



Canada Wildfire



FUELS FRIDAY

Synthesis Report of the Canadian Wildfire Management and Science
Workshop held in February 2021



ABSTRACT

This report provides a brief overview and synthesis of the four interactive sessions held in February 2021 concerning wildland fuel characteristics and measurement techniques. It contains a summary of the collective ideas, suggestions, and needs identified by a group of roughly 100 practitioners, scientists, researchers, and professionals from across Canada and around the world.

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List of Acronyms and Abbreviations

AI – artificial intelligence

CBD – canopy bulk density

CBH – canopy base height

CFFDRS - Canadian Forest Fire Danger Rating System

CFL – canopy fuel load

FBP System – Canadian Forest Fire Behaviour Prediction System

FMC – foliar moisture content

GIS – geographic information system

Lidar* – light detection and ranging

NG-CFFDRS – Next Generation - Canadian Forest Fire Danger Rating System

RPAS – remotely piloted aircraft system, also known as a drone

SH – stand height

UAV – unmanned aerial vehicle, also known as a drone

USFS – United States Forest Service

* Lidar technologies were a reoccurring theme in this workshop. Here is a short summary of the different types of lidar discussed (from lowest to highest characterisation of detail):

- Satellite or space-borne lidar: Profiling lidar onboard satellites that circle the Earth. These lidar systems typically have a wide beam divergence (about 25 m) and are operated in profiling mode, collecting the full waveform of the reflected laser pulse. Satellite-based lidars resolve vegetation height to about 1 m and are used for mapping surface elevation. Global coverage.
- Airborne lidar: Scanning lidar systems that typically emit laser pulses in 1064 nm (near infrared) and record up to four reflections from vegetation, understory, and ground surface elevation in three dimensions (3D). Depending on flying height, about 1 to 200+ reflections are recorded per m² of ground surface area, though parts of the understory may not be well-represented by 3D data. Local to regional coverage with many parts of the terrestrial biosphere already surveyed; however, repeat surveys are required.
- Drone-based lidar: Lightweight, low power lidar systems operating on remotely piloted aircraft systems (RPAS or drones). Laser pulses capture high structural detail of canopy, understory, and ground surface topography with about 100 to 300+ returns per m². Local coverage of up to a few hundred meters.
- Terrestrial lidar or terrestrial laser scanner: Lidar mounted on a tripod and used to scan into forest plots. Data density is hundreds of laser pulse reflections per m², allowing measurements of understory, ladder fuels, and downed woody debris, but may not fully represent the entire tree canopy. Occlusion (blocking of laser pulse reflections beyond trees in the foreground) can also be an issue; therefore, terrestrial lidar requires multiple scans into forest plots (from five or six locations) and from the centre, scanning outwards from the plot. Coverage within individual plots.
- Mobile lidar: Works similarly to a terrestrial laser scanner but is handheld or mounted on a vehicle. Scans into forests while walking in the stands or driving on a right of way. High pulse reflection densities of 10s to 100s of returns per m² depending on walking/driving speed; however, suffers from occlusion. Limited coverage to area surrounding scan path.

Introduction

Background

Parameters describing the physical structure of wildland fuels complexes are critical inputs for fire behaviour forecasting models and the associated wildfire operations, prevention, and mitigation work, including prescribed fire use (Keane 2014). As models evolve, so does the need to improve methods for collecting and analysing wildland fuels and fuel structure data. Emerging technologies allow researchers and practitioners to explore new methods to collect and analyse data more rapidly and at multiple scales.

There is currently a lack of universal standards and consistent protocols for wildland fuels data collection and reporting in Canada. Recent investment in wildfire research and the establishment of Canada Wildfire¹ presents an opportunity to address the need for standardised protocols for wildland fuel structure measurements. There are many structural parameters that contribute to wildfire behaviour and operational decision-making. As such, the subject of developing measurement standards and protocols is very diverse.

Overview

Fuels Friday is the result of a collaborative effort between researchers and practitioners. The planning committee responsible for the development of this workshop consisted of Jen Beverly (University of Alberta), Laura Chasmer (University of Lethbridge), Sandra Kinash (Canada Wildfire), Dave Schroeder (Alberta Agriculture and Forestry), Dan Thompson (Canadian Forest Service) and Brian Wiens (Canada Wildfire). The idea of a fuels workshop arose from ongoing discussions about disconnections between research and implementation. Ensuing conversations explored ways for practitioners and researchers to best use lidar and other emerging technologies and data streams to quantify fuels. After broader discussions, Jen Beverly, Laura Chasmer, Dave Schroeder, and Dan Thompson submitted a proposal for a workshop to Canada Wildfire. The proposal identified a need for consistent protocols for wildland fuels data collection in Canada.

This multi-organizational and collaborative effort coordinated by Canada Wildfire evolved into four unique online sessions. The sessions were held over four weeks with the intention of identifying and answering many of the questions and gaps surrounding fuels management, inventory, identification, mapping, and use of print and digital fuels mapping products in Canada. The workshop also aimed to provide students and researchers with exposure to practitioners while allowing practitioners to learn about current research. Due to the COVID-19 pandemic, the workshop was held online. Many of the presentations and online sessions are available to watch on [Canada Wildfire's YouTube Channel](#). An average of 113 participants (Figure 1) took part in each of the four sessions.

Workshop Objectives

A key goal was to create a forum that would bring together a group of wildfire practitioners and researchers, as well as practitioners and researchers from fields that are linked to wildfire operations, prevention, mitigation, and science. This group was initially assembled to address the following questions:

- 1) What are the minimum required wildland fuel structure parameters that need to be measured to predict fire behaviour and associated management objectives?
- 2) Which fuel characteristics can be measured vs. modelled using current data or methods in development?

Stemming from the first objective, the second objective was to create an initial set (<30 attributes per plot/pixel/polygon) of desirable fuels measurements to form a data standard. This involves creating an inventory of fuels collection methods utilized by different fire management agencies, research groups, and forest managers.

As is often the case in interactive workshops, the initially identified objectives evolved as experts met and discussed their individual and collective needs. While the two objectives were recognized as important and necessary outputs, the workshop ended up focusing on identifying gaps and opportunities for improvement and collaboration to advance the field of wildland fuels measurement. In the final weeks of the workshop, a task force was assembled from volunteer workshop participants to work towards fulfilling the objectives listed above and continue the advancement of fuels measurement and data analysis.

A list of the various contributors to Fuels Friday and this summary report can be found in Appendix 2.

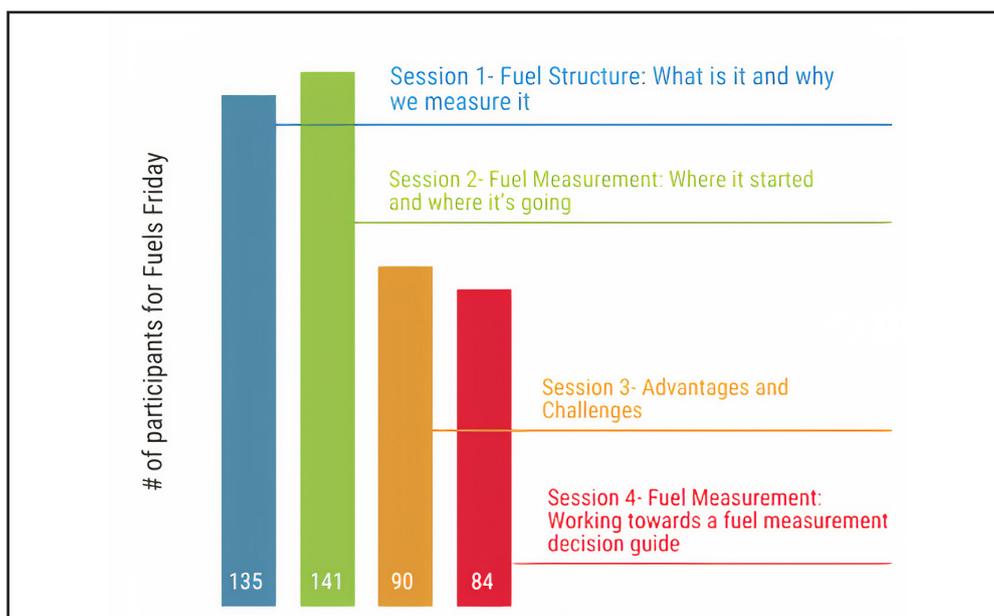


Figure 1: The total number of people who participated in the four unique online interactive sessions.

