EVALUATING RISKS AND BENEFITS OF WILDLAND FIRE AT LANDSCAPE SCALES

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ABSTRACT

Fire suppression has resulted in severe management challenges, especially in the wildland-urban interface zone. Fire managers seek to reduce fuels and risks in the interface zone, while striving to return the natural role of fire to wildland ecosystems. Managers must balance the benefits of wildland fire on ecosystem health against the values that need to be protected from fire, and they need to achieve this balance for entire landscapes. Although wildland fire managers have a full spectrum of strategies available for reducing fuels, they lack appropriate tools for effectively applying these fuels management strategies at landscape scales. Furthermore, many managers are locked into a reinforcing feedback cycle in that perceived risks lead to fire suppression, leading to increased risks and further fire suppression. Existing tools and approaches for planning fire and fuels management perpetuate this cycle by focusing on risk while ignoring the potential benefits of fire. A GIS model is currently being developed that will assess the potential benefits from wildland fire as well as the risk to values in the interface. The model estimates both fire risk and benefit as functions of three variables, all of which vary across landscapes: (1) probability of fire occurrence, (2) expected fire severity, and (3) the ecological, social, and economic value ascribed to an area. By generating maps of fire risk and benefit, the model provides critical information that can be used to prioritize areas for fuels treatment programs. Managers can use the model to simulate alternative fuels treatments and assess their effects on fire risk and benefit across a landscape. As such, the model represents a powerful tool that will help managers develop landscape-scale plans that maximize the benefits of wildland fire while minimizing the risks to values in the wildland-urban interface zone.

Keywords: wildland-urban interface, wildland fire use, GIS model

INTRODUCTION

Fire suppression has led to fuel accumulations, uncontrollable wildland fires, increased risk to human life and property, and the deterioration of fire dependent ecosystems. These consequences pose severe challenges for managers struggling to allow the natural role of fire in the face of extreme risks caused by accumulated fuels. This challenge is especially pronounced in the wildland-urban interface zone. The accumulation of wildland fuels must be reduced in order to reduce the human threat from fire as well as to maintain natural resource values. Wildland fire managers have a full spectrum of strategies available for reducing fuels including naturally ignited wildland fires, management ignited prescribed fires, thinning and other mechanical methods. In addition, they have a variety of tools and methods for predicting fire behavior and first order fire effects (e.g., Andrews, P. 1986; Finney, M. 1994; Reinhardt, E. et al. 1997). Even with these tools, however, managers are unable to effectively use the entire suite of fuel reduction strategies for at least three reasons:

1. *Inadequate tools for landscape planning.* Existing tools are inadequate for planning fuels management at the landscape scale. Most methods have been developed at the stand scale and cannot

account for contagion and other spatial processes and relationships that exist at landscape scales.

2. *Competing management objectives.* Wildland fires are suppressed when the goal of protecting social values overrides that of restoring the natural role of fire. Each decision to suppress wildland fire reinforces a feedback cycle where fuels continue to accumulate, risk escalates, and the tendency to suppress fires grows (Figure 1). As this cycle continues, the opportunities for using both wildland fire and prescribed fire diminish. The cycle is further amplified by trends and events that are typically outside a land manager's control such as increased development in the wildland-urban interface zone, prolonged drought, or an overextended national fire preparedness situation.

3. *Lack of information on fire benefits.* Although wildland fire managers need to balance the benefits of fire use with the risks it carries, existing tools and approaches focus only on the negative consequences of fire. Without information on the benefits of fire, the motive for using wildland fire as a fuels management strategy is limited. Furthermore, relying on predominantly risk-focused information helps perpetuate the cycle of risk and suppression (Figure 1).

