slash was consumed (Table 7.3). Most of the fine slash (<3 cm) and intermediate slash (3-7 cm) was burned (91% and 72%, respectively).

Table 7.3. Average organic matter consumption across 7 sites after low to moderate intensity broadcast burning in Northwest B.C. Source: Krannabetter & Macadam, 1998.



Average slash and forest floor consumption

Slash size class	Pre-burn	Post-burn	Consumed	% loss
		(tonnes/ha)		
Forest floor	90.7	64.3	26.4	29
< 3 cm	13.2	1.2	12.0	91
3–7 cm	13.7	3.9	9.8	72
> 7 cm	55.8	32.3	23.5	42
Total slash	82.7	37.4	45.3	55

If fine fuels less than 7 cm in diameter amounted to 27 t/ha on average, and 81% of this material was burned based on Kranabetter & Macadam (1998), that would leave fine fuel loading of 5 t/ha, not including forest floor horizons, a value which meets current recommendations. The BCWS Fuel

Management Prescription Guide indicates that fuel management treatments should meet a 5t/ha target for surface fuel loading of woody debris less than or equal to 7.0 cm.

Mooney et al. (2010) reviewed 26 fuel treatments (that did not necessarily interact with wildfire) and surveyed 43 fire experts, summarizing the range of target conditions in these treatments as follows:

- Fuel-free strips should be 10-30 m wide as an anchor for burnoffs.
- Reduce surface fuel to less than 5t/ha.
- Stem spacing of 4 to 8 m in thinning operations.
- Crown base height of 1.5 to 3.0 m.
- Crown closure should be less than 35%.
- Understory layers and ladder fuel reduction - e.g. remove 85% or 4 to 6 m spacing.
- Fuel break maintenance cycle of 5 to 10 years.
- Treatment should be about 1 kilometer from values.

Hvenegaard & MacKinnon (2020) evaluated partial harvesting as a forest fuel treatment in a mature Douglas-fir stand in B.C.'s Central Interior, in which the following practices were used:

- Removing smaller, less viable conifers, including dead and dying trees, while retaining larger conifers (over 40 cm in diameter) and all broadleaf stems.
- Pruning up to 3 m in height on all trees.
- Piling debris, followed by debris removal with forwarders, and a final cleanup using a hand-fed mulcher.

The authors of the Burns Lake case study noted that this resulted in an increase in fine woody debris by as much as 35% due to residual branches and delimbing processes (4.6 t/ha to 7.2 t/ha) and that coarse woody debris decreased by 69% (54.5 t/ha to 16.81 t/ha).

The Protecting Your Community from Wildfire Guidebook, produced by the Partners In Protection Coalition (2023), contains fuel reduction guidance for forest stands that include the removal of all understory trees, pruning lower branches of large trees to a height of 2 m and thinning the stand to reduce crown cover to < 40%, with a minimum 3 m spacing between crowns. Recommended practices also include using a two-stage approach when conducting treatments in dense stands to minimize tree loss from wind damage, with an initial biomass removal of 50% to 67%, followed by the remainder of the treatment 5–10 years later.

Case study – Burns Lake Community Forest

In a study of the feasibility of fuel reduction targets in the Burns Lake Community Forest, Brochez & Leverkus (2022) found that 17 t/ha remained following a raking treatment, 7.3 t/ha of which were fine fuels less than 7 cm in diameter. They found that less than one-third of the treated areas met the 5 t/ha surface fuel load target. They summarized the findings as follows:

- The current target of 1–5 t/ha is challenging to achieve with mechanical treatments.
- High economic and operational costs.
- Weather conditions and logistical challenges often delayed treatment (e.g. burning piles).
- Avoiding environmental impacts, such as soil degradation and CWD loss, was difficult.

The authors suggested that a target below 10 t/ha rather than 5 t/ha would be more operationally achievable. Based on their average post-treatment fine fuel loads of 7.25 (± 4.21) t/ha, which would be achievable.

The fuel treatment target required for a given management objective or desired outcome depends on several factors, including fuel type and stand structure, expected fire weather during a wildfire event, topography, values at risk, and available budget, among others. Findings in the literature for a specific set of conditions may not apply to fuel treatments at any particular site in the Bulkley Morice. An example of determining a treatment objective is shown in the text box. In this example, a pruning height of 5.5 m was required, which is not practical and could lead to unintended edge effects such as windthrow and higher wind penetration further into the stand. It is a matter of due diligence, therefore, to use tools such as the 90th percentile calculator, the prescribed fire complexity worksheet, the critical surface fire intensity worksheet, the crown fire initiation and spread model, and FuelCalcB.C. provided by B.C. Wildfire Service to evaluate driving factors, options, and the range of possible outcomes for the local set of conditions.

Fuel Treatment Targets – An Example

Expected weather: 90th percentile in Houston, B.C.

- FFMC of 92
- BUI of 103
- ISI of 9

Fuel type: C2 (mature boreal spruce)

Wildfire characteristics: continuous crown fire with a spread rate of 13m/min and intensity class of 6 (>10,000 kW/m) – cannot be suppressed with ground action

Objective: Fire intensity < 2000 kW/m

Treatment: prune to a 5.5m crown base height, and reduce fine fuels to 7.5 t/ha

Stand Level Treatment Guidance for the Bulkley Morice

This section provides preliminary guidance on potential treatments in the Bulkley Morice area. Many of these suggestions are inherently subjective, although based on the best available information and grounded in scientific principles of fire behaviour and experience in fire and forestry operations. The section should be read in conjunction with the entire report, taking into account the existing knowledge gaps and the limited empirical data on the effectiveness of mitigation treatments in this region. Fuel treatment prescriptions need a clear management objective and an understanding of the desired outcomes. Changes to contemporary thinking on desired outcomes and wildfire risk, or new scientific evidence, may yield new information or perspectives that warrant different approaches.

Firesmart B.C. and the B.C. Wildfire Service prioritizes wildfire risk-reduction treatments in the wildland-urban interface in areas where the provincial strategic threat analysis has been verified through ground-truthing. Their focus is on high-hazard areas (Shannon Irvine, Wildfire Prevention Officer – Fuels, pers. comm., 2024). Tactical wildfire risk reduction plans are being prepared for all Wildland-Urban Interface (WUI) areas, and land managers responsible for wildfire mitigation actions are required to act consistently with these plans and consider the broader fire environment.

Fuel treatments that consider climate change expectations are more likely to be robust over time. The advanced fire weather projections tool, located on the Climate Data Fire Weather site[25], indicates that, under an intermediate emissions scenario, fire season length, fire weather index, and drought code will all increase substantially during the fire season over the next 30 years.

A preliminary list of fuel management techniques that may be appropriate for some objectives and fire weather in the Bulkley Morice is provided below. It should be stressed that these treatments are examples only and must be carefully considered and strategically placed.

- Clearcutting with significant slash and pile abatement to reduce surface fuels.
- Establish a network of fuel breaks (400-500 m) just outside the WUI in strips or blocks to create a discontinuity matrix. Scale and cost will be important factors. Design and location should be consistent with POD analysis (see chapter 10).
- Establish narrower fuel breaks (50 to 100 m) anchored to fire-resistant features (colloquially known as stringing the pearls) whenever possible in high-priority areas within the WUI to reduce fire intensity, slow fire spread, create defensible space around infrastructure with reduced radiant heat, improved sight lines and lower probability of danger trees and potentially provide more time for direct suppression efforts and evacuations. This type of treatment will be most effective when weather conditions are below the 90th percentile in some fuel types.
- Thinning mature stands to a crown closure of about 35%, leaving space between crowns (as opposed to spacing between tree boles) of at least 3m in combination with ladder fuel and debris removal (where ecologically appropriate) - must be weighed against possible increase in stand drying and wind penetration.

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[25] https://climatedata.ca/fire-weather/

- Clearcutting dead pine stands to remove dead standing trees and prevent high future surface fuel loading, leaving sufficient stems of larger diameter (e.g. 30 stems/ha of large diameter trees to meet habitat objectives) but avoiding leaving danger trees.
- Avoid harvesting or felling broadleaf trees in stands where the broadleaf component is greater than 30%.
- Avoiding a reduction in crown closure in well-stocked 20 to 40-year-old conifer stands.
- Creating a fuel strata gap of 3+ m (or a lower or higher amount based on crown fire initiation analysis) by removing ladder fuels near or on residual trees after thinning.
- Reducing surface fuel loads to 10t/ha by physically removing or burning materials or other such numbers that correspond to a critical surface fire intensity of 2000kW/m.
- Use mastication strategically when debris removal from the site cannot be accomplished otherwise. Ensure breaks in horizontal distribution, depth does not exceed a maximum average depth of 7.5 cm, and materials are not dispersed within 100 meters of residential structures or critical infrastructure.
- Prescribed fire or cultural burning.
- During stand establishment phases, planting an ecologically suitable mix of trees at a stocking standard of 1600 to 2000 stems/ha.
- Fuel retreatments at 5 to 10 years (moist sites) or 15 years (dry sites) based on a field assessment at earlier dates.

Preliminary Strategies for Developing Treatment Prescriptions

Considering fuel management principles described in preceding sections, evidence from past practices, and the potential treatments noted above, preliminary strategies for the most common treatment types are summarized in the tables below. These targets should be viewed as a starting point for experimentation rather than rigid rules. The estimates of efficacy and uncertainty in the tables are subjective classifications that depend on numerous site-specific factors and should be considered relative rather than absolute.

Treatment Type – Thinning, Pruning and Pile Burning

Stand Type/Conditions:

The most likely candidates are mature or near-mature live stands, generally greater than 60 years old.

Table 7.4. Objectives, expected efficacy, and treatment targets for thinning treatments.

Treatment Objective:	Reduce Spread Rate	Prevent Continuous Crown Fire	Reduce Fire Intensity	Reduce Spotting	Reduce Fuel Drying	Support Suppression
Mechanism:	Disrupt surface continuity	Remove ladder fuels and reduce critical surface fire intensity	Reduce surface fuel load and canopy bulk density (CBD)	Reduce surface accumulations and large torch-prone trees	Retain a closed canopy	Improve access, reduce surface fuel and fire intensity
Efficacy:	Low-Mod	High	Mod-High**	Mod	Low	Mod
Uncertainty:	Mod	Low-Mod	Mod	Mod	Mod	Low-Mod
Target Levels:	<2m/min*	No ladder fuels, 3-8m crown spacing	<10t/ha surface, <0.1kg/m^3 CBD	<3 piles/ha, no torch trees	Unknown	Not quantified

Colour coding: green = favourable, yellow = reasonable, orange and red = unfavourable.

*To enable suppression crews to take direct action in most fuel types and fire weather. Steep slopes can accelerate the rate of spread, making even lower rates necessary.

** The primary benefit of thinning is to reduce crown fuel rather than surface fuel. Thinning to reduce crown fuel has high efficacy, in terms of crown fire spread, but surface fuel reduction may be less effective in leading to higher intensity and spread rate. Efficacy assumes fire weather at the 90th percentile. In more extreme fire weather conditions, efficacy will be lower.