Session 1 - Fuel Structure: What is it and why do we measure it?

February 5, 2021

The objective of session 1 was to provide a baseline of fuels knowledge through three short pre-session videos, a live moderated Q&A discussion panel and two live presentations focusing on fuel inputs for wildfire modelling².

Panel Discussion: How does fuel structure affect the work of practitioners?

Three panellists answered questions about fuel structure and how it affects the decisions they make as practitioners. The panellists each brought a unique background and varying perspective to the discussion:

Mike May, RPFT (Senior Wildfire Training Specialist, Alberta Government) provided the perspective of an ignition specialist and educator for Alberta Wildfire. *Video titled: Fuel Continuity and Fuels Structure Through the Eyes of an Ignition Specialist - Mike May* <https://www.youtube.com/watch?v=CCA4FO6zS2o>

Jane Park, MSc (Fire and Vegetation Specialist, Parks Canada) answered questions from the perspective of a land manager, fire and fuel management practitioner, prescribed fire planner/implementer as well as an ignition specialist and wildland fire incident commander. *Video titled: Banff National Park - Landscape Fire Management and Fuels Data - Jane Park* <https://www.youtube.com/watch?v=fF3MQm4GVK4>

Sonja Leverkus, PhD (Independent Contractor, Owner of Shifting Mosaics Consulting and Northern FireWoRx) provided the perspective of an ecosystem scientist, professional forester, professional biologist, professional agrologist, environmental professional, and wildland fire practitioner. *Video titled: Fuels Fridays - Practitioner Talk by Sonja Leverkus* <https://www.youtube.com/watch?v=VbFEuf587Zs>

Questions submitted by participants highlighted some of the gaps and inconsistencies in fuels data across Canada. They also identified limitations of applying past fuels research in active wildfire scenarios.

The panellists acknowledged fuel structure research to date is helpful for planning and implementing prescribed fires. They agreed that there are many unanswered questions and a strong need for continued research. Key gaps and areas of interest identified included:

- studying modified fuels.
- increasing the number of classified fuel types and intra-fuel type variabilities to incorporate fuels (such as shrubs) missing from the current standard fuel types and account for intra-class variations.
- creating standardized methodologies to quantify and qualify appropriate fuel loading around values on the landscape (taking both ecological and economic restrictions into account).
- standardizing monitoring for the effectiveness of fuel treatments.

The importance of boots on the ground experience and familiarity with local fuels and landscapes was also highlighted, especially when dealing with an active wildfire situation. While the benefits of research are clear, nothing replaces being on the ground or in the air and watching how the fire is behaving when it comes to ignitions on wildfires. The importance of feeling what the weather is doing and seeing firsthand how the fuels are responding, feeling how they crunch in your hands, are all things learned through experience and are invaluable and irreplaceable.

Vertical fuel arrangement was identified as a key component of understanding and predicting fire behaviour. It was noted that an independent crown fire is a rare event and continuous crown fire spread is unlikely to occur in the absence of surface and ladder fuels. Being able to accurately measure fuels throughout a forest's vertical structure is an important metric for predicting fire behaviour. There was a clear interest in emerging technologies to replace and supplement current manual fuels data collection methods. Tools such as drone imagery and lidar are not currently used widely; however, there is interest in their use. If these technologies are to be integrated into fuels data collection, standards and best practices must be developed to ensure consistent and accurate data collection.

The potential benefits of developing growth and fuel load models were also discussed, and one key concern was the limitations of model value due to data constraints. Another option discussed is to look at the US Forest Vegetation Simulator (<https://www.fs.fed.us/fvs/index.shtml>) and see if we can cross-reference where we are on the trajectories of forest succession paths with the fuel models. It was acknowledged that models such as these are used for monitoring and planning, not for active wildfire situations.

The importance of being able to recognize invasive plants was also highlighted, both for understanding how fuel structure may be altered and for ensuring fuel inventory and wildfire crews are not contributing to the spread of invasives. The ability of some invasives to increase flammability and negatively alter native ecosystems means that they must be considered in all aspects of fuel and fire management.

A history of successful initial attack reducing the amount of fire on the land has resulted in an increased fuel continuity across the landscape. Increased fuel age, homogeneity, and loading, coupled with warmer and drier fuel conditions, means that when fire management agencies are unable to contain new fires, things can escalate quickly. When fires get going under extreme weather conditions, there is not much fire management agencies can do to successfully contain an escaped and rapidly growing fire except essentially waiting for favourable weather conditions or for the fire to run into a fuel discontinuity. To mitigate this challenge, we must work to create landscapes able to withstand more frequent fires and longer trajectories of drought. This can be done by restoring vegetation communities that are more resilient to frequent fire.

Researcher Live Presentations: How is fuel structure used for operational and research scale models?

This second part of session 1 focused on fuel impacts on fire behaviour and included presentations on current and future modelling frameworks.

Understanding fuels is crucial to understanding and predicting fire behaviour. Fuel type and structure directly impact the safety of fire line personnel and the effectiveness of suppression efforts. Byram's (1959) formula ($I=HWR$) for fireline intensity (I , kW/m) multiplies the net low heat of combustion (H , kJ/kg), fuel consumed in the active flame front (W , kg/m²), and the linear rate of spread (R , m/sec), thereby providing an estimation of the rate of heat energy released per unit time per unit length of the fire front. Identifying and quantifying fuels is a critical component of understanding how much heat a fire will generate, and thus understanding and anticipating fire behaviour and suppression difficulties.

Some important questions to ask when quantifying fuels include:

- What fuels do we need to measure?

- Is there value in knowing the total biomass in a given area?
- Alternatively, is it more useful to know the biomass of the fuels available to burn (W in Byram's equation) and contributing to fire intensity?

In terms of fire behaviour and wildfire modelling, we need to identify and quantify the available fuels, typically small diameter materials that may be consumed in the passage of the fire front. Once identified, we can work on understanding if, and when, these available fuels will be consumed depending on the type of fire.

The sixteen standard fuel types in the Fire Behaviour Prediction (FBP) System of the Canadian Forest Fire Danger Rating System (CFFDRS) are based on observations of fire behaviour over decades of experimental burning and wildfire documentation across Canada (Forestry Canada Fire Danger Group 1992). While they account for a range of forest fuels and structures, the fuel attributes are not modifiable. There is increased interest in a flexible system to provide fire behaviour prediction for a broader range of stand structures, including an ability to account for the impacts of fuel modifications (such as pruning or stand thinning). Thus, development of the Next Generation - Canadian Forest Fire Danger Rating System (NG-CFFDRS) was initiated with an expected completion date in 2025. While the main fuel moisture indicators are not expected to change, stand and site-specific adjustments are being made to allow the new system to account for differences in fuel drying due to stand closure. Ladder fuels and stand density will also be essential drivers in the new FBP System in the NG-CFFDRS.

What does this all mean for future fuels data collection? To apply stand and site-specific adjustments accurately and efficiently, we will require data on metrics such as canopy closure, overstory height, stand composition (% coniferous and % deciduous), stand bulk density, and canopy fuel load. Data on ladder fuels as well as ground and surface fuels are also needed. Moving forward, researchers and fire management agencies need to determine how to measure these attributes and develop standardized Canada-wide field sampling techniques. Evolving technologies such as terrestrial lidar should be utilized to capture some of the harder to measure attributes including canopy bulk density (CBD) and crown base heights. Other attributes can likely be garnered from remote sensing data, and forest resource and inventory plots.