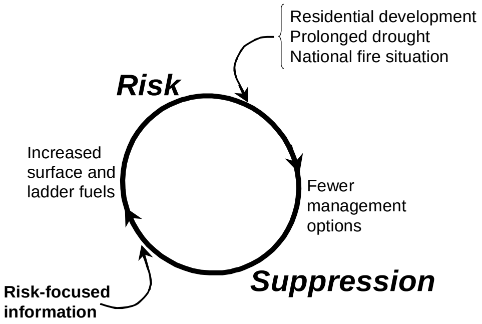

Figure 1. A positive feedback cycle between fire suppression and risk can be amplified by events and trends outside of a fire manager's control (e.g., development in the interface, drought, national fire situation) and by relying solely on risk-focused information for decision support.

To meet the challenge of reducing fuels and risks from fire, wildland fire managers need to take advantage of all available strategies, including prescribed fire and wildland fire use. Using wildland fire to reduce fuels may be the least expensive alternative, and it may be the best option for restoring the natural role of fire in wildlands. To use wildland fire effectively, managers need a tool that quantifies the benefits of wildland fire as well as its risks. This information must be provided at a landscape scale if fire managers are to effectively prioritize their fuels management activities. A landscape scale approach is also essential because fire is a spatial process whose spread and severity is strongly influenced by a variety of landscape features.

In this paper, we describe a model currently being developed that will help managers develop landscape-scale plans that maximize the benefits of wildland fire while minimizing the risks to values in the wildland-urban interface zone. Although this model is still in development, we provide output from a preliminary version to demonstrate the modeling approach and to illustrate the utility and application of the model.

BACKGROUND

The Federal Wildland Fire Policy Report of 1995 declares that "wildland fire, as a critical natural process, must be reintroduced into the ecosystem." This report supports the Wilderness Act of 1964 which legislated that wilderness be managed "to preserve its natural conditions" and in such a way that it is "affected primarily by the force of nature." However, suppression remains the dominant strategy in wilderness fire policy across all agencies and the number of acres burned each year is far short of that needed to restore natural fire regimes (Parsons, D. and Landres, P. 1998). Although the current lack of wildland fire in wilderness directly conflicts with federal law and policy, the perceived risk of fire to values in adjacent lands prevents compliance with these laws and policies. The pressure to suppress wildland fire increases with the perceived risk, whether the risk is due to the presence of values in the adjacent wildland urban interface, extreme drought conditions, or a national fire situation that has overextended firefighting resources (Bunnell, D. and Zimmerman, G. T. 1998). Each decision to suppress wildland fire contributes to a reinforcing cycle (Saveland, J., 1998) within which risk increases and the decision to suppress fires becomes more likely (Figure 1).

The risks from fire can be mitigated by manipulating and reducing fuels. Techniques for manipulating fuels include disposal (on-site reduction), rearrangement (on-site redistribution), removal (off-site), conversion (changing flammability), and isolation (fuel breaks and fire breaks) (Omi, P. 1996). These techniques can be implemented using combinations of wildland fire, prescribed fire, or mechanical treatments. Determining how to apply these treatments across landscapes to produce desired outcomes in the future, however, is a relatively new challenge for fire management and research (Omi, P. 1996).

A variety of research efforts have “scaled-up” information originally developed at the stand scale (e.g., Finney, M. 1994; Keane, R. et al. 1996). Several approaches and tools have been developed specifically to support management decisions and planning efforts, but most focus on the occurrence or movement of fire without considering fire effects and the values that may be affected by fire (Finney, M. 1994; Perkins, J. 1994; Wiitala, M. and Carlton, D. 1994; Lasko, R. and Tine, P. 1995; Sapsis, D. et al. 1996; Burgan, R. et al. 1997). Approaches explicitly treating fire effects and values at risk have ignored the potential benefits from fire (Close, K. and Wakimoto, R. 1995; Burton, D. et al. 1998).