Discussion:

Thinning treatments to produce a shaded fuel break are among the most commonly employed treatments, and one of the most diverse in terms of implementation. Thinning can include several components such as removal of merchantable and non-merchantable live and dead trees; pruning; mastication; raking, piling and pile burning; understory burning; and removal of unmerchantable surface fuels from the site (for utilization or disposal). The option of mastication is discussed separately below.

The ratings in the table above assume thinning, pruning, raking and pile burning. Thinning alone with merchantable stem removal has rarely been shown to be successful. One of the most important features of this type of treatment is the size of the treatment. Larger treatments (greater than 300 m in width, for example) could meet most fire management objectives but need to be considered alongside of other objectives as well. In terms of the space between trees, on moist sites, larger spaces may create more opportunity for shrub development, which in some cases, and some seasons, may provide a more shaded, moister fuel environment. This needs to be balanced with a potential increase in wind penetration.

The primary function of pruning is to remove ladder fuels; however, it is a lower priority if the stand is sufficiently thin and trees prone to torching (see below) have already been removed. If raking and piling is undertaken, the piles should be burned later in the year. Piles should be constructed beyond the drip line of tree crowns. A few piles could be left unburned for habitat (volume of each <5 m^3 following the Chief Forester's 2023 Best Management Practices for Pile Burning), and about six pieces of CWD that are > 20 cm diameter and 10m long per hectare (15 to 20 in NDT4 areas) should also be left to meet biodiversity objectives. Trees prone to torching are generally those with a low crown base height, high canopy bulk density, flaky and resinous bark, drought stress (resulting in low foliar moisture content), and those with large accumulations of needles and other fines at their base.

Treatment Type – Mastication

Stand Type/Conditions:

The most likely candidates are mature or near-mature live stands in which thinning treatments have been undertaken, and it is too expensive or difficult to use larger machinery to rake, pile, and burn.

Table 7.5. Objectives, expected efficacy, and treatment targets for mastication treatments.

Treatment Objective:	Reduce Spread Rate	Prevent Continuous Crown Fire	Reduce Fire Intensity	Reduce Spotting	Reduce Fuel Drying	Support Suppression
Mechanism:	Alter fuel structure, disrupt continuity	Reduce critical surface fire intensity	Reduce surface fuel load	Reduce surface accumulations	Retain a closed canopy	Improve access, reduce surface fuel and fire intensity
Efficacy:	Mod-High	Mod	Low - Mod	Mod	Mod	Low-Mod
Uncertainty:	High	Mod-High	Mod	Low	Mod-High	Mod-High
Target Levels:	<2m/min*	<7.5cm chip bed depth	<10t/ha	<3 piles	Unknown	Not quantified

Colour coding: green = favourable, yellow = reasonable, orange and red = unfavourable.

*To enable suppression crews and give ground forces time to take direct action in most fuel types and fire weather conditions to construct fire lines and perform direct suppression. Steep slopes can accelerate the rate of spread, making even lower rates necessary.

Discussion:

As with thinning treatments, several methods can be used to implement this treatment, including dispersing chips or mulch, removing them from the site for disposal or reuse, burning them, or burying them. There has also been experimentation in the U.S. with inoculating chip beds with fungi to accelerate decomposition (Ravage and Czaplicki 2023), a process known as cold fire. The ratings in the table above assume chips are left on site. The maximum average depth of chipped material left on site should be <7.5 cm. Masticated material should be dispersed with breaks in the horizontal continuity and kept away from remaining tree stems if burning is planned. Note that mastication can increase fine fuel loads and it may take some time before sufficient chip degradation has occurred to achieve a reduction in surface fuel intensity.

There is uncertainty regarding unintended ecological consequences that are not addressed here.

Treatment Type – Broadcast Burning

<u>Stand Type/Conditions:</u>

The most likely candidates are recent clearcuts, although opportunities for under-burning exist in thinned areas and older natural stands. This treatment type does not include pile burning as described under Thinning or as required for hazard abatement.

Table 7.6. Objectives, expected efficacy, and treatment targets for broadcast burning treatments.

Treatment Objective:	Reduce Spread Rate	Prevent Continuous Crown Fire	Reduce Fire Intensity	Reduce Spotting	Reduce Fuel Drying	Support Suppression
Mechanism:	Reduce fine fuel load	Reduce critical surface fire intensity	Reduce fine surface fuel load	Reduce surface accumulations	Retain a closed canopy	Provide a control line
Efficacy:	Low-Mod	n/a - High	Mod-High	Mod-High	n/a	Low-Mod
Uncertainty:	Low	Mod	Low	Low	n/a	Low
Target Levels:	<2m/min*	< 2000 kW/m	<10t/ha	<3 piles	n/a	Not quantified

Colour coding: green = favourable, yellow = reasonable, orange and red = unfavourable.

*To enable suppression crews and give ground forces time to take direct action in most fuel types and fire weather conditions to construct fire lines and perform direct suppression. Steep slopes can accelerate the rate of spread, making even lower rates necessary.

<u>Discussion:</u>

Broadcast burning requires significant planning and preparation, including notifications and information sharing, favourable fire weather, such as a good venting index, and skilled crews. There is also a considerable risk associated with escape burns, and there is less control of outcomes than with mechanical treatments. Smoke management and carbon release are also concerns, and the impact on ecological function needs to be considered. Conversely, it is reputed to be one of the most cost-effective options for reducing surface fuels on a per-hectare basis when larger areas are treated. In a mature stand, a controlled understory burn can help reduce fine fuels and avoid the critical surface fire intensity threshold at which crown fire initiation occurs. Larger treatment areas are preferred with good access and proximity to water sources. Note that the spread rate is a function of FFMC, wind speed, and buildup index (not fuel load) and while broadcast burning will reduce fine fuels, it is unlikely to change the potential spread rate.

Treatment Type – Regeneration Establishment

Stand Type/Conditions:

These stands are either recent cutblocks or well-stocked stands that are already 20 to 40 years old[26]. In the latter case, the "treatment" is to leave the stand untreated (or at least ensure that it is not thinned below about 1600 stems/ha) to help prevent wind penetration. In the case of a recent cutblock, the treatment involves establishing a stocking level, in association with a site-preparation treatment that reduces fuel loading or interrupts surface fuel continuity.

Table 7.7. Objectives, expected efficacy, and treatment targets for regeneration establishment.

Treatment Objective:	Reduce Spread Rate	Prevent Continuous Crown Fire	Reduce Fire Intensity	Reduce Spotting	Reduce Fuel Drying	Support Suppression
Mechanism:	Maintain a closed canopy	Maintain a closed canopy	Reduce surface fuel load/continuity during site preparation	Reduce surface accumulations	Retain a closed canopy	Provide a control line
Efficacy:	High	High	High	High	Mod-High	Mod
Uncertainty:	Low	Low-Mod	Low	Low	Mod	Low-Mod
Target Levels:	<1m/min*	>1600 stems/ha	<10t/ha surface,	<3 piles	>85% crwn closure	Not quantified

Colour coding: green = favourable, yellow = reasonable, orange and red = unfavourable.

*To enable suppression crews and give ground forces time to take direct action in most fuel types and fire weather conditions to construct fire lines and perform direct suppression. Steep slopes can accelerate the rate of spread, making even lower rates necessary.

Discussion:

The ratings in the table above refer to the establishment of well-stocked stands intended to reduce the potential for crown fires when the stand reaches full crown closure. Thinning treatments in 20- to 40-year-old stands should be avoided because they open the stand, allowing better wind penetration, and because the felled trees increase the fine-fuel load. When establishing a stand in a new cutblock, it is also beneficial to undertake site preparation treatments to reduce slash, such as broadcast burning, piling and burning, or altering slash continuity through disc trenching or scarification.

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[26] Note that some studies have found resistance in younger stands (10 years) and it is possible resistance extends past age 40.

Treatment Type – Bladed Fire Guard

Stand Type/Conditions:

Considering other values and objectives for the area, a bladed fire guard can be constructed in any stand type, provided topography or soil types do not prevent the use of heavy machinery. This type of treatment can be used at the stand level but is more typically used on a broader scale.

Table 7.8. Objectives, expected efficacy, and treatment targets for bladed fire guards.

Treatment Objective:	Reduce Spread Rate	Prevent Continuous Crown Fire	Reduce Fire Intensity	Reduce Spotting	Reduce Fuel Drying	Support Suppression
Mechanism:	Remove all fuels	Remove all fuels	Remove all fuels	Remove all fuels	n/a	Provide a control line, staging area, safe zone
Efficacy:	Low-High	High	High	High	n/a	Mod - High
Uncertainty:	Low - Mod	Low	Low	Low	n/a	Low
Target Levels:	>30m wide	No fuel	No fuel	No Fuel	n/a	Not quantified

Colour coding: green = favourable, yellow = reasonable, orange and red = unfavourable.

Discussion:

A fire guard is a type of control line specifically designed to act as a barrier to wildfire. It is typically a cleared strip of land where all flammable vegetation and materials have been removed down to mineral soil. Some fire guards are reseeded with replacement vegetation, such as grasses, to control fuel levels and, in some cases, to utilize for grazing or hay production. This, of course, can increase the fire rate of spread when the grass is cured. The ratings in the table above assume a fuel-free fire guard. A primary benefit is creating defensible space by providing safe anchor points for firefighting operations such as backburning or aerial operations (bucketing and retardant lines). There are also negative consequences to habitat and timber supply. Fire guards often fail to prevent fire spread, primarily because of ember transport across them. If a fire guard is intended to be a permanent fuel break, it must be much wider than if it is only used during suppression operations, and it will require periodic maintenance. The economic and practical difficulty of constructing and maintaining large fire guards must be weighed against the fire management benefits, given that they can still be breached by long-distance ember cast. If the guard is only meant to support suppression response, the width could be minimized.

Knowledge Gaps

The B.C. government has established an important framework for developing effective fuel management strategies and practices, and the B.C. Wildfire Service has developed numerous useful tools and templates. There is also a substantial body of research and practical experience within the Bulkley Morice area. Despite this information, several critical knowledge gaps remain that need to be addressed to improve wildfire management in the area. Addressing these gaps through research, adaptive management, and practical application can be achieved through a combination of long-term and short-term work and requires substantial funding support. The following section outlines some knowledge gaps exposed by the synthesis of knowledge in this chapter.

Fire Behaviour

Fuel Types

Fuel management starts with the science that underpins fuel treatment decisions. Actual fire behaviour (intensity, spread rate, and crown involvement) is not always consistent with predicted fire behaviour in the Canadian Forest Fire Danger Rating system. Understanding why this can occur is important when planning wildfire mitigation. One potential reason is that fuel types in B.C. are not all well-characterized in the Canadian Fire Behaviour Prediction system (FBP), particularly those found in the SBS biogeoclimatic zone in the Bulkley Morice.

Fuel Type Characterization

Baron et al. (2024) reported a poor match between field assessment data and provincial fuel types in interior British Columbia, with 58% of plots lacking a suitable match. This mismatch was attributed to the accuracy of forest inventory data and the limited applicability of the Canadian FBP System.

In 2018, Perrakis et al. developed algorithms for mapping fuel types in B.C. using VRI data, considering specific factors like the impact of the mountain pine beetle. While they believed this mapping would aid in fire behaviour prediction, they acknowledged its limitations. They noted an increasing interest in modelling fire behaviour based on physical attributes rather than categorical fuel types, suggesting that incorporating fire management data into the VRI database could enhance fire behavior prediction capabilities.

