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Photo provided by Kody Wohlers. Canadian Prairies Prescribed Fire Exchange. Site: St. Dennis National Wildlife Area. Burn: October 2022

A look back at implementing the danger rating system

By Lynn Johnston[1], Colin McFayden[2]
[1] Forest Fire Research Specialist, Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, lynn.johnston@nrcan-rncan.gc.ca
[2] During this project: Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry, Aviation, Forest Fire and Emergency Services. Currently, Forest Fire Knowledge Exchange Project Leader, Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, colin.mcfayden@nrcan-rncan.gc.ca

We recently spent some time chatting with retired/semi-retired folks about their experiences in development of the Canadian Forest Fire Danger Rating System (CFFDRS) and how it became used operationally. Our motivation was to learn about what helped (or didn't help) this implementation process for both the researchers developing the danger rating system and the practitioners ultimately using the system. By adapting the perspectives and lessons learned from what is arguably one of the most successful examples of **knowledge exchange (KE)** in the Canadian fire business, we hope to improve the effectiveness of our future collaborative problem-solving efforts in fire science and management.

Knowledge exchange (KE) is an overarching process in which knowledge is collaboratively created, shared and transformed through stages of problem identification, enquiry, synthesis and application. KE is not a one-way push from knowledge producer to user, but is based on reciprocal learning to discover, create, or address something with mutual understanding and benefit. It is crucial for the successful development and integration of fire science and fire management.

The team working on this project included federal and provincial fire researchers (Colin McFayden, Colleen George, and Daniel Johnston from Ontario / Lynn Johnston, Mike Wotton, Meghan Sloane, and Josh Johnston from the CFS) and the project is described in detail in a journal article (McFayden et al. 2022). Here, we just wanted to give a brief overview of what we aimed to achieve and some of the results.

We sent out a short written survey and then held individual semi-structured interviews near the end of 2021 (all on video calls – thanks covid) with 14 people who were involved in fire science and management from the late 1960s to 2010s. The participants consisted of some of the principal Canadian Forest Service researchers and fire management practitioners active in the development and implementation of the danger rating system in Ontario. We focused on just Ontario to keep the project at a manageable size and given the decades-long collaboration between the CFS and Ontario, it made for a good case

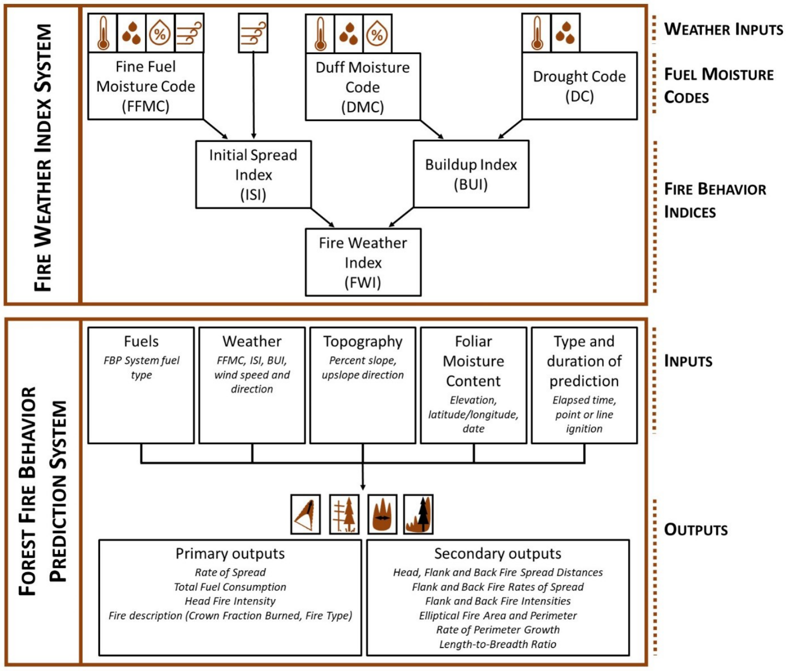


Figure 1: An overview of the inputs and outputs of the Canadian Fire Weather Index System (FWI System) and the Canadian Forest Fire Behavior Prediction System (FBP System), which are the two primary subsystems that make up the Canadian Forest Fire Danger Rating System (CFFDRS).

Figure 2: Photo of three of the interview participants - Tim Lynham (CFS), Bob Johnston (MNR), Doug McRae (CFS) - along with another MNR employee, from the aftermath of the Garibaldi, Ontario prescribed burn in 1986 that created a large vortex with enough power to exit the burning area and impale woody debris into the ground; relevant quote obtained from one of the interviews in this study.

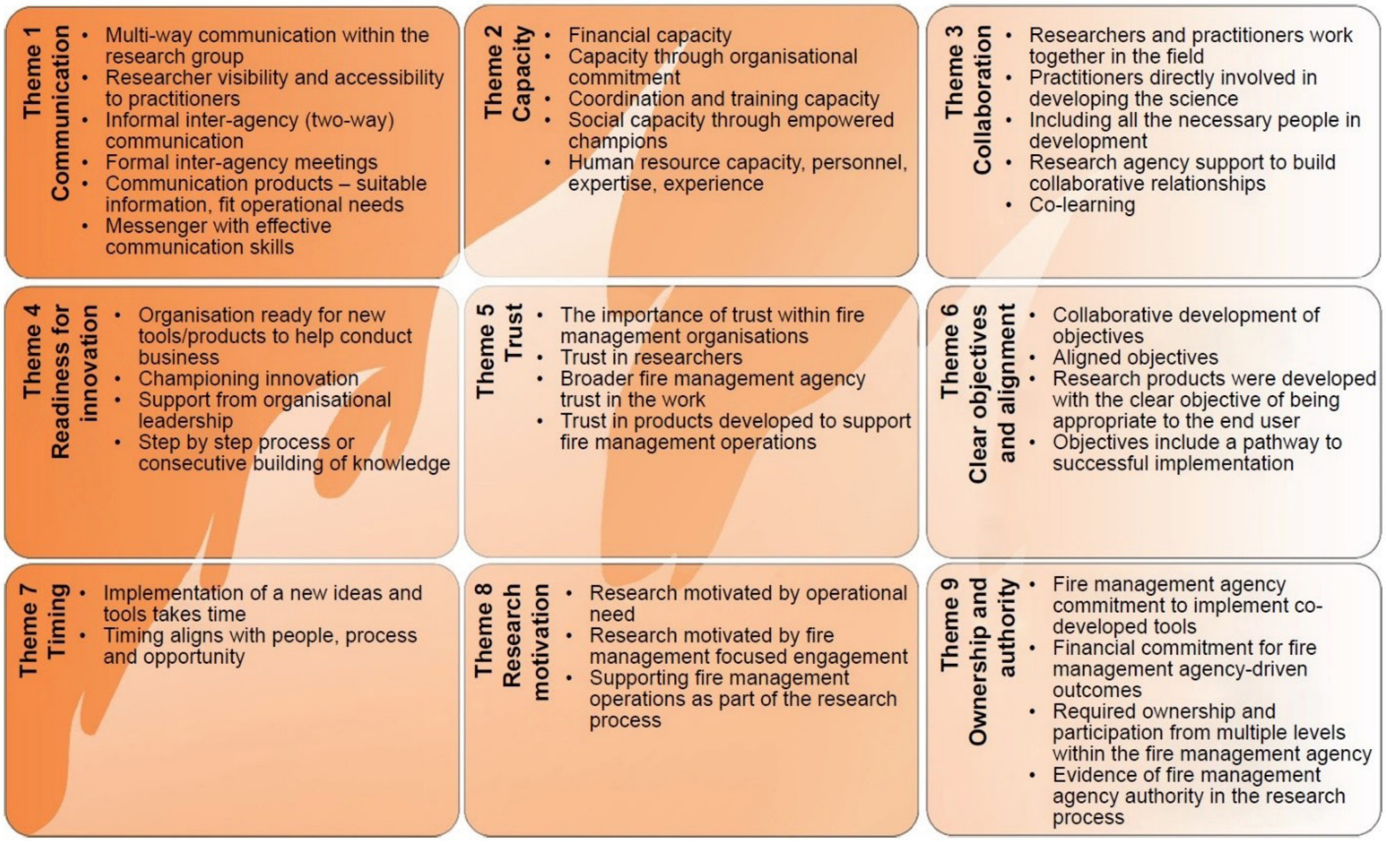
study. Other provinces and territories would have surely had unique experiences that reflect the context of their agencies and the relationships in them. Even though we focused on a single province, we assume some similar common themes would be likely. Most of the discussion was focused on the FWI and FBP Systems, as the main subcomponents of the CFFDRS (Figure 1), but all the interviews were fairly open-ended and framed by the participant's specific personal experiences in KE with a variety of initiatives (for example earlier implementation of fire occurrence prediction modelling).

