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Fuel Models and Fire Potential from Satellite and Surface Observations

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Abstract. A national 1-km resolution fire danger fuel model map was derived through use of previously mapped land cover classes and ecoregions, and extensive ground sample data, then refined through review by fire managers familiar with various portions of the U.S. The fuel model map will be used in the next generation fire danger rating system for the U.S., but it also made possible immediate development of a satellite and ground based fire potential index map. The inputs and algorithm of the fire potential index are presented, along with a case study of the correlation between the fire potential index and fire occurrence in California and Nevada. Application of the fire potential index in the Mediterranean ecosystems of Spain, Chile, and Mexico will be tested.

Keywords: Fire potential; Fire danger; Fuels; Fire model; Satellite data

Introduction

The need for a method to rate wildland fire-danger was recognized at least as far back as 1940, in fire control conferences called by the Forest Service, U.S. Department of Agriculture, in Ogden, Utah. By 1954 several fire-danger rating systems were in use across the United States. In 1958 John Keetch, Washington Office, Aviation and Fire Management, headed a team to develop a national system. By 1964 most fire control organizations in the United States were using a "spread index" system. In 1968 another research effort was established in Fort Collins, Colorado to develop an analytical system based on the physics of moisture exchange, heat transfer and other known aspects of the problem (Bradshaw et al. 1983). The resulting fire spread model (Rothermel 1972) was used in the first truly National Fire Danger Rating System (NFDRS), introduced in 1972 (Deeming et al. 1972, revised in 1974). This system has since been revised twice, in 1978 (Deeming et al. 1977) and in 1988 (Burgan 1988).

Decisions fire managers must make depend on the temporal and spatial scales involved as well as management objectives. Presuppression decisions are often aimed at allocation of firefighting funds, personnel, and equipment. Such decisions usually have a large spatial context, encompassing millions of hectares, and a time scale of 1 to 3 days. Once a fire occurs initial attack and suppression decisions are directed at attaining cost-effective management of the fire. This may include a decision to not suppress the fire if it is burning within predefined constraints. These decisions have a spatial scale of a few thousand hectares and a temporal scale of 24 hours or less. Once a decision has been made to extinguish a fire, decisions are required on a spatial scale of several hundred hectares or less and a temporal scale of a few minutes to a few hours. The attitude toward wildland fire in the United States is changing from that of simply extinguishment to realization that fire must play a role in maintaining forest health, thus the need for prescribed fires is being recognized (Mutch 1994). Methods to assess fire potential both strategically and tactically must also evolve.

Assessment of fire potential at any scale requires basically the same information about the fuels, topography, and weather conditions that combine to produce the potential fire environment. These factors have traditionally been measured for specific sites, with the resulting fire potential estimates produced as alpha-numeric text, and the results applied to vaguely defined geographic areas and temporal periods, with the knowledge that the further one is displaced (in time or space) from the point where such measurements have been taken, the less applicable the fire potential estimate is. This situation is rapidly changing because Geographic Information Systems (GIS) and space-borne observations are greatly improving the capability to assess fire potential at much finer spatial and temporal resolution.

Recent improvements to fire potential assessment technology include both broad scale fire-danger maps and local scale fire behavior simulations. In the context of local scale fire behavior, FARSITE (Finney 1994) and BEHAVE (Burgan and Rothermel 1984, Andrews 1986, Andrews and Chase 1989), provide methods to simulate fire behavior for areas up to several thousand hectares. In the broad area fire danger context, spot measurements of fire danger, calculated using the NFDRS at specific weather stations, are being interpolated and mapped on a national basis (Figure 1) through a system called the Wildland Fire Assessment System (Burgan et al. 1997) (http://www.fs.fed.us/land/wfas/welcome.html). The Canadians publish similar maps for their fire danger system on the internet (http://www.nofc.forestry.ca/fire/cwfis) (Lee 1995)(Stocks et al. 1989). The U.S. maps are produced using an inverse distance squared weighting of staffing levels. Staffing level defines the readiness status of the suppression organization. It is based on comparison of current fire danger index values with historical values. The staffing (or readiness) level increases as the current index approaches historically high values. Because fire managers across the United States have not been consistent in their selection of an NFDR index on which to base staffing levels, staffing level itself is the only common parameter with which to map fire danger. Staffing level normalizes all indexes against their historical values so it does not matter which of the several fire danger indexes a fire manager selected. However this method neither addresses the effect of topography on fire potential, nor provides fire potential estimates for specific locations or landscape resolutions.

An operational process that does provide 1 km^2 landscape resolution is the Oklahoma Fire Danger Rating System (Carlson et al. 1996) (http://radar.metr.ou.edu/agwx/fire/intro.html), although it still does not recognize the effect of topography. The Oklahoma Fire Danger Rating System represents the direction of future fire-danger systems research for the United States, but the intensive weather network it relies upon could make this type of system difficult for others to apply.

A wildland fuel map, terrain data, and a reasonable sampling of weather are inputs to most fire danger systems. This paper discusses development of a national 1 km^2 fuel model map for the United States and describes a Fire Potential Index (FPI) model that can be used to assess fire hazard at 1 km^2 resolution.

