Forest and Wildland Fire Management: a Risk Management Perspective

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Modern wildland fire management poses many challenging interdisciplinary problems that link forest ecology, forest management, computer science, physics, mathematics, statistics, industrial engineering and operations research. Fire management was originally driven by a desire for fire exclusion. However, over the past century it has evolved from an activity to an emerging paradigm of risk management, focused on multiple competing values and risks.

Throughout its history in Canada, fire managers have always looked to the best science available for assistance in characterizing important and highly variable aspects of their fire environment and for providing key intelligence to inform their decision making. As wildland fire management has evolved, so too has the range of scientific disciplines needed to support decision making deepened to include many more quantitative disciplines. This BIRS workshop that brought together a mix of researchers and end-users was the ideal forum for furthering ongoing collaborative initiatives and for developing new ones.

The workshop focused on the design and implementation of science-backed, data-driven forest fire management decision support tools and their application by end-users (i.e., forest and wildland fire managers). Three main areas were targeted: (1) The science underpinning decision support tools for fire management, (2) Fire regime modelling, and (3) Bridging gaps between researchers and fire managers. Emphasis was placed on a data science based approach for addressing emerging questions at the forefront of fire science and fire management. Representatives from fire management agencies discussed their perspectives and needs as well as provided examples of operational decision support tools currently in use.

This report provides background on the field of quantitative wildland fire science and decision support for fire management with a particular emphasis on the outcomes of the 5-day workshop at BIRS and ongoing related initiatives.

1 Overview of the Field

1.1 Decision Support Tools for Fire Management

In order to make progress on fire management objectives, mathematical and statistical expertise will need to be brought to bear on the issues of uncertainty which complicate operational planning. There is a need to deliver "the right amount of right fire at the right place at the right time at the right cost". For example, what is the best strategy for an individual airtanker? Is it better to have it return to its original home base where it was deployed at the start of the day, the base from which it was dispatched to its most recent fire after completing service on that fire, or should it fly to the base nearest to that fire? Although progress has been made on this kind of problem using tools developed by operations researchers, there is a very urgent need to develop and test better predictive fire occurrence models, especially ones that incorporate the clustering of arrivals which can overwhelm agencies. There is also a need to further our understanding of the initial attack system, including estimating the probabilities for same day initial attack, and what factors contribute to initial attack success since the larger project fires that result when the initial attack system fails are a large drain on crews and equipment and incur very large costs.

One strength of a probability-based model is that the variability in the data will be reflected in the standard errors associated with predictions or fitted values. However, one of he many challenges faced by fire managers and the researchers that collaborate with them, is the difficulty of conveying such uncertainty to the users of the modelling product. Two types of uncertainties need to be addressed directly: 1) the standard error of the predicted probability and 2) the fact that predicted probabilities have an inherent uncertainty in the sense that although the model returns a probability, the event of interest is binary. How can these uncertainties best be incorporated in decision support tools aimed at informing fire managers?

Other key risk management issues to be discussed include harvest scheduling optimization, optimal allocation of scarce fire suppression resources, and examining effects of changes in fire detection management and technology.

1.2 Fire Regime Modelling

The economic and social impacts of wildfire in Canada raise important challenging statistical questions. Once an area has burned, does the most recent fire reduce the surrounding area's risk of burning and if so, to what degree and for how long and can such effects be replicated by active management of forest fuels? What ecological and forest management strategies are needed to maintain the current landscape mosaic and levels of biodiversity while protecting people, property and other values at risk? There is an interest in developing methods for simulating seasonal boreal forest fire regimes, comprising frequency, size, and severity, noting that there is a strong need to "backcast" characteristics of past fire regimes if there had not been any fire suppression. In this context, the focus involves shifts to modelling aggregate behaviour of fire regimes, say over an entire year and across a large study area (e.g., a province), rather than modelling at fine scale resolutions. Historical records of individual burn scars for many fire seasons are now becoming available in digital format. Fires can be viewed as realizations of a marked spatio-temporal point process (where the points are the ignitions and the marks are the characteristics of each individual fire, such as its duration, intensity, size, and so on). The fire ignition records combined with the burn scar data can be viewed as approximately independent, replicated point pattern data. Important topics for discussion include developing tools for exploring and visualizing these data, for investigating inhibitory impacts of burn scars on the future intensity of points in that area, and for determining whether such marks are separable, and if not, how to jointly model points and marks.