All the participants had a lot to say (recordings of the interviews were almost 20 hours, with transcripts totalling almost 160k words), and from reminiscing to specific perspectives, there was such a genuine enthusiasm for sharing their experiences and belief in the importance of KE. Participants often highlighted the value of interpersonal relationships and informal dialogue as central to supporting mutual understanding, trust, buy-in, and the eventual implementation of research products. Shared field-based experiences as "currency" in the form of trust were a central element for many participants (Figure 2). The critical role of having the right individuals championing the work (within both researcher and practitioner roles) was also thought of as very crucial to success. Early engagement, and then bringing the researchers and practitioners along through the process together, helps build those needed relationships and inform the evolution of the research, and also to consider both the design of products and the training needs for end users.

We documented the perspectives on barriers and facilitators to KE throughout the interviews, closely studied what we heard in order to understand and contextualize what participants had said and identified emerging patterns. Using the general "themes" of barriers and facilitators to KE in wildland fire management we identified in previous work (McFayden et al. in press), we organized key findings from these interviews (Figure 3). Ultimately, we came up with a variety of specific barriers and facilitators specific to the FWI and FPB experiences in Ontario. We acknowledge that they could be categorized differently, and there are interactions between many of these elements – for example, factors that improve communication can also build trust.

In the publication of this work (McFayden et al. 2022), we outline each of the themes and provide an overview of the barriers and facilitators and some relevant quotes from the interviews. However, in our opinion, a lot of the most interesting information is in the supplemental, where we summarized perspectives for each theme and include examples of the supporting quotes from the interviews (fair warning: the supplemental is long! – but we think it's worth the read).

A mindful understanding of the potential barriers and facilitators in the KE process is important and can hopefully lead to more effective two-way flow of knowledge between researchers and practitioners. Though priorities shift (e.g. scientists must prioritize publication and international collaboration over local practical tools), organizational environments face increasing pressure (e.g.



Theme 1 Communication • Multi-way communication within the research group • Researcher visibility and accessibility to practitioners • Informal inter-agency (two-way) communication • Formal inter-agency meetings • Communication products – suitable information, fit operational needs • Messenger with effective communication skills	**Theme 2 Capacity** • Financial capacity • Capacity through organisational commitment • Coordination and training capacity • Social capacity through empowered champions • Human resource capacity, personnel, expertise, experience	**Theme 3 Collaboration** • Researchers and practitioners work together in the field • Practitioners directly involved in developing the science • Including all the necessary people in development • Research agency support to build collaborative relationships • Co-learning
Theme 4 Readiness for innovation • Organisation ready for new tools/products to help conduct business • Championing innovation • Support from organisational leadership • Step by step process or consecutive building of knowledge	**Theme 5 Trust** • The importance of trust within fire management organisations • Trust in researchers • Broader fire management agency trust in the work • Trust in products developed to support fire management operations	**Theme 6 Clear objectives and alignment** • Collaborative development of objectives • Aligned objectives • Research products were developed with the clear objective of being appropriate to the end user • Objectives include a pathway to successful implementation
Theme 7 Timing • Implementation of a new ideas and tools takes time • Timing aligns with people, process and opportunity	**Theme 8 Research motivation** • Research motivated by operational need • Research motivated by fire management focused engagement • Supporting fire management operations as part of the research process	**Theme 9 Ownership and authority** • Fire management agency commitment to implement co-developed tools • Financial commitment for fire management agency-driven outcomes • Required ownership and participation from multiple levels within the fire management agency • Evidence of fire management agency authority in the research process

Figure 3: Barriers and facilitators identified through the participant interviews in this study, organized by themes from McFayden et al. (in press); figure by McFayden et al. (2022).

fast pace and high-stakes decision-making in operations), and specifics surrounding some of the factors influencing KE might have changed in more recent times (e.g. we often heard the “black box” of computer-based data or approaches using new digital technology were huge barriers in the past), our hope is that the results of this work can be useful in future KE in fire science and management. On a personal level, participating in this research was an act of KE itself, and has changed the way we look at our approach to understanding problems and building solutions together.

Finally, we would like to thank the participants in this study: Bill Droog, Bob Elliott, Rob Frech, Norma Griffin, Robert Janser, Bob Johnston, Bruce Little, Tim Lynham, Rob McAlpine, Doug McRae, Susan Reany-Iskra, Brian Stocks, Al Tithecott and Paul Ward for their thoughtful reflections and eagerness to share in what we found to be very impactful discussions.

Check out the full story on this work:

McFayden CB, George C, Johnston LM, Wotton M, Johnston D, Sloane M, Johnston JM (2022) International Journal of Wildland Fire 31(9) 835-846. https://doi.org/10.1071/WF22015

McFayden CB, Johnston LM, Woolford DG, George C, Johnston D, Boychuk D, Wotton BM, & Johnston JM (in press) A Conceptual Framework for Knowledge Exchange in a Wildland Fire Research and Practice Context, published in Applied Data Science: Data Translators Across the Disciplines, edited by D Woolford, D Kotsopoulos, & B Samuels, [2023; in-press], Springer reproduced with permission of Springer Nature. The final authenticated version is in press; https://link.springer.com/book/9783031299360

Classifying forest fuels with fuel inventory data in fire-prone ecosystems of Alberta

By Nathan Phelps[1,2], Jennifer L. Beverly[1]
[1]Department of Renewable Resources, University of Alberta, Canada
[2]Current Affiliation: Department of Statistical and Actuarial Sciences, University of Western Ontario, Canada
Corresponding author: nphelps3@uwo.ca

Introduction

Wildfire behaviour is dictated by local fuel, weather, and topographic conditions. Of these three fire environment factors, only fuels can be managed (Keane 2015). Fuel characteristics are used to predict potential fire behaviour (Van Wagner 1983), map fire hazard (e.g., Keane et al. 2001; Fernandes 2009), and identify locations most susceptible to burning (e.g., Shang et al. 2020; Beverly et al. 2021). Currently, forest fuels in Canada are described using one of 12 standard fuel types defined by the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). In our study, we considered an alternative approach for classifying forest fuels that more explicitly considers the ways fuels influence wildfire behaviour. To do this, we used data collected in Alberta during a long-term fuel inventory program. In the following sections, we provide a condensed summary of the study, which is documented in detail in Phelps and Beverly (2022)[a].

Fuel inventory data

Detailed measurements of forest structure and composition were carried out by field crews at over 900 plots in the province of Alberta during the Alberta Wildland Fuels Inventory Program (AWFIP) between 2007 and 2019, inclusive. The resulting dataset offers an incredibly rich source of information, with dozens of observations collected for each of 1313 sampling events[b]. The observations include details about individual trees (e.g., height, diameter at breast height) and shrubs, as well as samples of soil, mulch, and many other fuel attributes. However, despite the richness of the data collected, the AWFIP dataset is far from perfect for conducting research studies.

One of the challenges of working with inventory data is that these measurements, and the underlying sampling design, were not devised as part of a specific research study. The long-term nature of the inventory program also introduced challenges due to adjustments to field procedures over time. Manual data entry measurements originally recorded on handwritten field sheets introduced typographical errors as well. Thus, while the AWFIP data has been used for prior research studies (e.g., Wilkinson et al. 2018; Thompson et al. 2020; Cameron et al. 2021, 2022a, 2022b), these studies tend to rely on small subsets of the inventory records (e.g., 79 sampling events). To enable broader use of the available data in research studies, we created a relatively large, cleaned subset of 476 sampling events. The cleaned dataset includes values calculated from the raw AWFIP data such as stand density, the proportion of conifer trees in the canopy, and a variety of fuel loads. More details about the process undertaken to create the cleaned dataset, as well as the dataset itself, are available in Phelps et al. (2022).

Fuel classification in Canada

In Canada, fuels are typically classified using the FBP System fuel types. A forest stand is assigned one of 12 possible forest fuel types based on vegetation, primarily to reflect overstory tree species but also other attributes such as stand density (Frederick 2012). These fuel types are used as inputs to decision support systems used by fire researchers and managers (Wotton 2009; Taylor et al. 2013). For example, in the FBP System, canopy fuel load (CFL) is used to calculate fuel consumption for input into Byram's (1959) fireline intensity equation, and each fuel type is assigned a default CFL for that purpose. However, it is well-

Figure 1. Two stands classified as C-2 Boreal Spruce with fuel structures that exhibit very different vertical and horizontal arrangements. These stands are both located in Alberta, approximately 10 km from each other. Photos are courtesy of Alberta Wildfire.

[a]Figures 2, 3, and 4, as well as selected text excerpts herein are reproduced from Phelps and Beverly (2022) under a under a Creative Commons Attribution 4.0 International License: https://creativecommons.org/licenses/by/4.0/.
[b]There are more sampling events than plots because some plots were sampled multiple times.

known that stands within the same fuel type can exhibit considerable natural variation in surface and canopy fuel characteristics (e.g., Alexander et al. 2004; Lavoie 2004; Johnston et al. 2015; Beverly et al. 2020). See Figure 1 for an example of two C-2 Boreal Spruce stands with very different fuel structures.

FBP System fuel types were designed to represent natural stand conditions. Structural modifications to a stand caused by harvesting or FireSmart fuel reduction treatments can create conditions that are not well-represented by any of the FBP System fuel types. FireSmart treatments generally involve the removal of trees to reduce stand density and/or pruning the lower limbs of trees and removing understory fuels to limit the potential for a fire spreading on the surface to move into the suspended canopy fuels and spread from tree crown to tree crown.

