INCORPORATING A GIS MODEL OF ECOLOGICAL NEED INTO FIRE MANAGEMENT PLANNING[1]

MaryBeth Keifer, Ecologist; Anthony Caprio, Ecologist;
Pat Lineback, GIS Coordinator; Karen Folger, GIS Technician
Sequoia and Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271-9651
Phone 559-565-3128
email marybeth_keifer@nps.gov, tony_caprio@nps.gov, pat_lineback@nps.gov, karen_folger@nps.gov

ABSTRACT

Land managers are mandated to protect the ecological integrity and health of the lands they manage. Based on research identifying fire as a keystone natural process within the Sierra Nevada in California, restoring fire in Sequoia and Kings Canyon National Parks has been an important management goal. A Geographic Information System (GIS) based "ecological need model" was developed to provide an index to rank areas in the parks based on the need to restore historic fire regimes. Inputs to the ecological need model included: (1) vegetation class; (2) historic (pre-Euroamerican settlement) fire return intervals for each vegetation class; and (3) fire perimeters from the known historic fire records (1921-present). Using these inputs, a derived index was calculated to quantify the departure of an area from its pre-Euroamerican settlement fire return interval. An index value greater than 0 indicates the number of historic fire return intervals that an area has missed. A negative number indicates that an area has burned within its historic fire return interval. The index values were divided into four categories of ecological need: low, moderate, high, and extreme. These categories were then mapped spatially across the parks using GIS. Fire Return Interval Departure (FRID) maps are updated annually as new fires (prescribed and wildland) occur. This model complements more traditional models based on fire hazard and ignition risk that are essential to sound fire management planning. The FRID model is a dynamic and valuable decision support tool that integrates ecological information to prioritize areas for initial treatment with prescribed fire, assist with scheduling successive burns, help provide economic accountability, and evaluate progress towards achieving landscape-level ecological goals.

Keywords: fire management planning, fire return interval, GIS, ecological need, hazard, risk

INTRODUCTION

Prior to Euroamerican settlement, fire played a key ecological role in most Sierra Nevada plant communities. The cause of these fires is usually attributed either to lightning or to ignitions by native Americans (these causes cannot be determined for any particular pre-historic fire). At the landscape level, fire history research shows an inverse relationship between fire frequency and elevation in areas of conifer forest (Caprio, A.C. and Swetnam, T.W. 1995). The seasonal occurrence of pre-settlement fires was similar to the contemporary lightning-caused late summer-early fall fire season (Caprio, A.C. and Swetnam, T.W. 1995). Historic fire size varied from a single tree or a few trees to multiple watersheds (Caprio, A.C. unpublished data). Fire intensity was also variable both spatially and temporally (Stephenson, N.L. and others 1991; Caprio, A.C. and others 1994). In much of the mixed-conifer forest zone, fires were primarily non-stand replacing surface fires, with some exceptions (Caprio, A.C. and others 1994). Currently, fire history information is lacking for the foothills area of the park and limited for higher elevation forests.

Beginning with Euroamerican settlement (around 1850-1870), fire regimes in the Sierra Nevada changed dramatically (Kilgore, B.M. and Taylor, D. 1979; Warner, T.E. 1980; Caprio, A.C. and Swetnam, T. W. 1995). Factors that contributed to the decline in fires during the latter portion of the nineteenth century include the reduction in native American populations that used fire as well as heavy livestock grazing that reduced herbaceous fuels available for fire spread (Caprio, A.C. and Swetnam, T.W. 1995). Fires of large size decreased dramatically during the twentieth century due to active fire suppression. These changes in fire regimes have lead to unprecedented accumulations of surface fuels in many plant communities. Changes in vegetation structure and composition, along with the increase in

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surface fuels, have resulted in an increased probability of widespread and unusually severe fires (Kilgore, B.W. 1973).

Land management agencies use fire for a variety of reasons, including the following: fuel reduction for protection of human safety and developments, resource protection and enhancement, site preparation, thinning, elimination of undesirable species, protection of desirable species, and reintroduction of fire as a natural process. National parks and large wilderness areas are particularly suitable for restoration of the natural process of fire. In recent years, federal land management agencies have begun to re-emphasize the return of fire to the ecosystem. Reintroducing fire as a natural process after nearly a century of fuel accumulation is not easy for many reasons. Some issues include difficulties in fire control and associated costs, unnatural or unwanted fire effects, and social acceptance of fire including smoke impacts on neighboring communities. Despite these issues, prescribed fire is a key tool for restoring fire to the ecosystem (USDI and USDA 1995).