One research scale model discussed during this workshop was FIRETEC, a model that simulates the physics of fire at a high rate of space and time. This model requires very detailed fuel and wind inputs and allows the user to investigate how heat and air interact in various weather and ignition scenarios. FIRETEC requires detailed fuels data at the individual tree level, including individual tree information about height, crown width, and live crown base height. Fuel moisture is also included for each fuel cell. Ideally, moisture values are taken within an hour or two of ignition on site. Currently, only fuels that will be consumed in the initial flame front (also known as thermally thin fuels) such as needles, lichen, fine woody debris, and other fine fuels are included in the model. The inclusion of thermally thick fuels in the model is anticipated in the coming years.

FIRETEC also considers the physical structure of the stand. Stand structure affects the fuel bed continuity while also influencing a feedback cycle with atmospheric dynamics (such as canopy wind drag and its impacts on turbulent mixing when compared to an open grass area). These feedbacks greatly impact fire behaviour. While it is currently a research tool used primarily for experimental fires, there are hopes FIRETEC can be used for complex prescribed fire planning. Once the highly detailed fuels data are available, researchers hope to use FIRETEC to model areas (and specific fuel modifications) where experimental burning is difficult, and wildfire observations are scarce.

High-resolution UAV imagery has already been used to recreate the physical structure of a stand post-burn and supplement available fuels data inputs in open stands for FIRETEC and similar models needing highly detailed spatial fuels data. Airborne lidar can be used to derive canopy structural metrics within grid-based map layers, representing the broad range of structural diversity across a study area or region. Likewise, high-altitude UAVs were also discussed as an emerging technology and potential mechanism of collecting high-resolution imagery (e.g., visible, infrared, and potentially lidar), detailed fuels data for model input, research and analysis, wildfire behaviour forecasts, early fire detection, and monitoring. Evolving technologies and remote data collection methods are crucial for future data collection, especially considering the detailed nature of fuels inputs required for research models such as FIRETEC.

Session 2 - Fuel Measurement: Where it started and where it's going

February 12, 2021

Session 2 consisted of a series of presentations³ intended to build upon the baseline of fuels information from session 1, and prepare the participants for breakout discussions in sessions 3 and 4. Fuel experts were interviewed for a series of short podcasts that were created and delivered as pre-session material.

Surface fuels sampling

Common uses of fuels data include assessing fire risk or potential, developing prescribed burn plans, developing and using fire behaviour prediction models, and predicting post-fire effects such as carbon emissions, depth of burn, tree mortality, and regeneration success. From a wildland fire fuels standpoint, we typically only sample what will burn due to budget, operational, and time constraints. This generally includes the forest floor (litter, humus, lichen, and moss), herbaceous plants, dead and down woody debris, as well as shrubs and regenerating vegetation, plus fine aerial fuels. Typically, these samples are taken along a transect and include measurements of fuel load, depth, bulk density, and moisture. While methods for fuel moisture measurements are fairly standardized, other fuel sampling methods can vary widely depending on the fuel type and structure as well as the equation(s) selected to estimate fuel characteristics. Approaches also vary amongst provinces and territories for evaluating down-dead woody debris.

Collecting data on fuel consumption and forest floor sampling requires specific training and finesse. Accurate fuel consumption calculations require resampling the exact same transect lines before and after fire to compare the pre- and post-burn amounts. Resampling can be difficult as fuels often change position during a fire (e.g., a snag falling onto the forest floor). Techniques exist to help in accurately marking and properly relocating sample materials. It is recommended forest floor sampling be done outside of experimental plots to avoid disturbance (e.g., trampling) prior to burning (Alexander et al. 2004). While it is customary in soil science to separately sample the litter, fermentation, and humus layers, in Canadian forest fire behaviour research the organic layer is more commonly separated into layers of 2-cm thickness. Metal pins installed before burning readily allow for the measurement of depth of burn (McRae et al. 1979). Data on depth of burn, coupled with the 2-cm thick organic layer fuel loads, provide the necessary inputs to calculate forest floor consumption.

There are two important questions when considering the prediction of forest fire behaviour:

- (1) What type of fire will occur (i.e., surface or crown)?
- (2) What overall head fire intensity can we expect?

Estimates of surface fuel consumption and fire spread rate, live tree crown base height, and the moisture content of the needles of the trees (foliar moisture content, FMC) are needed to calculate the critical surface fire intensity required for crowning (Van Wagner 1977). Critical surface fire intensity is then used to predict if the fire will stay on the surface or move up into the crowns of the trees (Alexander and Cruz 2016). Prediction tools and models such as CanFIRE and the CFFDRS can provide information on expected fire behaviour (including intensity) and the anticipated ecological fire effects post-burn, but these models require reliable inputs to yield accurate results (Alexander and Cruz 2013).

Fuel weight and bulk density

Fuel weight and bulk density data are important inputs for fire behaviour research and operational forecasting, including fire growth prediction modelling. Bulk density refers to the weight of the fuel (fuel load) per unit volume. Flammable materials with the same weight will burn differently depending on bulk density. Bulk density, therefore, affects the rate at which fuel is consumed and the proportion of total fuel available for combustion. Data collection for these metrics is expensive and time-consuming; therefore, data points are sparse in terms of both time and space. Equations for estimating crown fuel weights are generalized and do not consider regional differences of tree species. One suggestion to mitigate this is to undertake crown fuel weight sampling studies at all experimental burning sites; however, time and expense limitations may render this infeasible.

In order to calculate canopy bulk density (CBD), you must know the canopy fuel load (CFL), stand height (SH), and the canopy base height (CBH) (Figure 2). From these variables, CBD is calculated as the CFL divided by the live crown depth, where the live crown depth is equal to the SH minus the CBH.

$$CBD = \frac{CFL}{\text{live crown depth}}$$
$$\text{live crown depth} = SH - CBH$$

Other methods of determining these variables have been proposed by the US Forest Service (USFS). For example, the USFS defines CBD as the maximum density at any given 1.0 m vertical interval. However, this specific definition is not compatible with Van Wagner's (1977) theory of crown fire initiation and propagation (Cruz and Alexander 2014), which calls for a canopy-averaged CBD concept, as shown in the equation above.

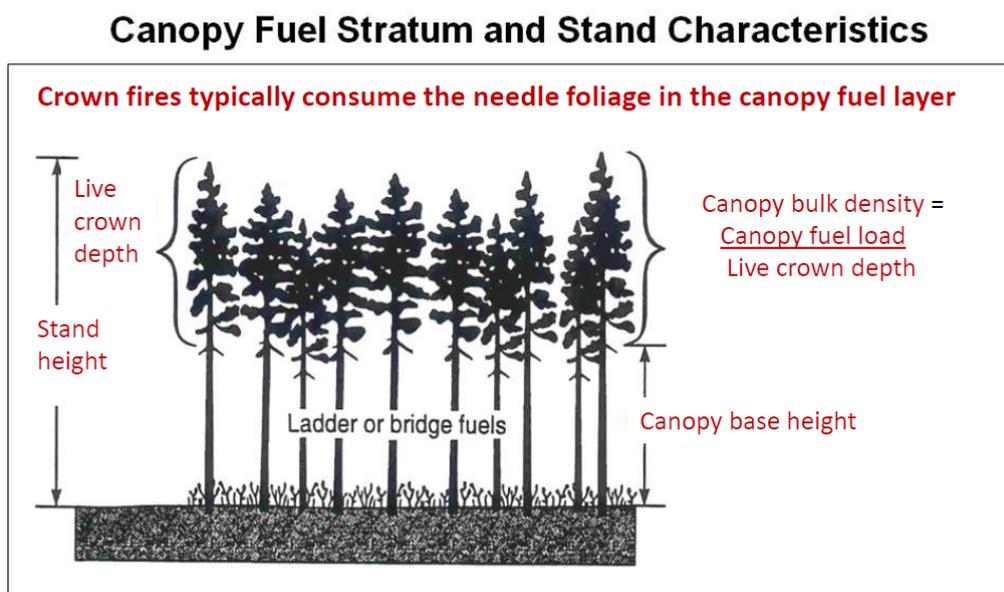


Figure 2: Profile of a stylized conifer forest stand illustrating several stand and canopy fuel characteristics. Adapted from Cruz and Alexander (2014).