The FBP System fuel types are an example of classification done using the association method described by Keane (2013). An alternative approach for describing fuel characteristics is to use direct classification, in which fuel data measurements are used to uncover groupings, or classes, in the data, using analytical methods like clustering. We used direct classification of the AWFIP fuel inventory data to explore: (1) predicted crown fire behaviour among data-derived fuel classes; (2) alignment of our data-derived classes with assigned FBP System fuel types; (3) the factors that influence a stand's membership in a given data-derived fuel class; and (4) the impact of fuel reduction treatments in the most flammable fuel class on predicted crown fire behaviour.

Fuel classification using clustering

Prior to our study, a direct approach to fuel classification through clustering had yet to be applied in Canada, but was used previously in several other parts of the world, including the USA, Mexico, China, and the Mediterranean (e.g., Miller et al. 2003; Poulos et al. 2007; Wu et al. 2011; Elia et al. 2015; Berkey et al. 2021).

Methodology

Here, we highlight key aspects of our methodology. A comprehensive description of the methods used along with technical details are provided in Phelps and Beverly (2022). Clustering is a machine learning technique that is used to put similar observations in the same group and dissimilar observations in different groups. We considered two different clustering methodologies: agglomerative hierarchical clustering and K-means clustering (Hartigan and Wong 1979). Ultimately, we chose to use K-means clustering to classify our forest stands based on fuel attributes. We called the resulting clusters fuel class clusters (FCCs).

An important part of the clustering process is the selection of the features inputted to the clustering algorithm. In our case, we were interested in categorizing the stands according to their potential crown fire behaviour, so we focused on three fuel attributes relevant to crown fires: surface fuel load (SFL), live canopy base height (CBH), and canopy bulk density (CBD). SFL included measurements of litter, forbs, grass, understory trees, mulch, and fine woody debris (diameter <1 cm). Shrub and duff fuel were initially explored as potential contributors to SFL calculations but were excluded; however, clustering results were similar regardless of the inclusion of these fuels.

Measurements of SFL, CBH, and CBD are not readily available from the AWFIP records. We computed CBH and CBD for all records within our cleaned subset of the AWFIP data. SFL was computed by simply adding the fuel loads for the individual components of surface fuel. Details of these computations are provided in Phelps et al. (2022).

To compare our FCCs and FBP System fuel types, we used a series of plots. To help us understand the drivers behind FCC membership, we used a decision tree and a random forest, two supervised machine learning algorithms. Stand characteristics that we thought could potentially influence FCC membership were the stand's FBP System fuel type, proportion of live trees, moisture regime classification, average litter and duff depth, canopy and understory stand density of live conifers, average age of coniferous and deciduous trees, and treatment status (i.e., managed or natural stand state). The decision tree was used to provide a rudimentary understanding of the decision pathway determining which cluster a stand belongs to, while the random forest provided rankings of the relative importance of each stand characteristic examined.

We used two different approaches to evaluate potential crown fire behaviour. First, we used Byram's (1959) equation to calculate fireline intensity and Van Wagner's (1977) equations to determine if a surface fire is sufficiently intense to move into the crown and then sustain itself as a crown fire. Our second approach used empirical equations developed by Cruz et al. (2004, 2005) for computing the probability of crown fire occurrence and active crown fire rate of spread. For a detailed description of these methods, refer to Phelps and Beverly (2022).

Results

Four FCCs were identified (Table 1, Figure 2):

- Black FCC (n=93): low SFL, moderate CBH, high CBD
- Blue FCC (n=100): low SFL, high CBH, low-moderate CBD
- Green FCC (n=54): high SFL, low-moderate CBH, low CBD
- Red FCC (n=229): low SFL, low CBH, low CBD

Fuel Class Cluster	Mean SFL (kg/m^2)	Mean CBH (m)	Mean CBD (kg/m^2)	Min. ROS for Crowning (m/min)	Min. ROS for Sustained Propagation of Crown Fire (m/min)
Black	1.37	5.71	0.23	5.60	12.92
Blue	1.31	9.29	0.12	12.15	25.56
Green	2.92	4.22	0.06	1.66	48.50
Red	1.21	3.35	0.06	2.85	51.25

Table 1. Summary of fuel attributes and predicted fire behaviour by fuel class cluster (FCC): mean surface fuel load (SFL), live canopy base height (CBH), and canopy bulk density (CBD). Minimum rate of spread (ROS) for crowning and sustained propagation of a crown fire are shown for the centroid of each FCC, assuming 100% foliar moisture content.

From Table 1, we can see that crowning is plausible for all four FCCs, but the Red and Green FCCs need very high rates of spread for a crown fire to propagate through the canopy. In the Blue FCC, an active crown fire is plausible under comparatively less extreme conditions, but this FCC is also the least receptive to crown fire initiation. The Black FCC is the most susceptible to an active crown fire; a crown fire can initiate with a lower rate of spread than the Blue FCC, and a much lower rate of spread is required for sustained propagation of a crown fire than any other FCC. Applying the empirical equations of Cruz et al. (2004, 2005) to the centroids of each FCC provided results consistent with this interpretation, solidifying our findings about the relative susceptibility of the FCCs to active crown fires.

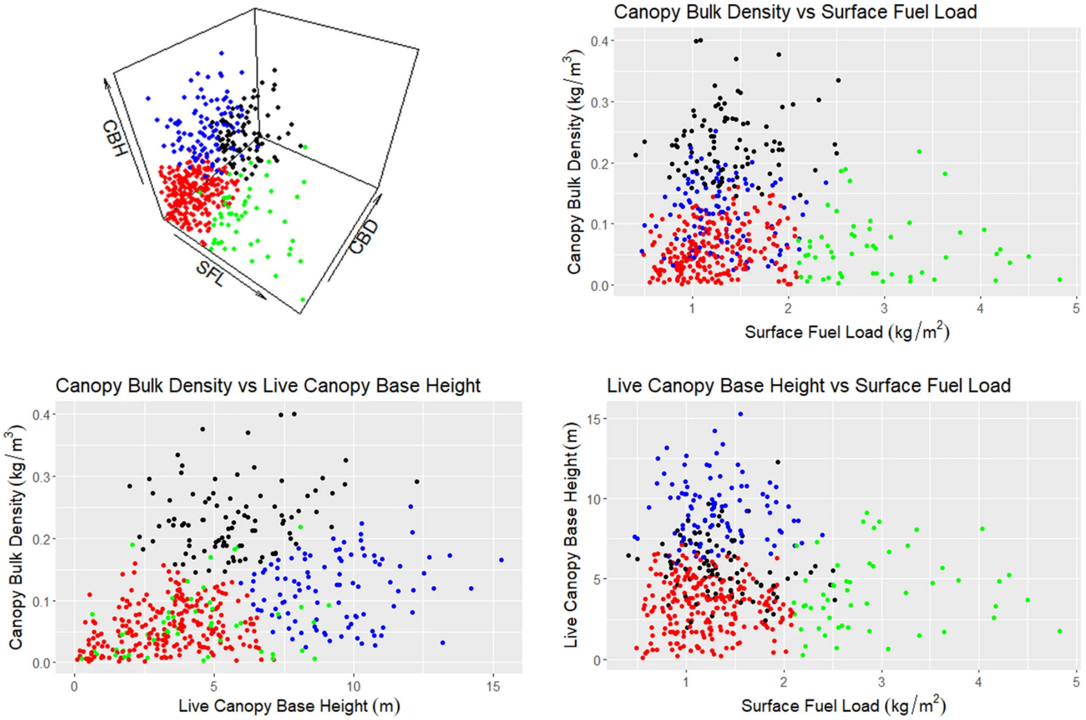


Figure 2. Scatter plots of surface fuel load (SFL), live canopy base height (CBH), and canopy bulk density (CBD), and corresponding fuel class cluster (FCC) membership denoted by red, blue, black, and green colour reference.

In Figure 3, we show the same plots as in Figure 2, but colour-coded based on FBP System fuel type. We note that some stands did not align with any FBP System fuel type, so they were labeled as Mixed Conifer, as described in Phelps et al. (2022). Although there are some patterns evident in the plots (e.g., Deciduous stands have very low CBD), clear clusters are not evident like they are in Figure 2. This is not surprising given that we would expect the structural characteristics of a given stand to reflect natural environmental variability associated with different stand ages, site conditions, and life histories. Figure 4 shows the distribution of FCCs in each FBP System fuel type and vice-versa. Perhaps the most notable observation from this figure is that the C-2 Boreal Spruce fuel type is largely composed of stands from two FCCs, the Red and Black FCC, which have very different fuel structures.

