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Evaluating wildland fire danger and prioritizing vegetation and fuels treatments

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Abstract

We present a decision support application that evaluates danger of severe wildland fire and prioritizes subwatersheds for vegetation and fuels treatment. We demonstrate the use of the system with an example from the Rocky Mountain region in the State of Utah; a planning area of 4.8 million ha encompassing 575 subwatersheds. In a logic model, we evaluate fire danger as a function of three primary topics: fire hazard, fire behavior, and ignition risk. Each primary topic has secondary topics under which data are evaluated. The logic model shows the state of each evaluated watershed with respect to fire danger. In a decision model, we place summarized fire danger conditions of each watershed in the context of the amount of associated wildland–urban interface (WUI). The logic and decision models are executed in EMDS, a decision support system that operates in ArcGIS. We show that a decision criterion such as relationship to WUI can significantly influence the outcome of a decision to determine treatment priorities. For example, we show that subwatersheds that were in the relatively poor condition with respect to fire hazard, behavior, and ignition risk may not be the best candidates for treatment. Additional logistical factors such as proximity to population centers, presence of endangered species, slope steepness, and road access all might be taken into account in selection of specific watersheds within a management area for treatment. Thus, the ecological status of each ecosystem can be placed in one or more social values contexts to further inform decision-making. The application can be readily expanded to support strategic planning at national and regional scales, and tactical planning at local scales.
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1. Introduction

Wildland fuels have accumulated in many western forests of the United States (US) for the past 100 years due to 20th century management activities (Agee, 1998; Hessburg and Agee, 2003), and ever-changing climatic conditions (Burkett et al., 2005; Schoennagel et al., 2004). As demonstrated by recent fires, added fuels are fostering more intense wildfires that are more difficult to contain and control. Consequently, valuable property and natural resources have been destroyed, costs of fire management have escalated, fire-dependent forest ecosystems have deteriorated, and risks to human life and property continue to rise (GAO, 2002, 2003, 2004).

Historically, fires of varying size, frequency, and intensity maintained spatial patterns of forest vegetation, as well as temporal variation in those patterns (Agee, 2003; Hessburg et al., 2005; Schoennagel et al., 2004; Turner, 1989). In fact, many agents interacted to shape vegetation patterns and their spatio-temporal variation, including forest insect outbreaks, forest diseases, fires, weather and climatic events, and intentional aboriginal burning (Hessburg and Agee, 2003; Whitlock and Knox, 2002). Their interactions resulted in characteristic landscape patterns and caused variation in forest structural attributes, species composition, and habitats that resonated with the dominant disturbance processes. Patterns of forest vegetation were directly linked with the processes that

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created and maintained them (Pickett and White, 1985; Turner et al., 2001).

Circumstances are different today—patterns and processes are still tightly linked, but not as before. Human influences have created anomalous vegetation patterns, and these patterns support fire, insect, and disease processes that display uncharacteristic duration, spatial extent, and intensity (Ferry et al., 1995; Hessburg et al., 2005; Kolb et al., 1998). For example, 20th century fire suppression and prevention programs significantly reduced fire frequency in many dry mixed coniferous forests. Contemporary wildland fires are now larger and more intense on average than those of the prior two or three centuries (GAO, 2002, 2003, 2004; U.S. Government, 2003). In short, settlement and management activities have altered spatial patterns of forest structure, composition, snags, and down wood at patch to province scales. As a result, significant changes in fire frequency, severity, and spatial extent are linked to changes in forest vegetation patterns at patch to province scales (Agee, 1998, 2003; Ferry et al., 1995; Hessburg et al., 2005).

Here, we present a decision support system for evaluating danger of severe wildland fire and prioritizing subwatersheds for vegetation and fuels treatment. In our descriptions, we adopt standardized nomenclature of the National Wildfire Coordinating Group (NWCG, 1996, 2005) and Hardy (2005). The decision support system consists of a logic model and a decision model. In the logic model, we evaluate danger as a function of three primary topics: fire hazard, fire behavior, and risk of ignition. Each primary topic has secondary topics under which data are evaluated. The logic model shows the state of each evaluated landscape with respect to fire danger. In the decision model, we place the fire danger summary conditions of each evaluated landscape in the context of the amount of associated wildland–urban interface (WUI). The logic and decision models are executed in EMDS (Reynolds et al., 2003), a decision support system that operates in ArcGIS. We show that a decision criterion such as relationship to WUI can significantly influence the outcome of a decision to determine treatment priorities. We demonstrate use of the system with an example from the Rocky Mountain region in the State of Utah, which represents a planning area of about 4.8 million ha and encompasses 575 complete subwatersheds. We discuss considerations for extending the application to support strategic planning at national and regional scales, and tactical planning at local scales.

This decision support system is comparable in some aspects to the National Fire Danger Rating System (NFDRS, Deeming et al., 1977; Burgan, 1988), but there are important differences and advances too. For example, the NFDRS summarizes fire danger information pertaining to fire hazard, fire behavior, and ignition risk, the primary topics of fire danger, at a regional scale using annual weather and forest conditions information. The fire danger variables computed by FIREHARM and used in this application reflect a broader set, are computed at a stand or patch scale and summarized to subwatersheds, and the variables are computed as probabilities of exceeding a severe fire threshold using 18 years, rather than a single year of data.

