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Development and application of a geospatial wildfire exposure and risk calculation tool

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ABSTRACT

Applying wildfire risk assessment models can inform investments in loss mitigation and landscape restoration, and can be used to monitor spatiotemporal trends in risk. Assessing wildfire risk entails the integration of fire modeling outputs, maps of highly valued resources and assets (HVRAs), characterization of fire effects, and articulation of relative importance across HVRAs. Quantifying and geoprocessing wildfire risk can be a complex and time-intensive task, often requiring expertise in geospatial analysis. Researchers and land managers alike would benefit from a standardized and streamlined ability to estimate wildfire risk. In this paper we present the development and application of a geospatial wildfire risk calculation tool, FireNVC. We describe the major components of the tool and how they align with a geospatial wildfire risk assessment framework, detail a recent application of the tool to inform federal wildfire management and planning, and offer suggestions for future improvements and uses of the tool.

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1. Introduction

Wildfires, though under many circumstances desirable from an ecological perspective, can threaten human lives and property, degrade air and water quality, and damage natural and cultural resources. Prospectively assessing wildfire risk can help land managers better understand where fires are more likely to occur and with what impacts to highly valued resources and assets (HVRAs). Fundamentally assessing wildfire risk is built upon modeling the likelihood and intensity of wildfire interactions with HVRAs, as well as the magnitude of potential HVRA response to fire, which can be positive or negative (Finney, 2005; Miller and Ager, 2013; Scott et al., 2013). This information is useful for informing investments in loss mitigation and landscape restoration, in particular for pre-fire decisions relating to reduction of hazardous fuels and location-allocation of suppression resources. Assessment results can also be used to monitor trends in risk across space and time.

Assessing wildfire risk in a quantitative, spatial framework is essential for landscape planning (Thompson and Calkin, 2011). A quantitative framework for wildfire risk is consistent with actuarial principles and standard economic notions of risk, and further enables cost-effectiveness analysis as a basis for evaluating risk mitigation options. A spatial framework recognizes that wildfire is a spatial process with significant spatial variation in environmental factors driving wildfire likelihood and intensity, as well as resource and asset vulnerability.

Quantitative, spatial wildfire risk assessment frameworks are increasingly being applied, with growing sophistication, to inform wildfire management in the U.S. and elsewhere (Fiorucci et al., 2008; Bar Massada et al., 2009, Atkinson et al., 2010; Chuvieco et al., 2010; Thompson et al., 2011; Román et al., 2012). Applications vary, although many share the premise of coupling spatial information on fire likelihood with resource or asset vulnerability, and integrate multiple disciplinary perspectives including fire and fuels modeling, fire ecology, and resource economics. In particular the use of advanced spatial burn probability modeling techniques is gaining popularity (Carmel et al., 2009; Scott et al., 2012a; Parisien et al., 2013). The basic framework for exposure and risk assessment is flexible and scalable, applicable at national

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(Thompson et al., 2011), regional (Ager et al., 2013), landscape (Thompson et al., 2013a), and project-level (Ager et al., 2010) planning scales.

In recent years the application of risk analysis and use of risk-based decision support tools has greatly expanded for federal wildfire management in the United States (Miller and Ager, 2013). A particularly salient example is the Wildland Fire Decision Support System, which provides functionality for burn probability modeling and exposure analysis to support risk-informed incident decision making (Calkin et al., 2011a). There is great opportunity to expand efforts beyond the incident decision support realm to provide risk-based information for hazardous fuels and preparedness decisions. Along those lines, in recent years the list of “early adopters” has continued to grow, with risk-based assessments performed on federally managed lands throughout the western United States including the Beaverhead-Deerlodge National Forest, the Black Hills National Forest, the Bridger-Teton National Forest, the Deschutes National Forest, the Inyo National Forest, the Lewis and Clark National Forest, the Pike-San Isabel National Forest and the Cimarron and Comanche National Grasslands, the Sequoia National Forest, the Sierra National Forest, the Stanislaus National Forest, and the Grand Teton National Park.