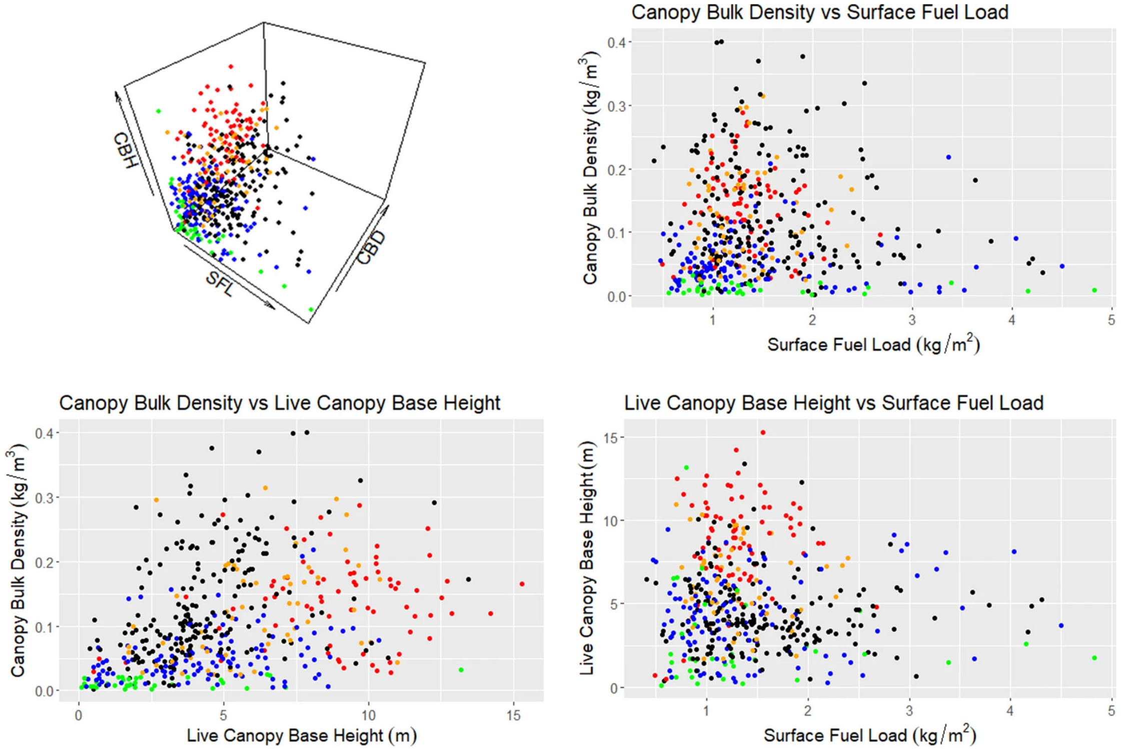


Figure 3. Scatter plots of observations of surface fuel load (SFL), live canopy base height (CBH), and canopy bulk density (CBD) and corresponding FBP System fuel type denoted by reference colours: C-3 Mature Jack or Lodgepole pine, red; M-1/M-2 Boreal Mixedwood, blue; C-2 Boreal Spruce, black; D-1/D-2 Deciduous, green; and Mixed Conifer, orange.

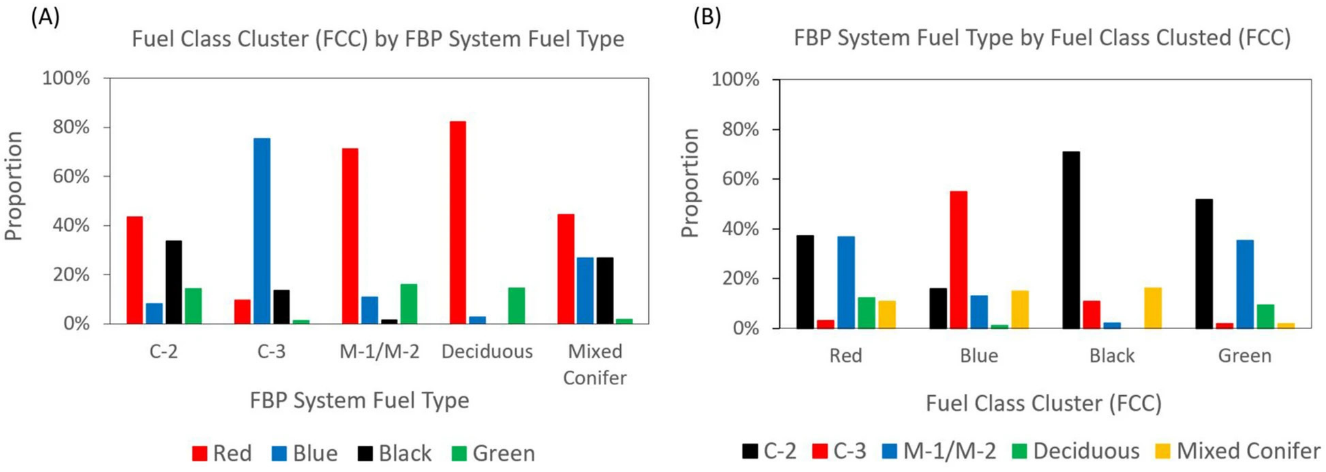


Figure 4. A Distribution of fuel class clusters (FCCs) by Canadian Forest Fire Behavior Prediction (FBP) System fuel type. B Distribution of FBP System fuel types by FCC.

When we studied the probability of crown fire occurrence and active crown fire rate of spread under several values of wind speed and fine fuel moisture content using the equations from Cruz et al. (2004, 2005) for all C-2 Boreal Spruce stands in the dataset, two important observations were highlighted. The first was that crown fire behaviour is highly variable, even within a single FBP System fuel type. Second, when colour-coding the lines in the plots by FCC, we could see that the FCCs explained much of the variability in crown fire behaviour within the C-2 fuel type, as shown in Phelps and Beverly (2022, Fig. 6).

When we created a decision tree to help us understand what drives cluster membership, we found that stand density of live conifers in the canopy and FBP System fuel type were the most important features. Our analysis using the random forest provided the same findings. Notably, fuel treatment status was of very little importance – it ranked third last, ahead of only the average age of the deciduous trees and depth of duff. However, when we analyzed nine stands from the Black FCC (pre-treatment) with both pre- and post-treatment data, we found that eight of the nine stands moved to a different FCC after treatment. The primary impact of the treatment was in reducing the vulnerability to active crown fire spread, as opposed to initiation of a crown fire.

Discussion and conclusions

We used fuel inventory data and K-means clustering to identify fuel class clusters (FCCs) based on three fuel attributes: SFL, CBH, and CBD. Our FCCs were not well-aligned with FBP System fuel types. The attributes we used in our cluster analysis were selected because they are all highly relevant to crown fire behaviour. It was therefore not surprising that FCCs explained more of the stand-to-stand variability in modelled crown fire behaviour than FBP System fuel types.

Our results show that potential crown fire behaviour is highly variable, even within the same FBP System fuel type. This provides some insight into the uncertainty of the fuel input data utilized in a wide range of models, such as fire behaviour predictions and fire growth simulations, that are widely relied upon in research studies and for supporting fire management decisions (Wotton 2009; Taylor et al. 2013). Our clustering also illustrates that different stand types, composed of different tree species, can have fuel structures that are similar with respect to their susceptibility to crown fire.

Fuel treatments were not a significant determinant of FCC membership; however, they generally reduce stand density, which was the most important determinant of FCC membership of the stand characteristics we considered. Fuel treatments conducted in the FCC most conducive to crown fire initiation and active crown fire spread (i.e., the Black FCC) were effective at changing the stand's fuel class and inhibiting crown fire spread. Fuel treatments did not substantially affect the modelled potential for crown fire initiation in these stands.

FCCs are assigned to a given forest stand using field measurements of fuel attributes that are not widely available due to the time and cost involved. At localized sites, such as an experimental burning project or fuel treatment block, rapid fuel assessment methods could potentially enable assignment of our FCCs through coarse estimates of SFL, CBH, and CBD obtained with hemispherical photography (e.g., Cameron et al. 2021), nadir photography (e.g., Cameron et al. 2022a), or photographic fuel load reference guides (e.g., Lavoie et al. 2010; Keane and Dickinson 2007).

Rapidly evolving remote sensing methods may one day enable broadscale FCC development and mapping across large landscape areas using technologies such as LiDAR to estimate fuel attributes such as CBD (e.g., Cameron et al. 2022b) and SFL (e.g., Stefanidou et al. 2020). The FCCs and associated fuel attributes summarized in this study could also provide useful reference data and potential inputs to new fire behaviour models and fire behaviour modelling studies.

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Grassland fire research database – analysis of the impact of fire on grassland productivity and diversity

By Roy Vera-Velez[1,2,] Dinyar Minocher[1], Renny Grilz[3], and Eric G. Lamb[2]
[1] Canadian Prairies Prescribed Fire Exchange, Saskatoon, Canada
[2] Department of Plant Sciences, University of Saskatchewan, Saskatoon, Canada
[3] Meewasin Valley Authority, Saskatoon, Canada
Corresponding author: rveravelez@meewasin.com

Introduction

Fire is a key driver of ecosystem structure and function in grasslands, but we live in a fire-deficit era. Thousands of years of burning cycles and grazing have led to the co-evolution of plants turning grassland into stable plant communities that require periodic ecological disruptions (Anderson 2006). Burning and herbivory are necessary ecological processes to maintain a suitable habitat for plants and animals. 'Near' extinction of bison in the early 1800s and subsequent fire suppression have caused an ecosystem imbalance, such as tree and shrub overgrowth and increased intensity and frequency of wildfires (Campbell et al. 1994). Understanding that fire is an essential component of grasslands and parkland ecosystems, it is crucial to address fire application constraints and halt the decline of prairies' health.