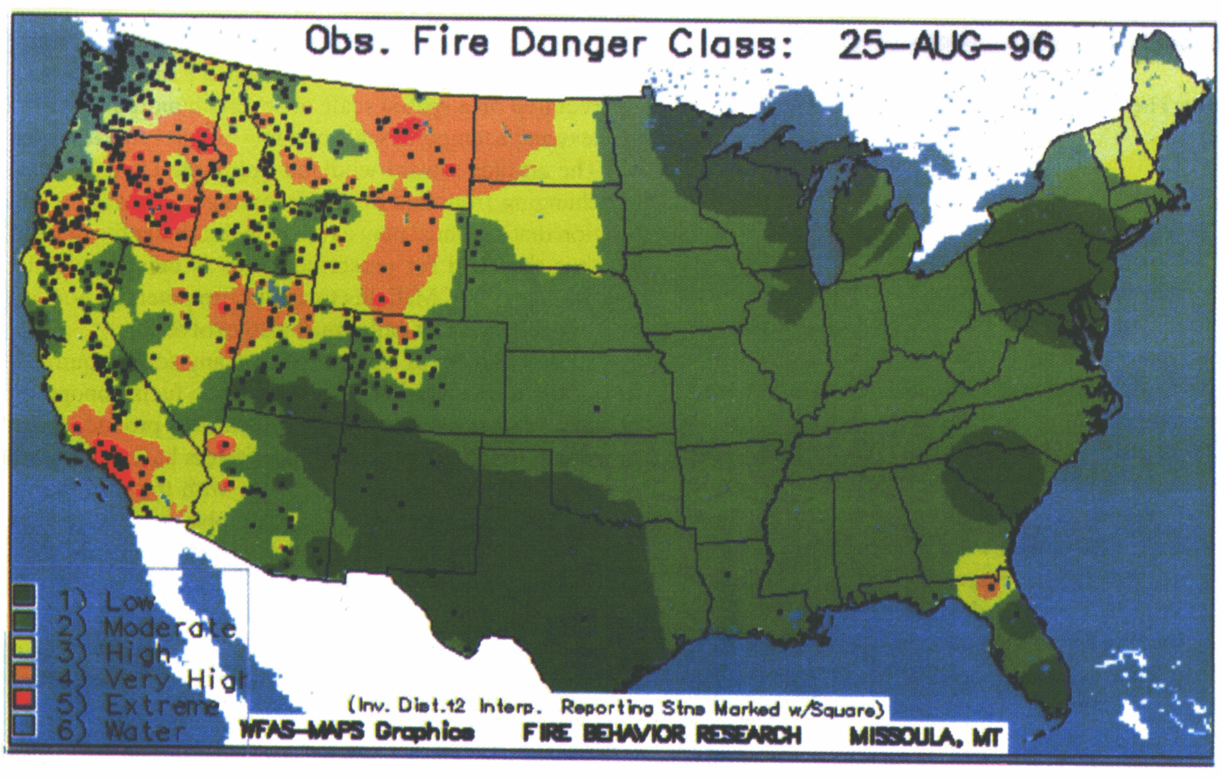

Figure 1. National Fire Danger Rating System indexes are calculated for each weather station, then the indicated staffing levels are interpolated and mapped on a national basis (http://www.fs.fed.us/land/sfas/fd_class.gif).

The NFDR Fuel Model Map

Traditionally 1 to 4 fire danger fuel models (Deeming et al. 1977) have been assigned to each fire weather station. These fuel models represent the most common or most hazardous vegetation types occurring in the vicinity of the weather station. The exact geographic location represented by each fuel model has not been well defined. Progress in assessing fire potential across the landscape obviously requires much better fuels information.

In 1991, the U.S. Geological Survey's Earth Resources Observation Systems (EROS) Data Center, Sioux Falls, South Dakota, prepared a 159 class, 1 km^2 resolution, land cover characteristics database (Loveland et al. 1991) that portrayed vegetation patterns across the conterminous United States. The initial vegetation map was produced by unsupervised clustering of eight monthly composites of Normalized Difference Vegetation Index (NDVI) (Goward et al. 1990) data for 1990. A postclassification refinement was accomplished through use of several ancillary data layers, however ground truth data was not used. It was obvious this map could provide the basis for a national fire danger fuel model map for the next generation National Fire Danger Rating System. However, because the vegetation map was designed to satisfy a wide range of applications, it was necessary to obtain ground sample data specifically for the purpose of developing an NFDRS fuel model map.

The first author and Colin Hardy of the Intermountain Fire Sciences Laboratory collaborated with the EROS Data Center to collect ground sample data for numerous locations across the U.S. Help was enlisted from numerous federal and state land management agencies to collect the ground data. (Burgan et al. in preparation). A total of 3500 1 km^2 ground sample plots were located on seven hundred 7 1/2 minute USGS quadrangle maps (1:24000) (Figure 2). Data was obtained from 2560 of these plots. Percent cover, height, and diameter data were recorded on the four major tree and shrub species, and percent cover and depth were recorded for subshrubs, forbs, mosses and grass. Shrub and grass morphology and density classes were also recorded. Up to four 35 mm slides were taken for many of the plots. All data were entered into a database for analysis, and the slides and graphical analysis summaries were recorded on a CDROM and are available for viewing with a standard browser (Burgan et al. 1997).

Because a major objective of the ground sampling was to relate fire danger fuel models to the EROS Land Cover Classes, a fuel model assignment was required for each plot. The fuel model assignments were not made in the field however, because it was felt the diversity of people involved would produce large inconsistencies in making these assignments. Instead, one knowledgeable person was asked to review the data sheets and plot photographs to make the fuel model assignments, which were then added to the database. The Land Cover Characteristics