Measuring fuel weight and fuel depth is relatively straightforward for some fuel complexes. However, the complexity and effort of field data collection can increase depending on the forest type as the CBH must be measured for a selection of trees in an experimental plot or stand. Like all fuel metrics, fuel weight and bulk density change over time and accounting for sampling timelines is an important consideration when applying these metrics to models or other analyses. Individually measured trees at the inventory plot level must be aggregated in order to determine canopy fuel characteristics for the larger stand area (Cruz et al. 2003). The question is, are the aggregated data scalable and representative of the larger stand? Natural forest structures are highly variable, so perhaps another method would be more suitable. Lidar, when available, is a useful tool to help map fuel structures at the stand-level in high resolution while still preserving variability (Figure 3).

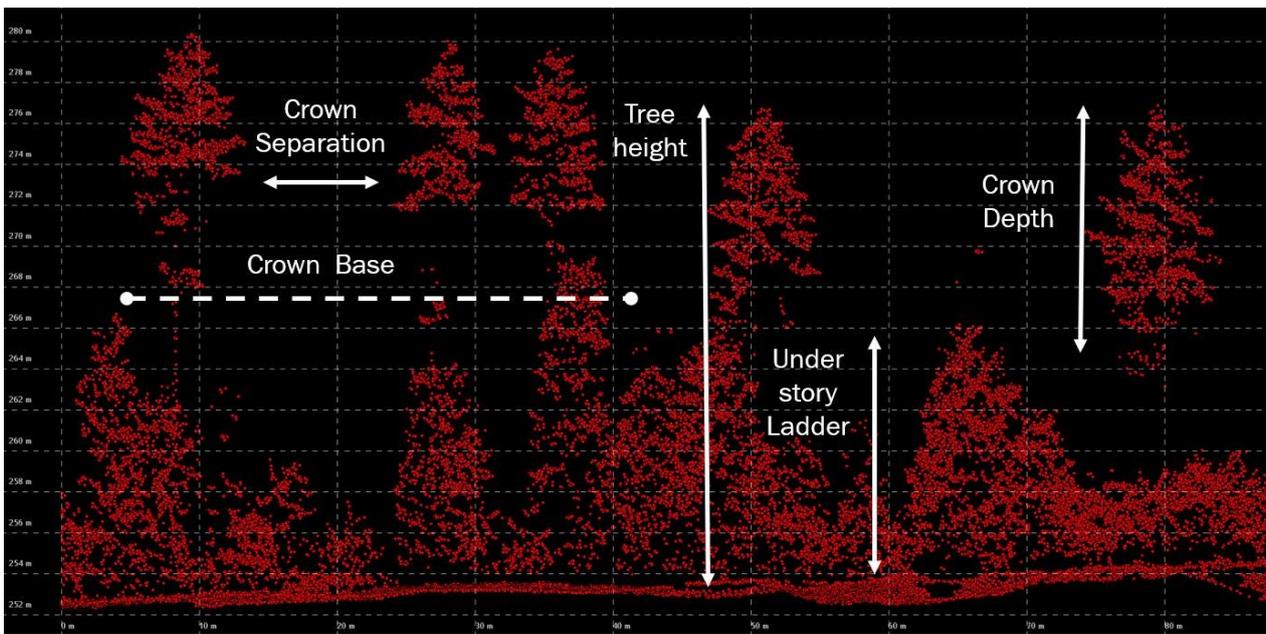


Figure 3: Airborne lidar point clouds showing measurements that can be used to assess fuels and their structure. Provided by Laura Chasmer.

Canopy base height

Canopy base height is an important metric used in certain fire behaviour prediction models (Alexander and Cruz 2016) to help determine when a surface fire will transition to a crown fire. A critical surface fire intensity (based on FMC and CBH) must be reached before a surface fire can transition into the tree crowns of a stand or forest (Van Wagner 1977). Despite CBH being a crucial metric, it is often difficult to measure in the field. CBH is the height above ground where sufficient canopy fuels are present to propagate fire vertically throughout the canopy. This is a somewhat subjective definition speaking to a generalized stand-level characteristic.

In Canada, CBH is typically defined by the work of Van Wagner (1977), in which the CBH is calculated using the average of the live crown base height measurements in a stand. Live crown base height is measured as the lowest height above ground where live fuels have the ability to extend a surface fire upwards into the tree's crown. This can at times be quite subjective. The definition becomes even harder to apply when considering trees with gaps in crown foliage or asymmetric morphology. One potential solution to this problem is to measure live crown base height as the lowest point above ground where fuels start to become vertically continuous, although this is not a standardized use of measure.

Taking a step back, we need to ask if live crown base height or CBH are the best metrics for describing (and determining) whether a surface fire will transition to a crown fire. Live crown base height does not account for the buildup of ladder fuels and clumping of trees. Even if live crown foliage is high above the ground, the presence of snags and an abundant ladder fuel component of dead branches and lichen can provide an easy route for a surface fire to climb into the overstory tree canopy. Likewise, regeneration, seedlings and saplings, and a tall shrub layer must also be taken into account. Perhaps an updated metric where ladder fuels are also considered when describing live crown base height and CBD would improve upon the basic crown base height metrics.

Remote sensing is becoming an increasingly common means of measuring canopy fuel parameters. So far, lidar seems to outperform optical remote sensing in dense and closed-canopy forests as laser pulses can penetrate the canopy and provide detailed structural information of the fuel layers, including understory and ground cover. While the use of remotely sensed data is extremely appealing, we need to keep in mind the difficulties of developing models to measure parameters, many of which we already struggle to define and measure accurately on the ground (e.g., lack of control data).

Existing and emerging technologies

There were a series of micro-talks⁴ about new and emerging technologies and protocols for documenting and measuring fuels presented.

Key highlights from each micro-talk:

- *Rapid fuel characterization with in-stand and overflight photographs* (<https://youtu.be/jFULJZKbg5g>) - Jen Beverly (Assistant Professor, University of Alberta) - Fuel load estimation from photographs is well established with the use of photo guides. Can new technologies and protocols enable the expanded use of photo-based assessments for documenting fuels in settings where time and resources are limited? Key considerations include: what level of detail and precision is necessary for such methods? What insights about fuels and fire behaviour can be gained by readily available data and documentation captured during suppression operations?
- *Extracting fuel data from drone and satellite imagery with applications* (<https://youtu.be/Esuv7mJr0qE>) - Jeff Boisvert (Associate Professor, University of Alberta) - Drone and satellite imagery can be used to classify tree type (deciduous vs. coniferous), calculate tree density, height, and size when the ground is visible through the crowns. If the crowns are overlapping, then these measurements become much more difficult and impractical due to occlusion.
- *Airborne lidar forest mapping* (<https://youtu.be/UGxlZvjQ7Lo>) - Chris Hopkinson (Research Chair and Professor, University of Lethbridge) - Airborne lidar can provide detailed point cloud information on tree canopy, understory, and ground surface elevation. These datasets can be used to derive grid-based structural models. Statistical descriptors of the point cloud can be used to provide information about topography, biomass, carbon, habitat, timber volume, and fuel loads. Field plot data are needed to develop regression models to predict some of these various forest attributes (e.g., above ground biomass, timber volume, and fuel load). To use lidar in this way over large spatial areas, an adequate number of field plots samples are required for each new area.
- *Using lidar to characterize and measure fuels* (<https://youtu.be/gy5ZqPm-jlo>) - Hilary Cameron (Restoration Specialist, Parks Canada) - Lidar can be used to characterize, measure, and map fuels in much finer detail and

⁴The list of presentations from session 2 – micro-talks, as well as links to the recordings, can be found in Appendix 1.

over broader areas compared to field measurements. To map fuels with lidar, a model must be created by comparing field measured variables to corresponding lidar metrics. Forest parameters that may be acquired via lidar include canopy height, canopy fuel load, canopy bulk density, stem density, and canopy base height. Once models are created to provide these metrics, they can be applied to other areas with similar forest types. Field data are still necessary to validate the use of models in new forest stands and quantify confidence in model outputs; however, the number of sample sites required to characterize a stand can be greatly reduced.