Returning fire to the prairies has been one of the main goals for environmental agencies during the last couple of decades. A lack of accessible training opportunities, public support and awareness, and proper equipment, coupled with insurance liability concerns, have been among the main limitations to putting fire on the land. The Canadian Prairies Prescribed Exchange (CPPFE) is an inter-agency collective established to identify and overcome such limitations and increase the capacity to conduct prescribed fires in a safe and effective manner.

One of the objectives of the CPPFE is to share fire science. For the CPPFE, this involves seeking research opportunities and sharing existing relevant findings in the field with fire practitioners. Within this context, we have compiled numerous scientific documents in an annotated bibliography on grassland fire research that will strengthen the inter-agency collaboration in conducting controlled burns in the prairies with the best possible information. To narrow things down on the scope and applicability of the grassland fire research database (GFRD), we first explored two primary reasons for using prescribed fire as relevant indicators: forage productivity and species diversity.

A major case often cited for using prescribed fires is to increase grassland productivity and diversity. Many individual studies have examined fire effects on Western Canada, but no quantitative reviews or summaries of this work exist. This is a significant gap because the principal conservation justification for using prescribed fire has not been systematically measured. Most existing studies are focused on rangeland productivity, and a clear ecological justification is needed when fires are proposed. This study aims to synthesize data from individual studies on fire through a formal meta-analysis (Koricheva, Gurevitch & Mengersen 2013). This will allow us to 1) confirm the value of fire in maintaining the ecological integrity of small grassland patches and 2) evaluate the rate of grassland recovery post-fire. These objectives are critical in 1) establishing the use case for prescribed fire in remnant grasslands and 2) determining appropriate fire intervals (i.e., time between fires).

Methodology

We searched for primary research and peer-reviewed articles on the impact of fire on grassland productivity and diversity by using ISI Web of Knowledge (www.isiknowledge.com) and google scholar (www.scholar.google.com). We used a number of keyword combinations for our search effort enclosed in a 30-year timeframe, yielding more than 2000 published papers, where ca. 233 were selected and fully examined (Figs. 1 and 2).

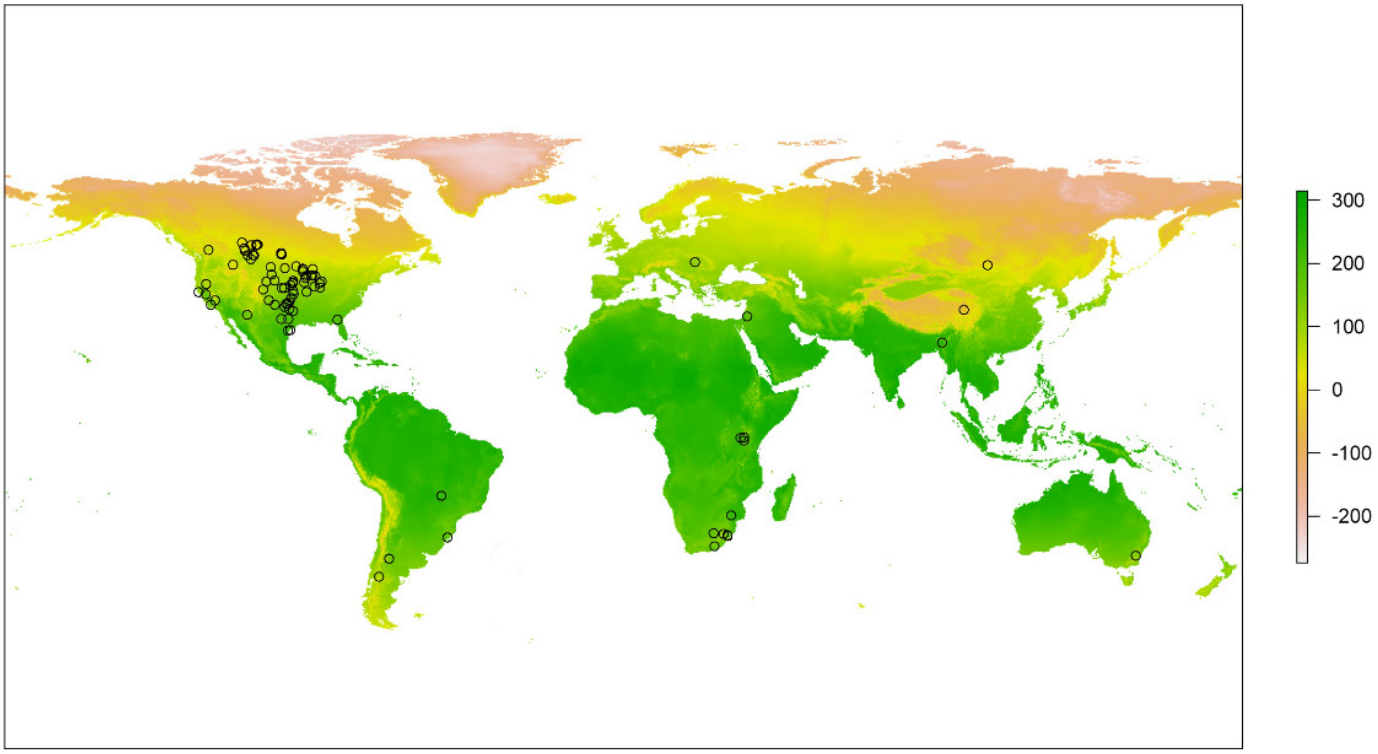
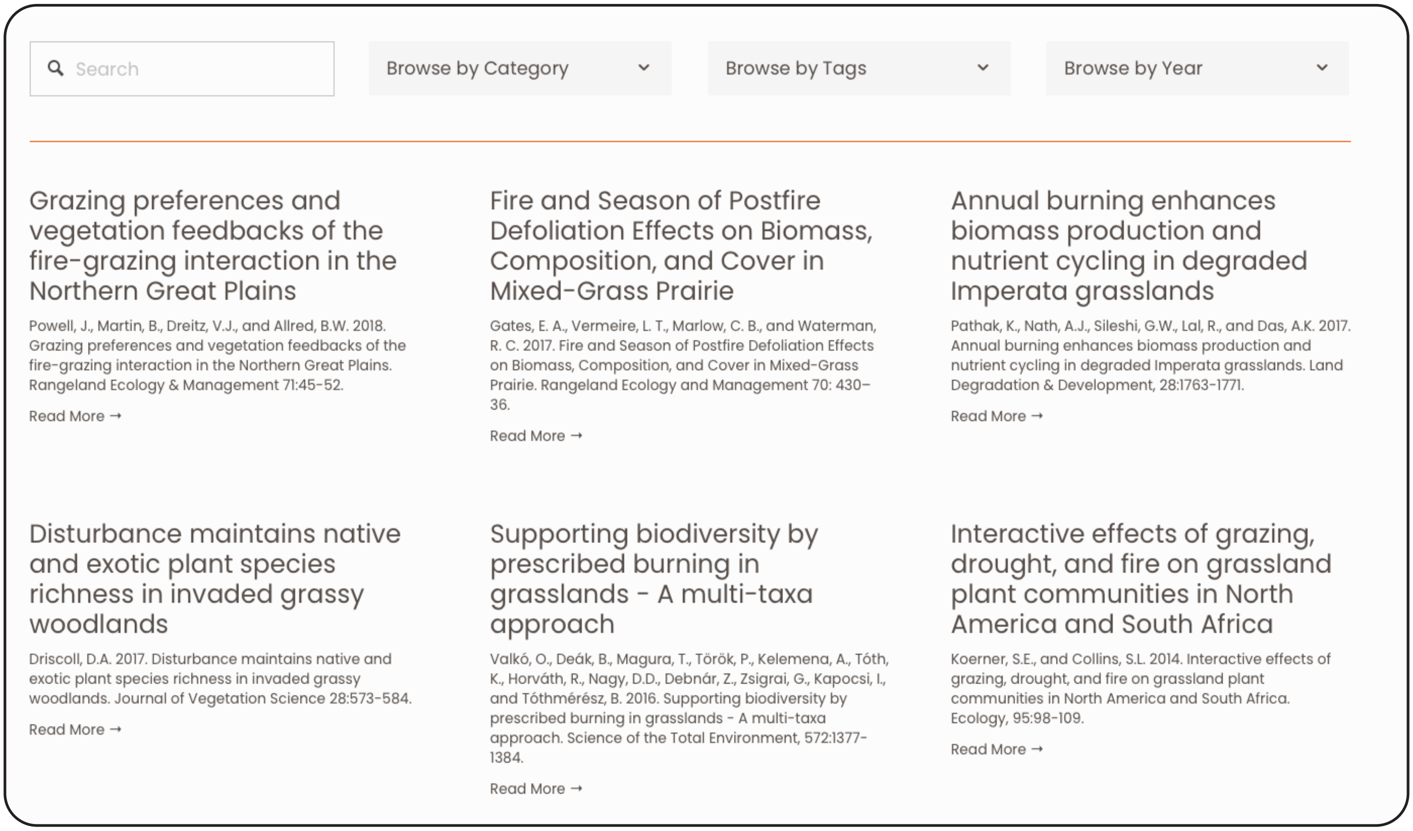


Figure 1. Global map showing the location of the selected peer-reviewed articles. Colour gradient represents variation in precipitation. Right side displays the scale of the average annual rainfall in mm.