1.3 Bridging Gaps Between Researchers and Fire Managers

Many factors, including climate change, changing land use patterns, fuel build-ups, government fiscal realities and the fact that fire is a natural ecosystem process contribute to the emergence of more and increasingly complex and challenging fire loads. Hence, there is a growing and urgent need for decision support systems that fire managers can use to enhance their planning and decision-making processes. The development of such decision support systems calls for bringing experts from the mathematical and decision sciences together with ecologists, fire scientists and fire managers to develop collaborative team-based efforts to address such problems.

It is also recognized that it is simply not enough to produce advances in science. To have a significant impact, potential end-users of research results must be able to interpret and trust the output from these models. Tools are needed to aid a manager who, with little lead time, must resolve complex decisions under considerable uncertainty and be responsible for the outcomes of such decisions. For example, fire managers need to know about the potential for periods of extreme fire activity–situations when the fire management system can become overwhelmed. To plan effectively, they need tools that capture the scientific understanding of what causes multiple occurrences of large (and expensive) fires and hence, allows them to quantify the probability that multiple regions will be overwhelmed at the same time, preventing one region from assisting another region through intra and inter-agency resource sharing. Making accurate forecasts of such events requires models for the stages of the "lifetime" of a fire together with models which can predict where fires will be ignited; such knowledge can lead to improved prediction as to how fire load changes both spatially and temporally.

2 Presentation Highlights

The objective of the workshop was to bring together researchers and end-users from a variety of disciplines (e.g., operations research, statistics, actuarial science, mathematics, computer science, ecology, forestry and the environmental and health sciences) to provide a forum to discuss fire management needs and to initiate interdisciplinary team-based collaborations aimed at addressing important problems in forest fire management. Several themes were spread across the 5 day workshop, an overview of highlights follows below.

2.1 Monday Morning: A High-Level Overview

In the opening session senior managers from two Canadian forest fire management organizations presented their agency's perspectives on the challenges they have experienced in recent years and the problems they would like researchers to address. Wally Born, the Executive Director of Wildfire Management Branch of the Province of Alberta's Agriculture and Forest ministry discussed some of their challenges moving forward from the Fort MacMurray wildfire in May of 2016. He placed wildfire management within the context of its modern role of having to balance multiple values on the forest landscape: 97% commitment of land with commercially viable forest for harvest, species as risk (with caribou as a species of major public interest), 500 forest communities in their protection zone and major industrial development and infrastructure. Some of the key questions he identified as being highly relevant to his organization were: What resources are needed over the next 10 years (and moving forward) to maintain the performance of the organization, particularly within increasing population and commitments of land; how much of what kind of fuel management of mitigation effort around communities will be needed to produce a measureable impact in reducing risk, suppression needs and costs; how do we set and define performance measures, in particular for the prevention program.

Tony Falco a senior manager from the Province of British Columbia's (BC) Wildfire Management Branch gave the group a detailed update on the unprecedented 2017 fire season in BC and the multiple challenges that the province had to deal with. Since that fire season was just wrapping up at the start of the workshop, Tony pointed out that there were still many after action reviews to be carried out; however he identified some of their ongoing research priorities as understanding fuels mitigation and maintenance fr risk reduction as well as general fuel typing issues with BC forest types.

This morning session was wrapped up by a panel discussion lead by Al Tithecott (former Director of Ontario Ministry of Natural Resources and Forestry's Aviation, Forest Fire, and Emergency Services (OMNRF-AFFES) branch). The panelists included Wally Born, Tony Falco as well as Rob McAlpine (Manager of Wildfire Response and Operations, OMNRF-AFFES). Discussion with the workshop group included greater elucidation on research needs identified in the formal presentations as well as other topics and challenges facing wildfire management organizations.

2.2 Monday Afternoon: Fire Operations

The afternoon session built on the high level perspective on wildfire management challenges presented by the senior operational managers in the morning. This session brought the discussion to a more operational level to provide examples of some specific research needs and solutions being developed currently. David Martell from the University of Toronto opened the afternoon, placing his decision support focussed research activity into a framework of data analytics familiar to many today. Examples of completed and ongoing research that fit into the framework of Descriptive, Predictive and Prescriptive Analytics were presented and some of the opportunities and challenges of carrying out such research with operational agencies were discussed. Key among these was was the critical need for researchers to develop close collaborative relationships with fire managers to support not only the flow of the data they need for their analytics research but also, critically, to help them develop a sound understanding of the data and the caveats surrounding its observation and overall reliability. The session then included presentations from fire science specialists from the fire management agencies in Ontario highlighting how the needs of operational decision maker are changing. To be able to management wildfire in the future it is anticipated that a more defined risk management structure will be needed.