Stand-Level Data

Effective fuel treatment requires reliable stand-level fuel data. Pre- and post-treatment data on fuels and fire weather conditions, as well as their correlations with fire behaviour, are critical to adaptive management. FP Innovations, on behalf of the B.C. Wildfire Service and Yukon Wildland Fire Management, has developed some tools that might help ensure such information is obtained (for example, the Rapid Response Kit: Data Collection Methods For Documenting Encounters Between Wildfires and Forest Fuel Treatments (Mar. 2017), the Fuels Management Field Collection Form

(2016), and the Fire Behaviour Field Collection Form (Mar. 2016)[27]. Finding a way to capitalize on this excellent opportunity to build knowledge during a wildfire event would be beneficial. More recently (Nov. 2025), the B.C. Wildfire Service developed a Roadmap to systematically integrate fuel management assessment into BCWS operations and to provide pathways for findings to be shared broadly amongst a diverse group of end users (BCWS 2025b).

Empirical Data and Case Studies

Although there is considerable evidence on the efficacy of fuel treatments, many uncertainties remain. Some suggestions to fill these knowledge gaps include:

- Develop standardized protocols, based on treatment type, for evaluating the efficacy of fuel treatments.
- Establish monitoring plots for fuel treatments to measure pre- and post-fire conditions and ecological impacts relative to desired outcomes.
- Conduct controlled burn experiments at 90th percentile weather indices to assess fuel treatment effectiveness in high-risk or fire-resistant fuel types. Exploring fuel treatments by emulating wildfire is valuable, despite challenges such as weather conditions, costs, implementation variables, authorizations, personnel availability, and escape risks.
- Given the uncertainty regarding the effectiveness of thinning and shaded fuel breaks, specific research into the effectiveness of these treatments is a key knowledge gap. Empirical trials could test different levels of removal, measure changes in site-level moisture and wind, and compare treated areas with untreated areas and clearcuts under different fire weather conditions.
- Explore the viability of in-stand alternative fuel reduction patterns, such as clumped fuel configurations.
- Evaluate the effectiveness of mastication as a fuel treatment, including:
    - the ideal pattern and depth of masticated material,
    - flammability across different fire indices and fuel types, and
    - environmental impacts in terms of soil impacts, vegetation development, and off-site impacts like leaching.
- Explore the efficacy of broadleaf stands, particularly aspen, in favourably affecting fire behaviour (when, where, and how).
- Research on the impacts of large woody debris – exploring trade-offs between the removal and retention in terms of impacts on communities and the environment.
- Explore the efficacy of alternative fuel treatments such as cold fire (an experimental approach in which dead wood and leaf litter are inoculated with different types of fungi to decompose these materials to reduce fuel loading).

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[27] https://library.fpinnovations.ca/link/fpipub49430

Treatment Longevity

One of the most significant knowledge gaps is understanding how long treatments remain effective. While thinning, prescribed burning, and mastication can reduce wildfire risk in the short term, it is less clear how long these treatments provide benefits, especially under extreme fire weather conditions. However, quantifying fuel treatment longevity and the need for fuel break maintenance on selected sites by measuring the build-up of fuels year over year is a long-term project.

Another gap is understanding the mechanisms that make densely stocked young forests (from ages 20 to 40 years) resistant to fire, and how long those stands remain resistant beyond age 40.

Similarly, there is a need to quantify the influence of prior burn mosaics on subsequent wildfire behaviour. Information on the impact of wildfire on fuel loading can be obtained, to some extent retrospectively, by evaluating areas that have burned in the past. Still, it will be more accurate if long-term monitoring plots (such as B.C.'s permanent sample plots) are established in major fuel types (including clearcut and partial cut areas) that have recently burned in a range of severity classes. A third area of study could be the impact of repeated treatments. Understanding how fuels recover after each treatment (a fuel succession model) allows managers to adjust methods and frequency to achieve better outcomes, ensuring resources are used efficiently, and provides information on ecological impacts (such as long-term losses of forest floor materials).

Another area for further investigation is increasing understanding of which treatments remain effective under extreme fire weather (i.e. greater than the 95th percentile), the conditions that pose the greatest risk to communities and ecosystems. Related to this is a better understanding of stand conditions and indices that lead to deep-root burning and holdover fires during pile burning.

An Adaptive Approach

Stand-level treatments, such as thinning followed by broadcast burning, piling and burning, fuel mastication, or other mechanical treatments, have proven effective in other ecosystems but are largely untested in the Bulkley Morice ecosystems. Similarly, broadcast burning conducted as a stand-alone treatment also shows promise. At the landscape level, strategic fuel breaks, landscape heterogeneity, and combined treatment approaches could offer a comprehensive defence against wildfires. However, increasingly, severe weather overwhelms resistance to burning, particularly at the 95th percentile, and so fuel management treatments should not be expected to always be effective. Fuel treatment objectives and expected outcomes must be carefully developed, taking into account the limits based on fuel loading and type, site conditions, and expected fire weather.

Much of the empirical evidence on the effectiveness of fuel treatments originates in dry forests, which could have very different fire ecology and fire behaviour. Because fuel management was only undertaken in a very limited area before about 2018, there are few examples of treatments on the landscape that can serve as learning laboratories. There has been an expansion in fuel treatments since then, and those programs continue to grow. Practitioners are "learning by doing", but gaps in knowledge make it difficult to develop plans and prescriptions with confidence.

A critical approach that merits greater emphasis is for managers to be clearer about the objectives of any treatment, so that treatments can be matched to those objectives. This is particularly important for being clear about the type of fire weather that the treatments are expected to perform under. With a changing climate, extreme fire weather is becoming increasingly frequent, and this trend is expected to continue.

Even in the face of these uncertainties, a body of work can be applied today, but it must be done in a way that reflects these uncertainties. A program of designed adaptive management would embrace that uncertainty and apply operational treatments with the express goal of monitoring their performance over time.

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8.0 Forest Practices and Fuel Management

By Larry McCulloch

Introduction

Forest operations, or commercial logging, and their associated management policies, play a critical role in influencing forest fuels and wildfires. Commercial logging affects the amount and distribution of fuels on the landscape by altering fuel levels and types through timber harvesting and by creating and maintaining road access. Cutblocks can help reduce or eliminate crown fuels and may have either a positive or negative impact on surface fuel loading. Access routes provide firefighters with opportunities to conduct suppression and enable residents to evacuate the area. They can also serve as fuel breaks, control lines, and safe zones.

This chapter draws a review of relevant literature and interviews with representatives of major forest licensees operating in the Bulkley Morice area, including Canfor, West Fraser, and B.C. Timber Sales.

In this chapter, we summarize current operational practices of forest licensees and discuss their implications for wildfire management. We also explore opportunities to integrate fuel management strategies into these practices. It is important to note that this chapter does not cover suppression practices carried out by the B.C. Wildfire Service (B.C.WS) or industry. Additionally, this chapter is distinct from the section on stand-level fuel management, which focuses on treatments primarily aimed at managing fuels (which may include logging) rather than on forest practices that prioritize timber extraction.

Regulation and Policy

Fire Hazard Abatement

Forest practices are regulated under the B.C. *Forest and Range Practices Act* (FRPA) and the associated regulations, as well as the *Wildfire Act* and *Wildfire Regulation*. The legislation outlines responsibilities and obligations related to fire use, wildfire prevention, wildfire control, hazard assessment and abatement requirements, and rehabilitation. Fire hazard assessment and abatement are legally required for industrial activities such as timber harvesting. The *Wildfire Act* governs who, where and when a fire hazard is to be assessed and abated. The *Wildfire Regulation* sets timelines for assessing and abating fire hazards. In summary, a licensee must reduce the fuel hazard as necessary to ensure that it does not increase the risk of a fire starting on the site and, if a fire were to start, would not increase the fire behaviour or fire suppression associated with the fire, or as specified by a professional forester or registered forest technologist.

In 2025 the B.C. Wildfire Service released "A Guide to Fuel Hazard and Abatement in British Columbia", which includes a Defined Hazard Assessment and Abatement Strategy (DHAAS) to help inform the application of the provincial legislation. Per Shannon Irvine (a B.C.WS Wildfire Prevention Officer – Fuels, pers. comm. 2026), this new guidance allows for greater flexibility based on distance to the value at risk and other fire behaviour considerations. It is important to note that this document is a guideline rather than law, and it will ideally be used in conjunction with other fire management practice principles like those mentioned in previous sections.

In their 2019 investigation of fire hazard and abatement in the Shovel Lake Fire area, the B.C. Forest Practices Board found that the DHAAS allows significant amounts of fuel to be left on the ground. This is especially true in areas not classified as "High" or "Severe" risk (determined by proximity to communities). The Board provided an example of an allowance of 99 t/ha of fine fuels for S1 fuel type (lodgepole pine slash) on a flat (0-15%), south-facing slope. Conversely, a licensee operating near Smithers in an area with a "Severe" risk class would need to undertake abatement to achieve between 1 and 5 t/ha in the same S1 fuel type on any slope >15% on any aspect - a level that is very difficult to achieve.

Forest Harvesting Practices

Timber Harvesting and Debris Disposal

During interviews in 2025, licensees operating in the Bulkley Morice area stated that wildfire considerations are generally not explicitly incorporated in their cutblock design. However, hazard abatement is integral to logging operations. It is common practice for licensees in the Bulkley Morice area to forward whole trees to the roadside where they are limbed and topped, after which the debris is piled and burned. BC Timber Sales (BCTS) reports that in the Lakes area, 60 to 80% of the timber is processed at the stump, and stump-side processing results in larger accumulations of fine fuel on site. All licensees note that, on average, logging will result in about two debris piles per hectare of harvested area after abatement is complete.

Fuel abatement is typically accomplished through fuel removal from the site, piling and burning, chipping and/or mulching, or, in rare cases, broadcast burning. While fine fuels contribute most to rapid fire spread, it is impractical to separate fuels by size, and abatement efforts will typically reduce ground fuels, fine fuels, and coarse fuels. Raking slash into piles and burning them is the most common treatment. Some licensees have noted that they use a "feathering" technique to ensure maximum reduction adjacent to roads or block perimeters, with a gradual increase in loading in other areas, to achieve the stringent abatement thresholds in "High" and "Severe" risk class areas.

Broadcast burning was widely used in the past to manage dispersed fuels. However, due to changes in liability and growing community concerns about the health effects of smoke, its use significantly declined after the mid-1990s. Although pile burning continues to be favoured by industrial users, public acceptance of burning has decreased. In response, the Ministry of Forests has implemented policies to reduce pile burning to minimize carbon emissions, enhance fibre utilization, and decrease waste production (MoF 2023a). Burning operations to abate forest fuels after logging must comply with the *Wildfire Act* and its regulations and adhere to the conditions outlined in the *Open Burning Smoke Control Regulation* (OBSCR) under the *Environmental Management Act*. However, Resource Management Open Fire (RMOF) activities (for example, silviculture treatment, forest health management, wildlife habitat enhancement, fire hazard abatement, ecological restoration, range improvement, or purposes identified by Indigenous Peoples) are exempt from the venting/ventilation requirements of OBSCR, although an approved burn plan and burn registration number are required (see section 23 of the Wildfire Regulation).