Recently, two approaches have been developed to aid in the reintroduction of fire and fire regime restoration. Both use the departure from the historic fire regime to determine what level of fire activity or fuels management is necessary for fire regime restoration (Hardy, C. et al., in press) or to estimate the ecological need for fire (Caprio, A. et al. 1997). Caprio, A. et al. (1997) used a Fire Return Interval Departure (FRID) index to identify areas having the greatest need for fire regime restoration. These areas can then be targeted for prescribed fire activities. Fires spread across landscapes, however, and the fire return interval at one location can be influenced by the frequency of fires at downslope and upwind locations. This spatial dependence of fire occurrence must be considered when planning at the landscape scale. Furthermore, the FRID index does not provide information about the fire severity that would result from a wildland fire. For example, in a short fire-interval ecosystem, the FRID index identifies areas that have been without fire the longest. Unfortunately, these may also be the same areas that will experience fire severities far greater than historical severities; choosing to use wildland fire in such areas may not be prudent. Indeed, Caprio, A. et al. (1997) used the FRID index to identify areas for *prescribed* fire, where the severity of the fire can be better controlled than in a wildland fire. The approach taken by Hardy, C. et al. (in press) attempts to identify areas that would experience such abnormally high severity fires, thereby identifying areas requiring fuel treatment before wildland fire is used. However, the purpose of the approach used by Hardy, C. et al. (in press) was a coarse-scale national assessment and they used broad fire regime classifications to estimate departure from historic conditions. These classifications are too broad for planning at the smaller landscape scale.

The spatial nature of fire and the resulting spatial interactions across a landscape require more than simply aggregating stand-scale fire effects data to larger spatial scales. Therefore, a shift to a landscape perspective of managing fire and fuels may require a new set of tools and modeling approaches. Modeling approaches based on biophysical processes will ensure their applicability to a broad range of vegetation, fuels, climate, topography, and fire types (Schmoldt, D. et al. 1999). Geographic Information System (GIS) technology offers the ability to provide spatially explicit data over large areas and the adaptability to new data. When developing models to be used in a planning context, communication between modelers and managers is critical. Input from managers must be central to the model building effort and model features should include an easy-to-use graphical interface that allows managers to “game” with multiple scenarios. Furthermore, model logic should be clear enough for managers to understand and interpret the output (Schmoldt, D. et al. 1999).

RISKS AND BENEFITS

Definitions

The definition of “risk” found in a standard English dictionary is “exposure to possible loss or injury.” Rewritten in a quantitative context, this definition becomes “the probability of loss or injury,” a definition that is very different from the definition(s) of risk commonly used in the fire literature. Many authors use “fire risk” as synonymous with “fire occurrence” (e.g., Wiitala, M. and Carlton, D. 1994; Close, K. and Wakimoto, R. 1995; Sapsis, D. et al. 1996), thus connoting that all fires have negative impacts. Fire can produce many benefits, however, including removal of accumulated fuels, creation of plant establishment sites, enhancement of habitat diversity, increased water yield, etc. (Mooney, H. et al. 1981; Crutzen, P. and Goldammer, J. 1993; Greenlee, J. 1996). If fire risk is the probability of a loss due to fire (Rowe, W. 1975; Suter, G. 1993), then it can be quantified in terms of the probability of fire-damaged property, loss of life, diminished air quality from smoke, etc. Following this definition, fire benefits can be defined as the probability of a gain resulting from fire (Rowe, W. 1975).

Conceptual Framework

Adopting these definitions, we developed a conceptual framework for evaluating fire risks and benefits that integrates the biophysical environment and the social environment (Figure 2). Risk and benefit are