Grazing preferences and vegetation feedbacks of the fire-grazing interaction in the Northern Great Plains

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Fire and Season of Postfire Defoliation Effects on Biomass, Composition, and Cover in Mixed-Grass Prairie

Gates, E. A., Vermeire, L. T., Marlow, C. B., and Waterman, R. C. 2017. Fire and Season of Postfire Defoliation Effects on Biomass, Composition, and Cover in Mixed-Grass Prairie. Rangeland Ecology and Management 70: 430–36.

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Annual burning enhances biomass production and nutrient cycling in degraded Imperata grasslands

Pathak, K., Nath, A.J., Sileshi, G.W., Lal, R., and Das, A.K. 2017. Annual burning enhances biomass production and nutrient cycling in degraded Imperata grasslands. Land Degradation & Development, 28:1763-1771.

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Disturbance maintains native and exotic plant species richness in invaded grassy woodlands

Driscoll, D.A. 2017. Disturbance maintains native and exotic plant species richness in invaded grassy woodlands. Journal of Vegetation Science 28:573-584.

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Supporting biodiversity by prescribed burning in grasslands - A multi-taxa approach

Valkó, O., Deák, B., Magura, T., Török, P., Kelemena, A., Tóth, K., Horváth, R., Nagy, D.D., Debnár, Z., Zsigrai, G., Kapocsi, I., and Tóthmérész, B. 2016. Supporting biodiversity by prescribed burning in grasslands - A multi-taxa approach. Science of the Total Environment, 572:1377-1384.

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Interactive effects of grazing, drought, and fire on grassland plant communities in North America and South Africa

Koerner, S.E., and Collins, S.L. 2014. Interactive effects of grazing, drought, and fire on grassland plant communities in North America and South Africa. Ecology, 95:98-109.

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Figure 2. Sample of the annotated bibliography on grassland fire research uploaded to the Canadian Prairies Prescribed Fire Exchange (CPPFE) website www.grasslandfire.ca.

We extracted the metadata of the selected papers, including details such as study community, location, geographic coordinates, plot size, and burn frequency. The mean and standard deviation of control and burned samples were obtained by categories of life form (i.e., forbs, grasses, and woody plant species) and time since fire. We used SMD - *standardized mean differences* (Hedges 1981; Hedges and Olkin 1985) to evaluate the response of grassland biomass and diversity (i.e., species richness) to fire. Precipitation and temperature from each published article's research site were also extracted using an extrapolation algorithm in R (R Core Team 2021) and bioclimatic information from 'WorldClim' (Fick and Hijmans 2017). Climatic information helped us to test the relationship between the response of grassland to fire based on varied levels of precipitation and temperature.

Preliminary Findings

We found a wide number of studies on prescribed fires in grassland ecosystems under a range of weather parameters. Our models suggest that grassland productivity and diversity response to fire vary with annual precipitation and temperature (Fig. 3). Post-fire biomass growth seems more sensitive than plant diversity to these weather factors, and while there is a general decline in total biomass response to fire, burning has an apparent positive effect on plant diversity in grasslands (Fig. 4).

These results show that climate is critical in grassland productivity response to fire. As such, these models can guide controlled burns for specific goals, such as improving forage and livestock production. Further, these models could be helpful as a potential prediction tool for the impacts of fire on grassland diversity that could be valuable for fire practitioners and wildlife managers to enhance habitat restoration.

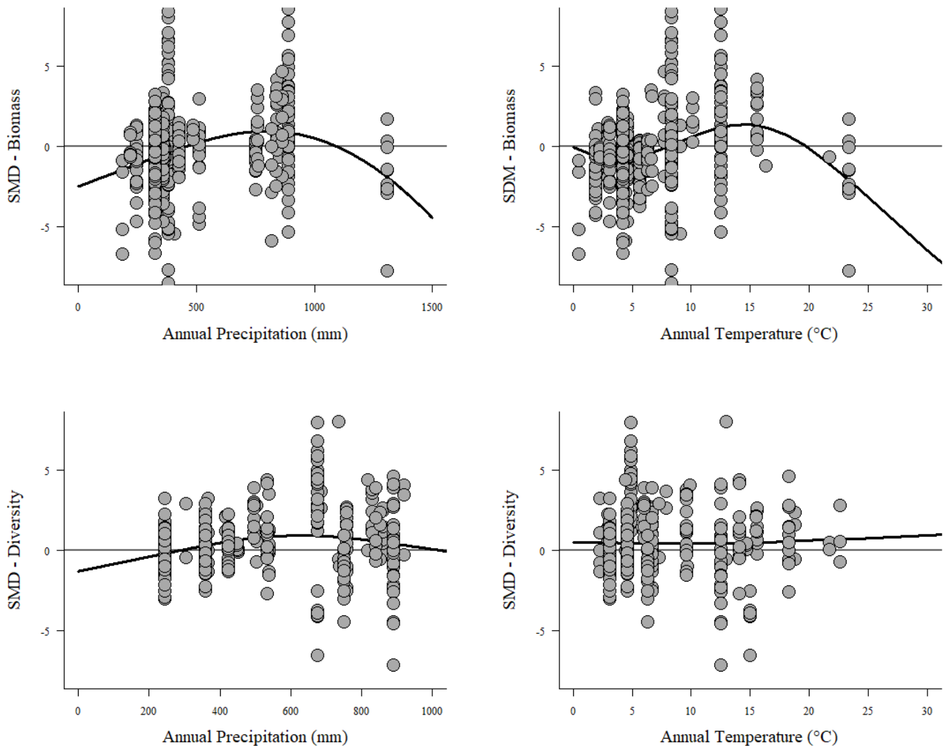

Figure 3. Scatter plots showing non-linear relationships between weather variables and the standardized mean difference of biomass (top panels) and diversity (low panels), respectively. Each circle represents a single study, and black lines display the predicted trajectory of the grassland vegetation response to fire.

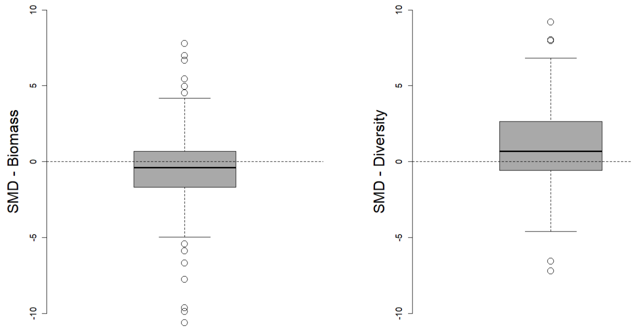

Figure 4. Box plots displaying the variability of total grassland biomass and diversity response to fire. Both panels show the accumulated values of three plant functional groups (i.e., grasses, forbs, and shrubs).

Finally, the annotated bibliography of the GFRD is available on our website, www.grasslandfire.ca. This fire research database is continuously updated with new primary research conducted in the prairies. In addition, we are currently working on a manuscript with detailed results on the meta-analysis of the impact of fire on grassland productivity and diversity; we expect to have this paper published soon. Data from the meta-analysis will also be available on our CCPFE website. Finally, we are happy to work on future research projects. If people have ideas or papers they want in our database, they are welcome to write to us.

Acknowledgments

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Wildfire science in a century of emergencies

By Al Pankratz, retired from Environment and Climate Change Canada's Prairie and Northern Region Air Quality Research Section with 13 years of experience in smoke forecasting. He is the former editor of the Canadian Smoke Newsletter, the predecessor of this publication.

Background

To say that the first two decades of the 21st century have been eventful from a wildfire perspective would be a considerable understatement. Unprecedented wildfires burned in Greenland[1]. Arctic regions in Siberia experienced extreme heat waves and widespread fires[2]. Australia's 2019-20 bushfire season resulted in over 24 million hectares burned[3], thousands of buildings destroyed, and over 4 billion dollars incurred in immediate costs, along with devastating effects on animal species. In the western US, numerous towns were destroyed by fire, including Paradise, CA in 2018. Pacific Gas and Electric, California's largest power company, filed for bankruptcy protection under the threat of $30 billion in claims related to damage from wildfires.

In Canada, three cities were partially consumed by fire (Kelowna in 2003, Slave Lake in 2011, Fort McMurray in 2016), and one village was leveled (Lytton in 2021). Many other Canadian towns and cities spent weeks or months under blankets of smoke in the BC Interior (2010, 2017, 2018), Yukon (2004) and the NWT (2014). Summer temperatures in southern BC approached 50°C in 2021, demolishing Canadian records. Extended periods of smoke and evacuations from homes added untold stress to the lives of those affected. Of particular concern to Canada is the fate of the boreal forest. North American and Eurasian boreal fire emissions, normally responsible for 10% of global wildfire CO_2 emissions, contributed 23% in 2021[4].