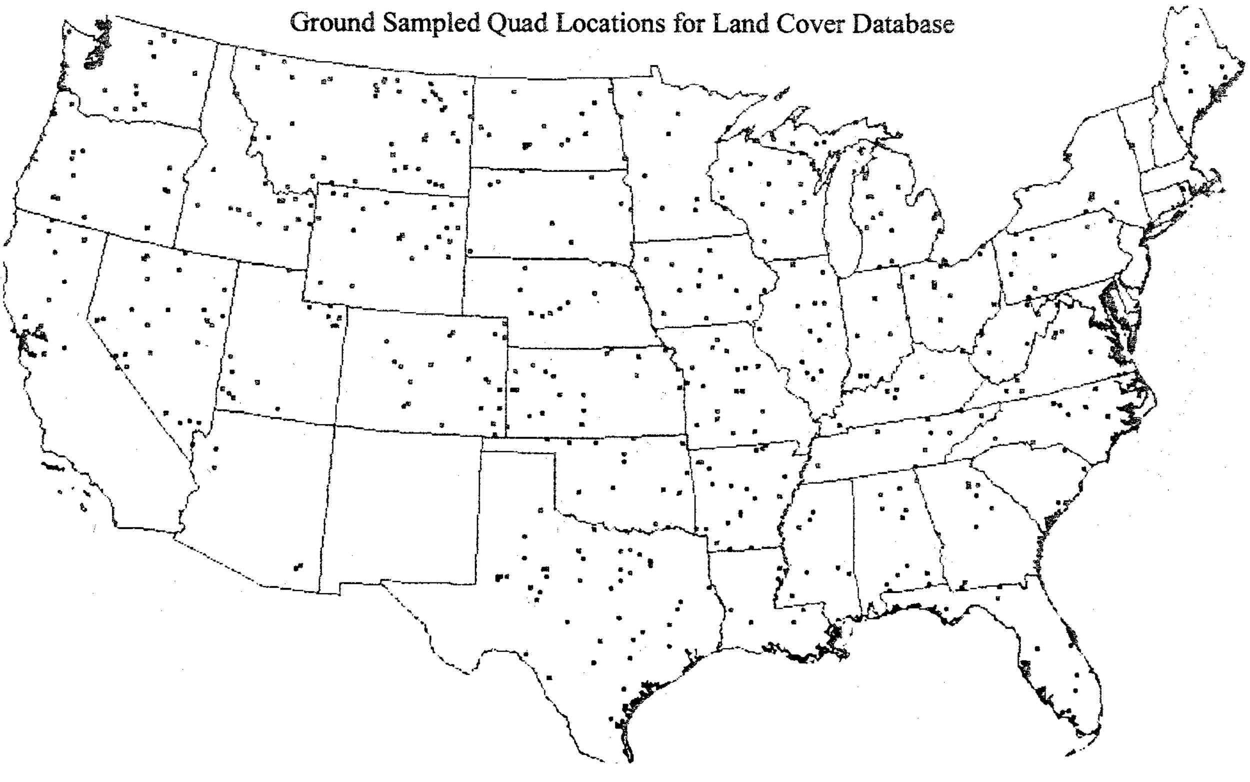

Figure 2. Ground sample data was collected from 2560 plots on these 7.5 minute USGS quadrangle maps. There were up to 5 plots per quadrangle map.

Database also contained a map of Omernick Ecoregions (Figure 3) of the conterminous U.S. (Omernick 1987), so the ecoregion for each plot was also recorded. With this data, a frequency count of fuel model by Omernick Ecoregion and Land Cover Class was obtained through a contract with Statistical Sciences Incorporated, 1700 Westlake Ave. N., Seattle, WA 98109. The purpose of including ecoregion data was to permit regionalizing fuel model assignments. The fuel model/ecoregion/landcover associations were manually inspected and entered into a computer program that produced a 1 km^2 resolution fuel model map for the conterminous U.S. The program built the NFDR fuel model map by using the ecoregion and landcover class values read from separate binary data files. With these inputs a table lookup method was used to determine the fuel model assignment for each 1 km square pixel. This became the "first draft" NFDR fuel model map.

Because the ground data sample size was small for many fuel model/ecoregion/landcover combinations, some fuel model assignments were made with inadequate data, thus it was felt that review by fire managers from throughout the U.S. was necessary. This was accomplished by having individual fire managers come to the Intermountain Fire Sciences Laboratory to use the GRASS (U.S. Army Construction Engineering Research Laboratory 1988) GIS software for detailed review of the fuel model map within their area of knowledge. This process permitted alteration of fuel models by Land Cover Class within individual ecoregions by modifying the lookup table based on ecoregions and landcover class. Although there were changes, they were surprisingly limited considering the sparseness of the ground sample data. Fire danger fuel models E, I, J, and K (Deeming et al. 1977) were not used. Satellite observation of seasonal changes in vegetation greenness eliminates the need for using model E as a winter season subsititue for model R, and the slash models I, J, and K don't cover sufficient area to be considered. The Preliminary NFDR Fuel Model map (Figure 4) may undergo future revisions, and the most current version is on the Forest Service home page (http://www.fs.fed.us/land/wfas/welcome.html) .

The Fire Potential Index Model

Justification and Inputs

The Fire Potential Index (FPI) model was developed to incorporate both satellite and surface observations in an index that correlates well with fire occurrence and can be used to map fire potential from national to local scales through use of a GIS. The primary reasons for developing the model were: 1) to produce a method to depict