Following the fires of 2018, 2023, and 2024, there is a growing interest in hazard mitigation. West Fraser has recently undertaken prescribed burning on several blocks, for example. There have also been instances where BCTS, Canfor, and West Fraser have conducted raking and disposal of dispersed accumulations beyond what is required for hazard abatement, both to reduce hazards and improve planting conditions. In most cases, piling and burning slash is the preferred method due to its ease of implementation, cost, and efficacy. However, the lack of suitable weather, an appropriate venting index, and timing issues with waste assessments often make implementation challenging.

Licensees also point out that legislated measures, such as wildlife tree retention, riparian management, and old-growth management, can conflict with wildfire management objectives by creating wicks or bridges that allow wildfires to spread. Without specific guidance on when and where wildfire management should be prioritized over other management considerations, there is some uncertainty on how to implement fire management strategies. A solution when there are areas with conflicting objectives may involve managing the timing and placement of fuel treatments based on updated mapping of values and fire hazard, to mitigate conflicts. There may be an opportunity within the Forest Landscape Planning (FLP) process to enable Wildfire Risk Reduction (WRR) while maintaining conditions favourable to other overlapping values.

The Forest Practices Board conducted a special investigation to assess how regulated forestry activities impact wildfire risk reduction in the WUI. The investigation revealed a lack of compliance, indicating that these regulated forestry practices are not fully achieving their potential to reduce wildfire risk in the interface. The Board's report also raised concerns about the effectiveness of regulated practices in reducing wildfire hazards, implying that this issue requires further investigation (Forest Practices Board 2025).

Forest Practices Board report finds fire hazard abatement shows both progress and challenges.

In the Board's 2025 Special Investigation, it was found that many licensees effectively reduce risks through methods such as chipping, piling, burning debris, and managing access in high-risk areas. However, barriers, including lengthy timelines, failure to follow prescribed measures, and regulatory restrictions, allow hazardous fuel loads to persist.

The Board found that sixteen percent of sampled cutblocks failed to meet legal requirements, and 21 percent needed further work within the allowed timeframe. In addition, regulatory compliance can be met without meaningfully reducing wildfire hazards, as long as industrial activities do not intensify fire behaviour or complicate suppression efforts. Smoke control regulations and abatement costs are major obstacles. Addressing these issues and providing economic incentives could improve wildfire mitigation efforts. (Forest Practices Board 2025)

Utilization

In some cases, markets exist for value-added activities where debris is piled and processed on-site for bioenergy, pulp, or biochar. To date, commercial utilization has had very limited uptake and usually occurs in the immediate vicinity of communities with lower transport costs. The government has also explored policies to encourage the utilization of residual fibre through either funding support or increased waste penalties.

Roads

Resource roads can play a crucial role in a wildfire context, particularly by supporting suppression efforts by providing access for control lines, anchor points, and water acquisition. Moreover, at a landscape level, roads could be managed to maintain fuel breaks in strategically located areas (see Chapter 10: Landscape Fuel Management).

While current practices often leave road development, location, construction, and maintenance to licensees, regional tactical planning or the Forest Landscape Planning process could better inform road development and maintenance, with wildfire objectives. Discussions with licensees in the area, however, indicate that, to date, the use of main roads as fuel breaks has not been a strategic consideration, and they feel that the government must lead such initiatives.

Fibre Utilization Policy in B.C.[29]

The B.C. government implemented a Residual Fibre Utilization Policy in 2022 to increase the recovery and use of wood fibre left behind after logging, which included Coast Fibre Recovery Zones where triple stumpage (or $2.00/m3, whichever was greater) was applied to avoidable waste left on harvest blocks (Ministry of Forests 2022).

Other programs, such as the $30 million Forest Enhancement Society of BC (FESBC) 2025-27 Fibre Utilization Funding Program, attempt to incentivize increased utilization of trees damaged by recent wildfires and waste left over from harvest that would otherwise be burned in slash piles (FESBC 2025). In April 2025, the Province announced an additional $19 million in funding for 64 projects, including 31 led by First Nations, across British Columbia to use residual material to support mills and energy producers instead of burning it in slash piles.

At the stand level, designing cutblocks with narrow strips along roads to meet visual quality objectives may diminish the effectiveness of these roads as fuel breaks. These visual barriers could act as wicks, increasing the risk of candling and spotting, which may reduce the effectiveness of suppression efforts. Conversely, there may be some benefit in terms of reducing wind levels within a cutblock.

Silviculture Practices

Reforestation Stocking Standards

Licensees are required under FRPA, section 29, to establish free-growing stands that conform to approved standards. These standards dictate the selection of species and stocking levels. Most stocking standards have been developed with timber as the primary objective. The Ministry of Forests has also developed a guidance document to assist professionals in creating regional stocking standards with a focus on wildfire management (Fire Management Stocking Standards,

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[28] https://archive.news.gov.B.C..ca/releases/news_releases_2024-2028/2025FOR0017-000370.pdf

2016). These standards stress reduced stocking levels based on the principle that widely spaced trees can reduce canopy bulk density and crown fuel continuity.

It is uncertain whether reduced stocking will result in a reduction in fire spread rate in all forest types. Relative to conventional stand establishment, it may allow for greater wind penetration and a potential increase in shrubs and ladder fuels that might establish in a more open stand. According to North et al. (2019), as cited in Clason et al. (2024) and Thompson et al. (2011), plantations dominated by open microclimates are subject to strong winds, high temperatures, and greater insolation and can contain abundant flammable understory vegetation (Weatherspoon & Skinner 1995). Although reduced stocking may lower the likelihood of crown fire in mature stands if ingress is minimal, open-stand conditions with full crowns and lower levels of self-pruning could also result in easier crown fire initiation.

Plantation density

Researchers have found that well stocked 20- to 40-year-old plantations can be resistant to wildfire and act as an effective barrier because of a reduction in wind penetration into the stand and/or because the surface fuel level, composition, and arrangement after site preparation and decomposition of fines does not carry fire well (Kuntzemann et al. (in prep, 2025), Clason et al. 2024, Jette et al. 2024, McCulloch 2020, Utzig 2019, Pritchard et al.

Regional fire management stocking standards have not yet been created for the Bulkley Morice area. However, some licensees, such as B.C. Timber Sales and the Wetzin'kwa Community Forest Corporation have developed fire stocking standards with reduced stocking within the WUI (BCTS 2024, Wetzin'kwa Community Forest Corporation 2024). This type of fire management stocking standard remains untested against actual wildfire in the Bulkley Morice area.

Species Selection

In the Bulkley Morice area, the current practice is to reforest harvested areas with lodgepole pine, hybrid spruce, subalpine fir, and, more recently, minor components of Douglas-fir and western larch, at approximately 1200 to 2000 well-spaced stems/ha. None of the commonly planted species in the Bulkley Morice area are particularly fire-resistant. While Douglas-fir and western larch are more resistant to fire damage, they do not necessarily reduce fire behaviour. Properties that make trees less prone to damage from fire include things like increased rooting depth, thicker bark, self-pruning branching habit, open canopies with lower canopy bulk density, and lower resinous chemical compounds (Ministry of Forests 2016).

(Ministry of Forests 2016). Nesbit et al. (2023) undertook a review of the influence of aspen on fire occurrence, behaviour and severity. They found that "the presence of aspen reduces fire occurrence, fire behaviour, and fire severity, but this effect is dependent on many factors, including the percentage of aspen vs conifers in the overstory, load and type of understory fuels, weather, and season." They concluded, "the claim that aspen stands are firebreak or 'asbestos' forests is too general, and more specificity on site and stand characteristics, and their relative influences on fire, is needed."

Recent forest health issues, such as the sinuating leaf miner, cankers, and drought, have led to the death of many aspen trees. This decline has resulted in some stands becoming less resilient and potentially more susceptible to fire. Table 8.1 summarizes the relative resistance to fire damage of mature tree species that are being established in the Bulkley Morice area.

Table 8.1. Tree Species Resistance to Wildfire Damage. Some mature coniferous and broadleaf trees species that are being used in the Bulkley Morice area and their fire resistance (adapted from the Ministry of Forests, 2016)

	Fire Resistance			
	High	Moderate	Moderate-Low	Low
Coniferous	Western larch Ponderosa pine Douglas-fir Whitebark pine	Lodgepole pine	Engelmann spruce White spruce	Amabilis Fir Subalpine fir Black spruce
Broadleaf	Black Cottonwood		Trembling Aspen Paper Birch	

Other Silviculture Practices

Other silviculture practices in the Bulkley Morice might include site preparation, brushing, and spacing activities. While these activities are not explicitly used for wildfire risk reduction, they can have a secondary effect by creating discontinuities in surface fuels left after harvest activities (FRDA 1992). Site preparation techniques, such as disc trenching, ripping, and scarification (see Chapter 7: Stand Level Fuel Management), are not as commonly practiced today as they were in the past. Disc trenching is not currently being used by either West Fraser or Canfor, and mounding is applied on less than 10% of the annually harvested area. Mounding will create some gaps in surface fuels and may act as a barrier or slow the spread rate, but the scale of the treatments is limited. West Fraser reported an interaction with wildfire in one mounded area and felt that the rate of fire spread was reduced.

Clason et al. (2024) in an analysis of factors affecting fire severity in six fires in the Bulkley Morice area, found that silviculture treatments were generally the least important predictors of wildfire severity compared to stand age, crown closure, fire weather indices, and other factors,

Brushing techniques used in the past in the Bulkley Morice region include manual, chemical, machine-operated, mechanical, and grazing methods. While chemical brushing is losing favour in most of the province due to concerns about environmental impacts, manual brushing is still used on some sites to manage competing vegetation. With the exception of grazing activities aimed at reducing vegetation, brushing generally increases surface fuel accumulations in the short term by adding dead material to the fine fuel load. All the licensees operating in the Bulkley Morice who were interviewed indicated lower levels of brushing compared to the past.

Spacing is a tool that can be used to control density, increase diameter growth, or achieve specific objectives respecting wildlife, forest health, or biodiversity (Ministry of Forests 2024b). The Ministry of Forests Spacing Guidebook (2024b) defines spacing as "the cutting of undesirable trees within a young stand to reduce competition among the residual trees for water, nutrients, and sunlight". Typically, spacing increases surface fuel loading of fine fuels, as cut trees are not usually removed from the site (Ministry of Forests 2024b), and therefore increases fire hazard in the short term (approximately 5 years). Should wildfire risk be a consideration in areas where juvenile spacing is planned, additional treatment may be required to remove fuels. No licensee reported undertaking any spacing in recent years.

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9.0 Wildfire Response

By Dr. Kira Hoffman and Brad Martin

This chapter provides a brief overview of wildfire management, including suppression, the use of managed wildfires, prescribed fire and Indigenous fire stewardship. We then discuss some of the effects of wildland fire suppression on ecosystem resilience.