- *Identifying 3D thematic information from lidar to inform fire fuels from tree to region* (<https://youtu.be/ClaWqRv8HS0>) - Laura Chasmer (Assistant Professor, University of Lethbridge) - To understand available fuels from lidar-derived biomass, classification of vegetation species is necessary. If additional detail is required, terrestrial lidar is a good alternative for quantifying understory ladder fuels. Terrestrial lidar can also be used to determine tree species at the tree and plot level (Xi et al. 2016).

Standardizing data collection

Standardizing fuel sampling methods would benefit many areas of study. When data collection methods and standards exist, data can be shared among, and utilized by multiple agencies and research organizations. Various groups can contribute their data to a larger dataset, effectively leveraging data and sharing the burden of time-intensive and costly fieldwork. This may require some agencies to alter the way data are collected or require the collection of additional metrics; however, increased access to wider sample sets should offset or even outweigh additional costs and time requirements incurred by adopting new standardized methods of collection. Duplication of measurements should also be reduced as the data would ideally be stored in an easily searchable and mappable system, allowing users to identify if plots already exist in a given area, and the last time they were sampled.

Sharing standardized field plot data should increase the temporal resolution of data. If each agency or research group can reduce the number of sample plot sites they are required to sample each year (by avoiding duplication), they should be able to increase the frequency in which they are able to return to plots and resample them. One clear benefit of resampling is maintaining up-to-date fuel type maps.

Another secondary benefit is the accumulation of time series data. Time series data captured in naturally growing forest stands can be used to help develop and test biomass growth curves (Hopkinson et al. 2016).

A few questions to consider before creating data collection standards include:

- Is individual tree or stand variability influencing fire behaviour at these fine scales, or is coarser data (aggregated plot data) more appropriate for this purpose?
- How important are fuel load and bulk density at the landscape scale?
- Are other fuel structure parameters more important as we scale out?
- How do we match what is measured with what is needed at each scale?
- How can we adapt existing practices to new data?

New technologies have much promise in terms of increasing the spatial extent of data collection and reducing the amount of physical human hours spent collecting data on-site. This promise is tempered by the potential of

misapplication. Limitations and proper application of new technologies (including logistical challenges) must be properly understood prior to their inclusion in operational data sets. A national standard for fuel characterization data would meet this need.

Session 3 - Advantages and Challenges

February 19, 2021

The third session of Fuels Friday consisted of three breakout sessions where participants were split into four groups. The purpose of these sessions was to:

- better understand the needs of practitioners and managers as well as the gaps at three scales of influence based on a diagram (Figure 4) modified from Moritz and Odion (2005) and Oddi (2018);
- determine resource limitations for understanding;
- discuss what should be measured and potential new ways of measuring fuels.

To address these objectives, a series of questions were asked in each breakout session. The first breakout session focused on the scale of a flame, the second of a wildfire, and the third breakout session expanded to fire regimes.

Session 3 - breakout session scales and questions

Breakout Session 1: Flame Scale

Question 1: At the local scale of the flame to stand, what wildfire fuels do we absolutely need to measure?

Question 2: What are the barriers to information or fuels data gathering at this scale?

Breakout Session 2: Wildfire Scale

Question 1: At the wildfire (forest to regional) scale, how do we turn fuels data from basic research into information relevant for operations and community planning?

Question 2: Are there new ways to measure wildfire fuels beyond traditional measurements/Van Wagner (1977) methods?

Breakout Session 3: Fire Regime Scale

Question 1: At the scale of the wildfire to the broader level of fire regimes and disturbances, what is our 'minimal' unit of measurement? E.g., what can be collected rapidly across large areas to inform fuel structure?

Question 2: What are appropriate levels of uncertainty of fuel measurements across all scales?

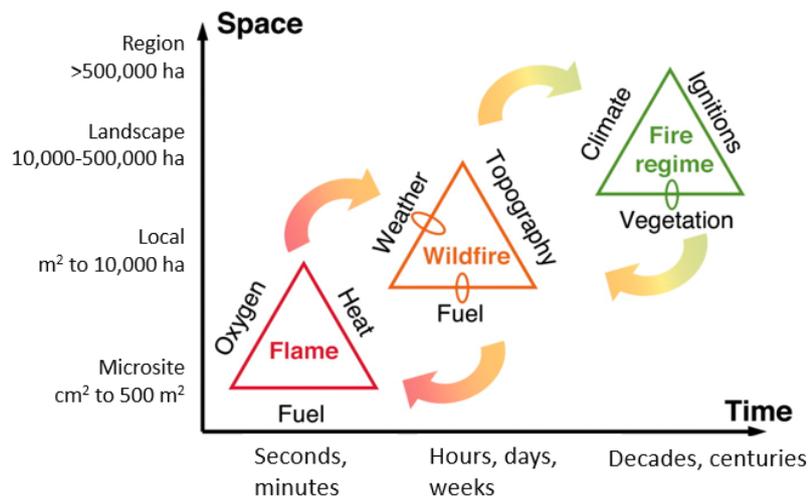


Figure 4: Graphical representation of the scales of influence for wildfire practitioners and managers. Diagram modified from Moritz and Odion (2005); Oddi (2018).

Scaling from flame to fire regime

Determining “relevant fuels” to measure depends on the type of fire and the kind of ecosystem under consideration. Measurements that inform the transition of fire from surface to crown include the ladder fuels (e.g., canopy base height), and the continuity/variability of vertical and horizontal fuels. Fine fuel attributes like quantity, density, composition, compactness, fuel stratum gaps, and vertical and lateral distribution all play a significant role in fire behaviour. However, there remains the question of what microrefugia do and do not contribute to fire behaviour. The Van Wagner (1977) model states that the most significant contributor to crowning is the height to live crown base, but in practice defining where the live crown base starts has proven challenging in both field studies and those involving airborne lidar. The effects of ladder fuels in this regard are also not fully understood. Upon transition to a crown fire, the CBD of the stand comes into effect. Still, considerations must be made to account for differences in its effect in a pure conifer forest, mixedwood, or even deciduous stands.

At a fine scale, there are measurements that have not been incorporated into traditional fuel characteristics and data collection that would be of use, such as the abundance of and the aerodynamic properties of fuels that may contribute to ember transport. This information could help improve our understanding of spotting and drive the next generation of models to predict the potential distance travelled by ember type in various conditions. Defining when certain fuels, and fuel complexes, become relevant is also important. For example, normally benign fuel complexes such as peatlands (often considered as a natural fire break or barrier) can become extremely flammable and contribute to “wicking” under drought conditions.

Moving to the wildfire scale, it is recognized that our focus cannot be solely on wildland fire management and science. We must also consider the extension into other disciplines such as forest ecology, biodiversity, soil science, microclimatology, health and safety, and other fields. Exchanging measurements, data, and technology with other non-fire related interest groups could advance our access to, and understanding of, other data sources with potential relevance to fire and fuels management.

Community protection and validation of FireSmart treatments both contribute to the desire for more readily available and higher-detailed data in and around values-at-risk, especially communities. In the hinterlands, less detailed data may suffice. The participants determined that existing provincial and territorial FBP System fuel type maps are sufficient for the immediate and essential needs of fireline safety in some cases; however, map efficacy varies over time and space, and they may no longer be sufficient for wildfire management and ecosystem planning. There is also a need to consider fuel structure before and after fuel treatments to gain information about how fire behaviour is changing due to treatments. The potential fire behaviour pre-treatment is just as important as the fire behaviour post-treatment.