Effective planning is essential to the success of fire management programs in order to achieve the goals of fuel hazard reduction and fire regime restoration and maintenance. Hazard and risk models are important decision support tools for fuels and fire management planning. Knowing where fuel hazards and risk of ignition are highest is important to prioritize treatment areas to reduce threats to life, property, and natural resources. In addition, the National Park Service's mission mandates that the agency "protect and preserve" natural resources, which includes restoring and maintaining natural ecological processes. Restoring the process of fire is an important component in working towards this goal. Therefore, a valid measure of both ecological and economic accountability in fire management planning is essential to sound resource stewardship of park lands. For these reasons, incorporating an ecological need model into an ecosystem-scale fire management planning process is critical in addition to traditional hazard and risk considerations.

METHODS

Project Area

Sequoia and Kings Canyon National Parks are located in the southern Sierra Nevada range in interior central California (Figure 1). The parks encompass some 350,000 hectares and are topographically diverse with elevations ranging from 500 to 4,400 meters. Major drainages consist of the Kern, Kaweah, Kings, and San Joaquin Rivers. Three broad vegetation zones dominate the park. The foothills (500 – 1500 meters) are composed of annual grasslands, oak and evergreen woodlands, and chaparral shrubland. The mixed conifer forest (1500 to 3000 meters) includes ponderosa pine (*Pinus ponderosa*), white fir (*Abies concolor*), and red fir (*Abies magnifica*) forests. Within the mixed conifer forest, well-defined groves of giant sequoia (*Sequoiadendron giganteum*) are found. The subalpine/alpine zone (3000 to 4200 meters) is comprised of subalpine and alpine vegetation, as well as unvegetated landscapes. Each broad zone is subdivided into more discrete vegetation classes.

The Mediterranean-type climate has cool, moist winters and warm summers with little rainfall (seasonal summer thunderstorms occur sporadically at higher elevations). Precipitation increases as elevation increases, averaging 100 centimeters annually from 1500 to 2400 meters on the west slope of the Sierra, and then decreases as one moves higher and to the east. Substantial snow accumulations are common above 1500 meters during the winter.

European settlement of the area began in the 1860s with extensive grazing, logging, and mineral exploration. The parks were founded in 1890, originally with the intent of protecting sequoia groves from logging, but were expanded to include much of the surrounding rugged, high mountains.

Ecological Need Index Calculation

An ecological need model provides an index to rate areas based on the need to restore historic fire return intervals (Caprio, A.C. and others, in press). The Fire Return Interval Departure (FRID) was calculated for all areas within the parks' 12 broad vegetation classes. This rating allowed for the assignment of priorities for all areas of the parks based on ecological need ranks.

Inputs to the ecological need model include: (1) vegetation class (Figure 2); (2) historic (pre-Euroamerican settlement) fire return interval for each vegetation class; and (3) fire perimeters from the known historic fire records (1921-present; Figure 2). The historic fire return interval values were based on fire history chronologies reconstructed using tree-ring samples obtained from fire-scarred trees in and around Sequoia and Kings Canyon National Parks or based on published literature if local information was not available (Caprio, A.C. and Lineback, P. in