Keeping focused on bridging gaps between researchers and fire managers and with the objective of furthering collaborative research efforts, day one of the workshop wrapped up with a discussion of both the morning and afternoon sessions. Some key fire management agency needs and research opportunities were identified. This discussion focussed on the information and tools needed for risk analysis, risk reduction strategies and evaluating the effectiveness of the suite of potential mitigation, preparedness, response and recovery strategies that are available.

2.3 Tuesday Morning: Operations Research

The morning session of day two sought to highlight mathematical approaches and solution to problems using the Operations Research/Analytics methods that David Martell had spoken about on the previous day.

The session began with a keynote address by Mikael Rönnqvist of Laval University, who presented a talk entitled “Calibrated Route Finder: Improving the Safety, Environmental Consciousness, and Cost Effectiveness of Truck Routing in Sweden”, describing how he and his colleagues had used operations research methods to develop their award-winning research on transportation logistics in the forest sector in Sweden. This talk provided some concrete examples of how modern analytics research methods can be exploited to develop decision support systems that had very significant demonstrated award-winning impacts on the forest resource sector and other sectors other than fire management.

Yu Wei from Colorado State University presented a talk entitled “Building operations research models to improve our ability to address uncertainties in wildland fire management” to share his current and past experience at bringing advanced mathematical programming methods to bear on fire management problems in the United States.

Matthew Thompson of the US Forest Service presented a talk entitled “Optimizing fire management strategies on the basis of risk and control opportunities” in which he described how he and his colleagues are exploiting analytics to develop spatially explicit decision support systems that fire managers can use when they develop and evaluate strategies for managing fires that have both beneficial and detrimental impacts and need not necessarily be managed using traditional fire exclusion strategies and tactics.

Jeremy Fried, also of the US Forest Service, presented a paper entitled “Modeling Stand Level Fuels Management Effectiveness and Economic Feasibility at Landscape Scale in the U.S.: a Forest Inventory Informed Approach.” He was invited because of his extensive experience at modelling the use of forest harvest residue for biomass to produce energy and at the same time, achieve fuel management objectives.

2.4 Tuesday Afternoon: Game Theory, Artificial Intelligence and Applied Analytics

Kate Larson, a computer scientist from the University of Waterloo presented a talk entitled “The Strengths and Limitations of Game Theory for Fire Management”, based in part on her research on resource sharing. Her talk was particularly timely because of the needs of Canadian forest fire management agencies to share so many fire management resources among themselves and with international fire management agencies in recent years.

Mark Crowley, another computer scientist from the University of Waterloo presented a talk entitled “Fighting Fire with AI: Using Artificial Intelligence to Improve Modelling and Decision Making in Wildfire Management” based on his collaborative research with colleagues in the United States. He was invited in part, because of the growing recognition of the need for fire management agencies to exploit new methods being developed by artificial intelligence researchers.

David Martell of the University of Toronto presented a talk entitled “Prescriptive analytics to inform forest and wildland fire management” in which he outlined some of what he considered to be emerging fire research needs. This was followed by Colin McFayden of the Ontario Ministry of Natural Resources and Forestry who served as a discussant and then facilitative an open discussion.

2.5 Wednesday Morning: Risk

Greater understanding of risk management and the use of risk analysis techniques were identified by fire managers earlier in the workshop as needed to address the complexity of current and future wildfire management. as being seen by operational fire management. Day three opened with a keynote speaker who has specialized in financial risk management. Matt Davison of the University of Western Ontario described some of the analytical techniques he has used in a variety of applied research settings and highlighted where these may be applicable in the environmental risk management area. Ideas like diversification, leverage and hedging were presented and discussion ensued about how they may be relevant in the wildfire context. For example, thinking about community protection in a diversification context may allow novel framing of the risk reduction potential of a suite or "portfolio" of mitigation and prevention solutions.