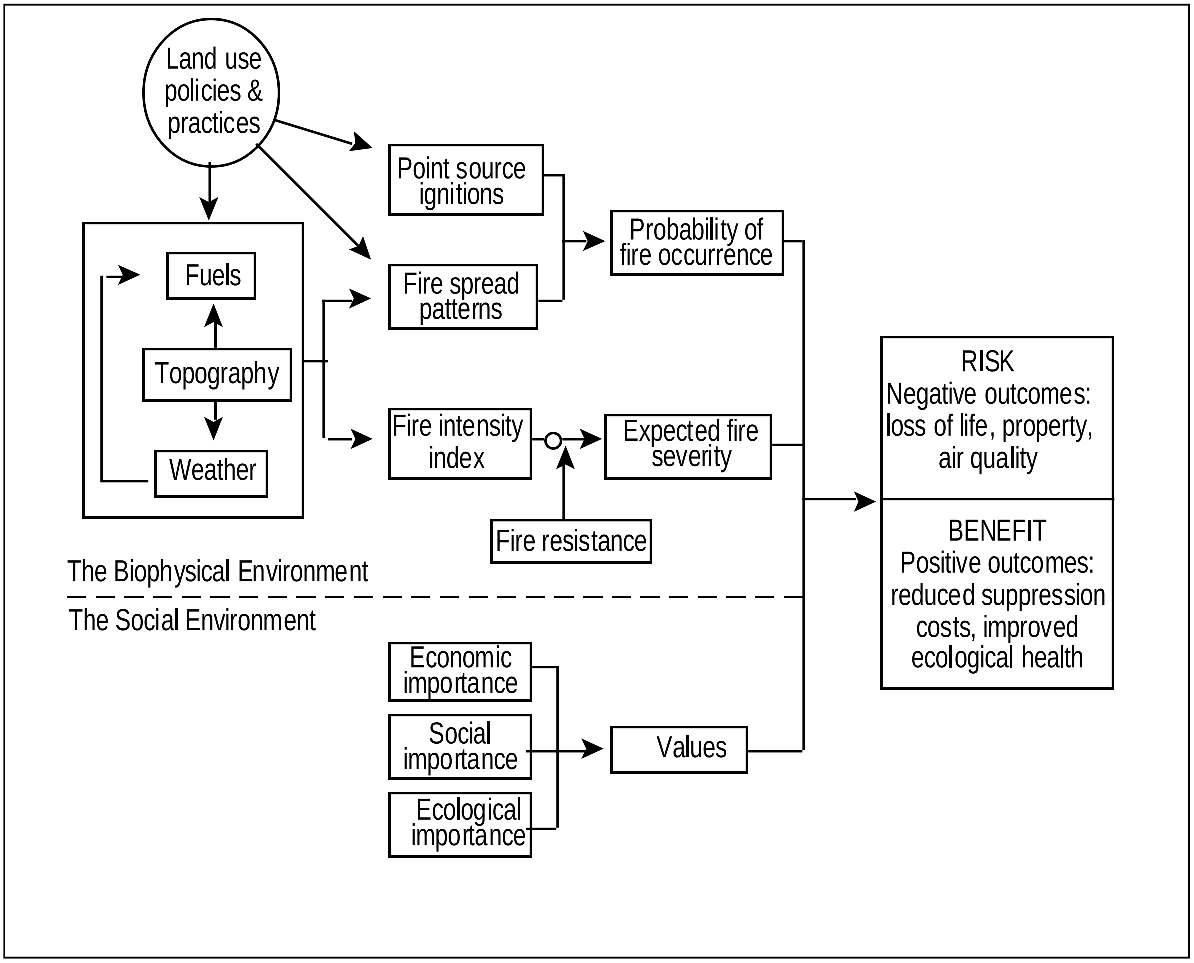

Figure 2. Conceptual framework for evaluating fire risks and benefits at landscape scales.

functions of three variables: (1) the probability of a fire occurring within a specific area, (2) the expected fire severity if a fire did occur, and (3) value of the area. Below, we briefly describe how each of these variables might be derived.

Fire Occurrence

The probability of fire occurrence has two parts, both of which vary spatially across landscapes: (1) point source ignitions (lightning- and human-caused fires), and (2) fire spread patterns. Maps of historical ignitions can be used to estimate the probability of fire occurrence due to point source ignitions and spatial model functions can be developed to determine the contribution of landscape fire spread to the probability of fire occurrence for an area.