Wildland Fire Management and Managed Wildfire Response

Wildland fire management refers to a coordinated, planned, and strategic approach to wildfires, focusing on containing and suppressing them, protecting lives, property, and forested areas, and mitigating long-term environmental impacts. It involves not only reacting to a fire once it has started but also preparing for and preventing fires before they occur. A **managed wildfire response plan** is a comprehensive strategy that balances the protection of human lives and property with the ecological and cultural benefits of fire. This allows fire to play its natural and cultural role in particular ecosystems. Integrating prevention, suppression, cultural and prescribed fire, and post-fire recovery can help reduce wildfire risk, promote ecosystem health, and improve overall fire resilience. Effective communication, risk assessment, and interagency coordination are key to ensuring that the plan's objectives are met safely and efficiently.

Managed wildfires are intentionally allowed to burn or are carefully controlled by fire management agencies under specific conditions to achieve specific land, community, and ecosystem management goals.

The objective is to reduce the buildup of excess vegetation (fuel) and prevent larger, more destructive wildfires in the future. Managed wildfires can also support the implementation of cultural and prescribed fire by increasing fire perimeters with intentional fire ignitions. Managed wildfires can enhance ecosystem health by mimicking natural fire processes and increasing social acceptance of fire.

Prescribed Fire and Indigenous Fire Stewardship

Prescribed fire is the planned use of controlled fire to meet a specific objective or goal, such as reducing wildfire risk, restoring habitat, and maintaining ecological integrity (see Chapter 7: Stand Level Fuel Management). **Indigenous Fire Stewardship**, one aspect of which is cultural burning, involves the intergenerational teaching of fire-related knowledge, beliefs and practices among fire-dependent cultures (Lake & Cardinal Christianson 2020).

Despite the potential benefits, the use of controlled fire is a controversial and underutilized technique for wildfire mitigation (Kolden 2019).

Agencies Involved in Wildfire Management in B.C,

B.C. Wildfire Service (BCWS): The B.C. Wildfire Service, part of the Ministry of Forests, is the primary agency for wildfire prevention, detection, and suppression in B.C. It works in collaboration with other organizations and local governments to respond to and provide support for wildfire management.

Local Governments: Local governments are responsible for deploying personnel, equipment and strategies to control and extinguish fires within their fire protection boundaries, including community evacuations. Fire departments have designated areas within and adjacent to their communities where they are the primary responder to provide structural and wildfire response. Local governments are also responsible for managing and staffing a local Emergency Operations Centre (EOC) when required.

First Nations Emergency Services Society: The First Nations Emergency Services Society of B.C. (FNESS) supports First Nations communities before, during, and after emergencies. FNESS focuses on emergency management, fire services, and forest fuel management to build safer and more resilient communities. They provide training, resources, and support to help communities prepare for, respond to, and recover from various emergencies.

Emergency Management B.C. (EMBC): Provides coordination and support to local governments and communities when life, property and/or critical assets are threatened by or have encountered a wildfire. EMBC works closely with BCWS. They are responsible for managing and staffing the Provincial Regional Emergency Operations Centre (PREOC)

Canadian Interagency Forest Fire Centre (CIFFC): A national agency that facilitates the coordination of resources and support between provinces.

Key Effects of Fire Suppression on Ecosystem Resilience

Many ecosystems, particularly those in fire-adapted landscapes, have evolved with fire as both a natural and cultural process. Fire is integral to maintaining the structure and function of these ecosystems, promoting biodiversity, and cycling nutrients (see Chapter 3: Fire Ecology and Chapter 5: Fire Effects).

When fire is suppressed, the absence of low, moderate, and high-severity fire effects can disrupt fire regimes, leading to increased fuel loading and an abundance of dry and dead material. When a fire does eventually occur, the accumulation of fuel can lead to more intense and impactful wildfires. In particular, high-severity, stand-replacing fires can be destructive to ecosystems that were once maintained with the routine application of low-severity fire. Impacts can include soil damage, changes to hydrological systems, and lasting effects on wildlife habitats.

Ecosystem, plant and animal response strategies to wildfire are complex. Fire suppression can lead to the decline or loss of fire-adapted and fire-dependent plant and animal species, reducing pyrodiversity and ultimately biodiversity. (see Chapter 5: Fire Effects for a more comprehensive discussion).

Fire suppression can also alter vegetation composition at decadal intervals, allowing certain ecosystem types (e.g., conifer leading forests) to become more dominant, often at the expense of more open parklands, meadows, and grasslands with annual species such as grasses. Over time, this can alter the ecosystem's structure and function, making the landscape less resilient to other disturbances, such as drought, disease, or the introduction of invasive species. Fire also plays a crucial role in nutrient cycling. By reducing fire frequency, nutrient cycling slows down, which can potentially lead to soil degradation and a decrease in soil richness. This can limit the ability of ecosystems to regenerate and thrive in the face of stressors such as climate change.

Pyrodiversity[29]

Pyrodiversity refers to the variety of fire regimes as described by the patterns of fire behaviour, frequency, intensity, and seasonality across a landscape or region. Just as biodiversity refers to the variety of life forms in an ecosystem, pyrodiversity examines the different types of fire dynamics that shape and maintain ecosystems.

Fire suppression can also affect hydrological processes. In recent years, high-severity wildfire events have created hydrophobic soils that are less effective at regulating water flows, leading to an increased risk of flooding and water quality degradation. This can lead to compounding disasters with numerous long-term impacts on ecosystems, communities, and infrastructure.

Fire suppression can also create feedback loops, where ecosystems become less resilient to fire over time, requiring more intensive and costly suppression efforts in the future. While fire suppression is often seen as necessary for protecting human interests, its long-term effects on ecosystem resilience can be profound. By disrupting natural fire cycles, increasing fuel loads, and altering vegetation and species dynamics, fire suppression can reduce an ecosystem's ability to recover from disturbance and adapt to changing environmental conditions. As such, a more balanced approach that integrates natural, cultural and prescribed fire alongside fire suppression efforts is increasingly seen as essential for promoting ecosystem health and resilience.

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[29] Zachary L. Steel, Brandon M. Collins, David B. Sapsis, Scott L. Stephens; Quantifying pyrodiversity and its drivers. Proc Biol Sci 1 April 2021; 288 (1948): 20203202. https://doi.org/10.1098/rspb.2020.3202

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10.0 Landscape Fire Management

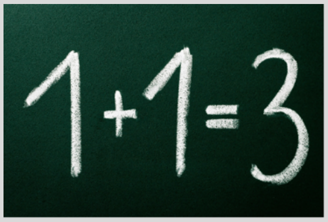
By Larry McCulloch

Introduction

Landscape-level treatments can include any of the stand-level strategies discussed in the stand-level fuel treatment chapter, applied in a planned, strategic manner over larger areas, such as blocks or strips of land, to reduce the amount, type, or continuity of fuel. These treatments may involve mechanical methods, prescribed burns, or managed wildfires. They can also encompass timber harvesting, silvicultural practices, and other land uses such as agricultural activities and right-of-ways. When applied at the landscape level, the impact of these treatments on fire extent, rate of spread, and severity is expected to be noticeable beyond the treatment areas (Jain T. in USDA 2023a). In landscape-level treatments, there is greater focus on scale, design, and interconnections.

The landscape effect

With landscape treatments, the objective is to mitigate wildfire behaviour beyond the treatment footprint.



A key concept widely used in landscape fire management is that of fuel breaks. There is considerable variation in terminology used to describe fuel breaks, including shaded fuel breaks, primary fuel breaks, and potential control lines.

What is a fuel break?

In British Columbia, a fuel break is defined under the *Wildfire Regulation* as a barrier or a change in fuel type or condition, or a strip of land that has been modified or cleared to prevent fire spread.

The B.C. Wildfire Service (BCWS) defines a fuel break as a linear feature placed appropriately on the landscape to mitigate wildfire risk to a value(s) that will be at least 1 km in length if feasible. All fuel breaks must begin and end at an anchor point[1] (B.C. Wildfire Service, 2024a).

The B.C. Forest Practices Board describes fuel breaks as part of landscape fire management strategies, but they are not considered a stand-alone strategy. Fuel break designs often link to existing natural barriers, such as lakes and wetlands, rock outcrops, or alpine areas, or human-made barriers, such as agricultural clearings or rights-of-way. These create a network of low fuel that is anchored, accessible and defendable. Fuel breaks range in width and level of vegetation removal, from cleared primary breaks to shaded fuel breaks with wider inter-crown spacing, reduced surface and ladder fuels. Access roads are necessary for the design and maintenance of tactical fuel breaks and should be

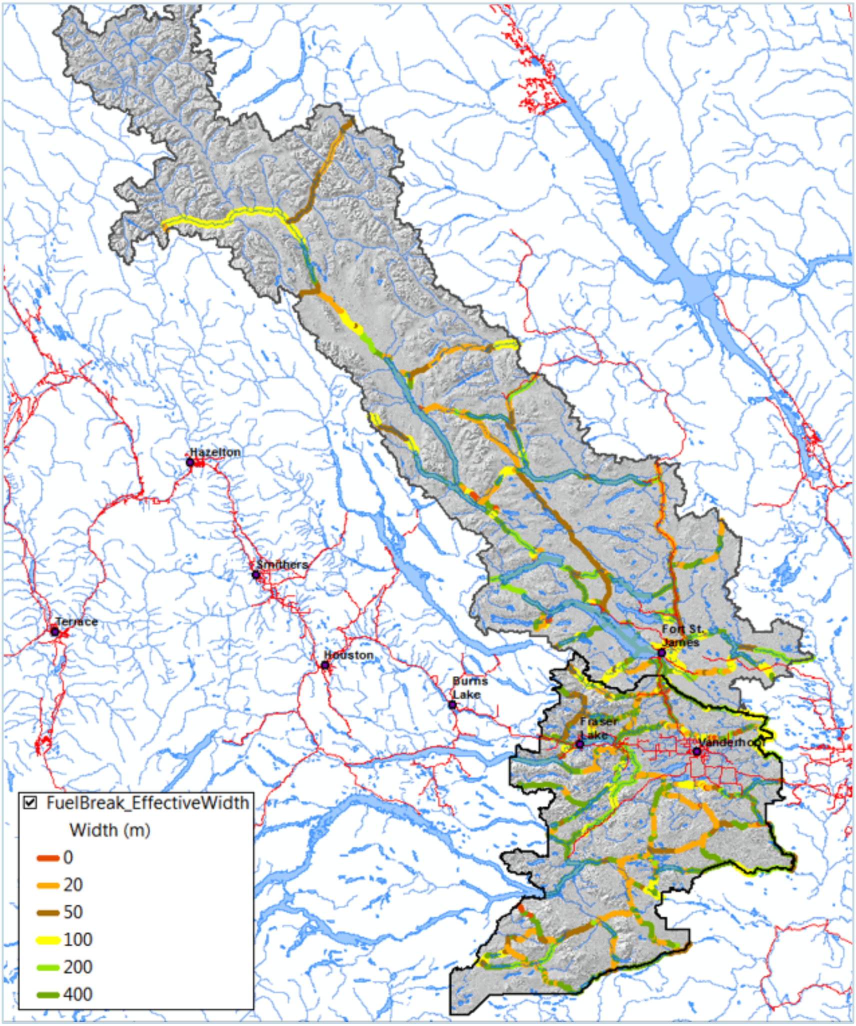


Figure 10.1. An example of proposed fuel breaks for the VanJam zone colour coded by current effective width.

considered in forest planning. Tactical fuel breaks can be used to impede the spread of fire and support operations, such as planned ignitions (Forest Practices Board 2023).