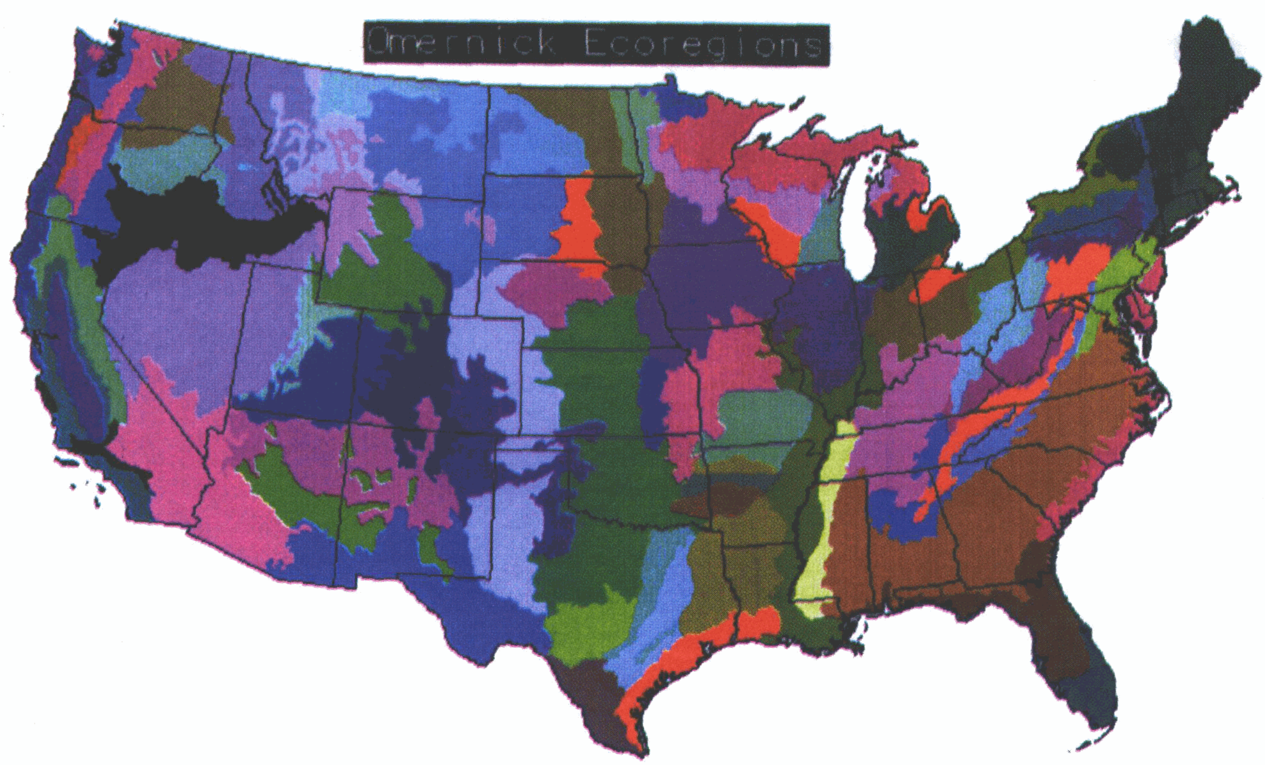

Figure 3. Omernick ecoregions were used to localize refinements to the NFDRS fuel model map.

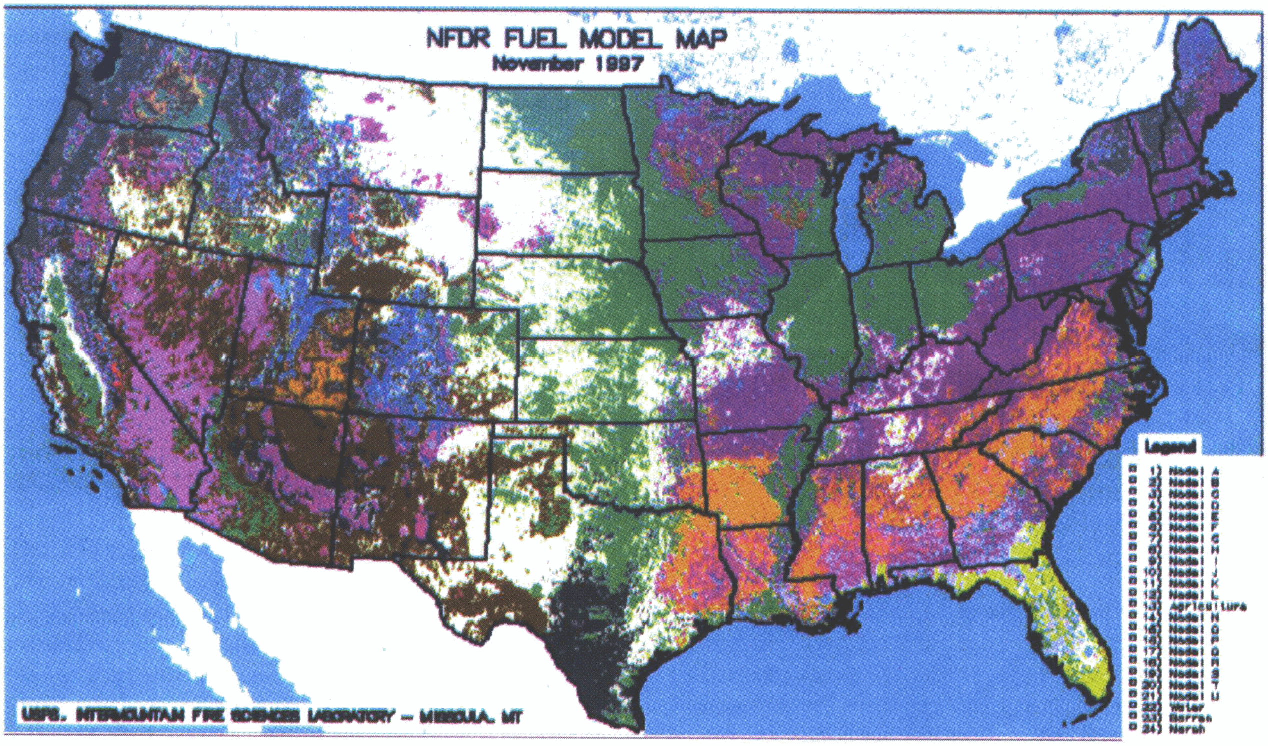

Figure 4. The 1km resolution fire danger fuel model map will be used in the next generation fire danger rating system (http://www.fs.fed.us/land/sfas/nfdr_map.htm).

fire potential at continental scale and at 1 km resolution, 2) provide a method of estimating fire potential that was simpler to operate than the current U.S. National Fire Danger Rating System.

The assumptions of the FPI model are: 1) fire potential can be assessed if the moisture level of live and dead vegetation is reasonably represented, 2) vegetation greenness provides a useful parameterization of the quantity of high moisture content live vegetation, 3) ten hour timelag fuel moisture should be used to represent the dead vegetation because the moisture content of small dead fuels is critical to determination of fire spread, and 4) wind should not be included because it is so transitory. Thus the inputs to the FPI model are a 1-km resolution fuel model map, a Relative Greenness (RG) map (Burgan and Hartford 1993) that indicates current vegetation greenness compared to historical maximum and minimum values, and a 10 hour timelag dead fuel moisture (Fosberg and Deeming 1971) map . Ten hour timelag fuels are defined as dead woody vegetation in the size range of 0.6 to 2.5 cm in diameter. These inputs must all be in raster format and provided as byte data representing 1-km pixels. The output is a national scale,1-km resolution map that presents FPI values ranging from 1 to 100.

Fuel Models

In the traditional sense, fuel models are a set of numbers that describe vegetation in terms that are required by the Rothermel fire model. Thus fuel models used in the U.S. National Fire Danger Rating System have numerous parameters that define live and dead fuel loads by size class, surface area to volume ratios of the various size classes, heat content, wind reduction factors, and mineral and moisture damping coefficients. The FPI model uses much simpler fuels information, consisting of just total live and dead fuel loads of the 1978 NFDR System. The summation of the 1, 10, and 100 hour timelag dead fuel loads constitutes the dead fuel class, and summation of the 1000 hour timelag dead load and live herbaceous and live woody fuels loads constitute the live class. (Table 1). Thousand hour dead fuel load is included in the live class for calculation of the FPI because 1000 hour timelag dead fuels react to moisture changes on a time scale similar to the live vegetation (Burgan 1979). These loads may be adjusted to better represent local vegetation and to provide the best representation of fire potential as expressed by the resulting FPI maps.

