

Large-Scale Fire Disturbance: From Concepts to Models

Abstract

Assessing and predicting the effects of fire at large spatial scales are some of the most difficult, yet relevant, problems in fire science. The complexity of fire regimes in the Pacific Northwest and other regions is widely recognized, although information for addressing fire effects generally is available only at small spatial scales. This Special Issue of *Northwest Science* discusses the variability of fire regimes, critical issues related to scaling fire data up to large spatial scales and new modeling approaches for simulating fire effects. Increased integration of fire-effects data and models in resource management and planning is improving the management of disturbance regimes as components of ecosystem dynamics.

Fire is the most important periodic natural disturbance in most forest, shrubland and grassland ecosystems of western North America (Rogers 1996). Although they occur infrequently, large and high-intensity fires can cause rapid changes in vegetation, soils, nutrient cycling, microclimate and many other ecological properties. From a human perspective, large fires have potential impacts on the economic value and uses of natural resources and structures. The interface of human values with ecological impacts provides a context for the development of social policy and resource management with respect to fire phenomena.

The effects of fire on ecological systems in North America have been formally studied for over half a century. This research has included a wide range of ecosystems and perspectives, and we now understand many of the physical and biological impacts of fire on ecological systems. One could fill an entire bookcase with books and journal articles on the topic. With all this information available, why is there an increasing interest in fire in the Pacific Northwest and elsewhere in western North America?

There are two principal reasons. First, fire is now being increasingly studied and managed at large spatial scales (Schmoldt et al. 1998). This modification of spatial focus follows the current trend of developing approaches for managing watersheds, ecosystems, landscapes and biogeographic regions, that is, entities of not only large size but significant complexity (Quigley et al. 1996). Second, fire is increasingly viewed as a critical component of disturbance regimes and

spatiotemporal diversity at large spatial scales (Frelich and Reich 1995). Fire is no longer perceived as an isolated phenomenon, and its role in the dynamics of ecological systems is now viewed as not only an important disturbance but a necessary one.

Scientific and managerial assessment of large-scale fire has often been problematic, a situation that was illustrated during and following the large fires in the Yellowstone National Park region of 1988. Although fires of approximately 5,000 km² had occurred in this region during past centuries (Romme and Despain 1989), resource managers, administrators and the public seemed to have limited awareness of the role of extreme disturbance events in forest ecosystems.

Large fires are heterogeneous with respect to physical characteristics and biological impacts (Lertzman et al. 1998). Even most "catastrophic" fires generally have considerable variability in energy release, rate of spread, flame length and residence time, which result in spatial variability in vegetation mortality, plant regeneration, soil chemical properties, erosion and hydrological cycling. This variability creates remarkable diversity in physical and biological structure at large spatial scales. Ecologists have long recognized this heterogeneity and have been frustrated at the difficulty associated with sampling and understanding it.

One of the greatest barriers to understanding and managing large fires is a lack of data at large spatial scales (McKenzie 1998). The vast majority of scientific data on fire has been collected at

scales of 10^{-1} to 10^2 km² (McKenzie et al. 1996), and applying small-scale data to large-scale fire phenomena can result in significant errors in predicting fire effects, because critical processes differ at different spatial scales (Simard 1991). This problem is inherent not just to fire but to scaling in nearly all ecological systems and processes. It is one of the critical problems in ecology today and has severely limited our ability to translate small-scale ecological data into large-scale managerial applications (Peterson and Parker 1998a, b).

Fire regimes in western North America are characterized by variable frequencies, intensities and spatial scales (Baker 1989), depending on characteristics of the vegetation, fuels and other environmental conditions (Agee 1998). In the Pacific Northwest, ecosystems ranging from temperate coniferous rain forest to alpine meadows to semidesert shrub-steppe encompass a broad spectrum of climates and fire regimes. Retrospective analyses such as fire history studies show that fires generally occurred more frequently in most Western forests prior to the twentieth century. For example, ignitions from lightning and humans (Native Americans and later Euroamerican settlers) caused average fire frequencies of less than 10 years in some Western ponderosa pine (*Pinus ponderosa*) forests (Agee 1993). Fire frequencies during the twentieth century generally have been lower due to fire exclusion, including fire suppression and fragmentation of landscapes by logging and various human land uses (Baker 1993). As a result, fire severity in some forests is expected to be higher during the next century because of high fuel accumulations. In fact, there is some concern that recent large fires in forest ecosystems on the eastside Cascade Range (> 800 km² area in 1994) are evidence that fire regimes are already being pushed from low or moderate severity to high severity.

While some ecologists speculate about the implementation of "ideal" fire regimes based on historical fire frequencies, this is unrealistic in most cases. With the exception of a few parks and wilderness reserves, public and private lands are managed for timber and a diversity of resources, and human activities and structures are distributed throughout most landscapes. Resource managers are now looking at creative ways of integrating various aspects of disturbance regimes with

human activities such as timber production (Lertzman and Fall 1998). Knowledge of disturbance rates and patch size can be used to develop silvicultural and landscape management strategies that include fire or have some of the characteristics of historical fire patterns (DeLong 1998).

The spatial and temporal complexity of fire regimes presents enormous challenges for scientists and resource managers. It is unlikely that there will ever be sufficient data to confidently assess fire effects at large spatial scales because of the expense and time required to collect those data. Therefore, the most logical approach to resolving the "scale problem" is to develop models that can simulate large-scale processes and predict large-scale effects with reasonable accuracy.

The occurrence of large fires can be modeled with various statistical distributions and mathematical relationships (Alvarado et al. 1998), thereby simplifying the analysis of fire occurrence in specific regions. Determining the effects of fire at large spatial scales can be facilitated with a number of simulation modeling approaches (Keane and Long 1998), although the appropriate modeling strategy may vary depending on the ecosystem and spatial scale of interest. The ultimate scale problem now facing us is the potential impact of changes in the global atmospheric environment on the Earth's ecosystems. Altered disturbance patterns, including fire regimes, may be the greatest effect of global climatic change on many ecosystems. Fortunately there are now simulation modeling tools that address the effects of a changing climate on fire severity at large spatial scales and link them to dynamic vegetation models (Lenihan et al. 1998).

The authors of this Special Issue of *Northwest Science* outline critical issues related to large-scale fire effects in the Pacific Northwest and beyond, articulate the variability in fire-ecosystem interactions and highlight conceptual barriers related to scaling up from existing data. They also offer state-of-the-art approaches for scaling fire-effects data and for simulating fire effects at large spatial scales. The discussions extend beyond theory and concepts to the integration of scaling and modeling in management applications. The paradigm of science-based management is flourishing in North America. With a long history

of fire research behind us and a variety of analytical tools becoming available, we are well-prepared to integrate fire science in resource management. The social and political climate of the next decade will determine how fast this process occurs.

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