These events are individual snapshots within a broader trend toward warmer temperatures, and that trend has been rapid, more rapid than at any time in the past 65 million years[5]. In a recent paper[6], Weitzman notes that in 800,000 years of recorded carbon dioxide (CO_2) fluctuations from air trapped in ice cores, increases remained below 25 ppm for any 1000 year period. Our planet has seen a rise higher than 25 ppm in just the past decade.

Whether the rapidity of climate change has been unexpected is a matter of some debate[7]. The current global average temperature rise is within the range of previous predictions, including internal studies done by oil companies going back so far as the 1970s[8]. Nevertheless, how that rise has played out has surprised many. Past IPCC predictions have already been eclipsed by events to greater or lesser degrees[9]. Therefore, questions arise as to the appropriateness of basing policy on middle-of-the-road scenarios.

While we cannot predict individual wildfire and smoke events in the remaining decades of this century, some things are known. We know that over the past several decades, our planet has warmed significantly[10]. Climate patterns are shifting and many ecosystems are struggling to adjust[11]. And climate models, despite having areas of uncertainty, have generally performed well in predicting observed warming[12].

Two more considerations should give us pause:

- Climate change has the potential to render our planet so drastically changed that many of its inhabitant species will either be decimated or rendered extinct. In other words, climate change carries the ultimate downside risk.
- Despite four decades of global climate conferences, programs, plans, frameworks, initiatives, reports, regulations and expenditures, greenhouse gas (GHG) concentrations continue to rise. [13]

Risk

The financial crisis of 2008 arose in part because market returns were modelled using the assumption that they followed a normal probability distribution, and that the risk of price moves beyond three standard deviations from the mean was so low as to be discountable. Subsequent research has shown that those returns would have been more appropriately depicted using skewed distributions with much fatter tails[14,15].

The other important factor at play in the financial crisis was that the risks being discounted were high-impact events, potentially involving market contagion, and with dire implications for the world's financial system. In the end, governments were forced to step in and rescue banks from the results of their own folly for fear of having the international finance system implode. Such were the consequences of misapprehended financial risk.

There are significant similarities in how we approach climate risk today. At present, our actual actions (not our rhetoric, but our actions) are again indicating that we view the tail risks of climate disaster as discountable. This is unwise for the following reasons:

- we cannot predict the choices or non-choices that future societies will make with respect to GHG emissions;
- we do not fully understand self-amplifying climate feedbacks, such as methane release from permafrost or clathrate melting, or the variability of ocean CO_2 absorption[16];
- we do not fully understand tipping points in the climate system that may propel us into new stable modes of climate which are not guaranteed to be human-friendly[17,18];
- we do not have complete knowledge about how the global climate system operates. At present, we are gambling that the inevitable surprises will all be benign.

It goes without saying that altered regional climates, rapid increases or decreases in insect and animal populations and plant species succession will have implications for human society, affecting farming, irrigation, logging, tourism and transportation of goods, to name just a few. Complicating matters is the fact that associated extreme events will not confine themselves to one area nor one point in time. Such events all have indirect effects that can take decades to play out fully, and their effects can still be occurring or spreading when the next disaster strikes. Crises are under no obligation to allow sufficient recovery time. Kemp et al.[19] note that disasters that could individually be managed during normal times may overwhelm institutions which are struggling to recover from previous disasters or from more gradual knock-on effects that have arisen from previous disasters, e.g., economic dislocations, migrations, chronic deficits or societal divisions that take decades to fully manifest.

Therefore, in the business of climate risk assessment, it is more prudent to assume that extremes and disasters will exhibit greater amplitude and frequency than in the past. Historical statistics such as a one-in-100-year downpour of precipitation will no longer provide reliable benchmarks for future infrastructure. Risk assessments should take into account that:

- every system is connected in some way to every other system;
- there are positive and negative feedbacks linking these systems, as well as tipping points into new stable modes. Climate risks therefore aggregate and cascade in unforeseeable ways;
- wildfire extremes are in a class of phenomena that exhibit regression to the tail, rather than regression to the mean. There is no probability mean for damage from climate disasters - rather, they display infinite variance, with no upper limit[20] ;
- infinite variance means that climate risk is a moving target. As our atmosphere, oceans and related ecosystems evolve into new modes, our current perceptions of risk will be rendered obsolete by newer extremes;
- the extremes and emergencies in store for us this century and in the centuries that follow have the potential to threaten the existence of our species.

Taking risk into account in a responsible way means accepting that our future will be filled with huge uncertainty. Because of that uncertainty, we will need to make very consequential (and politically fraught) decisions based on insufficient information, and we will need to make those decisions before the crises actually occur. Waiting for absolute certainty means never acting.

> *"Perhaps more emphasis should be placed on research about the extreme tails of relevant [probability density functions] rather than on research about central tendencies.*[9]*"*
>
> Martin L. Weitzman,
> Paper: Fat-tailed uncertainty in the economics of catastrophic climate change

Is climate science too conservative?

There has been no shortage of papers in the scientific literature over the past several decades pointing out disquieting climate-related trends, from rising temperatures[10] and sea levels[21] to the collapse in wildlife populations[22]. Media regularly interview wildfire scientists about megafires and forests being decimated by insects that now survive winters due to warming temperatures. Given all this exposure, can it really be an issue that climate science is too conservative?

In a theoretical sense, it is clearly possible. One can easily imagine a climate disaster trend line that is exponential but which is mistakenly assessed as rising linearly, especially in its early stages. One can also imagine a curve that is recognized as exponential but not to the correct extent. In other words, it is possible to recognize trends but nevertheless misjudge the rate at which they are rising, falling or accelerating. So, has this actually been occurring? Or has bias taken different forms?

A 2012 paper by Brysse et al.[9] addressed the question of whether climate change prediction is overly conservative by looking at past predictions. Among the findings:

- IPCC reports to that point in time substantially under-predicted observed sea level rise. Actual tem-perature rise was within the range predicted but at the high end. CO_2 emissions, rainfall in already rainy areas, ocean absorption of heat, glacier and ice-sheet melting and Arctic sea ice decline were all occurring faster than predicted.
- Potential amplifying feedbacks such as permafrost melting and associated GHG release were not included in IPCC models prior to 2012, omissions which significantly biased predictions downward. Even today, some feedbacks are only partially accounted for due to scientific uncertainty (e.g., the effect of warm ocean currents on Antarctic ice sheets).

According to Kemp, none of the fourteen special reports published by the IPCC have covered extreme or catastrophic climate change. The flip side of this absence is the disproportionate attention paid to benchmarks such as limiting global temperature rise to 1.5 degrees (a goal likely to be missed in the near future[23]). Such is the power of anchoring bias[24].

In 2020, Schwalm et al.[25] looked at the IPCC's Assessment Report 5 (AR5) and concluded that:

> *"RCP8.5, the most aggressive scenario in assumed fossil fuel use for global climate models, will con-tinue to serve as a useful tool for quantifying physical climate risk, especially over near- to midterm policy-relevant time horizons. Not only are the emissions consistent with RCP8.5 in close agreement with historical total cumulative* CO_2 *emissions (within 1%), but RCP8.5 is also the best match out to mid-century under current and stated policies with still highly plausible levels of* CO_2 *emissions in 2100."*

The paper goes on to state:

> *"Furthermore, moving from emissions to concentrations in the context of forecasting long-term eco-nomic growth, the likelihood that* CO_2 *concentrations will exceed those assumed in RCP8.5 by 2100 is at least 35%."*

In other words, the highest GHG emission scenario posited by the IPCC (an additional 8.5 W/m^2 of radiative forcing by 2100) is the best match for actual emissions to date. The paper also recommends this scenario as useful in representing the next several decades. Most notably, it posits that this scenario has a roughly one in three chance of being exceeded by 2100.

If we accept that past assessments have avoided dealing adequately with extremes, what might lie behind this? Brysse suggests that reticence to fully explore extremes arises from significant negative criticism of scientists who have ventured into such areas (e.g., Hansen, Mann, Santer[26]), as well as a long-standing scientific bias away from claims that differ dramatically from current consensus. The two forces combine to make scientists reluctant to fully explore risk. They self-edit their own best guesses and bias their conclusions toward the safe side of the mean. Brysse calls this *"erring on the side of least drama"*.

Our current societal and political context

The precautionary principle is a logical approach in the face of deep uncertainty and huge tail risk. First, do no harm. However this flies in the face of modern philosophies like *"move fast and break things.*[27]*"* Human history is replete with examples of actions taken prior to understanding, and the present day is no exception. Untested mass introduction of social media and the headlong rush toward widespread use of artificial intelligence are two examples. There is a fundamental conflict between a philosophy of balanced stewardship of the planet for future generations and a mindset of *"get what you can while you can"*.

Human mindsets, and the social realities that accompany them, will be difficult to change. For example:

- Politics as currently practiced is overwhelmingly shortterm. Western democracies have a huge problem in sustaining focused action on generational time scales. One need only look at the policy fish tailing that occurs when a party that believes climate change must be addressed loses power to a party that denies that climate change exists or that humans are the primary cause.

