Research and management issues in large-scale fire modeling

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Abstract

In 1996, a team of North American fire scientists and resource managers convened to assess the effects of fire disturbance on ecosystems and to develop scientific recommendations for future fire research and management activities. These recommendations – elicited with the Analytic Hierarchy Process – include numerically ranked scientific and managerial questions and responses. Currently, understanding fire effects and extrapolating fire-effects knowledge to large spatial scales is limited, because most data have been collected at small spatial scales for site-specific applications. Although we need more large-scale fire-effects data, it is more efficient to concentrate efforts on improving and linking existing models that simulate fire effects in a georeferenced format while integrating empirical data as they become available. A major component of this effort should be improved communication between modelers and managers to develop modeling tools that can be used in a planning context. The priority issues and approaches elicited in this workshop setting provide a template for current and future fire science and fire management programs.

1 Introduction

Fire is the most important periodic natural disturbance in most forest, shrubland, and grassland ecosystems of western North America. Although large fires are infrequent temporally, they are responsible for rapid changes in vegetation, soils, biogeochemical cycling, microclimate, and many other ecological properties. There is a substantial scientific literature on the effects of fire in terrestrial ecosystems, but the vast majority of scientific data has been collected at scales of 10–1 to 10 km^2 (McKenzie et al. 1996). Our ability to understand and manage for the effects of large fires has been limited by a lack of data at large spatial scales. Applying these data to fire phenomena at much larger scales can result in substantial errors in estimating fire effects, because relevant processes are different at different spatial scales (Simard 1991, Table 1).

Simulation modeling is a convenient and practical alternative to the expensive and time-consuming collection of large amounts of data at large spatial scales. Nevertheless, extrapolating ecological effects of fire across spatial scales using models can result in many sources of error, including: (1) extrapolating fire behavior models directly to larger spatial scales, (2) integrating fire behavior and fire-effects models with successional models at the stand level, then extrapolating upward, and (3) aggregating model inputs to the scale of interest. Regardless of which approach is used, extreme fire events (i.e., large-scale fires) pose a major problem for modelers due to the problem of propagating and compounding errors across spatial scales (Rastetter et al. 1992).

Given the complexity of large-fire phenomena, how do we improve our current scientific assessment and management of natural resources with respect to fire disturbance and to the wide range of fire regimes in complex ecosystems? We cannot afford to wait for decades for the data and techniques that would improve our understanding and managerial approaches. We need to establish priorities now in order to optimize research programs, develop resource management strategies, and encourage cooperation between scientists and managers in the years ahead.

2 Articulating fire issues: a knowledge elicitation approach

In 1996, a group of scientists and resource managers gathered at the Fire-Disturbance Workshop in

Table 1. General classification of scales and examples of relevant fire characteristics, processes, and influences for each scale. Adapted from Simard (1991).

Scale classification	Fire characteristics, processes, and influences
Micro	Energy flux, pyrolosis, personal attitude
Mechanical	Temperature, radiation, ignition, individual behavior
Sensory	Weather observation, fire behavior, suppression, human activity
Meso	Thunderstorm, fire danger, dispatch, supervision
Synoptic	Cold front, fire severity, mobilization, production
Strategic	Drought, fire season, fire planning, organizational budget
Macro	Climate, fire ecology, fire policy, government
Global	Climatic change, fire history, treaty

Seattle, Washington (USA) to articulate the modelling issues presented above. The objectives of the workshop were to: (1) identify the current state-of-knowledge with respect to fire effects at large spatial scales, (2) develop priorities for a scientific approach to modeling large-scale fire disturbance and its effects, and (3) develop priorities for assisting scientifically-based decisionmaking with respect to fire disturbance in resource management. A structured workshop process was used to conduct workshop discussions, compile information, and to elicit knowledge from participants.

A strawman document was developed to provide a template and generate discussion by suggesting key questions and responses for the four workgroup topics (Table 2). Partici-

Table 2. Summary of proposed key questions in the strawman document.