Fire Severity

Expected fire severity across a landscape can be estimated from an index of fire intensity, which can be computed from maps of fuels, topography, and weather conditions (Rothermel, R. 1972). This fire intensity index can be estimated for a series of different drought conditions. The degree to which a fire of a particular fire intensity affects a specific area depends on the fire resistance of the attributes of interest within the area. For example, an area that has many houses with flammable wood siding and roofing will suffer more severe effects than an area that has fire-resistant houses.

Values

Finally, the ecological, social, and economic values that are present affect the level of fire risk or benefit that is expected for an area. Like the fire severity component, the value component of risk-benefit is dependent on the attribute of interest. If an area contains only exotic noxious weeds, a low fire risk may be assigned to the area because the weeds hold little value. If instead the area contains threatened or endangered plant species, a higher fire risk may be assigned because the consequences of their loss are high.

RISK-BENEFIT MODEL

Model Description

We are currently developing a Geographic Information System (GIS) model that closely follows the conceptual framework described above and represented in Figure 2. GIS layers are being derived for probability of fire occurrence, expected fire severity, and values. These layers will then be combined to estimate fire risks and benefits, which will be reported in terms of probabilities. This GIS model is grid-based with a resolution of 30 m, and requires a set of fairly basic spatial data for input: vegetation and/or fuels, topography, and ignitions. In addition, local weather information is required.

Probability of Fire Occurrence

The number of 30×30 m grid cells that have experienced a fire start is very small when examined across the full extent of a study area. Therefore, fire start probabilities cannot be directly estimated from the frequency of fire starts for each 30×30 m cell. Instead, fire start probabilities are estimated by aggregating the 30×30 m cells into larger units, and then a smooth surface is interpolated through these points at a resolution of 30×30 m.

The fire spread component of the probability of fire occurrence is determined from slope, wind, and vegetation and is based on simple assumptions such as: fires tend to burn up-slope, fires tend to burn downwind, and certain vegetation types burn more readily than others. The slope factor is a multiplier that represents the likelihood of fires spreading into a grid cell because of slope-related spread. From the 30×30 m digital elevation model (DEM) each grid cell will be classified according to slope steepness (percent slope) and relative slope position. Relative slope position is a scalar that takes on values from 0 (stream bottoms) to 100 (ridge tops). Relative slope position and percent slope will be combined to generate the slope factor, which will increase with uphill positions and slope steepness. Similarly, a wind factor represents the likelihood of fires spreading into a cell because of wind-driven fire spread. A combination of average wind direction, percent slope, and aspect is used to approximate the exposure of each grid cell to the prevailing wind. The vegetation factor is a multiplier that represents the likelihood of fires spreading into a cell because of proximity to highly flammable fuels. This factor is derived for each vegetation type from characteristic rates of spread under similar conditions (e.g., Anderson, H. 1982). The slope, wind, and vegetation spread factors are combined to derive the probability of fire occurrence due to fire spread. The overall probability of fire occurrence is the average of the fire start probability map and the spread factor surface.

Expected Fire Severity

Fire severity is defined as the effects from a fire on vegetation, and will be estimated from the fire intensity, which can be calculated for each 30×30 m grid cell, and the resistance of the vegetation to fire (Figure 2). Fire intensity is the rate of heat release per unit length of fireline, and is a complex function of vegetation and fuel type, weather, and topography (Rothermel, R. 1972). Because this research focuses on patterns of fire severity rather than intensity, we will derive an index of fire intensity that is a function of an index of drought, slope steepness, and vegetation. The drought index is adjusted for each grid cell according to the cell's topographic relative moisture index (TRMI). TRMI combines relative slope position, slope configuration, slope steepness, and slope-aspect into a single scalar that identifies potential moisture of sites on a landscape (Parker, A. 1982). We compute the fire intensity index for a series of drought index values that represent different percentile weather conditions representing various degrees of fire weather conditions. Fire resistance of vegetation is ranked according to vegetation species and size structure and is used to relate the fire intensity index to a class of fire severity.