National level fuels grids are based on FBP System fuel types and are quite coarse (250 m), even when considering the broader scale of fire regimes and disturbances. Some provincial and territorial agencies have fuel types mapped at ~1 ha (100 m x 100 m) resolution or better; however, data are inconsistent and often outdated. One suggestion is to standardize the use of Sentinel imagery to update maps to a higher resolution (10 m x 10 m to 60 m x 60 m) for fire regime and disturbance studies.

Barriers to gathering data

The collection of data at the local (flame) scale is time and resource intensive. Due to the high variability at this scale, the number of sampling sites required to ensure adequate coverage is almost always beyond resource and budgetary means. To further complicate things, ecosystems are dynamic and continuously changing, begging the question of how long field data are valid before they are no longer representative. A striking example embracing these challenges is fine fuel moisture, a metric which varies with weather conditions throughout the day and allows the calculation of ignition probability and fire spread potential. One suggestion is to add systematic resample timeline recommendations into sampling protocols for each metric.

Another barrier present at all scales is that what data should be collected, and definitions surrounding the data types themselves, are not consistently defined. This can result in measuring attributes with the hope it will have value when no clear connection to an intended use is predefined. Such practices result in inefficient resource use. Once a set of necessary attributes is consistently defined, we must then determine the required frequency of repeat measurement over time to maintain up-to-date fuels information.

Further complicating the issue is the movement of some wildfire protection and management responsibilities to non-forestry-related agencies such as public safety and defence. The risk of such movements is the loss of a forest ecology lens when planning and conducting fuels measurement, mapping, and treatments. To gain and maintain agency support and resourcing for fuels data collection, we must learn to talk about fuels and the importance of fuels data with non-forestry practitioners.

Time, resources, and budgetary constraints pose additional barriers to data collection. Collecting accurate and consistent fuels data is challenging and requires training in both collection methods and recognition and correction of personal bias. Significant database and information management challenges exist when storing such a large and diverse data set, especially when consideration is given to the reality that data collection protocols will likely change over time. Many jurisdictions do not have defined methods for capturing, submitting, and keeping fuels data, and the adoption of such processes will require devoted time, training, and resources.

Potential solutions

At all scales, practitioners are often aware that data are available; however, the use of these data is often impeded by a lack of sufficient knowledge about how to access and/or properly use the data and corresponding models. Targeting training and improving researcher-practitioner relationships can help close this knowledge gap. Practitioners need to know what data are available, where to find it, how to access it, when it is appropriate to use, and how to use it. One recommendation was to create a national fuels data map or atlas⁵. A national archive would allow sharing of data and the extension of research beyond a single study site. However, it was noted that a map or atlas must be updated regularly and would require long-term dedicated resources.

In addition to an atlas or map, the participants also clearly voiced the need for a Canadian national fuels database. Such a database may logically fall in as an extension of the National Forest Inventory (<https://nfi.nfis.org/en/>) or the Canadian Wildland Fire Information System (<https://cwfis.cfs.nrcan.gc.ca/home>). The creation of a national database

would require a task force to bring the data together from different sources and make them universally available. Such an endeavour would need additional resources for the creation of data collection protocols, training of field personnel, standardization of data analysis programs and processing, physical data storage space and backup, and database management to ensure data are stored in a standardized manner.

Participants also expressed a strong interest in how data from non-wildfire-related research could contribute to answering wildfire-related questions and felt it was necessary to consider including “externally sourced data” in a national fuels database. There is a need to define relationships between various data inputs at various scales. Coupling field campaigns with artificial intelligence (AI) analysis could allow extrapolation from local to regional scales through surrogate measurements. By harvesting data from other disciplines and combining forms of data inputs, we can reduce costly and resource-intensive field campaigns. The establishment of long-term sampling sites would also be beneficial.

Participants concluded that minimal data resolution standards must consider that measurement coverage and accuracy are more critical in areas with values. This recognition could potentially allow for a sliding scale of sampling strategies and resolution requirements in the future. Part of the standardization of fuels measurements must include determining what level of precision and thus uncertainty are appropriate at various spatial and temporal scales. Spatial resolution refers to the area and detail of the field survey, or minimum mapping units as they represent fuel variability through space, while temporal variability refers to the repeat interval of measurement required to capture changes in fuels through time, whether these are field or remote sensing observations. Data resolution can be envisioned as a set of spatial (temporal) scales ranging from excellent (frequently resampled) data at a single location to coarse (out of date) data over an entire region. The acceptable ranges of error depend on the variables being assessed, their non-linear relationships to fire behaviour, proximity to values-at-risk, and how key threshold values may affect extreme wildfire events.

While increasingly high-resolution information is continually being captured by ever-improving remote sensing techniques, the models used operationally to predict fire behaviour may not be able to incorporate this data. There are many exciting new and emerging technologies; however, limitations need to be understood to avoid misrepresentation of data. Though we are all searching for more efficient ways to capture fuels data, we must also remember that field measurements are extremely important for validating the information derived from new technologies.

The potential of using remotely sensed data to capture field measurements is very alluring to practitioners. The allure, however, is hampered by the realization that a remote sensing specialist is needed to properly process and interpret data to avoid misapplication, thus impeding the widespread use of such methods and data. Remote sensing experts participating in the workshop shared with the community that work is underway to democratize post-processing and analysing tools (through the development of open web-based tools) with the intention to open access and broaden the potential user groups of such data.

Session 4 - Fuel Measurement: Working towards a decision guide

February 26, 2021

The goal of the fourth session was to summarize and synthesize the collective content and discussions from the first three sessions to identify what is well understood and where gaps in knowledge exist. This was accomplished through three breakout sessions, each with a unique focus:

1. slow vs. fast thinking;
2. knowns and unknowns; and
3. priorities.

These sessions were designed to guide the participants through determining and prioritizing what needs to be focused on to move the field of wildfire fuels forward. The participants were asked to keep the following questions in mind during the three sessions; what do we do really well? and what do others do really well that we can adapt into the fuels measurement forum?

While the initial intention was to end the workshop with a clear outline of what has been done to date and compile a new set of priorities moving forward, the conclusion was made that such a task requires more time and discussion than was possible in the final two-hour session. It was decided to form a "Fuels Friday Working Group" (Appendix 2d) comprised of workshop volunteers. This working group would meet regularly and further the vision of identifying priority areas of study, standardization of protocols, and support the broader advancement of the field of wildfire fuels management.

Thinking "fast" vs. "slow"

Based on the research of psychologist Daniel Kahneman (2011), breakout session one focused on the fast and slow thinking systems in our brains. The fast system includes activities that are automatic and reactions that are associative, like intuition. Conversely, slow thinking systems require focused effort and attention. This can translate into rapid assessment and slow evaluation, respectively. In breakout session one, participants were asked to classify when in their collective experiences they have been thinking fast and when they have been thinking slow regarding fuels at the local and the landscape scales.

Classifying a stand according to the FBP System fuel type classification or the dominant species within the stand is an example of fast thinking for experienced wildfire practitioners. In an active wildfire situation, an experienced practitioner is rapidly, and instinctively, calculating potential fire behaviour and risk factors while doing a fly over or walk through. Promptly and accurately classifying vegetation cover into FBP System fuel types can convey a lot of information in a relatively short amount of time and is an integral part of wildfire assessment reports. Fire practitioners are often quick to identify fuel arrangement characteristics that pose a threat from the standpoint of wildfire initiation, spread and intensity, such as a dry fuel bed, dead-down woody debris fuel load, abundance of ladder fuels, and a low CBH. However, precise quantifications require measurements, and subtle variations within the stand may have large implications for fire behaviour.

Rapid assessments can be done from the air or by using up-to-date imagery from easily accessible satellite sources such as Google Earth. Examples of these quick assessments include:

- assessing the continuity of fuels and identifying fragmented landscapes (e.g., forests mixed with peatlands, or highways and water bodies breaking up forest continuity) versus continuous conifer forests;
- identifying areas of disturbance such as harvest blocks, old burn scars, windthrow, or tornado damage; and
- gaining a general understanding about the topography, such as different aspects or slope exposures and steepness of the terrain.

