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MODELING WILDFIRE PROBABILITY USING A GIS

Brett Davis, GIS Specialist
Carol Miller, Research Ecologist
Aldo Leopold Wilderness Research Institute
PO Box 8089, Missoula MT, 59807
bhdavis@fs.fed.us
cmiller04@fs.fed.us

To help land managers plan for Wildland Fire Use (WFU), we developed a GIS model, BurnPro, to predict the annual probability of burning for every cell on a raster landscape (Miller, 2003). BurnPro uses topography, historic weather, fuel model data, and historic ignition locations to estimate the likelihood of burning given the speed and direction a fire might spread from any ignition point. The approach in BurnPro follows logic similar to that used in the fire management application tool RERAP (Rare Event Risk Assessment Program), which estimates the likelihood that a fire will threaten a designated geographic location or point of concern before a fire ending event (i.e. precipitation) will occur (FRAMES 2003). Whereas RERAP is used to perform a nonspatial analysis for a single fire incident, BurnPro translates this concept to a spatially explicit landscape for multiple possible fire incidents occurring over time periods ranging from years to decades. The probability that fire will travel through space and time from an ignition source to any point on the landscape depends upon 1) the time required for fire to travel the distance from the ignition to the target, 2) the frequency distribution of fire-stopping weather events (e.g. heavy rains) within the fire season and 3) the time remaining in the fire season.

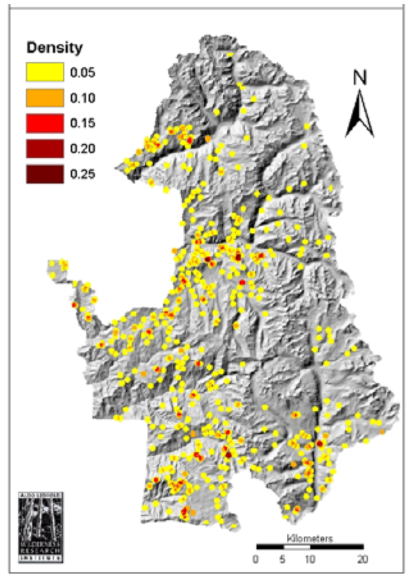

Figure 1. Annual density (km^{-2}) of lightning-caused ignitions in Sequoia-Kings Canyon National Parks, California.

The time required for fire to spread from an ignition point to any other point on the landscape was calculated using the ArcGIS function PATHDISTANCE. This function "calculates, for each cell, the least-accumulative-cost distance over a cost-surface from a source cell or set of source cells" (ESRI 1998).

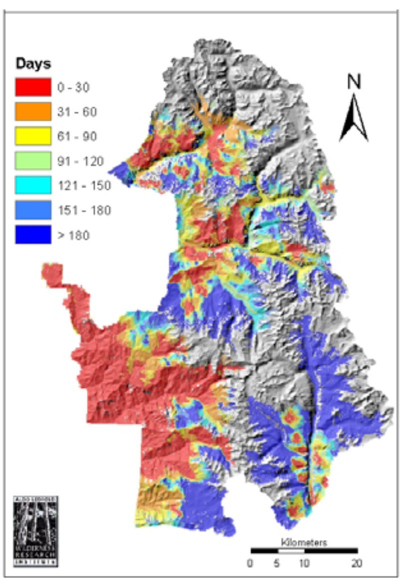

Figure 2. Cumulative spread time under 98th percentile SC fire weather conditions, SW winds, and the lowest density class (0.05 km^{-2}) June ignitions.

In this case the source cells are the ignition locations and the cost-surface is the time required for fire to pass through the cell. Point location data for 20 years of lightning-caused ignitions were separated into 4 months (June, July, August, and September) and then used to derive ignition density grids representing 1, 2, 3, 4, and 5+ ignitions per km^2 per month / 20 years (Figure 1). The resultant density grids were used as the source cells in the PATHDISTANCE function.

To derive the time required for fire to pass through each cell, we used the expected rate of spread under different weather conditions. 20 years of historic weather data were analyzed for 3 weather stations. FireFamilyPlus (Main et al. 1990) was used to compute the Spread Component (SC) index; these were used to define 4 classes (low, moderate, high, and extreme) of fire weather conditions. Expected rate of spread (ROS) was calculated using FlamMap (Fire Sciences Lab 2003) for every combination of the 4 weather classes and 8 separate wind directions. FlamMap computes potential fire behavior for every cell in a raster landscape. Because ROS varies greatly with diurnal variations in temperature and relative humidity we developed average daily ROS grids from multiple FlamMap runs. The inverse of ROS was calculated to determine the time required to pass through each cell. The resultant density grids were used as the cost surface in the PATHDISTANCE function.