The base dead fuel load for any given model is constant, but the live fuel load is transferred to and from the 10 hour dead fuel class, depending on current vegetation greenness. The 1-km fuel model map of the U.S. provides a key to the fuel model data to be used for each pixel. The EROS Data Center has completed a 1-km resolution land cover database for the world (Belward 1996) (Loveland et al. In press). These data will provide the key to development of fuel model maps for many countries.

Table 1. Fuel loadings and extinction moistures used in calculating the Fire Potential Index.

NFDR Fuel Model	Fuel Load (T/Hectare) Live	Dead	Extinction Moisture (%)	Vegetation Represented
A	0.67	0.45	15	Western annual grasses
B	25.78	17.93	15	California mixed chaparral
C	2.91	3.14	20	Pine grass savanna
D	8.41	6.73	30	Southern rough
E	—	—	—	Hardwoods (winter)
F	20.18	13.45	15	Intermediate brush
G	29.14	21.30	25	Short needle conifers with heavy dead load
H	6.73	10.09	20	Short needle conifers with normal dead load
I	—	—	—	Heavy logging slash1
J	—	—	—	Intermediate logging slash1
K	—	—	—	Light logging slash1
L	1.12	0.56	15	Western perennial grasses
M	—	—	—	Agricultural land
N	4.48	6.73	25	Sawgrass or other thick stemmed grasses
O	20.18	17.93	30	High pocosin
P	3.36	4.48	30	Southern pine plantation
Q	12.33	14.57	25	Alaskan black spruce
R	2.24	3.36	25	Hardwoods (summer)
S	3.36	3.36	25	Alpine tundra
T	6.73	3.36	15	Sagebrush-grass mixture
U	2.24	7.85	20	Western long-needle conifer
V	—	—	—	Water1
W	—	—	—	Barren1
X	—	—	—	Marsh1

Relative Greenness

Relative greenness is derived from the Normalized Difference Vegetation Index (NDVI) (Goward et al. 1990) which is calculated from data obtained by the Advanced Very High Resolution Radiometer (AVHRR) on board the National Oceanic and Atmospheric Administration's TIROS-N series of polar-orbiting weather satellites. The basis for calculating RG is historical NDVI data (1989 to present) that defines the maximum and minimum NDVI values observed for each pixel. Thus RG indicates how green each pixel currently is in relation to the range of historical NDVI observations for it. RG values are scaled from 0 to 100, with low values indicating the vegetation is at or near its minimum greenness. Specifically the algorithm is:

$$RG = (ND_o - ND_{mn})/(ND_{mx} - Nd_{mn}) * 100$$

where

ND_o = highest observed NDVI value for the 1 week composite period
ND_{mn} = historical minimum NDVI value for a given pixel
ND_{mx} = historical maximum NDVI value for a given pixel

The purpose of using relative greenness in the FPI model is to partition the live fuel load between the live and dead vegetation fuel classes. The RG map has a 1-km resolution and is registered with the fuels map.

Ten Hour Timelag Fuel Moisture

Given an ignition source, the probability that a wildland fire will ignite and spread is strongly dependent on the moisture content of small dead vegetation. The U.S. National Fire Danger Rating System separates dead fuel moisture response into timelag classes of 1, 10, 100, and 1000 hours (Deeming et al. 1977), meaning that their moisture content will change about 2/3 of the difference between initial and final conditions in one timelag period. Anderson (Anderson 1985) has shown that most dead wildland vegetation primarily involved in determining fire spread rate is in the 1 to 10 hour timelag response category, with only very fine fuels such as cheatgrass having response times of 1 hour or less. On this basis 10 hour timelag fuel moisture was selected to represent the moisture content of all dead vegetation in the 1 to 10 hour timelag size classes.

Ten hour fuel moisture is calculated from temperature, relative humidity, and state of the weather (cloudiness and occurrence of precipitation). These data are measured at surface weather stations and must be extrapolated across the landscape to meet the FPI model input requirement of 1-km resolution byte data. The process currently used to extrapolate this point data to a 1-km grid is an inverse distance squared algorithm. The advantage of this process is that it is convenient and simple to perform. The disadvantage is that it does not account for the influence of topography on fuel moisture. If the weather station network is reasonably dense, with weather stations at both high and low elevations, the resulting interpolations are quite useable. But if the weather station network is too sparse or all the weather stations are at low elevations, the interpolations are not adequate. Improvement of the interpolation process for calculating 10-h TLFM is the subject of further work.

The Model

The FPI model uses a fuel model map and the quantity and moisture of live and dead vegetation in estimating relative fire potential. The fuel model map is used to reference the fuel model data for each pixel, and Relative Greenness is used to determine the proportion of the total fuel load that is live and dead and to indicate live moisture. Dead fuel moisture is represented by ten hour timelag moisture, rescaled for compatibility with RG. The FPI index is scaled from 1-100. Calculation of the live and dead fuel loads is based on a linear weighting scheme similar to that established in the live fuel moisture model for the 1978 NFDRS (Bradshaw et al. 1983). The specific process for each pixel is to obtain the inputs from the 1-km fuel model, RG, and 10-h TLFM maps and perform the following calculations:

Set the fire potential index to zero

$$FPI=0 \tag{1}$$

Convert RG to a fractional value

$$RG_f = \frac{RG}{100} \tag{2}$$

Relative greenness is used in this equation to determine the current live fuel load for the model assigned to the pixel.

$$LL_p = RG_f * LL_{fm} \tag{3}$$

where

LL_p = live fuel load for the pixel
LL_{fm} = live load for the fuel model

The proportion of live load that's cured, plus the dead load for the fuel model is assigned to the pixel.