Linkages among fire effects, fuels and climate
What are the critical scientific issues regarding the impacts of fire on vegetation and fuels?
What are the critical management issues regarding the impacts of fire on vegetation and fuels?
What are the critical political issues regarding the impacts of fire on vegetation and fuels?
How can the relative impact of fuels and weather on fire regimes be quantified?
Fire as a large-scale disturbance
What are the most important aspects of long-term changes in fire characteristics on vegetation?
What is the current state-of-knowledge for the interaction of fire, vegetation, and climate?
What aspects of fire as a landscape/ecosystem disturbance are relevant to large-scale modeling?
Fire effects modeling structures
What existing models could be adapted or modified for proposed future research?
What are the relevant scale issues related to modeling fire impacts on vegetation and fuels?
What are some potential approaches for GIS-based modeling of fire impacts on vegetation?
How does one integrate climatic change scenarios in fire-vegetation models?
Managerial concerns, applications and decision support
How can a rigorous modeling approach be designed to be most useful to resource managers?
What are the most useful model structures for resource managers and decisionmakers?
How can decision support systems assist resource managers with fire effects issues?

pants had the option of using these questions and responses, modifying them, or developing their own. Workgroup objectives dealt with the overall accomplishments proposed for the workshop, namely describing, assessing, prioritizing, and recommending fire-disturbance research and managerial needs. A tactical plan for achieving the strategic objectives was also developed (Schmoldt and Peterson 1997, Schmoldt et al. 1998).

The decision-making and group discussion protocols included: (1) assignment of attendees into workgroups which were the foci for workshop discussions, (2) a conceptual structure for organizing workgroup discussion, and (3) a seven-step process for workgroup conduct that streamlined identifying, assessing, prioritizing, and recommending research and managerial needs.

Each workgroup developed key questions for their assigned topic. They were asked to provide corresponding responses for each key question. Workgroups also prioritized their list of key questions and, separately, their lists of responses within each question. Priorities were assigned for importance and for feasibility. The Analytic Hierarchy Process (Saaty 1980, 1990) was used within each workgroup to calculate priorities (Fig. 1). Following the workshop, statistical analyses (q.v., Schmoldt et al. 1998) were performed to determine which key questions – and which responses within each key question – differed significantly in priority.

3 Workshop output

3.1 Linkages among fire effects, fuels, and climate

The workgroup responsible for this issue developed five key questions which are presented below in order of importance. For each question, the group generated some general statements about the question's subject matter to establish a context for response discussions. The group then produced a set of responses to each question that define current research and management needs. The workgroup limited its discussion to just fuels and climate because it believed they are the most important factors.

Key questions

1. What, where, and when are the factors important to fire disturbance?
2. What do we know about linkages among fire effects, fuels, and climate?
3. At what scales are processes important?
4. How are linkages related in a landscape context?
5. What linkages are important to management?

The workgroup offered several general assessments of linkages. First, besides the importance of the fire-disturbance factors listed, it is their interactions that are truly significant. Second, extreme fire events are driven by climate, and through better understanding and predictability