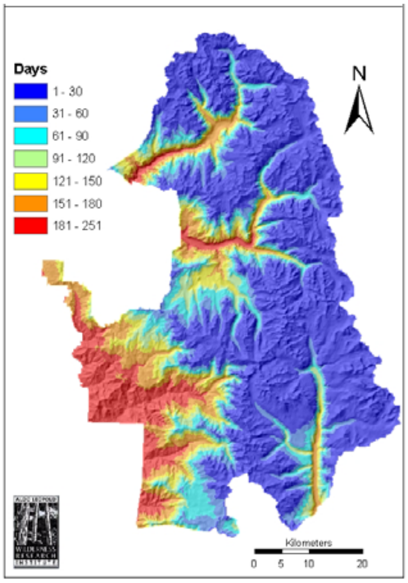

Figure 3. Length of the fire season approximated using a simulation model of soil moisture (Urban et al. 2000).

FlamMap calculates the ROS for the maximum spread direction (heading direction), but fire travels in other directions (i.e. backing or flanking) at lesser rates of spread as well. To account for this fact we used a combination of another FlamMap output, maximum spread direction, and the horizontal factor option in PATHDISTANCE to determine non-maximum spread direction times. The horizontal factor option adjusts the spread-cost, in our case time to cross the cell, for non-maximum directions of travel. The magnitude of the adjustment is largely dependent upon wind speed and slope (Anderson, 1983 and Fons, 1946).

These data were used to calculate least accumulative spread time grids, using PATHDISTANCE, for each unique combination of ignition density class, month, fire-weather class and wind direction (Figure 2). In this example, there were 640 least accumulative spread time grids (5 ignition densities x 4 months x 4 weather classes x 8 wind directions).

FireFamilyPlus (Main et al. 1990) was used to determine the frequency of significant rain events (at least 0.5 inches within 5 days or less; Latham and Rothermel 1993) for each month in the fire season. These frequencies were used to determine the probability that fire will spread to each cell on the landscape before such an event occurs. Subtracting the resultant probability from 1 gives the probability that fires are unhindered by precipitation during the fire season.

Fire season may range from several months at low elevations to perhaps only a few days at the highest elevations. We used a soil moisture model to calculate a drought-day index at 100-m elevation intervals (Urban et al. 2000), and used this index to approximate the length of the fire season across the landscape (Figure 3). The probability that fire will spread to each cell on the landscape before the end of the fire season was calculated for each of the 640 least accumulative spread time grids

These two probability calculations resulted in 1280 probability grids, two for each unique combination of ignition density, month, weather class and wind direction. The two probability grids were then combined into an overall probability of burning grid. This resulted in 640 probability of burning grids that, in turn, were combined using a weighted average approach where the weights were assigned according to the frequency of occurrence (Miller 2003). The result was an average estimate of the annual probability of burning (Figure 4).

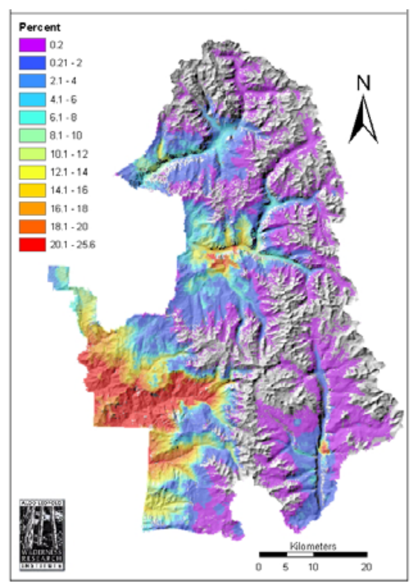

Figure 4. Annual probability of burning for current fuel conditions.

The average annual probability of burning is being used in combination with information on values at risk to help managers delineate zones where WFU may be a feasible fire management strategy. Where current conditions allow for WFU, we are evaluating if there are sufficient natural ignitions to restore natural fire frequencies. We are identifying those areas where restoration objectives can be most easily met through the use of natural ignitions; these areas could be given priority for implementing WFU programs. This information is also be used to help identify areas within candidate WFU zones where the number, location, and timing of natural ignitions are inadequate for restoring historic fire regimes. In these areas, the use of prescribed fire, or even accidental human-caused ignitions, is being evaluated in light of restoration objectives. We are currently conducting these analyses for three national parks (Yosemite, Sequoia-Kings Canyon, and Great Smoky Mountains) and two Forest Service wilderness areas (Selway-Bitterroot and Gila-Aldo Leopold).

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