- Our political-economic complex is highly invested in the status quo and resists significant or sudden change. When powerful interests are threatened, campaigns to sow doubt about science findings are funded, and politicians are pressured to go slow on necessary changes. Some of these campaigns go so far as to subject individuals in the scientific community to personal attacks[26].
- Within many federal and provincial government departments, a culture has evolved of using plans, goals, consultations, frameworks and budget allocations as a substitute for implementation and results. One need look no further than the adoption (or lack thereof) of the Canadian Wildfire Strategy of 2005 to see the effect of short government attention spans and repeated failures to implement on scales that will actually make a difference.
- Taken together, Canada's governments are politically risk averse. They prefer to follow rather than lead, to react rather than forestall. Their track record indicates that they do not hesitate to spend billions on crisis recovery but resist spending the millions needed to prevent those crises. They also have no stomach for imposing significant sacrifices[28] on the public, especially in the wake of the COVID-19 pandemic.

In the spirit of this essay therefore, it is most prudent to assume that Canada's equivalent carbon emissions (CO_2 + methane + other greenhouse gases) will continue to rise and may accelerate. An acceleration scenario assumes a continuation of the current institutional failure to deliver, combined with natural climate feedbacks taking hold, e.g., rising methane emission from melting permafrost[28] and increased emissions from wildfires.

> *"The critical part about what's been happening and what climate change is forcing us to do is: We have to look more at the extremes [29]"*
>
> Tom Buschatzke, Director,
> Arizona's Department of Water Resources

Three possible roles for wildfire science in a century of accelerating emergencies

Brysse's paper concludes in part: *"some phenomena in nature are dramatic. If the drama arises primarily from social, political or economic impacts, then it is crucial that the associated risk be understood fully, and not discounted."* If we accept this, and the premises of the previous pages, namely that we are facing fat tail risks with huge consequences, that science has a less drama bias and that governments are unlikely to act, what should be the response of the wildfire science community?

1) Stress tests and disaster simulations. After the 2008 financial crisis, rules were brought in that required banks to undergo stress tests to determine how they would fare under extreme situations. It therefore seems reasonable to begin by testing societies' systems with a program of wildfire/smoke-related stresses. The lessons arising from these tests can bring into focus gaps and areas where research, education and action are needed.

One possible path for carrying out stress testing activities would involve the following:

- **Earth systems models.** Such models would be run using a suite of inputs representing fat tails of wildfire and smoke risk.This could be done by:
    - expanding the range of intensities, durations and geographic extents of events that have already occurred,
    - placing historical events in new locations and seasons, or
    - creating extreme scenarios which have never before been experienced. Such inputs would incorporate interrelatedness, tipping points and cascades.

The point of these scenarios would not be to use them as predictions but rather to expose the weaknesses of systems that are affected by them.

- **Societal models.** Outputs from the earth systems models would be fed into models of:
    - agricultural output
    - public health
    - tourism
    - industrial output
    - transportation and supply chains
    - disaster response capability
    - social cohesion
    - migration
    - national and international finance
    - national and international conflict
- **Foresight exercises.** Agencies would regularly host foresight workshops and conferences bringing together experts and workers in multiple disciplines to explore the probability space of future emergencies. These exercises would employ techniques such as:
    - pre-mortems

- working backward from requirements to the chain of actions needed to realize them (also known as "working right to left[30]")
- narrative statements with implications
- gaming future scenarios using simulations
- expert panels.

For example, workshops could employ social/economic models to simulate what would happen to health care, tourism, agriculture and industrial output if:

- the 2014 summer of smoke in the NWT was placed over major metropolitan areas of southern Ontario and Quebec for several summers in a row
- the entire area burned during one season of Australian bushfires (2019/2020) was randomly placed in Canadian forests.
- Simulations could also explore the implications of a lack of trained professionals in all areas of wildfire response.

Lessons learned from the stress tests above would be combined with inventories of existing infrastructure to guide action such as:

- creating ranked lists of communities and regions most at risk from fat tail wildfire/smoke events (megafires/gigafires)
- creating lists of communities and regions most difficult to defend or evacuate in the event of being cut off by fire or smoke
- producing gridded maps of exposure to interconnected/overlapping hazards
- educating local authorities on particular vulnerabilities of their jurisdictions
- designing local supply chains that would be resilient to extended stresses
- proposing areas within Canada that could serve as safe havens for disaster victims or internal migrants
- mounting campaigns (with the aid of psychologists) to motivate the public to actively participate in their own protection and to avoid over-reliance on higher levels of government
- creating manuals of best practices for local communities to harden themselves against individual and overlapping emergencies, e.g., local stockpiling of water/food/medicine, clean air shelters, distributed power generation.

2) Research. Additional research activities could be undertaken to support and guide implementation as well as to understand future development of climate extremes. Such work could include:

- improvement of the earth systems and societal models used in the stress testing role
- investigating the role lightning might play in future wildfire regimes
- assessing whether pyroCBs will become more numerous and/or more intense, and researching the distribution of future smoke from pyroCBs within the troposphere and stratosphere
- determining the aggregate effect of near-continuous wildfire smoke on global heating or cooling
- downscaling global and national fat tail risk assessments to regional and local jurisdictions
- modelling non-gradualistic landscape changes employing interconnections, compounding cascades and tipping points
- modelling worst-case expanded methane and CO_2 sources
- modelling significant Canadian and Alaskan boreal forest die-off and subsequent species succession
- modelling human mortality or morbidity scenarios locally, regionally and globally due to direct and indirect effects of sustained wildfire and smoke
- modelling the demands that will be placed on health care infrastructure.

3) Implementation and Outreach. A natural question for the wildfire science community has to do with whether its activities should be expanded in a century of emergencies. Research has been the predominant activity thus far, carried out within academia and government, but there are a number of independent or semi-independent organizations such as Canada Wildfire (the publisher of this newsletter) that have specialized roles. This essay suggests that wildfire science expertise should be expanded to implementation work with an "all hands on deck" level of urgency. The stakes are high and accelerated results are desperately needed.

For example, in the absence of action by governments, new independent organizations or collections of organizations (see insert below) could be formed to:

- communicate and interpret wildfire science in terms that politicians and the public can understand
- hold regular lectures and workshops to educate the public and local governments in wildfire science, resilience and preparation
- act as an independent accountability bodies that sets goals related to wildfire preparedness and audit governments and communities for results
- act as think tanks that analyze global, national and regional wildfire trends, advise governments on strategic and tactical responses, draft policy documents and write proposed legislation
- consult with and train local authorities regarding procedures and reserve capacity for immediate use in wildfire emergencies, e.g., backup water capacity for both fighting fires and for drinking, inexpensive air quality monitors, clean air shelters
- establish and support local volunteer networks that undertake FireSmart work in communities.

Summary

It is an irony of life that if we give in to the very human desire to avoid thinking about bad things, we actually help to bring them about. Military history illustrates this well. Battles are fought in the moment, but their outcomes are frequently determined years or decades in advance by the preparations undertaken (or lack thereof).

These principles are not confined to the military sphere. Canada has already experienced significant wildfire disasters in the first two decades of this century. Recent history has shown us that governments have failed to sustain necessary work on the scale needed to head off similar future events. There is also reason to believe that climate models and scientific research have not provided us with the full picture of the risks we are running, nor have they dealt fully with the possible impacts of interlinked future disasters.

It therefore falls to individual organizations to pick up the torch and take those actions that will increase the chances of obtaining the futures we want, as well as giving more options to future leaders when they attempt to manage the crises that are yet to come.

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Canadian Futures Institute

A perennial problem that affects organizations and individuals equally is the inappropriate discounting of the future. A Canadian Futures Institute (CFI) could be set up to directly address this gap in our thinking. CFI's job would be to represent the needs of the future more directly to present generations and to work to make beneficial futures more likely. Such work would best be carried out via a distributed network of nodes, each responsible for an area of specialization, and interacting with peers directly in a sort of analog to the connectedness of the systems being studied.

For example, a CFI Wildfire Centre of Excellence in Kamloops might collaborate with a similar node specializing in forestry in Edmonton, and with a center of excellence specializing in water studies in Saskatoon. Each would apply their particular expertise to models of multi-hazard risk for Canada over near, medium and distant timeframes. CFI's communication and action arms would translate those findings into operational tasks. They would reach out to national and provincial governments, corporations, municipalities, communities to assist them in taking on the work of enhancing resilience.

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Explore Canada Wildfire's Knowledge Exchange and Research

Discover a wealth of knowledge and resources related to wildfires and wildfire research in Canada on the website www.canadawildfire.org. There is an array of webinars and information designed to educate and raise awareness about research on wildfires, their impact, and effective strategies for prevention and management.

Dive into topics like fire behaviour, risk assessment, emergency planning, community engagement, ecological impacts, and cutting-edge technology in wildfire management. With content developed by experts, you can stay up-to-date with the latest research and best practices. Join the community dedicated to understanding and protecting wildfire's effects on Canadian communities and ecosystems.

www.canadawildfire.org/knowledgeexchange

Canada Wildfire

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EDITORS: Renée Beaulac and Karen Blouin

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