$$DL_D = (1 - RG_f) * LL_{fm} + DL_{fm} \tag{4}$$

where

DL_p = dead fuel load for the pixel
DL_{fm} = dead fuel load for the fuel model

Perform remainder of calculations only if the DL_p is greater than zero. Calculate the fraction of the total fuel model load that is live.

$$L_f = \frac{LL_p}{LL_{fm} + DL_{fm}} \tag{5}$$

Calculate the fraction of the total fuel model load that is dead.

$$D_f = \frac{DL_p}{LL_{fm} + DL_{fm}} \tag{6}$$

Fractional 10-h TLFM is normalized on dead fuel moisture of extinction (Mx_d) for the fuel model, expressed as a percent (Table 1). Dead fuel moisture of extinction is defined as the dead fuel moisture at which a fire will not spread (Rothermel 1972). It varies from one vegetation or fuel type to another and is generally higher for moist climates such as the southeastern U.S. Ten hour fuel moisture is normalized to the moisture of extinction for the vegetation of any given climate to scale it the same as fractional relative greenness (0-1).

$$TN_f = \frac{FM_{10}}{MX_d} \tag{7}$$

where

TN_f = fractional ten hour fuel moisture
FM_{10} = ten hour moisture (percent)
MX_d = dead fuel extinction moisture (percent)

In the FPI equation relative greenness is used as a surrogate for live moisture. The concept is that live moisture will be high when relative greenness fraction is near 1 because that means the vegetation is as green as it gets, but live moisture will be low when the relative greenness fraction is low. Some of the live vegetation will be cured, and the rest is assumed to have a relatively low moisture content.

$$FPI_u = 100 - (RG_f L_f + TN_f D_f) * 100 \tag{8}$$

where

FPI_u = uncorrected fire potential index

In equation (8) the TN_f term limits the maximum value for the FPI depending on the dead fuel moisture of extinction, as follows:

$$FPI_{max} = 100 - \frac{2}{MX_d} * 100 \qquad (9)$$

where

FPI_{max} = maximum uncorrected fire potential index value

Given a minimum dead fuel moisture of 2 percent, this provides maximum FPI values of 86.67, 90.00, 92.00, and 93.33 for fuel models having a fractional dead fuel moisture of extinction of 0.15, 0.20, 0.25, or 0.30 respectively. The following correction, which increases the FPI minimally at low values and more at high values, must be applied to equation (8) to bring the FPI range to 0-100 for all fuel models:

$$FPI = FPI_u + \frac{2}{MX_d} * \frac{FPI_u}{FPI_{max}} * 100 \qquad (10)$$

where

FPI = final fire potential index value

Equation (10) produces FPI values that can range from 0 to 100. The FPI will equal 0 when the RG_f is 1 (the vegetation greenness equals its historical maximum) and the TN_f value is 1 (10 hour timelag fuel moisture equals the moisture of extinction for the fuel model). These circumstances do occur, but the FPI is limited to a minimum value of 1 so that clouds and snow can be identified with the FPI value 0. The FPI will attain a value of 100 if the RG_f is 0 (no live vegetation) and the 10 hour timelag fuel moisture is at its minimum value of 2 percent.

The RG image for the current composite period is processed by the EROS Data Center in a manner to indicate clouds, so areas appearing cloudy in the RG map can be mapped as cloudy (0) in the FPI map. Fuel model map pixels that indicate agricultural lands are identified as such through assignment of a value of 101, beyond the FPI range of 1-100. Water pixels are assigned a value of 255. A "C" program to perfom these calculations is available from the author. The resulting output is a gridded raster file that can be displayed and analyzed using a GIS, or from which a graphics image can be prepared.

Figure 5 illustrates the relationship between Relative Greenness, 10 hour timelag fuel moisture, and the FPI maps and standard NFDR maps for August 30, 1996.

Model Application

Fire Potential Maps derived from this model were first introduced to fire managers in California and Nevada in 1996. Their response was very favorable, but anecdotal. In the fall of 1996 we required a simple method to assess