Values

Although any number of ecological, social, and economic values can be included within this modeling framework, we will limit the number of values treated in the first version of the model. Property and human life will represent two values-at-risk while ecological health will represent a value-to-benefit from wildland fire.

To help determine how one might assess the ecological benefits from fire, we solicited (via e-mail) expert opinion from over 20 fire scientists and ecologists. We asked "What are the most important ecological values that benefit from fire?" Sustainability and biodiversity were the two most commonly mentioned values and there was general agreement that restoring and/or maintaining natural processes such as fire may be the best approach for protecting these values. From these responses, we concluded that an appropriate way to evaluate the ecological benefits of fire is to use a measure of similarity to the natural fire regime as an index of ecological values to gain from fire. This measure should incorporate both fire frequency and fire severity.

Preliminary Results

Although this work is still in progress, we have developed several parts of model and combined them to illustrate the model's potential as a decision support and planning tool.

A prototype of the model is being developed for the Selway-Bitterroot Wilderness and surrounding area in northern Idaho and western Montana. GIS data layers for vegetation, fuels, and topography were recently developed for this area (Keane et al. 1997) and were used as input to the model prototype.

Probability of fire occurrence is shown in Figure 3a and assumes that point source ignitions are randomly distributed across the landscape. Therefore, the probability of fire occurrence shown for each 30 m pixel represents the probability of fire occurrence due to fire spread, and was derived as a function of slope steepness, relative slope position, and fuel type (see Model Description, above). The brightest red pixels on this map are those that are toward the tops of steep slopes and are near areas with a lot of fine fuels. This probability map should vary depending upon the fire weather, but we have not incorporated this variability in the prototype. For demonstration purposes, this map can be assumed to represent average fire weather conditions.

Expected fire severity was derived from fuel type, slope steepness, and topographic relative moisture index and is shown in Figure 3b. The darkest areas on this map represent the driest locations, steepest slopes and/or heaviest fuel loadings. As with probability of fire occurrence, the map of fire severity should vary depending upon the fire weather. Again, we have not incorporated this variability in the prototype and the map shown here should be assumed to represent expected fire severity under average fire weather conditions.

We selected human life as the first value-at-risk to include in the model prototype. This layer was derived from maps of roads and trails. We assumed that population density was directly correlated with road density. Furthermore, we incorporated the estimated travel time to a primary road to determine those areas where human life is most vulnerable. Therefore, the dark blue areas shown in Figure 3c represent areas where there is a high population density, and that population