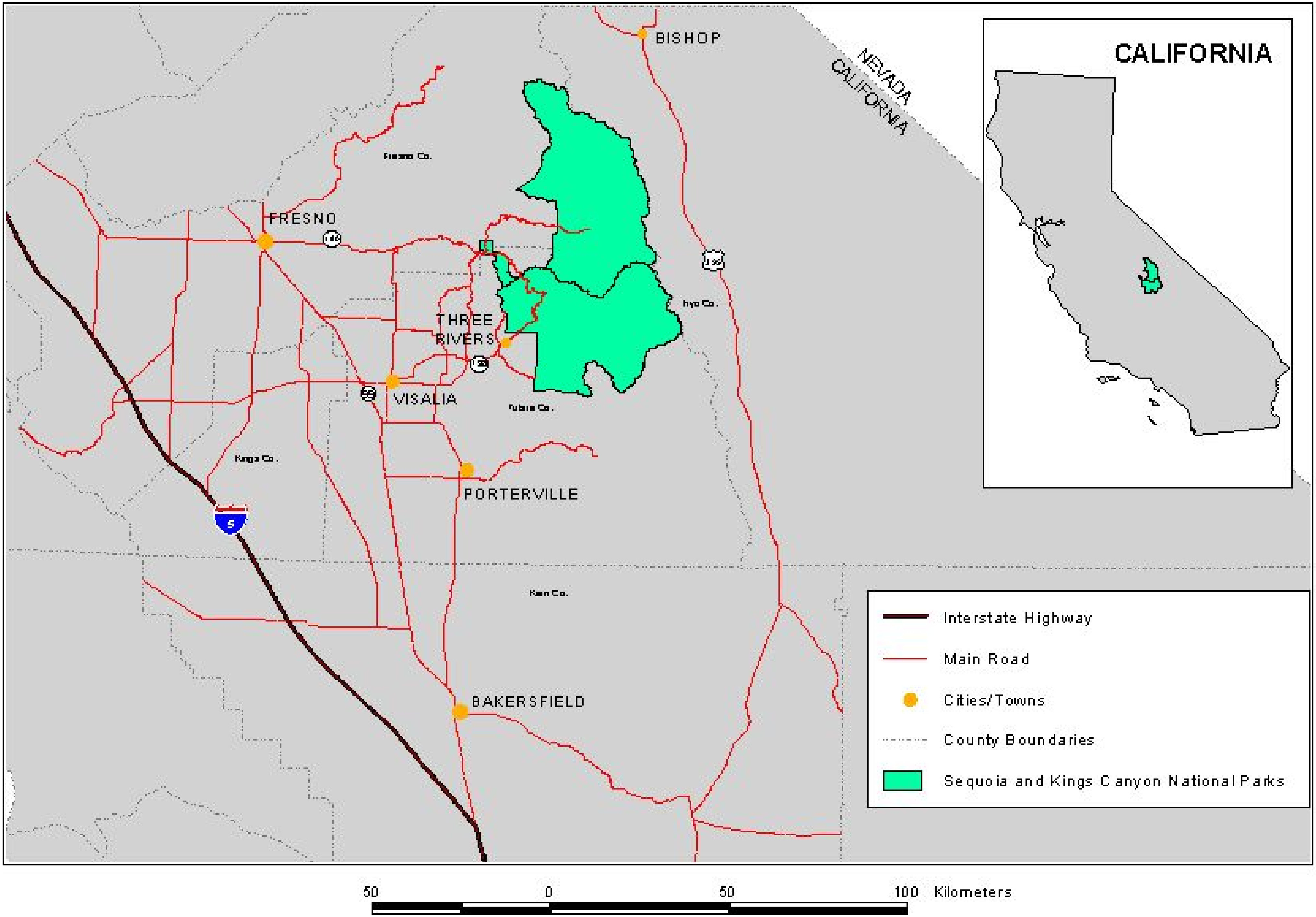

Figure 1. Sequoia and Kings Canyon National Parks vicinity map.