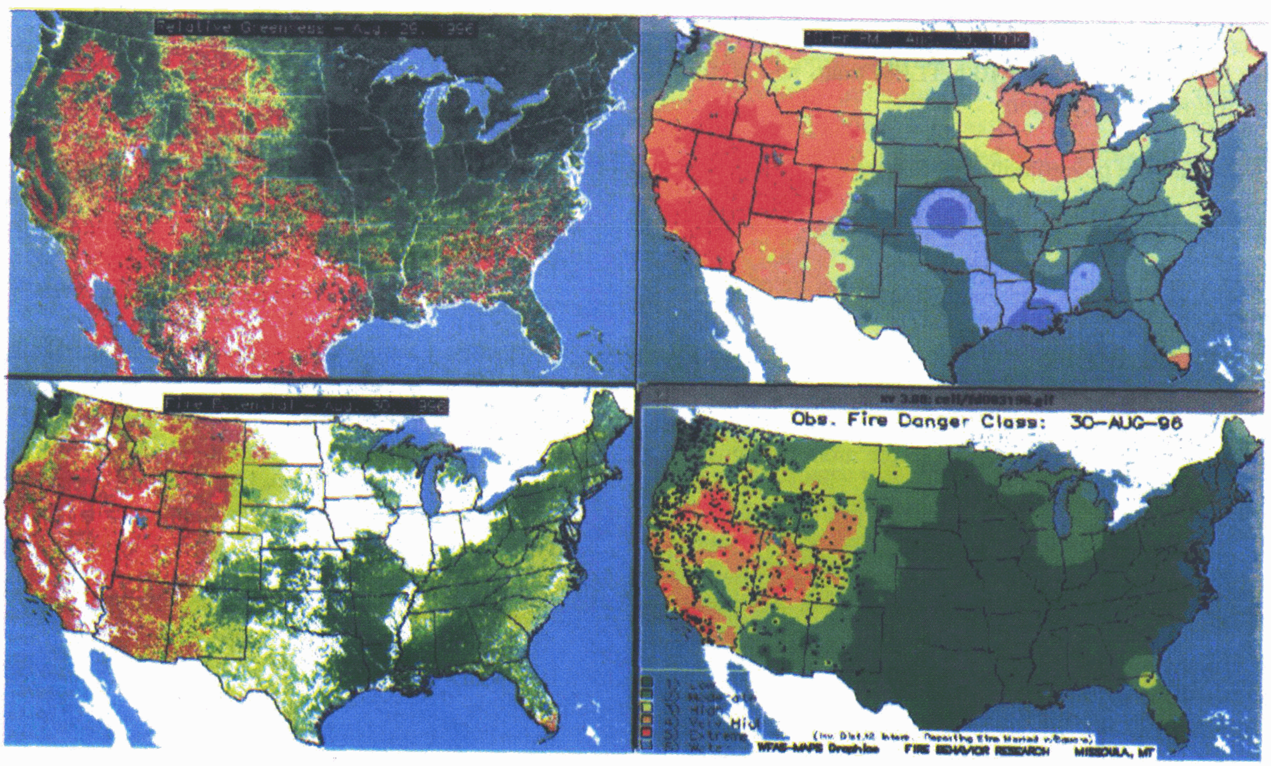

Figure 5. Relative greenness, NFDR fuel model (fig. 4), and 10-hour timelag fuel moisture maps are inputs to the fire potential index map. The standard NFDRS fire danger map is provided for comparison with the fire potential index map (http://www.fs.fed.us/land/wfas/exp_fp_4.gif).

fire potential in Mediterranean environments as part of a project sponsored by The Pan American Institute for Geography and History (PAIGH) (Klaver et al. 1997). PAIGH, in cooperation with the U.S. Geological Survey EROS Data Center, the Instituto Geografico Nacional, Spain, the Instituto Geografico Militar de Chile, and the Instituto Nacional De Estatistica Geografia e Informatica, Mexico is supporting the project "Digital Imagery for Forest Fire Hazard Assessment for the Mediterranean Regions of Chile, Mexico, Spain, and the U.S." In support of this effort we calculated daily FPI maps for mid-March to late October for the years 1990-1995, and performed statistical analyses of the correlation between fire occurrence and the FPI. The California Division of Forestry supplied the required weather data and the fire location data. We looked at the distribution of FPI values for 1990 -1994 in two contexts: 1) FPI for only those pixels in which a fire occurred (Figure 6), and 2) FPI for all the pixels within the study area (Figure 7), which was basically California and Nevada. For the first case the frequency distribution of FPI values was very similar for all years, indicating that in spite of fire season variability the relationship between fire occurrence and the FPI remains relatively constant. For the second case the frequency distribution of FPI values for all pixels varied between years, indicating that the FPI can discriminate fire season severity in the broad geographical sense. Correlation between the FPI and fire occurrence was very high, with r^2 values by year of: 1990, 0.44; 1991, 0.85; 1992, 0.87; 1993, 0.90; and 1994, 0.88. The r^2 value for all years combined was 0.72. The reason for the low correlation for 1990 is unknown, but could be due to changes in calibration of the AVHRR sensor, accuracy of fire location, or the two week rather than one week compositing period.

There is a strong positive relationship between FPI value and fire occurrence, up to an FPI value of about 80, beyond which the frequency of FPI values drops off sharply. This is due to the unintended upper limit of FPI resulting from the relationship between the 2 percent minimum 10 hour timelag fuel moisture and the moistures of extinction for the fuel models. This problem is corrected by inclusion of equation (10) in the algorithm, so that now FPI values will range from 1-100 as originally intended. Few fires occurred below an FPI value of 15.

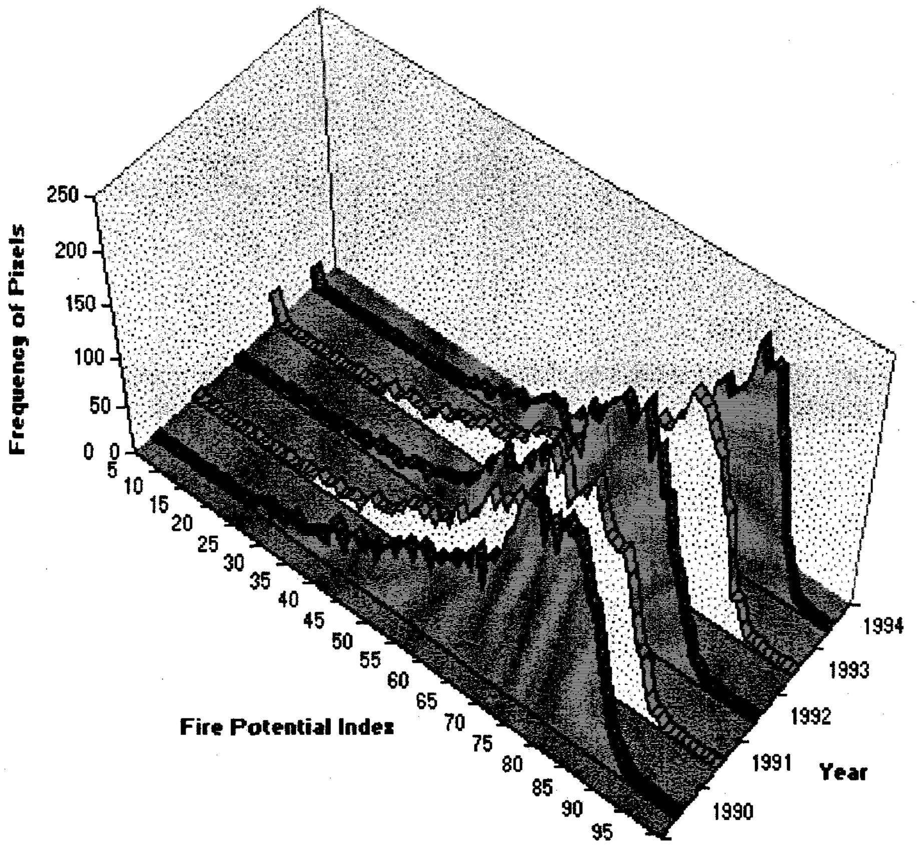

Figure 6. For only pixels in which fires occurred, in the years 1990 to 1994, the frequency of pixels is shown for Fire Potential Index values.