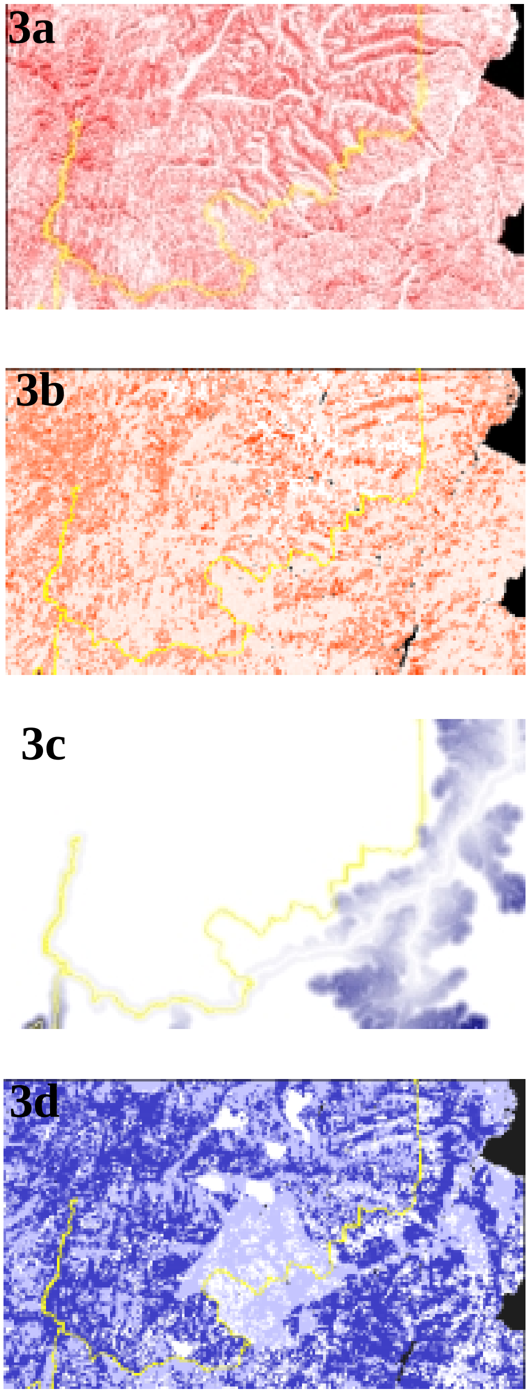

Figure 3. The major components of fire risk and benefit for a 33x55 km (182,000 ha) portion of the Selway-Bitterroot Wilderness: (a) probability of fire occurrence, (b) expected fire severity, (c) values at risk from wildland fire, and (d) values to benefit from wildland fire. White indicates low values in each case and darker colors indicate increasing values. Please refer to the text for how each component was derived. The black line indicates the wilderness boundary. Resolution is 30m.

is located far from a primary road and therefore may have difficulty escaping from a fire.

We quantified the ecological values that stand to benefit from fire with the use of an index that estimates the current departure from a natural fire regime. We computed the Fire Return Interval Departure (FRID) (Caprio, A. et al. 1997), but also incorporated the departure from the historic fire severity. The FRID index is calculated as:

$$FRID = \frac{TSLF - RI_{Max}}{RI_{Max}} \qquad (1)$$

where $TSLF$ is the time-since-last-fire, in years, and RI_{Max} is the average maximum fire return interval for the vegetation class in the presettlement era. We obtained time-since-last-fire from the fire atlas data for the Selway-Bitterroot Wilderness Area (M. Rollins, Univ. Arizona, unpub. data). We used the results of the fire history studies by Brown, J. et al. (1994) and assigned a historic return interval to each of the potential vegetation type classes in our GIS data set.

As we discussed earlier, FRID's usefulness as an index for "ecological need" or value-to-benefit is limited because it ignores fire severity. To account for expected departures from historic fire severity, we multiplied this index by a value between 0 (expected fire severity is much different than historic fire severity) and 1 (expected fire severity is no different than historic fire severity). We assigned each of the potential vegetation types from Keane, R. et al. (1997) to a historic fire severity ranking using the results of the fire history work presented by Brown, J. et al. (1994). Expected fire severity was estimated as described above and ranked on the same scale as the historic fire severity.

This modified FRID index is shown in Figure 3d. The darkest blue areas shown on this map are those areas that currently have the largest departure from historic fire frequencies, and where the expected fire severity is close to historic fire severities. These are areas where ecological health is expected to benefit the most from fire.

Overlaying the probability of fire occurrence and expected fire severity, with the values-at-risk layer generates a map of the probability of loss due to fire, i.e., fire risk (Figure 4a). A map of the probability of gain due to fire, i.e., fire benefit (Figure 4b), is created by overlaying the probability of fire occurrence layer with the ecological values-to-benefit layer, which also incorporates the expected fire severity.

Viewing both fire risk and fire benefit simultaneously provides a more complete picture for managers designing a fuels reduction program. Areas where fire benefit is high and fire risk is low (e.g., much of the area inside the wilderness boundary) may be ideal candidates for the strategy of wildland fire use. The strategy of prescribed fire may be best suited for areas where both fire risk and fire benefit are high because prescribed fires may provide the ecological benefits of fire while minimizing the risks. Finally, mechanical fuels treatments may be warranted in those areas with high fire risk but low fire benefit.