2. Methods

2.1. Study area

We selected one map zone as a proving ground for our modeling approach, but these methods could be applied to all US map zones. Map zones were developed in the US by the Earth Resources Observation and Science (EROS) Data Center (http://www.nationalmap.gov). They are broad biophysical land units represented by similar landforms, land cover conditions, and natural resources; there are 66 in the continental US (Fig. 1). Map zone 16 falls almost entirely within the State of Utah. Within this study area, we evaluated wildland fire danger for the 575 subwatersheds that were entirely contained within map zone 16 (Fig. 2). The average size of subwatersheds was 8300 ha, and size ranged from 2800 to 18,000 ha. For reference, a subwatershed represents the sixth level in the watershed hierarchy of the US Geological Survey (Seaber et al., 1987).

2.2. Data sources

Most spatial data used in this study came from the LANDFIRE prototype project mapping effort (Table 2, Rollins et al., 2006). The LANDFIRE project created spatial data layers of topography, biophysical environments, vegetation, and fuels at 30-m resolution for two map zones in the Rocky Mountains (map zones 16 and 19). All layers were available at the www.landfire.gov web site.

The fuels layers used in this study included two surface fuel classifications: (1) the 13 fire behavior fuel models (FBFM) of Albini (1976), defined by Anderson (1982), and mapped using methods described by Keane et al. (1998, 2000, 2007) and (2) the default fuel characterization classes defined in the Fuel Characterization Classification System (FCCS) described by Sandberg et al. (2001) (http://www.fs.fed.us/pnw/fera) and mapped using methods described by Keane et al. (2007). The FBFMs, which do not represent actual surface fuels, provided an indication of the expected surface fire behavior,[1] while the FCCS classes indicated the characteristics of the actual surface fuelbed, information useful for fire effects[2] simulation (Ottmar et al., 2004). In the next update of our fire danger model, we will incorporate the 40 fire behavior fuel models of Scott and Burgan (2005).

The canopy fuels layers used were the LANDFIRE canopy bulk density and canopy base height layers. Canopy bulk density (CBD) represents the mass of available canopy fuel per unit volume of canopy in a stand (Scott and Reinhardt, 2002) and it is defined as the dry weight of available canopy fuel per unit volume of the canopy including the spaces between the tree crowns (Scott and Reinhardt, 2001). Canopy base height (CBH) represents the level above the ground at which there is enough

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[1] When we refer to "fire behavior" we are referring to the physical characteristics of the combustion process (Rothermel, 1972).

[2] When we refer to 'fire effects" we are referring to the direct and indirect consequences of the combustion process (DeBano et al., 1998).

Fig. 1. Map zones of the United States from the Earth Surface Resources and Science (EROS) Data Center. There are 66 map zones in the continental United States. The highlighted area shows the position of the study area, map zone 16.

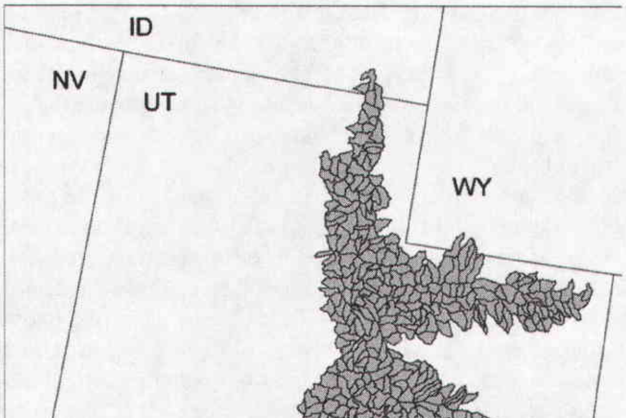

Fig. 2. Subwatersheds of map zone 16 in State of Utah, USA. The average size of subwatersheds was about 8274 ha (min 5000 ha, max 10,000 ha). A subwatershed represents the sixth level in the established US Geological Survey watershed hierarchy (Seaber et al., 1987).

aerial fuel to carry the fire into the canopy, and it is defined as the height from the ground to the bottom of the live canopy (Scott and Reinhardt, 2001) but may also include dense, dead crown material that can carry a fire. These two map layers were developed for the forested lands of map zone 16 using a predictive landscape modeling approach that integrated remotely sensed data, biophysical gradients, and field reference data (Keane et al., 2007). The canopy fuel characteristics were calculated for numerous plots distributed throughout the map zone using the FUELCALC model (Scott and Reinhardt, 2001) and each plot was described from a set of predictor variables computed and mapped specifically for the LANDFIRE project. The predictor variables were related to CBD and CBH using a classification and regression tree (CART) approach.