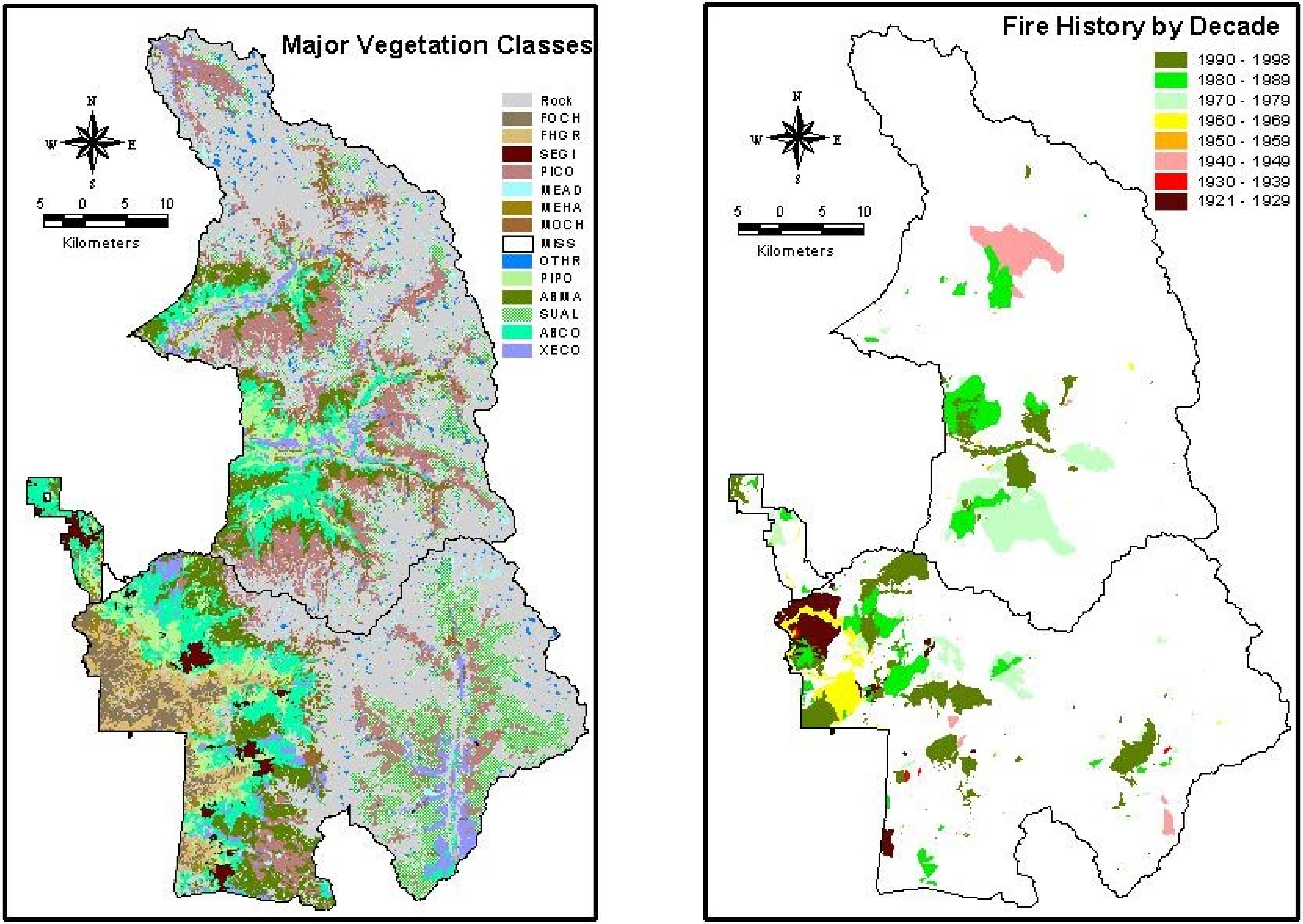

Figure 2. Major vegetation classes and fire perimeters for Sequoia and Kings Canyon National Parks. Vegetation class abbreviations are defined in Table 1.

press). Each vegetation class was assigned the maximum value of the historic fire return interval range (RI_{max}) to provide a conservative estimate of fire return interval (Table 1). For example, if the average historic fire return interval in the ponderosa pine-mixed conifer forest ranged from 1 to 6 years, then an RI_{max} of 6 was assigned for all areas in that vegetation class.

Vegetation Classification	**RI_{max}**
1- Ponderosa Pine-Mixed Conifer Forest (PIPO)	6
2- White Fir-Mixed Conifer Forest (ABCO)	16
3- Red Fir-Mixed Conifer Forest (ABMA)	50
4- Lodgepole Pine Forest (PICO)	163
5- Xeric Conifer Forest (XECO)	50
6- Subalpine Forest (SUAL)	508
7- Foothills Hardwood and Grassland (FHGR)	17
8- Foothills Chaparral (FOCH)	60
9- Mid-Elevation Hardwood (MEHA)	23
10- Montane Chaparral (MOCH)	75
11- Meadow (MEAD)	65
12- Rock (Rock)	-
13- Other (mostly water) (OTHR)	-
14- Giant Sequoia-Mixed Conifer Forest (SEGI)	16

Table 1. Maximum average fire return intervals (RI_{max}) for each vegetation class (Caprio, A.C and Lineback, P. in press).

The historic fire perimeters were used to assign a year value that reflected the most recent fire in every area. When subtracted from the current year (1998, in this case), an output was derived that displayed the time since the last fire (TSLF) for each area. If an area had not burned within the period of record (since 1921), the year 1899 was used as a conservative base year. This year was used because it represents the last widespread fire date recorded in the fire history reconstructions.