This chapter summarizes how to manage fires in landscapes effectively. It discusses strategies for designing fuel treatments in the landscape. It provides examples of what to include when making fuel breaks in the Bulkley Morice area and highlights areas where more knowledge is needed. Additionally, it covers how fuel breaks and specific treatments in nearby areas can create diverse habitats and reduce wildfire intensity in the landscape.

Does Landscape Fire Management Make a Difference?

When fuel breaks are strategically placed and effectively implemented, various case studies have shown that as wildfires enter these treated areas—regardless of their initial intensity—the fire intensity decreases. This reduction results in fewer spot fires, which are less likely to spread far from the main blaze. Additionally, while extreme fire weather may lead to greater wildfire extent, it does not necessarily reduce the effectiveness of treatments compared to untreated areas (USDA 2023b). Graham et al. (2004) suggest that a landscape approach is more likely to significantly impact fire spread, intensity, perimeter size, and suppression capability than treating individual stands in isolation. However, several researchers caution that fuel breaks alone are less effective than when they are combined with suppressive actions. Fuel breaks may fail under extreme conditions (Hersey 2022, Reid 2010, Mooney 2010).

In the Bulkley Morice, the application of landscape fire management is limited, as is its interaction with wildfire, which limits the availability of empirical data on treatment effectiveness.

Scientists at the Rocky Mountain Research Station (USDA, 2023a) state that a shift in perspective from stand-level thinking to landscape thinking is required. They summarize the broad considerations as follows:

Reduced Fire Behaviour: Well-planned and maintained fuel treatments can reduce the intensity and spread of wildfires, even outside the treatment areas. This includes lowering fire severity and making suppression efforts more manageable, which increases safety for firefighters.

Spatial Considerations: The effectiveness of fuel treatments depends on their extent, placement, and timing. Treatments across large areas that account for multiple fuel strata (such as crown, ladder, and surface fuels) are more effective in reducing wildfire severity.

Challenges in Maintenance and Adaptation: Maintaining the effectiveness of treatments requires periodic re-evaluation and retreatment, especially as the landscape changes. Treatments are less effective during extreme fire weather, emphasizing the need for adaptable and ongoing strategies.

Optimization of Resources: Given the inability to treat all forests at risk from wildfire, prioritization is essential. Tools for optimizing the placement of treatments based on fire risk can enhance overall landscape resilience to fire.

Jain et al. (2021) undertook a review of fuel treatment effects reported in simulation modelling, empirical analysis, and case studies over 30 years in the Western U.S. They concluded that *"There is overwhelming evidence that reducing tree density and returning low severity fire to dry mixed conifer forests reduces the severity of subsequent wildfires*" (reported in Moore 2024). The empirical studies, although limited in scope, provided evidence that fuel treatments were effective in reducing the rate of spread, progression, extent, or severity of actual wildfires, both within and outside treated areas. Their findings indicate that:

- Simulation studies showed that expansive treatment areas can reduce wildfire impacts. Studies have pointed to a threshold of approximately 30% of the landscape, beyond which further treatments yield diminishing returns.
- Fire suppression activities were critical for a fuel break to be effective, as less than 1% of wildfires are stopped by a fire break alone.

- Fuel treatments often reduce the negative outcomes of wildfires and sometimes promote beneficial ones.
- Effectiveness was influenced by weather and declined over time, highlighting the need for maintenance treatments.
- Treatments must address multiple fuel layers—canopy, ladder, and surface—to effectively reduce fire severity and spread.
- Treatments created fire suppression opportunities by reducing the rate of fire spread and creating anchor points that facilitated the construction of fire breaks, structure protection, and spot fire suppression.

Hersey (2022), Finney (2006) and McCulloch (2014) also note that landscape fuel breaks require active suppression for success.

Treatment Efficacy and Fire Weather

Treatment efficacy is not binary, effective or not effective; it scales with fire weather and spatial arrangement. Treatments designed to function up to the 90th percentile of fire weather can deliver significant benefits at the landscape scale. Several case studies have demonstrated that while treatments may not prevent the spread of large fires under extreme conditions, fuel breaks can still limit ember cast and the spread rate, thereby enhancing containment potential (USDA 2023b, McCulloch 2019).

Ott et al. (2023) conducted a systematic review of 86 simulation studies focused on the effectiveness of fuel treatment at the landscape level across North America. These studies compared various treatment scenarios that differed in terms of extent, placement, size, prescription, and timing. The review found that 92% of the treatment scenarios resulted in fewer fires or reduced fire impacts on the landscape compared to the control group. Key factors influencing the outcomes included the extent of treatment (the total area treated), the size of individual treatments, their placement, the type of treatment (with a combination of mechanical methods and prescribed fire being the most effective), and timing (where repeated treatments were found to be the most beneficial). The study consistently highlighted the importance of optimal treatment locations and sufficient treatment extent as influential factors.

Landscape Level Principles

The fundamental biophysical factors to consider in designing landscape-level fuel management strategies include: fire weather limitations, landscape heterogeneity, the extent and size of fuel breaks, placement, prior wildfire history, and coordinated interventions. Each topic is addressed below.

1. Fire Weather Limitations

At the landscape scale, fire weather emerges as a dominant force shaping the effectiveness and limitations of fuel treatments, particularly in the predominantly climate-limited firescape of the

Bulkley Morice. Landscape fire management must account for how fire weather drives fire spread across heterogeneous terrain, over large areas, and through varying fuel types. Talucci et al. (2022) in a study of mountain pine beetle outbreaks in the Tweedsmuir and Entiako provincial parks, point out that while fire weather is a primary driver in most cases, pre-fire vegetation is an influential predictor variable across all burning conditions. The probability of high-severity fire was highest when pre-fire vegetation was a mixture of both dead trees and live vegetation.

2. Heterogeneity

It is well-documented that restoring the stabilizing feedbacks that enable resilience to disturbance will require transitioning contemporary landscapes towards diverse mosaics of conifer, broadleaf, and mixed wood forests with closed and open canopies (Hessburg et al. 2019, Povak et al. 2023, Daniels 2024). Landscape-level practices should aim to increase landscape heterogeneity while reducing fuel accumulations. This can be achieved by taking advantage of fire-resistant natural features, such as water bodies, rocky outcrops, or stands of fire-resistant species, as well as man-made features like roads and fields (Forest Practices Board 2023a, Prichard et al. 2018).

For example, creating a mix of open stands, fully stocked 20- to 40-year-old conifer cover, and stands of fire-resistant species, such as broadleaf trees, can help slow wildfire spread and protect critical habitats. B.C. Wildfire Services (2024a) indicates that fuel management at the landscape level should incorporate a patches-and-corridor configuration to moderate fire spread and intensity, incorporate fire-resistant areas, consider the natural fire cycles, and recognize multiple values and complementary resource objectives. By increasing the diversity of vegetation types and stand structures, land managers can reduce overall fire intensity and rate of spread. In the Bulkley Morice, this approach is particularly important given the relative uniformity of topography and forest types.

3. Extent and Size

Extent, or the amount of fuel treatment required at the landscape level, is a common question in fire management. The impact of landscape treatments on the wildfire regime in the Bulkley Morice has not been tested. McCulloch (2020) assessed fuel management treatments that had interacted with wildfire across B.C. and found that small, narrow, and irregular treatment areas, typical of many thinning fuel treatments in B.C., were generally ineffective.

In an analysis of simulation studies across North America, Ott (2023) found that treatment effectiveness increased with larger treated areas and with strategic placement when guided by optimization algorithms or informed prioritization schemes (for example, proximity to the WUI or high-risk zones). The size of individual treatments is not as important as the treatment design, the extent of treatment(s) and their placement (USDA 2023a).

4. <u>Placement</u>

Ott et al. (2023) concluded that treatment effectiveness increased with strategic placement. Fuel treatments, especially those that reduce crown, ladder, and surface fuels, have been found to reduce fire intensity and support suppression efforts; they should be strategically placed near previous burns or natural barriers (Urza et al. 2023). *Placement should be complementary* (anchored) *to other treatments, previous wildfires, topographic firebreaks, and other natural and man-made fuel breaks* (USDA 2023a). When placing fuel breaks, it is also important to consider:

- Areas with high burn probability.
- Wind patterns and the influence of weather and topography.
- Values at risk and community resiliency.
- Access for fire crews and proximity to water sources for sprinkler deployment.
- Biodiversity and potential negative impacts like soil erosion, habitat fragmentation, and invasive species.
- Scalability and the ease of maintenance.

A cornerstone of effective fuel break design involves strategic placement, considering the values at risk and the characteristics of the land that reinforce other defences, reflect weather patterns and environmental functions, and support suppression activities.

5. <u>Prior Wildfire and Managed Wildfire</u>

While it is not uncommon for wildfires to occur in an area that has recently burned in the Bulkley Morice, the previous fire will change the size and severity of subsequent fires. Parks et al. (2016) in a study evaluating whether wildland fire affected the ignition and spread of subsequent fires in the western United States, concluded that previous wildland fires regulated the subsequent occurrence of fires. Moore (2023), summarizing a study by Jain et al. (2021), indicated that even low to moderate-severity wildfires could reduce the severity of future wildfires by 25 percent. However, this was not considered as effective as most fuel treatments implemented as part of a wildfire risk reduction strategy.

In 2018, Pritchard et al. used burn severity mapping to evaluate the influence of prior burn mosaics on subsequent wildfire behaviour, severity, and fire management options. The study examined three areas of mixed lodgepole pine, Engelmann spruce, and subalpine fir forests, located in the inland U.S. Pacific Northwest, central Idaho, and the Kootenay area in British Columbia. They found that:

- Past wildfires tended to decrease the severity of subsequent wildfires.
- Past wildfires tended to mitigate the amount of area burned.
- Burn severity generally increased with time since fire, as vegetation recovered and live and dead fuels accumulated.
- Past wildfires were only barriers to fire spread in the Kootenays for two to three years.
- In addition to past wildfires, fire weather and landform strongly influenced burn severity.

Allowing more wildfires to burn in designated areas during moderate fire weather could help reduce future burn severity and promote landscapes capable of withstanding the impacts of repeated fires, even in the face of climate change (Pritchard et al. 2018). As previously noted, however, caution is warranted when extrapolating findings from other fuel types and climatic regimes to the Bulkley Morice area. The observed effects will be contingent upon fire severity, residual fuel loading, and subsequent vegetation dynamics.

6. Coordinated Interventions

The B.C. Forest Practices Board (2023b) defines coordinated interventions as the integration of forest industry activities across both space and time. This approach requires collaboration among fire management specialists, forest professionals, and stakeholders to implement effective strategies throughout all land use zones. To achieve landscape-level impacts, careful consideration is given to road placements and the characteristics of cutblocks, including their shape, size, retention, and regeneration. Given that forests are continually evolving, regular treatments may be necessary to maintain fuel levels and attain a broader landscape effect rather than merely executing isolated projects.