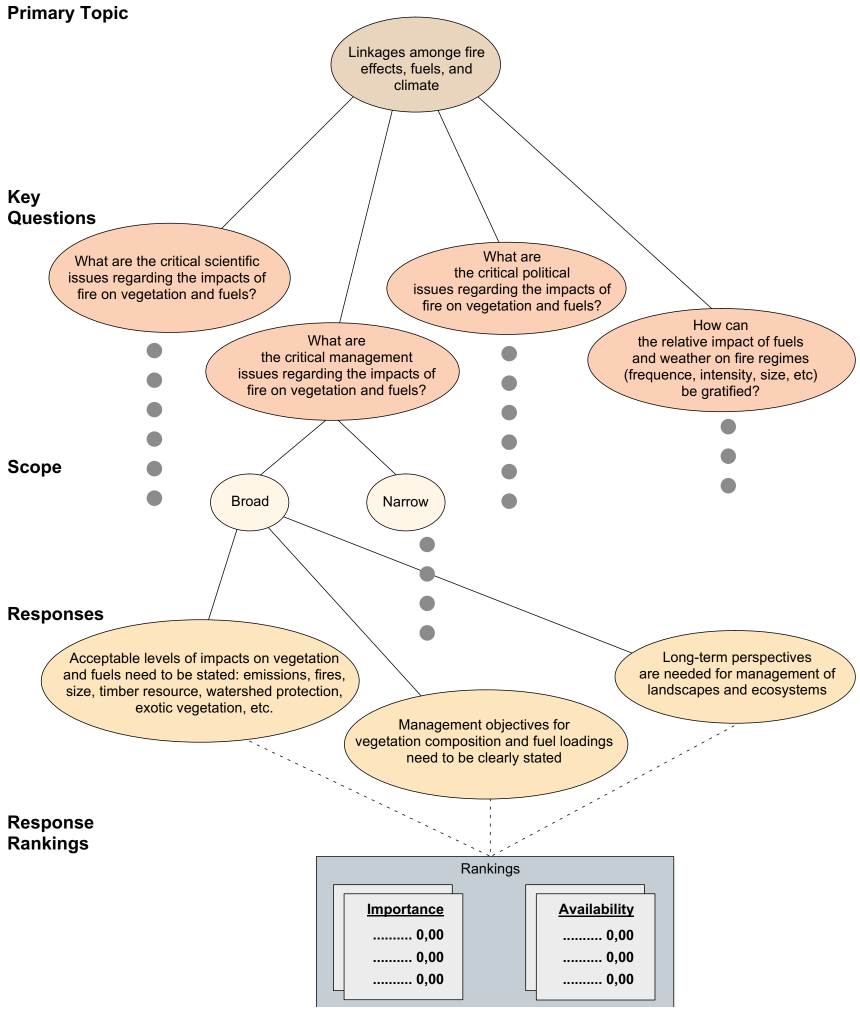

Figure 1.A graphical depiction of the hierarchical structure of the straw document illustrates a portion of one primary topic, including key questions, scope, and example responses for that key question. By ranking responses with respect to importance and feasibility/practicality, we have identified important issues and their feasibility/practicality, which then enabled us to make recommendations for (or prioritize) future research projects. Each of the other key questions were completed in a similar fashion.

of their precipitating conditions, researchers can greatly assist managers. Third, the probability of large-scale disturbances, combined with cost (= risk), needs to be computed more reliably. With respect to future needs, the workgroup noted that as fire suppression activities are reduced, smoke management will become a central fire-management issue.

3.2 Fire as a large-scale disturbance

The vast majority of fires, while important in the maintenance of ecosystem structure and function and the spatial heterogeneity of landscapes, may nevertheless be insignificant from the standpoint of broad-scale fire severity. It may not be necessary to model the behavior and effects of frequent, low-severity fire to the extent done for severe fire in a broad-scale fire severity model. For example, impacts on ecosystems or the atmosphere produced by low-severity fires (i.e., the majority of events) could be represented implicitly by model parameterizations that produce constant (or episodic) but relatively low levels of mortality, nutrient loss, or emissions in broad-scale simulations.

The key questions proposed by this workgroup are summarized below in decreasing order of importance. Due to the broad scope of these four key questions, the workgroup felt that more specific questions would better enable meaningful discussions. Therefore, the workgroup identified 17 focused questions (q.v., Schmoldt et al. 1998) across the four key questions. Responses were developed for the two or three most important focused questions under each key question.

Key questions

- What are the critical aspects of spatial and temporal dynamics of fire at large scales?
- What ecological role does fire play at larger scales?
- How can fire be managed at large scales?
- What are the critical characteristics of the fire-behavior environment?

3.3 Fire-effects modeling structures

Landscape-level changes resulting from fire are difficult to model due to climate and vegetation heterogeneity, lack of empirical data at large scales, and limited spatiotemporal scope of existing models. Nevertheless, because ecosystem composition and function change where disturbance regimes change, there is a critical need to model large-scale disturbances. Accurate simulation models will be needed to predict the outcomes of complex interactions among disturbances (particularly fire), climatic changes, and large-scale vegetation patterns. A principal difficulty in building large-scale fire-effects models is the extrapolation, or aggregation problem. In the past decade, models have been developed to predict fire ignitions, fire behavior, fire-effects, and vegetation change in response to fire (Schmoldt et al. 1998). Many of these models partially address the aggregation problem, but each type of model has identifiable sources of error when applied at broad spatial scales.

Scale issues and the aggregation problem framed the discussion and recommendations of this workgroup. Several of the key questions directly addressed scaling and aggregation error, while other more technical questions were motivated by previous difficulties in addressing these issues within models.

Key questions

- How does one validate a model's structure with respect to error propagation?
- What are the relevant spatial and temporal scale issues (including extent and resolution) related to modeling fire effects?
- What are the desired outputs of an "ideal" fire-effects model?
- How does one calibrate a fire-effects model?
- How does scale affect the modeling approach?
- What are the components of an "ideal" fire-effects model?
- What data exist for calibration, validation, and development of fire-effects models?
- What is the appropriate system structure (for example, an integrated system of separate models or a unified model)?
- How does one integrate climate into fire-effects modeling?
- What tools exist to generate data for the development of fire-effects models?

