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Foreword

Advances in understanding and managing wildland fire: communicating wildland fire research to land-management practitioners

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Abstract. The health and function of forest ecosystems throughout the world include periodic exposure to disturbances such as fire. Fire has been instrumental in the evolution of large segments of flora and fauna and in preventing fuel accumulations that resulted in extreme fire behaviour and ecosystem degradation. However, wildland fuels have been accumulating over several of the past decades because of suppression-orientated wildland fire policies, silvicultural and grazing practices, invasions of invasive species, increased density and range of flammable indigenous plants, landscape fragmentation, and related natural and anthropogenic causes. The additional fuels have contributed to increased severe fire behaviour, fire intensity, forest mortality, and post-fire soil damage and erosion. The aftermath of severe wildland fires include ecosystems degraded by extreme fire temperatures and duration, reductions in ecosystem function, altered forest structure, altered natural fire regimes, and increased wildfire risk and imminent threats to life and property from uncontrollable fires. We review 10 years of advances in fire science in the eight papers presented in this Special Issue. The studies and reviews are compiled to present the diverse disciplines of fire science that range from the social science of the public's perception of fire to basic research on the theory of fire spread.

Additional keywords: burn severity, community preparedness, decision support, fire behaviour, fire effects, forest thinning, fuel models, live fuels, mechanical treatment, risk assessment, social science, soil erosion, smoke transport.

Introduction and background

Wildland fire is recognised world-wide as a natural process and a critical land-management tool for wildfires, wildfire management and related science needs. Natural fire regimes and the extent and degree to which they have been altered by decades of wildland fire suppression are a critical component for developing effective strategies for the stewardship of fire as a natural process in fire dependent ecosystems. These systems have evolved competitive and reproductive strategies dependent on fire. Prescribed fire often restores and preserves fire-dependent ecosystems and prevents uncontrollable conflagrations. When planning and managing fire on the landscape there is a need to recognise the options for restoring fire and the consequences of these actions on short- and long-term wildland fire risk, biological diversity and biogeochemical cycles. Equally important is the understanding of how social factors influence the discussion between fire managers and members of the public in the utilisation of fire in planning for ecosystem restoration, sustainability and managing community expectations. Land managers seek to understand historical regimes for their landscapes, the severity and frequency of fires in the past, the adaptive responses of fauna and flora to fire, fire and its effects within climate change scenarios, and the interactions of people, their communities and their effects on ecosystem services. Fire and land managers continually strive to ensure that the most current science-based research information is integrated into fire and land-management goals, decisions and practices. The Joint Fire Science Program in the United States has spent its first 10 years collaborating with fire researchers and resource managers to provide the science needed to formulate fire-management objectives that will help meet Federal, State and private land-management goals. Providing this type of information to policy makers and land managers world-wide is critical to ensuring scientifically based fire-management programs that improve with new fire research knowledge.

The Joint Fire Science Program organised fire researchers to develop a 10-year retrospective synthesis of major fire research topics with the goal of summarising United States and international fire research efforts. The eight papers collected in this *IJWF* Special Issue represent a portion of the advances in fire research achieved during the first 10 years of the program. The Special Issue papers span the disciplines of fire risk analysis, social science dynamics, fuel loading and fire management, fuel reduction treatments, wildland fire behaviour, smoke transport modelling and tools for post-wildfire assessments. The papers have been organised to address major land-management concerns throughout the world with an emphasis on linking United States and international fire researchers and land-management agencies through advances in fire science.

Risk analysis for wildfire management

The urgency for risk-based analytical tools has developed globally in response to wildland fires that have increasingly affected communities and landscapes. Formal risk frameworks have been proposed that define the major components of risk: likelihood, intensity, effects and values. Many of the recent advances in risk assessments are a result of improvements in computer software, systems integration, readily available spatial data and simulation modelling technology. Miller and Ager (2013) present a review of recent advances in risk analysis approaches to wildland fire management and planning, with a focus on advances in data, modelling and analyses. Fire likelihood is represented as either ignition probability or burn probability. Previous approaches have explored spatial ignition patterns and probability of ignition occurrence, which contrast to natural ignitions that have been correlated with fuel loading, fuel moisture, relative humidity and temperature. The review presents recent advances in risk analysis, which include the ability to model temporal dynamics of fire risk and spatial optimisation of fuels management.

Social issues of fire science

The management of wildland fire has evolved from the physical and ecological science approaches to social science research. As wildfires increasingly intersected with the wildland–urban interface interest grew in understanding the role of social science dynamics. McCaffrey *et al.* (2013) have reviewed the development of human dimensions of wildland fire, including the social acceptability of fire and fuels management, public responses during fires and post-fire recovery. The review was based in grounded theory that identified conceptual categories and their relationships (Glaser and Strauss 1967). The literature was organised into pre-fire mitigation and preparedness, community agency dynamics, experiencing a fire and institutional considerations. The review found a general public acceptance of thinning and prescribed fire on public lands with high wildland fire risk based on familiarity of the treatment techniques and trust of the agencies implementing treatments. The public perception of wildfire risk was based on personal risk tolerance and trade-offs between the benefits of living in forested areas and risk of wildfires. The majority of residents in urbanised areas with high fire risk have taken some fire mitigation actions that were based on time, money and physical ability to perform treatments. Residents perceive themselves as responsible for reducing fire risk on their property but view government agencies as responsible for conveying the risk of fire and educating the public. Agency involvement with fire management decisions was best done early in the planning process and in an open and transparent forum.