A Framework for Fuel Break Design

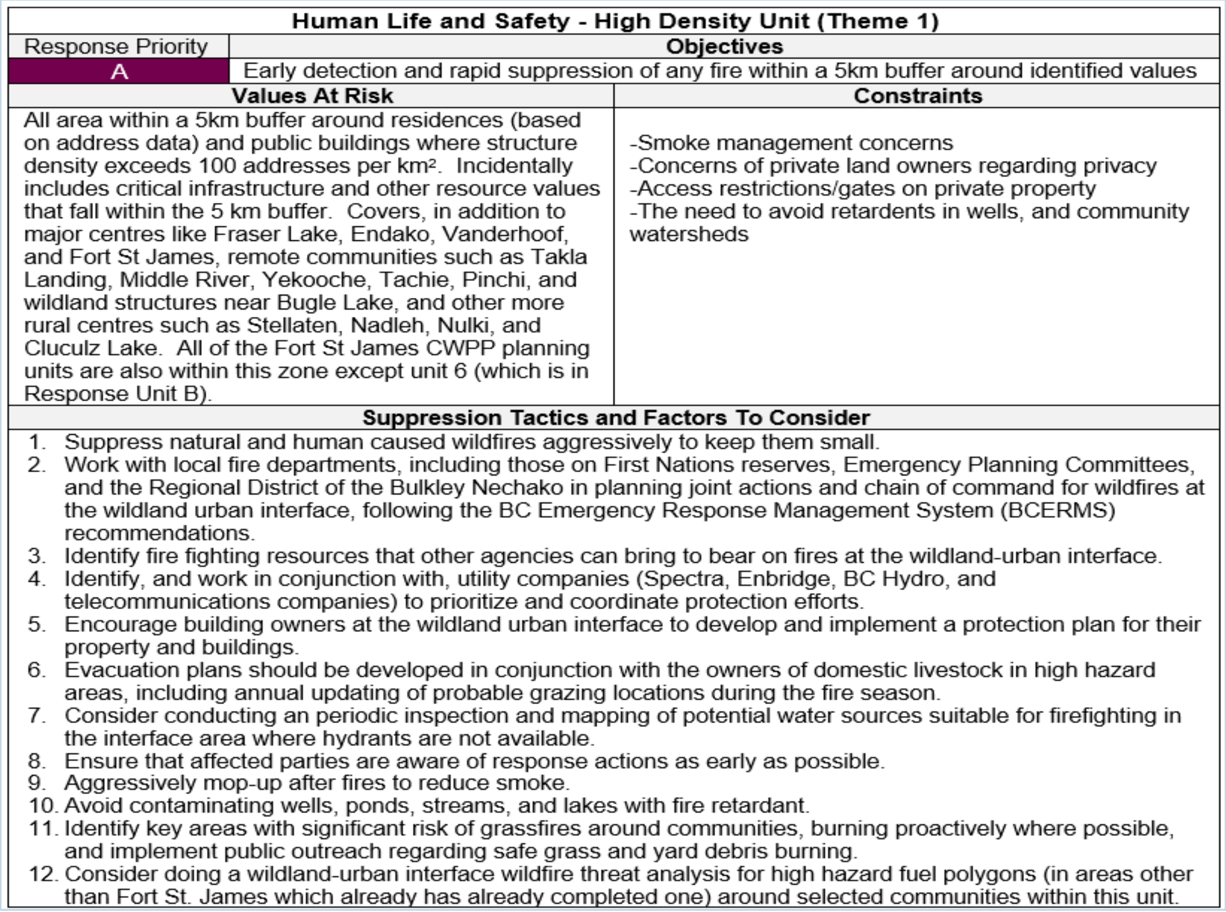
Two general approaches for designing fuel breaks and landscape treatment in the intervening forest matrix have emerged in recent years: a) conventional Wildfire Management Zoning, and b) Potential Operational Delineations or PODs. Each of these is described below.

Wildfire Management Zoning

Wildfire management zoning extends beyond fuel breaks to encompass opportunities and strategies for the entire land base. It involves delineating zones based on wildfire hazard and risk, values at risk, management objectives, treatment complexity, and constraints on wildfire operations.

The approach might include a package for each zone, featuring maps that show fuel breaks and access and egress routes, a description of suppression tactics and factors to consider, details on treatment options tailored to the area, and a communication plan.

The VanJam Landscape Fire Management Plan includes summary tables (Figure 10.2) and zone maps (Figure 10.3) showing tactical planning information, including proposed fuel breaks and their priority, proposed fuel treatment areas, values at risk, access and egress corridors, burn probability, fuel types, areas where fire would benefit ecosystem function, and tool and fuel cache locations.



Human Life and Safety - High Density Unit (Theme 1)

Response Priority	Objectives
A	Early detection and rapid suppression of any fire within a 5km buffer around identified values

Values At Risk	Constraints
All area within a 5km buffer around residences (based on address data) and public buildings where structure density exceeds 100 addresses per km². Incidentally includes critical infrastructure and other resource values that fall within the 5 km buffer. Covers, in addition to major centres like Fraser Lake, Endako, Vanderhoof, and Fort St James, remote communities such as Takla Landing, Middle River, Yekooche, Tachie, Pinchi, and wildland structures near Bugle Lake, and other more rural centres such as Stellaten, Nadleh, Nulki, and Cluculz Lake. All of the Fort St James CWPP planning units are also within this zone except unit 6 (which is in Response Unit B).	-Smoke management concerns -Concerns of private land owners regarding privacy -Access restrictions/gates on private property -The need to avoid retardents in wells, and community watersheds

Suppression Tactics and Factors To Consider

1. Suppress natural and human caused wildfires aggressively to keep them small.
2. Work with local fire departments, including those on First Nations reserves, Emergency Planning Committees, and the Regional District of the Bulkley Nechako in planning joint actions and chain of command for wildfires at the wildland urban interface, following the BC Emergency Response Management System (BCERMS) recommendations.
3. Identify fire fighting resources that other agencies can bring to bear on fires at the wildland-urban interface.
4. Identify, and work in conjunction with, utility companies (Spectra, Enbridge, BC Hydro, and telecommunications companies) to prioritize and coordinate protection efforts.
5. Encourage building owners at the wildland urban interface to develop and implement a protection plan for their property and buildings.
6. Evacuation plans should be developed in conjunction with the owners of domestic livestock in high hazard areas, including annual updating of probable grazing locations during the fire season.
7. Consider conducting an periodic inspection and mapping of potential water sources suitable for firefighting in the interface area where hydrants are not available.
8. Ensure that affected parties are aware of response actions as early as possible.
9. Aggressively mop-up after fires to reduce smoke.
10. Avoid contaminating wells, ponds, streams, and lakes with fire retardant.
11. Identify key areas with significant risk of grassfires around communities, burning proactively where possible, and implement public outreach regarding safe grass and yard debris burning.
12. Consider doing a wildland-urban interface wildfire threat analysis for high hazard fuel polygons (in areas other than Fort St. James which already has already completed one) around selected communities within this unit.

Figure 10.2. An example of a description for a Response Zone for the 2014 VanJam Landscape Fire Management Plan. There are 11 different tables with different themes and priority levels in that plan.

This type of plan is intended for land managers preparing for wildfire and seeking guidance on developing fuel breaks, undertaking fuel treatments, and creating maps for consideration by an incident management team, as well as for preparing communication plans.

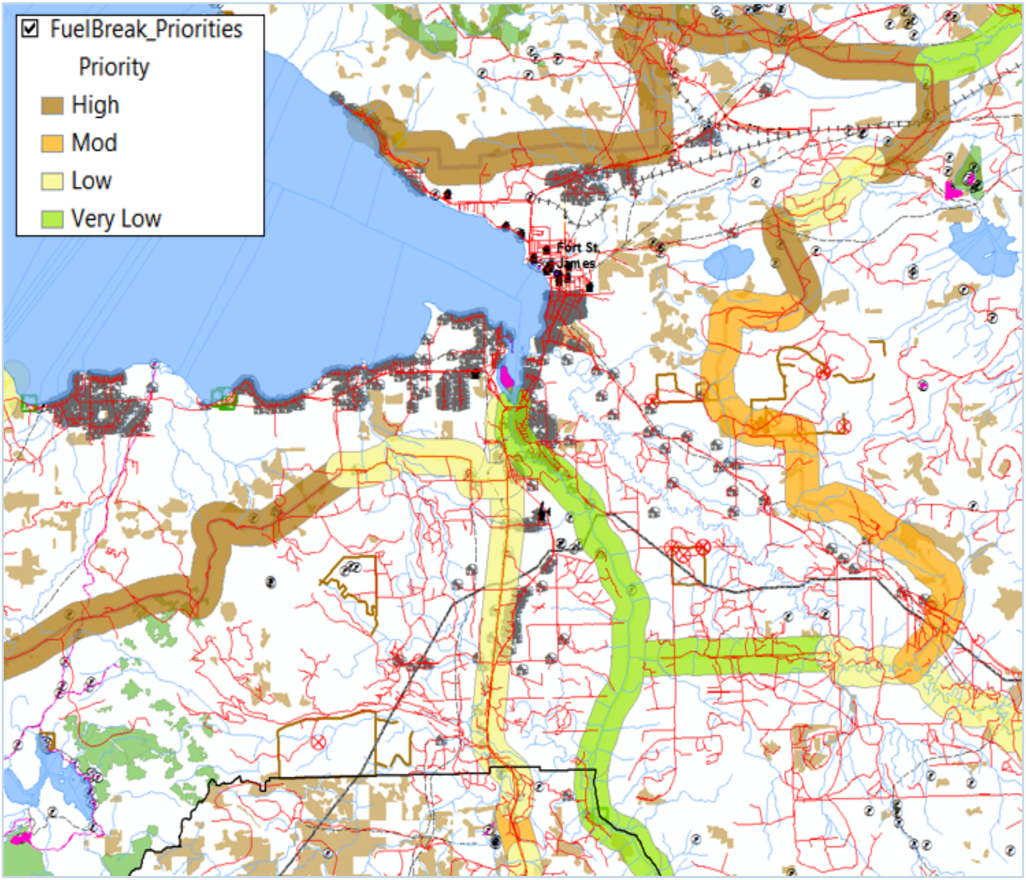


Figure 10.3. Excerpt from the 2014 VanJam Landscape Fire Management Plan fuel break map depicting fuel breaks and the relative priority for treatment, juxtaposed against various values (legend symbols for values not shown).

Potential Operational Delineations (PODs)

Initially developed in the U.S. (Thompson et al., 2022), Potential Operational Delineations (PODs) are described as an adaptive, cross-boundary approach to wildfire planning and response. It emphasizes integrating local expertise with spatial analytics to identify opportunities for wildfire control. PODs are response zones with distinct risk-informed strategic response characteristics that support both wildfire suppression and pre-identified management options. PODs are based on knowledge of the values at risk, predicted fire behaviour, and suppression difficulty. Potential control locations (PCLs) that occur within them are specific segments where suppression forces can anchor actions. Together, they provide a basis for tactical fire response planning (Figure 10.4).

Potential Control Lines (PCLS)

Potential control lines are either natural or man-made barriers, such as roads, ridge tops, and water bodies, used to stop or slow the spread of a wildfire. These lines can be constructed by firefighters or utilize existing features.