Using these inputs, a derived index was calculated to quantify the departure of each 30 m^2 area from its pre-Euroamerican settlement fire return interval (Figure 3). The calculation for the Fire Return Interval Departure (FRID) index is:

$$FRID = \frac{TSLF - RI_{max}}{RI_{max}} \quad (1)$$

where,

TSLF (time since last fire) = number of years that have passed since the most recent fire (from historic fire records or using the baseline date of 1899)

and,

RI_{max} = maximum average return interval for the vegetation class.

The FRID index ranged from -1 to 16 given the baseline last fire year of 1899 and a minimum RI_{max} value of 6 years. The index values were placed into four rating categories (low, moderate, high, and extreme) that were likely to capture current forest conditions and the need for burning based on historic fire intervals (Table 2).

Low	**Moderate**	**High**	**Extreme**
<0	≥ 0 and <2	≥ 2 and <5	≥ 5

Table 2. Fire Return Interval Departure (FRID) index range for each ecological need category.

These categories were then mapped spatially across the parks using GIS (Figure 4). The ecological need model is dynamic in that, as new prescribed and wildland fires occur, the TSLF layer is updated and a new FRID index is calculated and mapped annually.

RESULTS AND DISCUSSION

The dominant FRID category in the parks in 1998 was low (green, 47% of vegetated area; Figure 4) followed by moderate (yellow, 30%), extreme (red, 16%, and then high (orange, 7%). Much of the area in the low or moderate categories was located in the higher elevations of the parks, where fewer fires have been missed due to longer historic fire return intervals. Many of the high and extreme category areas (orange and red) occurred in the lower and mid-elevation conifer forests. These areas often have the highest visitor use and are consequently the greatest human safety concern to park managers.