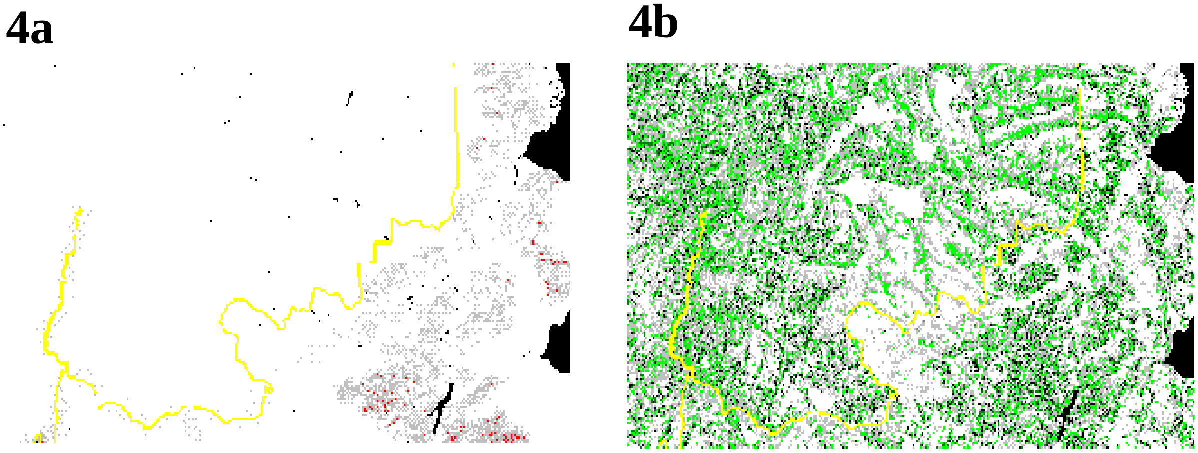

Figure 4. Output from the model prototype of (a) fire risks and (b) fire benefits for the area depicted in Figure 3. White indicates low values in each case and darker colors indicate increasing values of risk or benefit. Note the respective influences of the value layers from Figure 3c and 3d on the distribution of fire risks and fire benefits.

Prospectus

Model development is ongoing and we will add to and refine the functions used in the prototype. For example, the probability of point source ignitions will be derived from historical ignition data and wind influences will be incorporated in the probability of fire spread function. Multiple maps of probability of fire occurrence and expected fire severity will be generated to reflect different fire weather scenarios; these will result in multiple maps of fire risk and benefit, each map applying to a different fire weather condition. We will be soliciting input from fire managers and fuels specialists to determine which value layers are most critical to include in the first benchmark version of the model. The final version of the model will include a graphical user interface with pull-down menus and online help. Input data describing vegetation and fuels can be altered to reflect recent management activities or to examine the effect of future activities on fire risk and benefit.

The maps of probability of fire occurrence will be validated against existing fire atlas data for the area. Areas that have burned multiple times in the past century should correspond to areas predicted to have a high probability of fire occurrence by the model. A subset of these atlas data also contains information on fire severity, which will be used to validate the expected fire severity in the model.

This modeling framework is generic and was designed so that it could be applied to a wide variety of study sites. We will be testing the model using at least two other study sites with different vegetation types and in different climatic zones.

SUMMARY

Wildland fire managers need to reduce fuels and risks from fire while restoring the natural role of fire within wildlands, and they need to accomplish these goals at large spatial scales. Current tools and approaches are inadequate and may help perpetuate the reinforcing cycle between fire suppression and risk. To break this cycle, managers need information on the benefits of wildland fire as well as information on its risks. We describe a GIS model that integrates the biophysical environment and the ecological, social, and economic values of a landscape to evaluate the risks and benefits of wildland fire. Preliminary results from a prototype of the model developed for the Selway-Bitterroot Wilderness demonstrate the utility and feasibility of such an approach.

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