We need to use the modeling process carefully to identify gaps in data, knowledge, and theory. By quantifying the calibration necessary to match observed data, we can estimate the importance of missing spatial information or the magnitude of error associated with aggregation. Spatiotemporal variability, resolution, and extent were listed both as the most important scale issues and as the most feasible to solve. We need to be conscious of intrinsic limits of the accuracy and precision of our knowledge, and therefore, the predictive ability of our models. Judicious use of state-of-the-art aggregation techniques will be a key factor in optimizing models.

3.4 Managerial concerns, applications, and decision support

Good management rests on a foundation of solid science. There are two challenges that must be met to properly integrate management and science. First, research and management must collaborate through research-management partnerships. The key to this relationship-building challenge is communication. Second, biological, physical, and social science knowledge must be integrated as fire-disturbance models are developed. Fire-disturbance models are the nexus of fire management and research, and need to integrate all the sciences to provide an adequate foundation for successful management of fire on the landscape.

After some initial discussion covering a broad range of topics, the workgroup settled on a short list of key questions. These five management and application questions are

Table 3. Management concerns, applications, and decision-support key questions and their responses are rated according to importance and practicality as calculated with the AHP.

Importance	Key Questions and Responses	Practicality
0.43	**1. What are the most useful model structures and outputs, to support issues in planning, operations, monitoring and learning by resource managers decisionmakers, policy makers and researchers?**	**0.15**
0.53	Model to allow users to select fire regimes and show their probabilistic effects on the landscape	0.14
0.19	Data structures must be compatible with user capabilities	0.32
0.18	Develop hierarchical and selective modeling framework for fire regimes and fire effects	0.23
0.10	Communicate model limitations to users, and user needs to model builders	0.31
0.28	**2. How do we improve communication between users and model builders relative to the development life cycle?**	**0.44**
0.67	Pro-actively seek opportunities to communicate	0.85
0.33	Build long-term relationships	0.15
0.15	**3. How can we transfer research information rapidly and effectively?**	**0.17**
0.39	Improve documentation (user manuals, tutorials, on-line help, etc.) and model support (technical support, programming, scientific documentation, software distribution and support via Internet, etc.), apply product life cycles	0.13
0.27	Standardize and provide desired user interfaces	0.31
0.13	Explore alternate means for accomplishing data management (contracting, etc.) and technology transfer	0.33
0.13	Establish and support a development group	0.14
0.09	Apply free market principles (product development, support and distribution)	0.10
0.07	**4. How can we incorporate social and political issues into models/ decision support systems?**	**0.06**
0.66	Incorporate sociological research when developing decision support systems	0.53
0.34	Modelers and managers must be aware of emerging issues and anticipate future concerns	0.47
0.06	**5. How can relevant interdisciplinary resource management issues be incorporated into models?**	**0.18**
0.61	Improve communication between modelers and users	0.40
0.29	Involve a cross section of managers and policy makers in model development	0.38
0.10	Assign responsibility, develop measurement criteria, monitor accomplishment and provide accountability for both research and management	0.22

listed in Table 3, in order of importance. For each of the key questions, lists of responses are also enumerated in order of importance. This type of table was calculated for each of the workgroups, but only this workgroup's table is shown here because of limited space.

In general, the needs addressed by this workgroup include building "better" models (more accurate, more inclusive, more useful), integrating models into decision-support tools, improving communication, and strengthening relationships between management and research. Models need to have increased flexibility to cover a broad range of vegetation, fuels, climate, and topography. They also need to include more aspects of fire behavior, such as lightning strikes, crown-fire ignition, and crown-fire spread. In order to assist with decision support, modelers and users must communicate effectively in order to develop joint models that address current management issues, such as social and political needs and biodiversity concerns.

4 Conclusions and applications

The structured workshop process proved to be an effective way to develop issues, information, and approaches for addressing fire-disturbance effects on ecosystems. Application of this process and use of the strawman document (Table 2) varied among workgroups, but the availability of a prescribed process and conceptual template greatly facilitated timely discussion of topics and quantification of priorities. We observed that resource managers in the workshop appeared to adapt to the structured approach more readily than the scientists, a phenomenon we have observed in other workshops and settings as well (e.g., Peterson et al. 1994).

All of the recent "paradigms" that are currently part of the managerial lexicon of public agencies–ecosystem management, watershed analysis, landscape design, etc.–must be addressed within large spatial and temporal scales. The effects of fire disturbance on ecosystems are increasingly integrated into resource management plans as a "natural" process, or at least a strong consideration in fire management. The information compiled at the Fire-Disturbance Workshop offers a template for prioritizing future fire-effects research and for facilitating communication between scientists and research managers in the coming decade.

Acknowledgments

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