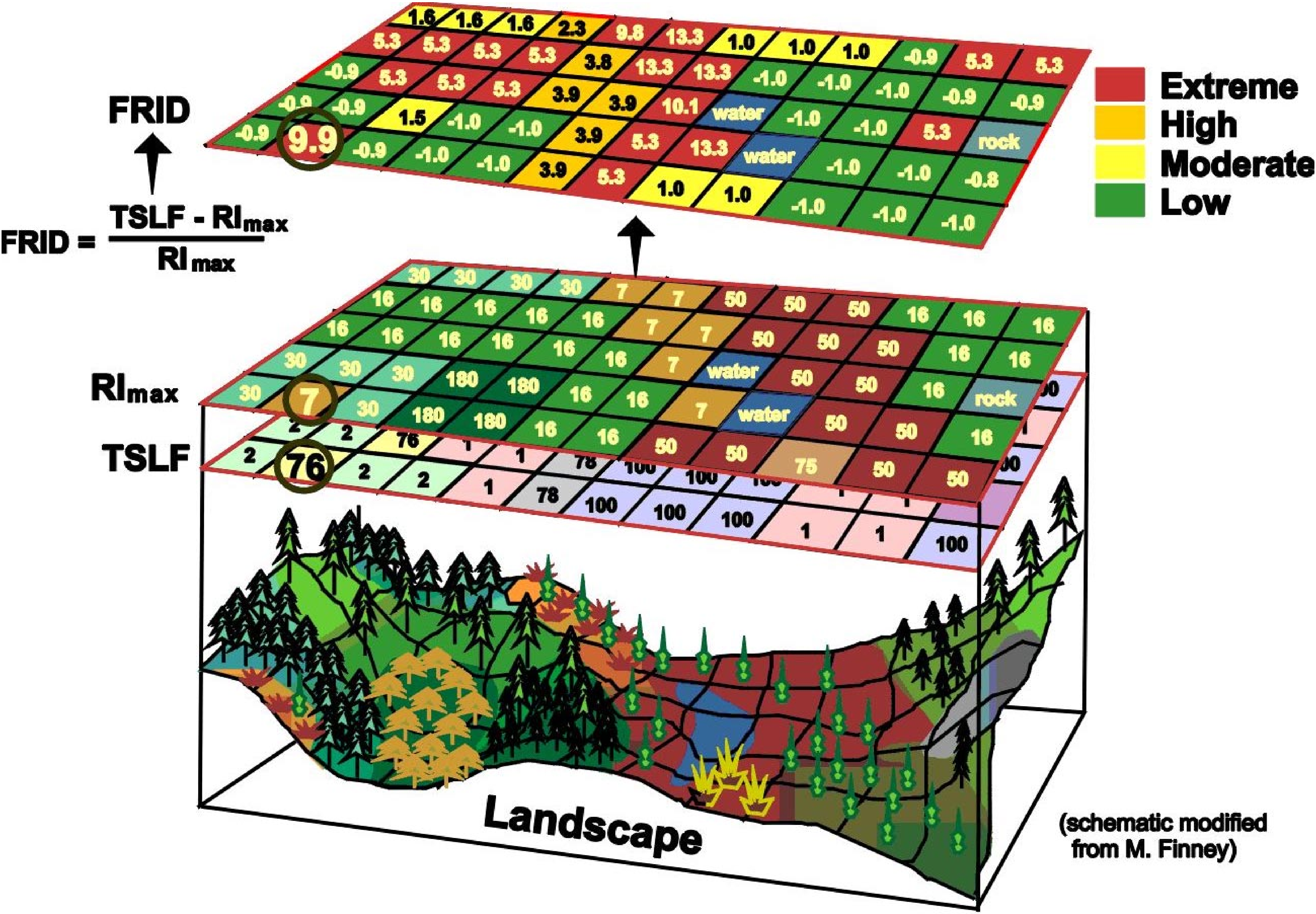

Figure 3. Fire Return Interval Departure (FRID) is calculated for each 30 m^2 pixel across the landscape using the time since last fire (TSLF) and maximum average return interval (RI_{max}) GIS layers.