In performing these geospatial risk assessments a number of significant process limitations became apparent. One key lesson learned from our experience is the need for a standardized and streamlined geospatial risk calculation tool. A potential bottleneck of calculating integrated risk scores is the large number of geoprocessing steps required, in particular the intersections of fire modeling outputs with HVRA maps and calculations of HVRA responses to fire. In practice these steps are repeated many times dependent on the total number of HVRAs, and are therefore quite time intensive and introduce the potential for human error. The computational time required for a landscape-level assessment using standard GIS software packages can take days to complete, making it difficult to use assessment results in a real-time workshop setting, or to quickly regenerate results if changes are warranted.

In order to address the limitations associated with the process, we developed a software toolbox, FireNVC, designed to perform risk calculations in a computationally efficient timeframe suitable for rapid analysis. We created FireNVC to provide a flexible research tool capable of landscape-scale exposure and risk assessment, and ultimately to provide decision support for land managers seeking to mitigate wildfire risk. Here we discuss the development of the FireNVC toolbox as well as the subsequent improvements in computational efficiency. As a demonstration of the tool's utility we detail a recent application of FireNVC for the U.S. Forest Service's Rocky Mountain Region.

In the subsequent sections we first describe in more detail the framework for wildfire risk assessment, as well as a geospatial modeling process to implement the framework. We then describe the development of the FireNVC tool itself, and next illustrate its application for the Rocky Mountain Region. Lastly we discuss strengths and limitations of both the framework and tool, and offer recommended directions for future work.

2. A wildfire risk assessment framework

A generalized framework for wildfire risk assessment entails four primary stages: problem formulation, exposure analysis, effects analysis, and risk characterization (Fairbrother and Turnley, 2005; Thompson and Calkin, 2011). In practice the process required to implement this framework entails multiple steps, and is based on an integrated, interdisciplinary perspective (Scott et al., 2013). In the sub-sections that follow we briefly review the wildfire risk assessment framework and process, informed by our experiences performing this process multiple times at varying planning scales.

2.1. Problem formulation

It is critical to begin by articulating the objectives of the assessment, the spatiotemporal scope of analysis, and the assessment endpoints. Assessment objectives relate to how assessment results are to be used and will fit into broader structured decision processes for wildfire management, ranging from project-level fuel treatment planning to strategic prioritization and budgeting. A critical step is the identification, characterization, and mapping of HVRAs that are likely to be impacted by fire and that are salient to wildfire management goals.

2.2. Exposure analysis

Exposure analysis explores the degree to which HVRAs are likely to interact with wildfire, and entails the coupling of fire modeling outputs with HVRA maps. Intersecting fire modeling outputs with rasterized HVRA maps allows for a fine-scale quantification of the likelihood of any given HVRA pixel burning, and further provides critical information in terms of the intensity with which fire will burn at that location. Pixel-based exposure can thus be quantified in terms of multiple metrics including expected HVRA area burned, expected HVRA area burned by flame length category, mean burn probability, mean fireline intensity, and conditional flame length (Salis et al., 2012).

2.3. Effects analysis

Effects analysis explores the potential consequences of varying levels of HVRA exposure, as a function of fire behavior – typically flame length – as well as other environmental characteristics that could influence HVRA susceptibility. There are at least two key reasons for contemplating fire effects. First, because wildfire can result in both negative and positive consequences, effects analysis can lead to the identification of areas on the landscape where resource protection or ecological restoration objectives are most appropriate. Second, fire effects are not necessarily directly proportional to probability and intensity, and thus areas of highest expected loss (or benefit) may not coincide with the areas of highest exposure; see Thompson et al. (2013a) for an illustration of this point.

In the framework described here, fire effects are quantified in terms of net value change (NVC), thereby explicitly recognizing the potential for both beneficial and detrimental effects. HVRA-specific tabular “response functions” determine NVC as a function of flame length, where NVC is expressed in relative terms as percentage loss or gain (e.g., complete loss $= -100\%$). The response function approach provides a flexible, yet consistent, platform for evaluating potential fire effects across HVRAs. Multivariate response function definitions can be readily incorporated, for instance differentiating likely post-fire watershed response according to erosion potential. Geospatial calculations combining burn probabilities with response functions result in an HVRA-specific estimate of expected NVC, or E(NVC).

2.4. Risk characterization

Characterizing wildfire risk is the process of synthesizing results of the prior analyses to provide information useful for decision making. Identifying the risk attitude of the decision maker and how