Fire behavior was simulated with these surface and canopy fuels layers assuming 90th percentile weather conditions using the FIREHARM (Keane et al., 2004) program. FIREHARM is a computer program that calculates four fire behavior variables (fireline intensity, spread rate, flame length, crown fire potential), five fire danger variables (spread component, burning index, energy release component, Keetch-Byram drought index (Burgan, 1993), ignition component), and five fire effects variables (smoke emissions, fuel consumption, soil heating, tree mortality, scorch height) for each day across an 18-year climate record (6574 days), and for every polygon in a user-specified landscape. Daily values across the 18-year period can be used to estimate probabilities that fire behavior, fire danger, or fire effects variables may exceed important thresholds. These probabilities can be mapped onto the landscape in a GIS, and maps can be used to prioritize, plan, and implement fuel or fire treatments. In this application, FIREHARM was used to estimate surface fire spread rate, flame length, and fireline intensity using the Rothermel (1972) fire spread model, and crown fire intensity and spread using Rothermel (1991) and the Scott (1999) crown fire algorithms.

In addition, LANDFIRE provided a fire regime condition class (FRCC) digital map created by simulating historical landscape conditions and comparing these simulations with current vegetation conditions derived from satellite images. FRCC is an ordinal index with three categories that describe how far the current landscape has departed from presettlement-era conditions (Hann, 2004) (see www.frcc.gov for additional details).

Several other data layers were used to derive ignition risk. Relative plant greenness was estimated from an AVHRR image from 1 June 2004 (Burgan and Hartford, 1993). These data were obtained from the USDA Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. The effects of long-term drought were estimated from Palmer Drought Severity Index (PDSI) data obtained from the National Climate Data Center (Table 2). Available PDSI data represented a span of 20 years (1971–1990), and data were derived from a 2.5° continental scale grid of PDSI reconstructed by Cook et al. (2004). Lightning strike data were obtained from the National Lightning Detection Network (Table 2).

Data made available for map zone 16 will ultimately be available for all 66 map zones of the continental US. Map zones of the western US to eastern Montana and New Mexico (map zones 1–24, 28) will be completed in 2006, and the entire continental US by the end of 2008 (http://www.landfire.gov/schedule_map.php).

2.3. *Broad outline*

We evaluate relative fire danger in individual subwatersheds of an entire map zone. We show how evidence for fire danger can be modeled as a logic-based discourse in a decision support system to support national, regional, and local landscape analysis and planning. Results of evaluations are expressed in terms of evidence for low wildfire danger in each subwatershed. This information is used subsequently in a decision model to prioritize subwatersheds for treatment, considering additional logistical information.

2.4. *Implementation steps*

Under the fire hazard topic (Table 1), we estimated for each elementary topic (lowest level in the model where data are evaluated) the percentage area and degree of aggregation of observations exceeding a specified threshold value using spatial data layers provided by the LANDFIRE project and a spatial analysis program (FRAGSTATS, McGarigal et al., 2002, Table 2). For each elementary topic under fire behavior and ignition risk, we estimated the probability that conditions within a given watershed exceeded a specified threshold value based on spatial layers of fire spread rate and intensity generated by the FIREHARM model using the Rothermel (1972) spread model. We constructed a logic model within the EMDS modeling system to show how all elementary topics contributed to an evaluation of fire danger. We evaluated evidence for low wildfire danger within watersheds of a map zone to provide an ecological basis for determining treatment priority. A decision analysis was then run in a separate but related decision model to incorporate ecological and logistical considerations for planning fuels treatment across the study area.

2.5. *Logic model design*

We graphically designed the logic model for evaluating the relative danger of wildland fire (hereafter, fire danger) with the NetWeaver® Developer (Rules of Thumb, Inc., North East, PA)[3] modeling system. We present the formal logic specification both as a topic outline for readability and compactness (Table 1), and as a dendrogram (Fig. 3). Each topic in a NetWeaver® model represents a topic for which a premise or proposition is evaluated. For example, the overall fire danger topic, representing the top level in the model, evaluates the proposition that wildland fire danger is low (Table 1, Fig. 3). All other propositions in the model similarly take the null form; i.e., the test for all topics is always for a low condition.

The complete evaluation of fire danger depends on three primary topics – fire hazard, fire behavior, and ignition risk – each of which incrementally contribute to the evaluation of fire danger, as indicated by the *union* operator (Table 1). Moreover, because the *union* operator specifies that premises incrementally contribute to the proposition of their parent topic, low strength of evidence for one topic can be compensated by strong evidence from others. Notice that if the fire danger topic is thought of as testing a conclusion, then the three topics on which it depends can be thought of as its logical premises. Similarly, each of the three topics under fire danger has its own logic specification that includes a set of secondary topics or premises. The full logic structure (Table 1), considered in its entirety, constitutes what we referred to earlier as the logical discourse. We note that this logic model represents one of many possible logical configurations, and the current configuration may be readily adapted. Any of the primary and secondary topics may be modified, and topics may be added or removed with relative ease. Likewise, thresholds of elementary topics (discussed below) can be modified to fit customized or evolving evaluations as a function of adaptation and learning.

2.5.1. *Primary topic—fire hazard*

Evaluation of fire hazard (Table 1, Fig. 3) depends on the *union* of topics addressing surface fuels, canopy fuels, and fire regime condition class, each of which depends on two additional elementary topics that directly evaluate data (Tables 1 and 2). Evaluation of each elementary topic under

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[3] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.