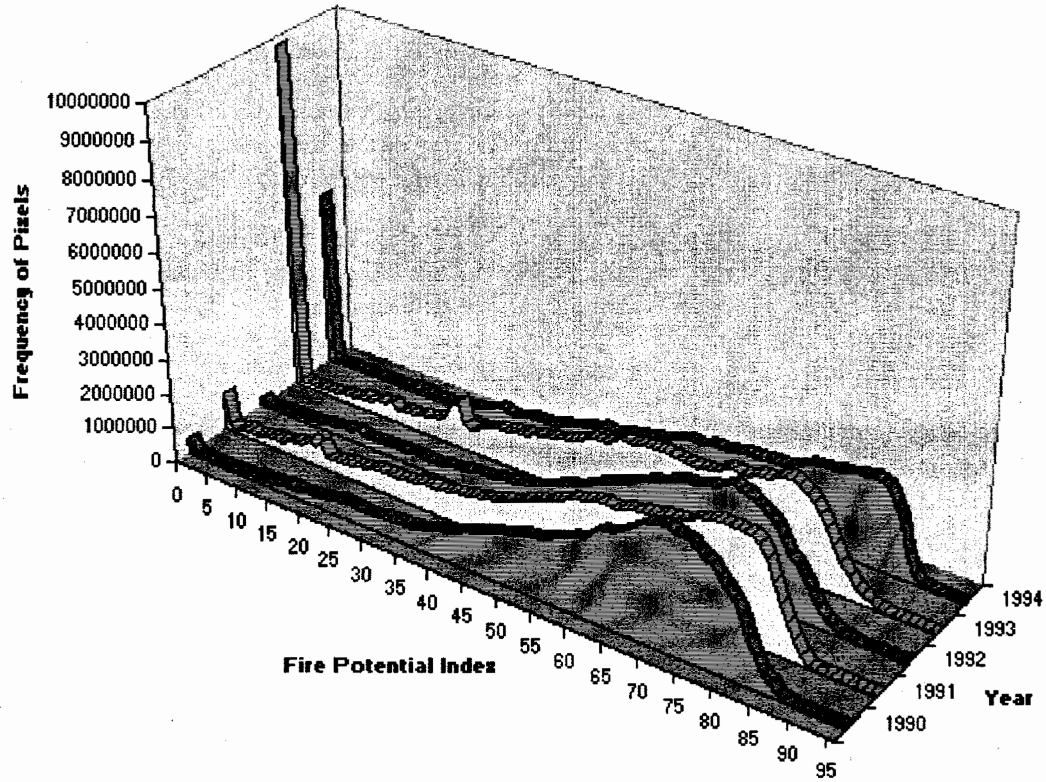

Figure 7. The frequency of pixels in the entire study area is shown for Fire Potential Index values calculated for 1990 to 1994.

Annual comparisons show that the linear equations for the FPI and fire density were statistically identical for 1991, 1993, and 1994 (r^2=0.825, df=1 and 318, F=375.05, p=0.0). The linear equation for 1990 was different from these years in both slope and intercept. The linear equation for 1992 had a greater intercept than the other years but the same slope (Figure 8). That is, fire occurrence was greater for a given FPI value in 1992 than for 1991, 1993, and 1994.

The FPI map is also being tested, along with several NFDR indexes, for application to the problem of assessing seasonal fire severity for the United States. This is an

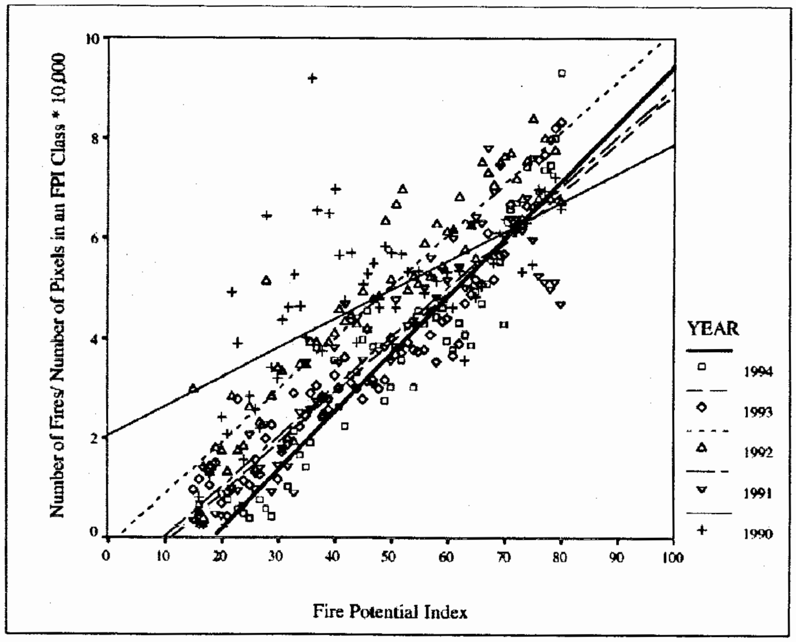

Figure 8. The slopes of the regression lines are very similar for all years except 1992.

important and difficult problem for which there is no standard procedure at this time. The problem is important because millions of dollars are made available to those Forest Service Regions that can show they expect to experience a fire season that is considerably more severe than average, and difficult because the decision of where to place the additional funds must be made 2-4 weeks in advance of the expected fire problems. The accuracy of these decisions depends on the accuracy of long range weather forecasting, so making the process simple in terms of weather requirements is important.

Conclusions

The FPI appears to be strongly correlated with fire occurrence and is well adapted to portraying fire potential across both large geographic areas and for local areas down to a few square kilometers. It is not a physically based model and thus requires enough historical data to develop the statistical relationships that can provide fire probability given a specific FPI value. Use of the FPI requires a fuel model map, access to current RG maps as calculated from AVHRR/NDVI data, and a reasonably dense network of surface weather stations. The 10-h timelag fuel moistures must be calculated from the weather station data and interpolated for all 1-km pixels. Efforts are underway to improve the interpolation procedure. The results of FPI tests for California and Nevada indicate that it may be a valuable tool for fire managers in other countries. This will be determined by future tests in the Mediterranean ecosystems of Spain, Chile, and Mexico.

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Update

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