Talks that followed this keynote presented specific risk analysis and modelling studies. Jennifer Beverly of the University of Alberta presented highlights from several studies of landscape fire risk and summarized up lessons learns from these analyses for other researchers exploring these areas. Cordy Tymstra from Alberta's Agriculture and Forestry Wildfire Management Branch discussed enhancing situational awareness of spring wildfire danger in Alberta using methods similar to those used in biosurrvellience applications. The day ended with Cristina Vega-Garcia from the University of Lleida presenting results from several studies using fire occurrence prediction models for improved wildfire risk management in Spain.

2.6 Thursday Morning: Ecology, Mapping Fire Risk

Thursday's session began with a focus on ecological aspects of fire activity with Steve Cumming from Laval University presenting some work he had done on hierarchical modelling of the joint distribution of annual fire counts and fire size. Lori Daniels from the University of British Columbia presented a perspective on the 2017 wildfires situation in BC from her perspective as a fire ecologist and talked about potential solutions moving forward. Patrick James from the University of Montreal concluded the ecological session with some discussion of spatial modelling linking Spruce budworm defoliation within changes in the probability of fire ignition. One of the themes emerging from the discussion session after these talks was that the complex linkages between insect disturbance and subsequent fire activity are not well agreed upon the scientific community. The relatively recent and large scale Mountain Pine Beetle epidemic in BC and the expanding spruce budworm outbreak in eastern Canada provide research opportunities; newer more advanced methods of spatial data analysis may be useful to attempt to gain insight in this area.

Thursday morning ended with presentations on two ongoing different fire risk analysis and mapping projects that were both sponsored by the Canadian Safety and Security Program (Defense Research and Development Canada-Centre for Science) and being led by research scientists at the Canadian Forest Service: Xianli Wang discussed the development of a national assessment of landscape fire risk in Canada. Steve Taylor talked about machine learning methods that are being used to develop a set of national (Canadian) daily fire occurrence models.

2.7 Thursday Afternoon: Examples Modelling Fire Risk and Beginning the Wrap-up

Thursday afternoon sessions carried on the theme of landscape ecology that began earlier that day, with a presentation from Geoff Cary of Australian National University on perspectives on quantifying the mitigation of wildfire risk from both an Australian and international modelling point of view. Ellen Whitman from the University of Alberta presented work conducted related to landscape patterns of burn severity in Canada's boreal forest. Brett Moore from Alberta Agriculture and Forestry discussed projection of potential fire growth using ensemble weather forecasts to provide probabilistic estimates of potential wildfire locations from an operational viewpoint. The last of the talks was given by Frederic Schoenberg of the University of California, a statistician, who discussed his experience modelling using point process frameworks to talk about model building and the issues of missing variables and the inclusion of variables that had little real influence on the overall process being studied.

Thursday ended with a session led by Rob McAlpine (Manager of Wildfire Response and Operations, OMNRF-AFFES) who gave a closing discussion that emphasized future collaboration going forward. Participants discussed potential future research projects including working on various aspects of appropriate response, optimizing helicopter deployment, fire risk modelling and risk in general, quantifying uncertainty, as well as other areas. It was clear that some new teams were beginning to form and that collaborative research, both existing teams and new initiatives, would continue beyond the workshop.

2.8 Friday Morning: The Connection to Banff and Parks Canada

Similar to a 2013 BIRS 5-day workshop "Managing Fire on Populated Landscapes" (Braun et al. 2013), we took advantage of the opportunity to engage Parks Canada. Jane Park, a fire and vegetation management specialist at Parks Canada who is stationed in Banff National Park was able to attend as a participant of the meeting. On Friday morning, there was a field trip to visit fuel management and prescribed burning operations sites in Banff National Park. Prescribed fires, which are fires that are intentionally set, planned and managed by fire specialist in order to help maintain forest health and biodiversity (Parks Canada 2018b). For an example including further information about recent prescribed burning during 2017 in Banff National Park see Parks Canada (2018a). This gave our BIRS workshop participants the unique chance to "get some dirt on their boots", which, in general, is not a common occurrence for quantitative researchers in the Mathematical and Statistical Sciences. Participants were able to see actual burn scars and burn sites up close and witness the forest succession that follows after such prescribed burn events.

3 Scientific Progress Made

Several members of the organizing committee are also involved as investigators/collaborators on a CANSSI (Canadian Statistical Sciences Institute) Collaborative Research Team grant. This BIRS meeting provided a forum for some members of that team, including both academic researchers and their graduate students and postdoctoral fellow to network and interact with other Canadian and international researchers who work in this area along with individuals from fire management agencies.