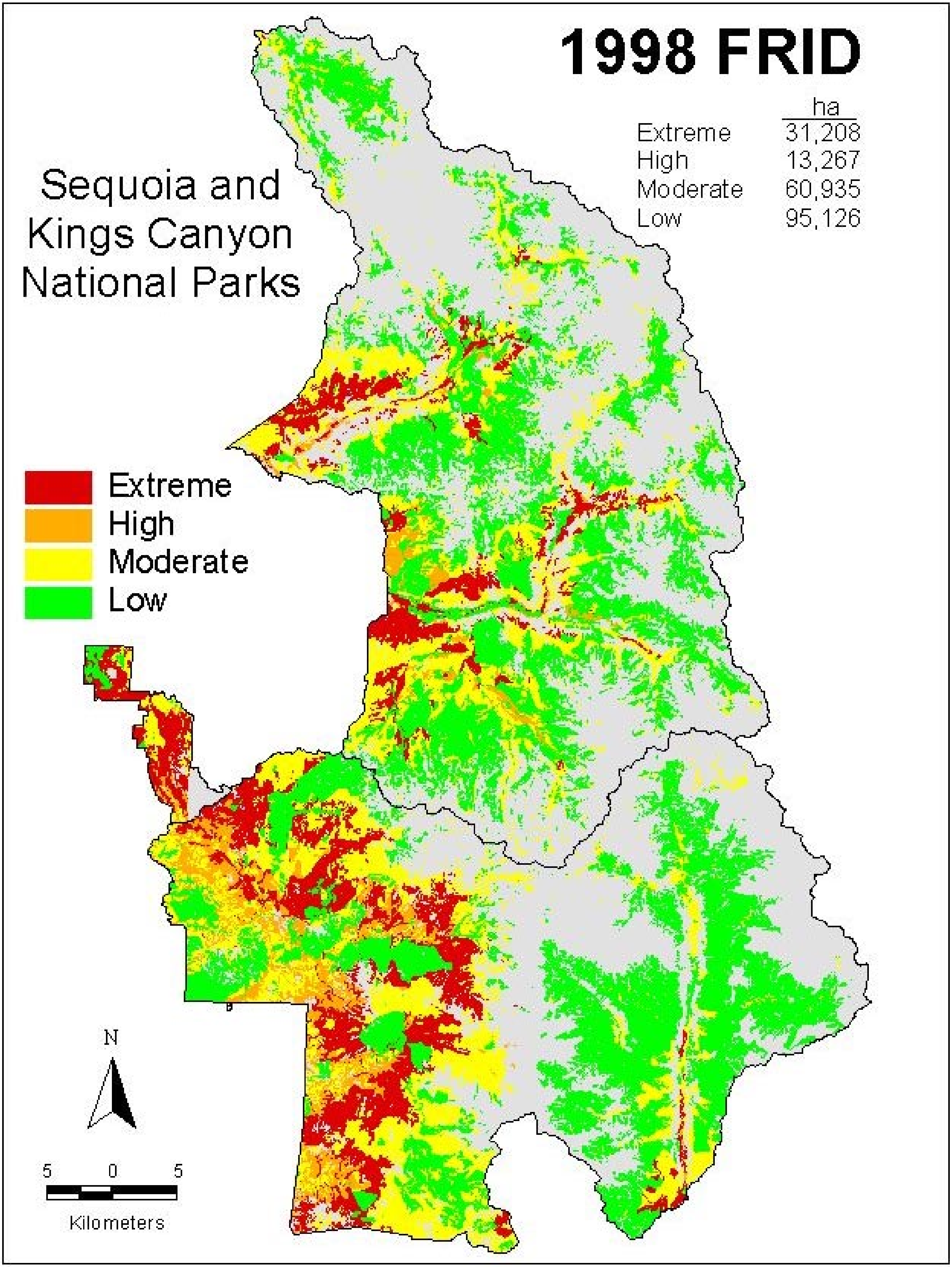

Figure 4. Fire Return Interval Departure (FRID) for Sequoia and Kings Canyon National Parks.

Model Applications

The FRID model outputs can be used as a decision support tool to prioritize areas for treatment by focusing treatments in areas with extreme or high FRID categories. The model can also be compared to current prescribed fire schedules already in place to validate or refine priorities. Managers can then analyze the effectiveness of the current treatment prioritization process relative to ecological need.

FRID can also be used to assist with scheduling successive burn treatments by assessing when previously treated areas should be re-burned before losing the numerous benefits gained from the initial prescribed fire. These areas are differentiated with a lighter shading of the FRID colors to indicate that they have undergone at least one restoration burn (Figure 5). The moderate FRID areas that have been treated with prescribed fire (light yellow; Figure 5) might then be considered high priority for subsequent treatment. Therefore, the benefits accrued from the initial burn treatment will be retained by not allowing the areas to return to high or extreme FRID after time and money was already spent on their treatment. This application will help meet the objective of, not only reintroducing fire, but also maintaining it as a natural process wherever possible.

The ecological need model is particularly useful to evaluate progress towards achieving landscape-level ecological goals. For example, two versions of FRID were calculated for areas where prescribed fires or wildland fires for resource benefit have burned. The first version projects what FRID would be now if those fires had not taken place (Figure 6a). The second version displays the actual 1998 FRID conditions because of the fire restoration activities that have occurred over the past three decades in those areas (Figure 6b). Differences in the amount of area in each category between projected and actual FRID are quite dramatic. In the projected FRID without fire use, 48% of the area is in the extreme category, while only 1% of the area has an extreme FRID in the existing conditions with fire use (Figure 6). Likewise, without fire use, 14% of the area is projected to have a low FRID, while almost 5 times as much of the area (68%) is in the low FRID category due to fire restoration over the last three decades. This analysis demonstrates the ability of the FRID model to track the amount of the landscape where fire regimes are being restored, one of the long-term, ecological goals for these parks. See Caprio, A.C. and Graber, D.M. (in press) for further analyses.

The FRID model can also help to provide economic accountability for fuels and fire management programs. If fire hazard, ignition risk, and ecological need models are used in combination, the intersection of the high priority areas from each model would yield the greatest benefit for the least cost (Figure 7).

Model Assumptions and Limitations

The FRID model is a conservative estimate of the departure from the historic fire return interval for two reasons: 1) the *maximum* average return interval is used; and 2) if an area had no known fire recorded since 1921, then 1899 was used as a conservative base year to calculate TSLF (many of these areas have not burned since well before that time). To obtain a potentially more realistic FRID index, the *average* fire return interval could be used in the model instead of the maximum average.

The FRID model presented here also assumes that historic fire return intervals are consistent within a broad vegetation class, which is not necessarily the case. Ongoing research indicates that differences in fire return intervals between north and south aspects can be as much as three-fold within a vegetation class (Caprio, A.C. unpublished data). Other topographic and site factors, such as elevation, slope, and watershed, probably affect fire return interval differences within a vegetation class. As new fire regime information for these areas is obtained, the FRID model will be refined and updated.

The fire return interval is just one of many characteristics of fire regimes. Other models could be developed to reflect other ecologically important aspects of fire regimes, such as severity and seasonality.

Conclusions and Future Needs

The FRID model is a valuable and intuitive decision support tool for prioritizing treatment areas and evaluating program success in a variety of ways. The model summarizes important ecological information that complements traditional hazard and risk models in fire management planning and has become an important part of parkwide fire management operations at Sequoia and Kings Canyon National Parks.