Theory of wildland fire spread

Prescribed fire planning and wildfire suppression has historically driven research on fire spread research. Increases in computational performance, geospatial technologies and the proliferation of fire spread models have put these tools into the hands of fire managers, but a review article by Finney *et al.* (2013) explores whether these advances have improved our understanding of how fire behaves. Four areas of fire spread are explored: fuel particle heat exchange, the role of convection, criteria for ignition and the burning of live fuels. The review of existing literature found that there was insufficient experimental information for determining fuel particle heat exchange during the flame front, which leads to the conclusion that there is insufficient basis for fire spread model assumptions. The basis for convection contributions to particle ignition in wildland fires was found to be inconsistent among the various modelling approaches. The current simulations of fluid flow and convective heat transfer within sub-grid ignition modelling assumptions were found to have no experimental basis. Similarly, the ignition criteria of wildland fuels were also found to be crudely approximated, thus limiting the theoretical basis for fire spread. Finally the review authors examined fire spread in live fuels and concluded that fire spread theory must consider live fuel moisture's role in fire spread, the roles of non-structural carbohydrates, fats and other compounds, and water lose during preheating of live fuels.

Risk-based wildfire effects management

The historical view of wildland fire management as a tool for fire suppression has changed to include ecological benefits. Hyde *et al.* (2013) have concluded that the current state of development in fire behaviour and effects science imposes severe limitations on the development of risk assessment analytical frameworks. The current state of risk assessment technology is a confusing array of *ad hoc* assessment tools that do not meet the decision support needs of fire managers. A risk-assessment framework for wildland fire includes procedural guidelines and risk-analysis probabilistic modelling, spatial attributes, multiple risks, socioeconomic concerns and ecological effects. Risk assessments are limited by fire behaviour and effects science, and spatial and temporal resolution. Fire behaviour modelling needs to focus on effects for predictions and include advances in fire- and fuels-measurement methods with increased spatial detail. First-order fire effects need to include linkages between fire behaviour modelling outputs and fire effects and the development of the effects models. Second-order fire effects need to include interacting changes in hydrology, sediment flux, biogeochemical cycling, changes in vegetation composition and structure and faunal habitat. A comprehensive risk-based management approach will need to address spatial and temporal interactions, gaps in fire behaviour, comprehensive planning and effective decision support systems.

Wildland surface fuel loading

Fuel loading characterisation is one of the important fire parameters collected and used by fire managers to achieve prescribed-fire management goals and to successfully plan and implement wildfire suppression activities. The fuelbed consists of a complex distribution of litter and woody debris from tree, shrub and herbaceous vegetation with many sizes, types and shapes that vary spatially and temporally. Keane (2013) reviews the major fuel descriptions systems developed in the United States, Canada, Greece and Australia. Major surface fuel systems are characterised into three categories: association, classification and abstraction. The diverse array of fuelbeds are composed of a disparate collection of grasses, needles, leaves, twigs, branches and logs, which are arranged in infinite 3-D spatial patterns. Fuel loading based on association summarises field fuel data or stratifies average fuel loading by extant classification categories, i.e. vegetation based classes. Classification of fuel beds are clustered into unique groups based on attributes evaluated and sampled in the field. The abstract fuel classification systems characterise fuels using fire behaviour characteristics. None of the current systems can be used in all phases of fire management: predicting fire danger, estimating emissions trajectory and concentrations, and calculating fire behaviour. The author calls for a new universal fuel description system.

Alternative fuel reduction treatments

Prescribed fire and mechanical fuel reduction treatments have been used in a variety of forest ecosystems in the United States and internationally. Prescribed fire has been used as a surrogate for wildfire because it mimics the ecological benefits of natural fire regimes. The historical trend of wildfire suppression throughout the world since the 1930s resulted in ecological changes in forest stand structure and function, and dramatic increases in fuelbeds. These changes to wildlands resulted in undesirable increases in extreme fire behaviour and undesirable ecological effects following wildland fires. Fire managers turned to forest thinning and fuelbed mastication techniques to reduce wildland fire risk and respond to the negative public's perception of wildfire and prescribed burning. McIver *et al.* (2013) present a meta-analysis of fuel reduction treatments in 12 seasonally dry forests throughout the United States. The goals of the analysis were to synthesise fire management findings based on the magnitude and duration of fuel reduction treatments, the efficacy of fuel reduction surrogate treatments, key management tradeoffs, habitat changes to fauna and flora, and successes and failure in the restoration of seasonally dry forest ecosystems. Surface fire and mechanical fuel reduction treatments were found to be successful in meeting short-term objectives of reducing fuels and altering stand structure. Mechanical treatments followed by intermittent fire were found to be most successful in fuel reduction, altering stand structure and reducing potential fire intensity. Mechanical treatments were not a surrogate for prescribed fire. Over the long-term mechanical treatments without fire resulted in stand structures that diverged from those in landscapes with mechanical treatments followed by prescribed burning.