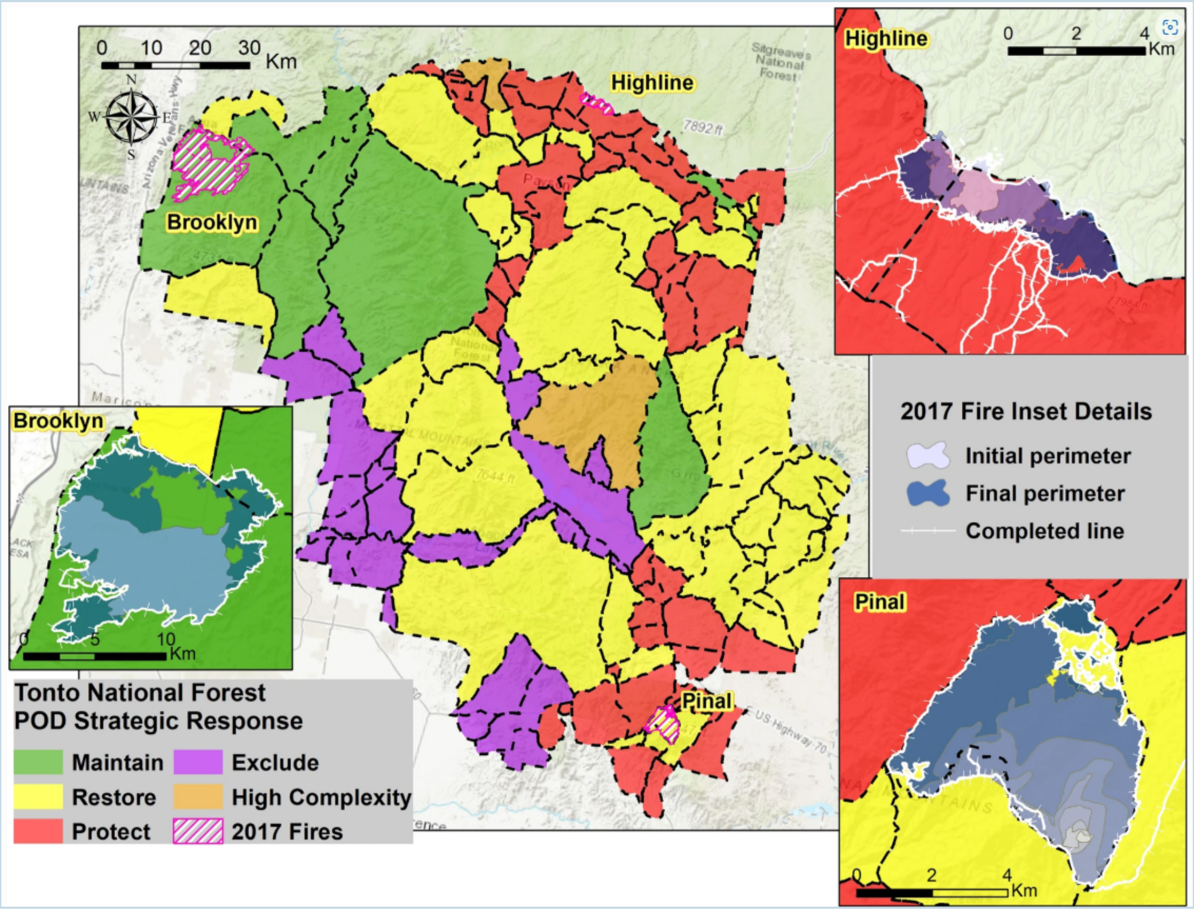


Figure 10.4. Potential operational delineations (dashed black lines) and risk-informed strategic response categories on the Tonto National Forest, along with the progression maps of three large 2017 wildfires and corresponding completed fire containment lines. Source: Thompson et al. 2022.

In Canada, the Canadian Forest Service has developed preliminary thoughts on the application of PODs in British Columbia (Walsworth et al. 2024, unpublished report). They describe the process as fundamentally a community-centric, landscape-segmentation approach to delineating landscape containers that provide the best chance of containing a wildfire. By pre-identifying control features, the boundaries can be utilized for contingency planning in wildfire suppression operations. Such an approach provides a strategic wildfire management zone to manage for other values within the POD (for example, for a fire exclusion objective, or for achieving a specific fire intensity to enhance wildfire resiliency and other ecological values) (BCWS Wildfire Prevention Officer – Fuels, pers. comm. 2026).

Strategies That May be Applicable in the Bulkley Morice

Conventional Zoning and PODs

emphasizes engagement and collaboration of stakeholders as a critical element of achieving buy-in and a shared vision. PODs also emphasize identifying potential control lines to support suppression activities. In comparison, wildfire management zoning emphasizes fuel treatments within the zone matrix. An effective strategy may be to use the key design and process elements of the PODs approach and, once established, define proactive fire management treatments within them. Such a plan would support suppression operations, wildfire risk-reduction planning, and the FLP process that balances other values within a broader forest management regime.

Harvesting and Silvicultural Practices

Landscape-level planning can identify locations where fuel breaks may be most beneficial; however, the costs associated with developing them can be prohibitive (Forest Practices Board, 2015). One potential solution is to direct or incentivize timber harvesting operations and silvicultural practices to take place in areas and at times that support strategic wildfire risk reduction. For example, prioritizing commercial forestry operations in high-hazard zones, as identified through the fire management planning process, and focusing on maintaining low post-harvest fuel loads (less than 10 t/ha) can help achieve fuel management objectives at a lower cost.

Other opportunities include leveraging existing stands with natural fire resilience, such as well-stocked plantations that are 20 to 40 years old (Figure 10.5), and ensuring that areas harvested as part of planned fuel breaks or designated fuel treatment zones are replanted with wildfire-resistant second-growth forests. These strategic approaches can help reduce the need for additional fuel treatments and lower overall costs.

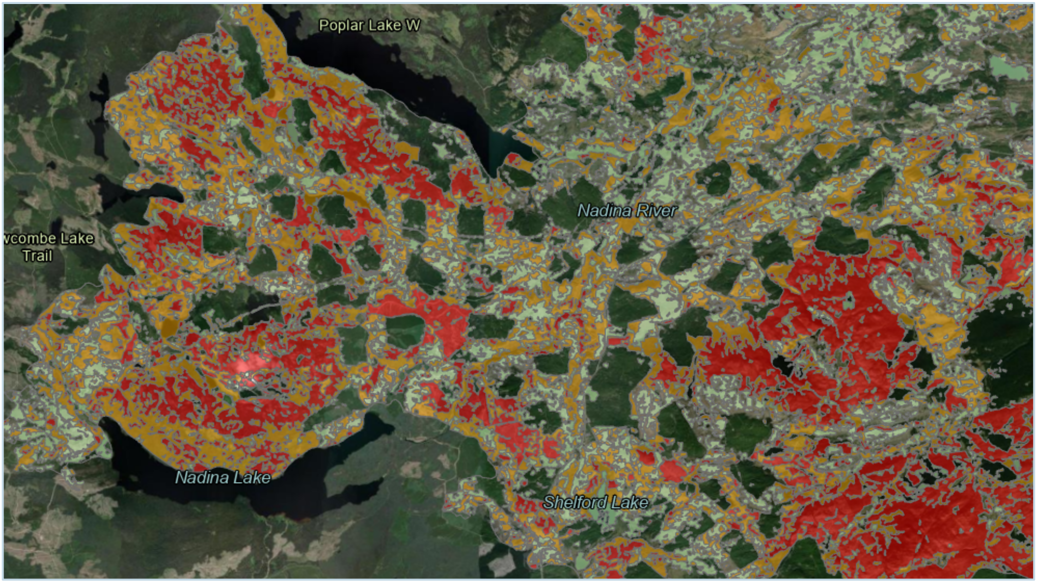


Figure 10.5. Satellite imagery of the 2018 Nadina fire with high fire severity polygons shown in red and moderate severity shown in orange, with an evident pattern of older, unburned stocked plantations scattered within the fire perimeter (dark green).

WUI Treatment Design

The wildland-urban interface is a unique zone due to the concentration of values and their priority for protection. In terms of funding for treatments, it will be a top priority. Fuel break design in the WUI will reflect the location of structures, critical assets and the density of roads. Ideally, fuel breaks will be anchored to the interface and follow roads, water features, and other low-hazard areas, such as fields or broadleaf stands. The objective is to create control lines that surround or create a break from areas of high hazard to the community. Where there are gaps in potential control lines, fuel treatments, and new access may be required to create fire-resilient areas that connect the anchor points. This may be accomplished through harvesting, silviculture practices and targeted treatments.

Because fuel treatment efficacy changes over time, it will be necessary to regularly maintain fuel breaks and treatment areas or to shift their locations. Friesen (2021) proposed a novel concept for creating a fuel break around communities, aiming to replicate natural disturbance regimes driven by wildfire with a 100- to 125-year fire return interval. The objective is to create a series of fuel breaks that shift through time (Figure 10.6).

Figure 10.6. Hazard reduction rings emulating a disturbance regime of 100 to 125 years. Adapted from Friesen (2021) using ChatGPT 4.0, OpenAI, 2025, https://chat.openai.com/

In this model, the rings are wide (up to 2 km), and the first ring, closest to the community, is harvested over 12 years, starting on the leeside of the prevailing winds. Subsequent harvesting occurs in the other rings over different periods until the entire area has been harvested. After harvesting and post-harvest fuel-reduction treatments, each area is planted with species and densities that contribute to fire resilience as noted in the previous section. At least one ring close to the community is always in a low-hazard state. After approximately 100 years, the first ring is ready to be harvested again, and the process is repeated.

Adaptive Management

Most fuel breaks created by humans, as well as many natural fuel breaks, are unlikely to remain static features on the landscape. As vegetation evolves, human development advances, and the impacts of climate change become more pronounced, there will be a need to adapt to these changes. This adaptation may involve incorporating new technologies, altering treatments, and utilizing available resources and funding.

Knowledge Gaps

Fire Management Attributes

Many of the unknowns respecting fuel management outlined in the chapter on stand-level fuel management also apply at the landscape level. In addition, landscape-level inventory information respecting fuel levels, condition, and continuity would enable more accurate fire behaviour forecasting.

Simulation Modelling to Test Landscape Treatment

Although extensive efforts have been made to model fire behaviour at the landscape scale—ranging from retrospective analyses that attempt to replicate known fire events, to proactive simulations based on established relationships among fire behaviour, risk, weather, fuel characteristics, and topography, including scenarios incorporating climate change - relatively little of this work has focused on the Bulkley Morice. An area of opportunity for the Bulkley Morice is to use simulations to explore how different spatial arrangements of fuel treatments (size, shape, and placement of fuel breaks) impact wildfire spread and intensity.

Operationalizing Landscape Fire Management

Another area of knowledge development that would benefit land managers in the Bulkley Morice area is information on operationalizing fuel break design and landscape treatments. Strategic and tactical landscape planning can provide valuable guidance, but its full implementation would be enhanced by information on how to achieve it. Multi-level training on planning and implementation, in recognition of different roles and base knowledge, will be needed at both the stand and landscape level.

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