This BIRS 5-day workshop was a strategic workshop. It brought together researchers from a variety of disciplines (e.g., operations research, statistics, actuarial science, mathematics, computer science, forestry and the environmental and health sciences) and provided a forum to discuss fire management needs, quantitative methods for solving problems in the fire science and fire management context, and foster ongoing and initiate new team-based collaborations aimed at addressing important problems in these areas. Building on the momentum provided by this BIRS workshop, a tactical meeting of a smaller group of individuals (many of whom were at this BIRS meeting) is planned for February 2018 in London, Ontario, Canada. The targeted areas identified, in part, through the discussions leading up to and at this BIRS workshop include:

1. Appropriate response, which is to minimize the total cost plus net loss on a fire-by-fire basis considering the impacts (positive and negative) and the cost of alternative approaches of fire response.

2. Fire risk modelling, which includes the development and application of probabilistic fire growth models, quantifying socio/economic impact and accounting for risk tolerance and preference.

3. Quantifying or accounting for uncertainty, which is prevalent in all fire management decisions. Uncertainty enters the decision systems in a) the state of the knowledge, b) data quality, c) human dimensions (biases/heuristics) and d) natural variability.

4 Outcome of the Meeting

Fire management agencies have the difficult task of addressing two competing concerns: the importance of fire from an ecological perspective and the danger of fire from a human perspective. Faced with the need to deliver "the right amount of right fire at the right place at the right time at the right cost" forest fire managers must make difficult decisions on a regular basis.

There is a growing need for quantitative expertise in data science-based decision support models for wildland fire management. The organizing committee recognized this need and, in particular, the need to transfer knowledge from the mathematical and statistical sciences to managers. This BIRS workshop, which brought together a wide mix of researchers and end-users from across Canada along with international participants was another step forward in accomplishing such objectives.

The proposed workshop was timely in today's environment where interdisciplinary, collaborative teams–that include researchers from quantitative fields–are an absolute necessity for tackling high-impact applied problems. It highlighted the growing community of quantitative researchers and exposed some newer researchers from the computational, mathematical and statistical sciences to the wide variety of problems

Through presentations, panel and informal discussions that took place at this meeting, it is clear that any such models must not only account for a wide range of specific information, such as values at risk, the current fire load and the probability of fire occurrence and detection, but also incorporate information about the current locations of crews and equipment and their associated dispatch and travel constraints. Another message that was clearly conveyed was that it is not enough to produce advances in science. To have an impact, end-users must be able to interpret and trust the output from these models. Tools are needed to aid a manager who, with little lead time, must make decisions and be responsible for the outcomes of such decisions. For example, fire managers need to know about the potential for periods of extreme fire activity–situations when the fire management system can become overwhelmed. To plan effectively, they need tools that capture the scientific understanding of what causes multiple occurrences of large (and expensive) fires and hence, allows them to quantify the probability that multiple regions will be overwhelmed at the same time, preventing one region from assisting another region through intra and inter-agency resource sharing. Making accurate forecasts of such events requires models for the stages of the "lifetime" of a fire together with models which can predict where fires will be ignited; such knowledge can lead to improved prediction as to how fire load changes both spatially and temporally. Joint modelling methodology from the Statistical Sciences has the potential to take what are predominantly marginal models for individual components of wildland fire regimes and couple them together in a joint framework. One presenter (Cumming) discussed his preliminary forays into this arena and other participants and researchers are actively pursuing work in this area.

This workshop addressed fire management decision making from an operations research perspective by providing a forum for decision makers in fire management agencies to form tangible working relationships with ecologists, fire scientists, industrial engineers, mathematical modellers and statisticians. Participants engaged in discussions about the use of mathematical and statistical models to develop decision support tools. Examples of such tools currently in operational use by fire management agencies that result from interdisciplinary collaborations with quantitative researchers were on display. This BIRS meeting represents a culmination of a long-term initiative engaging quantitative researchers with other researchers working in wildland fire and individuals from fire management agencies. It is our opinion that the success of this workshop along with the new scientific initiatives and research collaborations that continue to follow are a direct result of the ongoing support of BIRS as well as other Canadian mathematical and statistical institutes, which is gratefully acknowledged.

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