Modelling smoke trajectory and concentration

Smoke from wildland fire and prescribed burns can range from high concentration short duration events to low concentration long duration events with effects on visibility along transportation corridors and health effects on sensitive populations. Fire managers must balance the trade-offs between the positive effects of prescribed fire on ecosystem management, the protection of lives and private property during wildfire suppression, and the negative effects of smoke from all fires on transportation visibility impairment and inhalation exposures to firefighters and the public. Models for predicting the trajectory and concentration of smoke from wildland fire began in 1970 with a single box model and evolved into the sophisticated smoke modelling frameworks used today. Many of these models share four basic components: a description of the emission source, a determination of plume rise, the actual movement of smoke by ambient wind and the chemical transformation of smoke and emission gases downwind of the emission source. Goodrick *et al.* (2013) present a review of these modelling components than spans the development of simple smoke models to the embedded fuel, consumption, emissions, transport and dispersion smoke models incorporated into spatial and temporal smoke modelling frameworks. The authors review box models, Gaussian plume models, puff models, particle models, Eulerian grid models, full physics models and smoke modelling frameworks.

Post-wildfire erosion mitigation and assessments

Wildfires are a major concern throughout the world and this concern is growing as the number and severity of wildfires increase in response to climate change and urbanisation in the wildland–urban interface. Robichaud and Ashmun (2013) present finding on the effects of wildfires on hydrology and erosion, modelling and predicting these effects, and evaluating post-fire treatments to reduce flooding and erosion risk. The tools to assist fire and land managers were divided into post-fire assessment tools and post-fire treatment tools for decision makers. Post-fire assessments incorporate burn severity ratings that are classifies as low, medium and severe. Recent post-fire assessments have been divided into vegetation and soil burn severities. Vegetation assessments measure the effects of fire on vegetation and ecosystem effects. Soil burn severity assessments measure changes in the physical, chemical and biological properties of soil. Burn severity for soils was combined with climate, topography, soil type and vegetation to predict the hydrology and erosion response to burned watersheds. Hydrology and erosion models were adapted for burned landscapes and combined with economic evaluations to assess the economic feasibility for post-fire treatments.

Themes

Several overarching themes emerge from the full set of papers. Several authors make the point that research over the past decade has applied and extended existing knowledge in many useful ways, but that significant investment in fundamental science is needed to make substantive progress on many tough issues (e.g. Finney *et al.* 2013; Goodrick *et al.* 2013; Hyde *et al.* 2013). New science should be refocussed on central constructs or theories to be most effective (e.g. Finney *et al.* 2013; Hyde *et al.* 2013; Keane 2013). The need for model verification and validation was a common theme (e.g. Goodrick *et al.* 2013;

Hyde *et al.* 2013; Miller and Ager 2013), and the Smoke and Model Intercomparison Project (SEMIP) was cited as an excellent example of this work. The need for improved decision support systems to integrate new knowledge for fire and fuel applications surfaced in several papers (Goodrick *et al.* 2013; Hyde *et al.* 2013; Miller and Ager 2013). The need to expand and integrate the spatial and temporal scope of fire and fuels research and analysis is perhaps the theme with broadest applicability (e.g. Hyde *et al.* 2013; McCaffrey *et al.* 2013; Miller and Ager 2013; Robichaud and Ashmun 2013).

Together these themes trace an arch over the last 10 years primed by a technology fuelled explosion of new models, software systems and emerging model and data integration frameworks. Paper authors identify that predictive models need further evaluation and integration into decision support frameworks. New science should be directed towards expanding the spatial and temporal scope of investigations, and tackling longstanding fundamental science needs that can help build new conceptual frameworks.

Conclusion

We believe the collection of papers in this Special Issue will accelerate the dissemination and use of new wildland fire science research and information by both governmental and private partners, and to help frame new research needs. The authors present research into the science of preventing and mitigating the adverse effects of wildfires, utilising prescribed fire as a surrogate of natural fire regimes, identifying uncertainty to direct new fire research paths, and providing an international discussion forum for fire research. The review articles presented in this Special Issue focus on social science, fuels and fire management tools, risk analysis, fire behaviour, smoke modelling and post-fire treatment. The articles are not intended as an exhaustive review of fire science but rather a collection of major fire science topics during 10 years of research as part of the United States' Joint Fire Science Program. The articles present the current state-of-the-science and point to significant gaps in our knowledge of basis fire science knowledge and anticipate the improvements in fire behaviour, fire spread and emissions and smoke model performance as spatial data and computational power increases and becomes readily available to all fire management practitioners.

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