While air-based rapid assessments are incredibly useful, identifying fire regimes (other than stand replacing) and the resulting stand structure beyond the dominant species identified from the air requires slowing down and going into ecosystems rather than just flying over them. By stepping into the forest rather than simply viewing it from above, we gain a more accurate understanding of the local fire regime and forest ecology, especially when it comes to surface and mixed fire regimes.

Thinking slow often correlates to activities that run on longer temporal scales such as incorporating time-lag size class properties into fuel metrics, with one specific example referring to years with wet springs contributing to delayed spring dip and potentially late drying of the abundant fuels. Considering larger spatial scales also tends to slow down thinking due to incorporating legacy changes to the landscape (e.g., disturbance polygons), forest composition diversity, horizontal and vertical continuity, and ecological and societal values and goals.

When considering fuel mitigation strategies to reduce crown fire risk, time must be taken to measure the initial and the residual fuels on the forest floor, in the vertical columns from floor to canopy (ladder fuels), and in the crowns themselves. Such measurements would contribute to better understanding how fuel treatments impact fire behaviour, an important metric for practitioners to evaluate the effectiveness of fire mitigation strategies. There are no fast and intuitive methods to gather this information and connect the data to quantitative measures about the effectiveness of fuel treatments.

The division between fast and slow thinking or short- and long-term planning is not definitive. For example, one may immediately identify the need for fuel reduction in a FireSmart complex, but the long-term planning and maintenance of the complex requires long-term tracking and decision support. Operational wildfire organizations are being challenged to quickly adapt to the effects of climate change, which are accelerating the severity and prevalence of disturbances in fuel complexes and altering the interactions between them. To properly manage fuels, forests, and fires, adequate fuels measurements and data are needed to inform planning, policy, and decision making. An important question remains, what do adequate measurements and valuable data look like?

Knowns and unknowns

In breakout session two, participants were asked to use their knowledge and experience as well as what they learned in the past three weeks to identify knowns and unknowns in fuels management following the four-part scheme as presented in Figure 5. Important questions considered during this exercise included:

1. Which current information and knowledge that we have about fuels is certain and which is uncertain?
2. Which gaps in the information and knowledge about fuels are we certain of and which are currently uncertain or unknown?

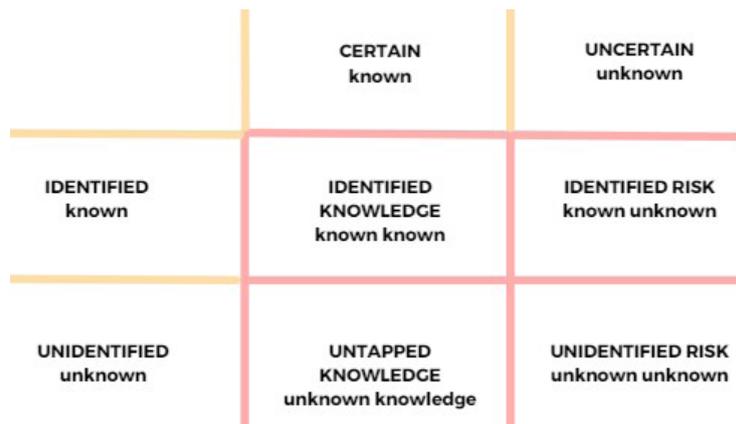


Figure 5: This modified “Rumsfeld Matrix” (Kim 2012) was used to consider fuel knowledge certainties and uncertainties as categorized into knowns and unknowns.

Identified knowledge (known known)

Generalized impacts of fuels on fire behaviour were classified as identified knowledge. These include the role of deciduous forests in dampening fire behaviour after spring greenup, the effects of a low crown base height on crowning, and other fire behaviour basics, such as how fire behaviour changes under different weather conditions. There was also a consensus in certainty when dealing with fuels similar to the sixteen benchmark FBP System fuel types.

Identified risks (known unknown)

Our knowledge base is relatively comfortable when remaining within the standard FBP System fuel types in known topography with accurate weather forecasting. This confidence decreases as we deviate into novel fuels, altered fuel types, hybrids, complex topographic arrangements, and uncertain or less confident weather forecasts. Legacy effects, such as previously burned areas, timber harvested areas, and barriers to fire spread, are not fully understood with respect to how effectively, and for how long they may limit fire spread. Understanding the impacts of natural fuel breaks and prolonged drought, identifying thresholds when non-fuels (e.g., wetlands) begin to contribute to a fuel complex, and distinguishing how other disturbances (e.g., mountain pine beetle and other insect defoliators such as spruce budworm) affect fuel dynamics are of particular interest. Similarly, further study of atmospheric effects on fire behaviour, fire growth, preheating of fuels, and localized wildfire-weather feedbacks are needed.

There are uncertainties about regrowth and succession after fuel treatments and how to classify such areas on fuel type grid maps. The impacts of climate change on fuel structure are unknown/uncertain, especially in areas of post-fire succession, further exacerbated in already dry ecosystems that have been disturbed by fires in the last decades. We also know when dealing with grasses that FBP System fuel types 01-a and 01-b are not always going to be 3.5 t/ha. Others suggest incorporating fluid dynamics into fire behaviour models to study wind effects, and to consider the chemical composition of different fuels to better understand how they burn. The effects of fuel treatments on the

microclimate are unknown, and the potential negative effects of fuel treatments on Canadian ecosystems are not well understood.

Untapped knowledge (unknown known)

Fuels and wildfires have been managed through Indigenous fire stewardship for generations. With respectful consultation and partnerships, Indigenous knowledge and traditional burning practices could inform our understanding of fuel structures. Ignition specialists also have a vast knowledge base built on experience and observation, but such knowledge is often implicit and hard to document and make accessible to others.

The ability to crowdsource knowledge via new and existing cell phone technologies is also an untapped source. Geotagged and uploaded forest photos could be used to auto-classify fuels and fuel complexes. Autonomous vehicles, which are continually scanning and analyzing data to map the environment around them, is another possibility. This kind of technology can be used to drive deep learning models. Stratospheric satellites and unmanned aerial systems operating at high altitudes above most weather systems and flight paths are becoming increasingly common and accessible, opening additional potential fuels data sources.

Unidentified risks (unknown unknown)

The nature of an unknown unknown is that it can only be identified in hindsight. With this in mind, the participants instead treated this category as identified but uncertain unknowns, or “uncertain risks”. Questions and topics identified as uncertain risks included:

- Are standard fuel treatments sometimes not possible in certain forest types such that complete stand removal is the only option for values protection?
- Surface fuels following fuel treatments have yet to be closely examined. How do we measure surface fuel quantities, and which tools should be used to connect this information with the well documented crown fuels and fire behaviour on a site-specific scale?
- What is the threshold when peatlands become wicks vs. fuel breaks, and what will be the resulting fire behaviour?
- Could agricultural activities or growing native plants and berries be a potential land use practice on firebreaks around communities?
- Can we incorporate Indigenous knowledge into fuel and fire behaviour guides and models?

Priorities

In breakout session three, the participants were asked to identify the priorities we need to move forward on as a community while also considering the urgency in importance (as visualized in Figure 6). Participants were also asked to consider what topics are not directly important to wildfire fuel measurement or are best addressed by other groups such as harvest planners, wildlife biologists, social scientists, ecologists, or even structural firefighters.

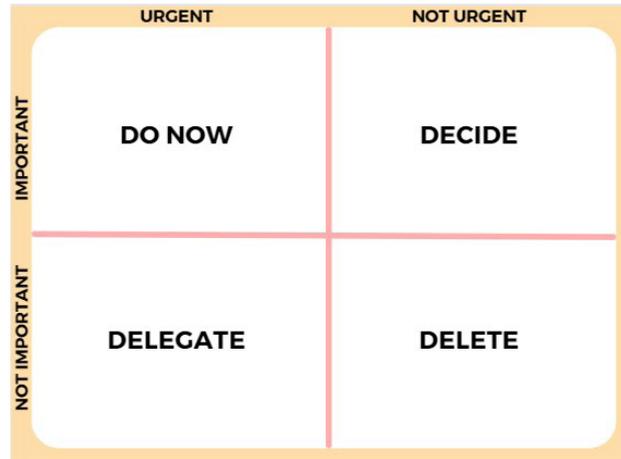


Figure 6: Matrix used to classify and prioritize topics depending on their importance and urgency (from Eisenhower 1954).

Important and urgent (do now)

Fuels, in general, are an expansive area of study. What is important and urgent will vary over time, space, and personal bias. The following important and urgent topics were identified when considering fuels for wildfire management in the broadest sense:

- Creation of guidelines for surface and ladder fuel load assessments.
- Updates to FBP System fuel type classification for spatial and temporal variations.
- Incorporating seasonality into fuels monitoring and modelling to account for different fuels being consumed in spring, summer, or late fall.
- Increasing communication and integration between research and operational disciplines, including data sharing, and resource leveraging.
- Knowledge translation and extension to facilitate the infiltration of research results into standard operating procedures and policies.

Important and not urgent (decide)

Questions surrounding scaling were considered important but not urgent. For example: how do we scale with climatic drivers within the season? And how do we transition from the two extremes of a weather-driven fire to fuel-driven fires?

The creation of a cloud geographic information system (more commonly referred to as a cloud GIS) or other integration of data and knowledge into an accessible network was also identified as important. Due to the magnitude of such a task, it was considered both urgent and not urgent, considering it would be a prolonged multistep initiative.

Participants deemed answering the following questions important:

- What approaches can update fuel type grids quickly?
- What accuracy is needed, and how often must updating occur?

The recording of these answers into standardized national protocols and procedures was also identified as important, and while not urgent, it requires prompt attention. The incorporation of fluid dynamics into fire behaviour models to study wind effects as well as considering the chemical composition of different fuels to better understand how they burn were also considered non-urgent priorities.

Urgent but not directly important (delegate)

Just as important as identifying high-priority urgent topics is the identification of topics that are not directly important to the cause and may be best served by, or in collaboration with, another group. Topics to be delegated cover a wide range of disciplines such as:

- Impacts of operational fire suppression activities (such as the creation of physical fire guards, use of chemical retardants, etc.) on forest fuels and ecosystems. Delegations to a 3rd party could remove bias.
- How to best implement the fire science side of fuels management for values protection in a way that is acceptable to the public from a social science standpoint.
- Structural values protection in interface communities and reducing fuels around homes.
- The potential for fuel treatments to be applied by specialists in the field, such as the forest industry, or by local stakeholders and community-based groups.
- Testing new approaches to vegetation management outside of the realm of FireSmart, such as pyric herbivory.
- Updates to policy and legislation incorporating new research results and societal priorities.
- Updates to forest inventories.
- Ecological concerns and the importance of leaving fuels to maintain habitats for flora and fauna.
- Carbon emissions from wildfire and how to better manage forests to reduce carbon losses.
- Collaboration with timber groups regarding replanting strategies to find a compromise between maximizing potential future timber harvest and planting with fire suppression safety and effectiveness in mind.
- Exploration of a “citizen science” approach to fuels identification, classification, and measurement via smartphone camera applications.

Not important and not urgent (delete)

Given the nature of the workshop, time and attention were focused on topics of importance and urgency. As such, topics deemed not important and not urgent were not thoroughly discussed.

Looking forward

Fuels Friday provided a forum to openly discuss fuels measurement and analysis needs of the wildland fire community. This diverse group of wildfire practitioners, managers, researchers, and individuals from adjacent fields was able to explore the topics from a variety of angles, providing a multidisciplinary view of contemporary fuels topics. The need to generate Canada-wide standards and protocols with respect to fuels measurements and data processing/analysis was universally shared by workshop organizers and participants.

A key outcome of the workshop was the development of the Fuels Friday Working Group⁶. This voluntary task force of individuals from agencies across Canada is actively working to continue the momentum begun in Fuels Friday. The Fuels Friday Working Group is filling the gap, providing a hub of coordination and knowledge to ensure the priority needs identified in the workshop receive the attention, funding, and resources necessary. As of the writing of this report, the Fuels Friday Working Group has started working on the mission and vision of the group by creating a prioritized list of needs. Members are also actively collaborating on funding applications from numerous sources to help bring to realization the creation of a Canadian Fuels Hub.

Considering the success of the initial workshop and the strong desire to continue advancing the field of wildfire fuels, discussions are ongoing about the possibility of Canada Wildfire hosting a second Fuels Friday workshop in the near future.

Thank you to all the individuals and organizations who contributed to the creation and success of the first Fuels Friday workshop. Without your participation, Fuels Friday could not have come to fruition.

Appendix 1- List of in session presentations

Session 1 (<https://www.youtube.com/watch?v=BgQc5Z8Blbs>)

- Panel discussion [link](#)
- Fire modelling and Fuels in the Canadian Forest Fire Danger Rating System - Mike Wotton and Jonathan Boucher (Research Scientists, Canadian Forest Service) [link](#)
- Fuels Data and Input into the FIRETEC Model - Dan Thompson (Forest Fire Research Scientist, Canadian Forest Service), Rod Linn (Team Leader, Atmospheric Modeling and Weapons Phenomenology Team, Los Alamos National Laboratory), and Ginny Marshall (Wildfire Analyst, Canadian Forest Service) [link](#)
- Fuel Continuity and Fuels Structure Through the Eyes of an Ignition Specialist - Mike May (Senior Wildfire Training Specialist, Alberta Government) [link](#)
- Banff National Park - Landscape Fire Management and Fuels Data – Jane Park (Fire Vegetation Specialist, Parks Canada) [link](#)
- Fuels Fridays Practitioner Talk – Sonja Leverkus (Independent Contractor, Owner of Shifting Mosaics Consulting and Northern FireWoRx) [link](#)

Session 2 (<https://www.youtube.com/watch?v=9w0UuCG8mfc>)

- Surface Fuels Sampling - Bill de Groot (Adjunct Professor, University of Toronto; Retired, Canadian Forest Service) [link](#)
- Challenges with Measuring Fuel Weight and Bulk Density - Hilary Cameron (Restoration Specialist, Parks Canada), Steve Hvenegaard (Research Scientist, FPInnovations), Dave Schroeder (Prescribed Fire Program Coordinator, Alberta Agriculture and Forestry) [link](#)
- Challenges with Measuring Canopy Base Height - Hilary Cameron (Restoration Specialist, Parks Canada), Brandon MacKinnon (Research Scientist, FPInnovations), Dave Schroeder (Prescribed Fire Program Coordinator, Alberta Agriculture and Forestry) [link](#)
- Computing Canopy Fuel Load and Canopy Bulk Density from Field Measurements - Marty Alexander (Proprietor, Wild Rose Fire Behaviour) [link](#)

Session 2 - Micro-talks

- Rapid fuel characterization with in-stand and overflight photographs - Jen Beverly (Assistant Professor, University of Alberta) [link](#)
- Extracting fuel data from drone and satellite imagery with applications - Jeff Boisvert (Associate Professor, University of Alberta) [link](#)
- Airborne lidar forest mapping - Chris Hopkinson (Research Chair and Professor, University of Lethbridge) [link](#)
- Using lidar to characterize and measure fuels - Hilary Cameron (Restoration Specialist, Parks Canada) [link](#)
- Identifying 3D thematic information from lidar to inform fire fuels from tree to region - Laura Chasmer (Assistant Professor, University of Lethbridge) [link](#)

Session 2 Podcasts Interviews:

- Marty Alexander – Proprietor, Wild Rose Fire Behaviour [link](#)
- Judi Beck – Director General, Canadian Forest Service [link](#)
- Brian Stocks – Wildfire Science Specialist, B.J. Stocks Wildfire Investigations Ltd. [link](#)

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Many others kindly offered to read working drafts providing useful suggestions, edits, and comments. Thank you!

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