Further work to integrate the ecological need model with hazard and risk models will improve fuels and fire management planning capabilities. Depending on program goals, the models can be used separately

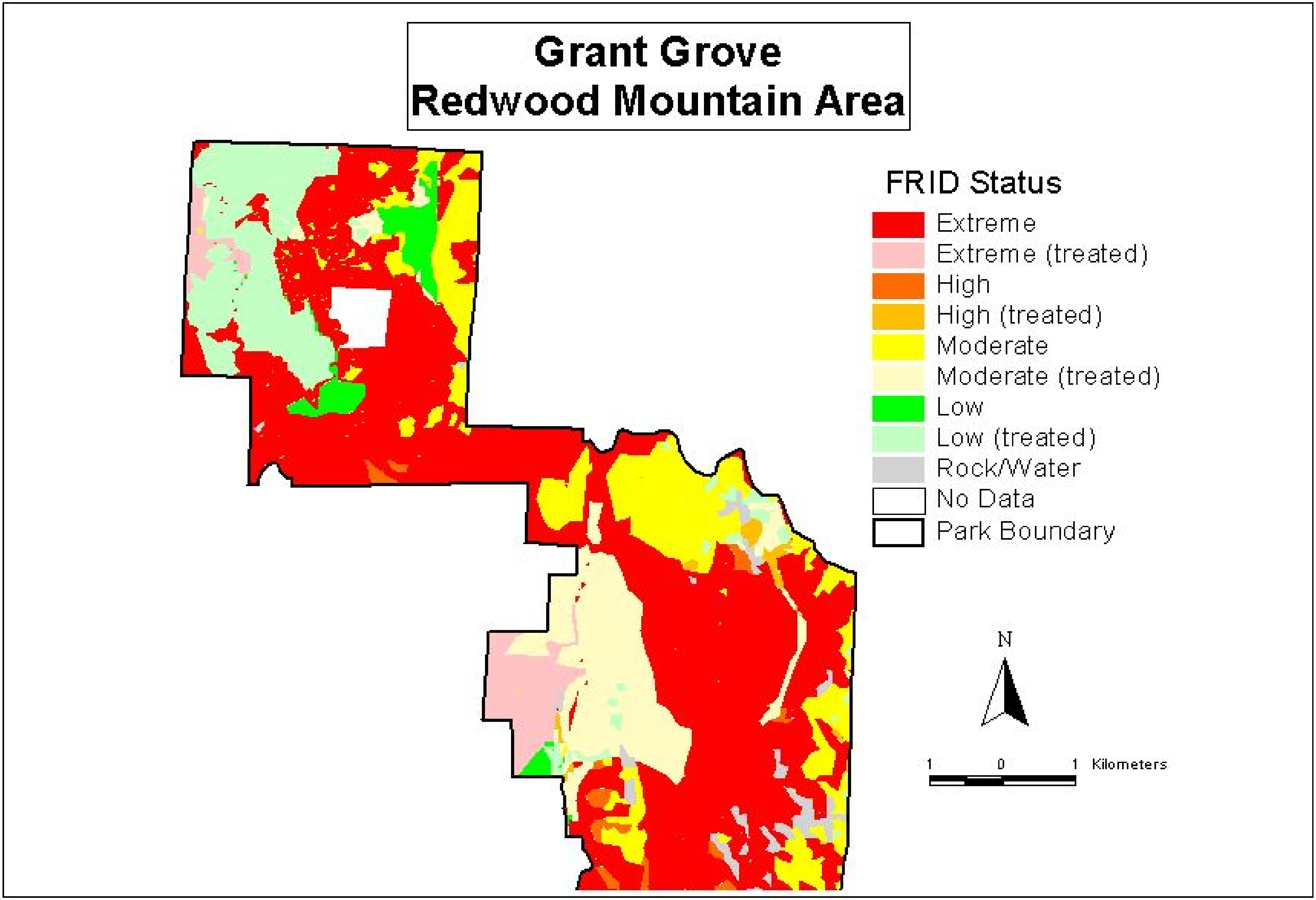

Figure 5. Fire Return Interval Departure (FRID) for the Grant Grove area of the park displaying differential FRID category shading to distinguish areas that have been treated at least once with prescribed fire (actual data modified for display purposes).

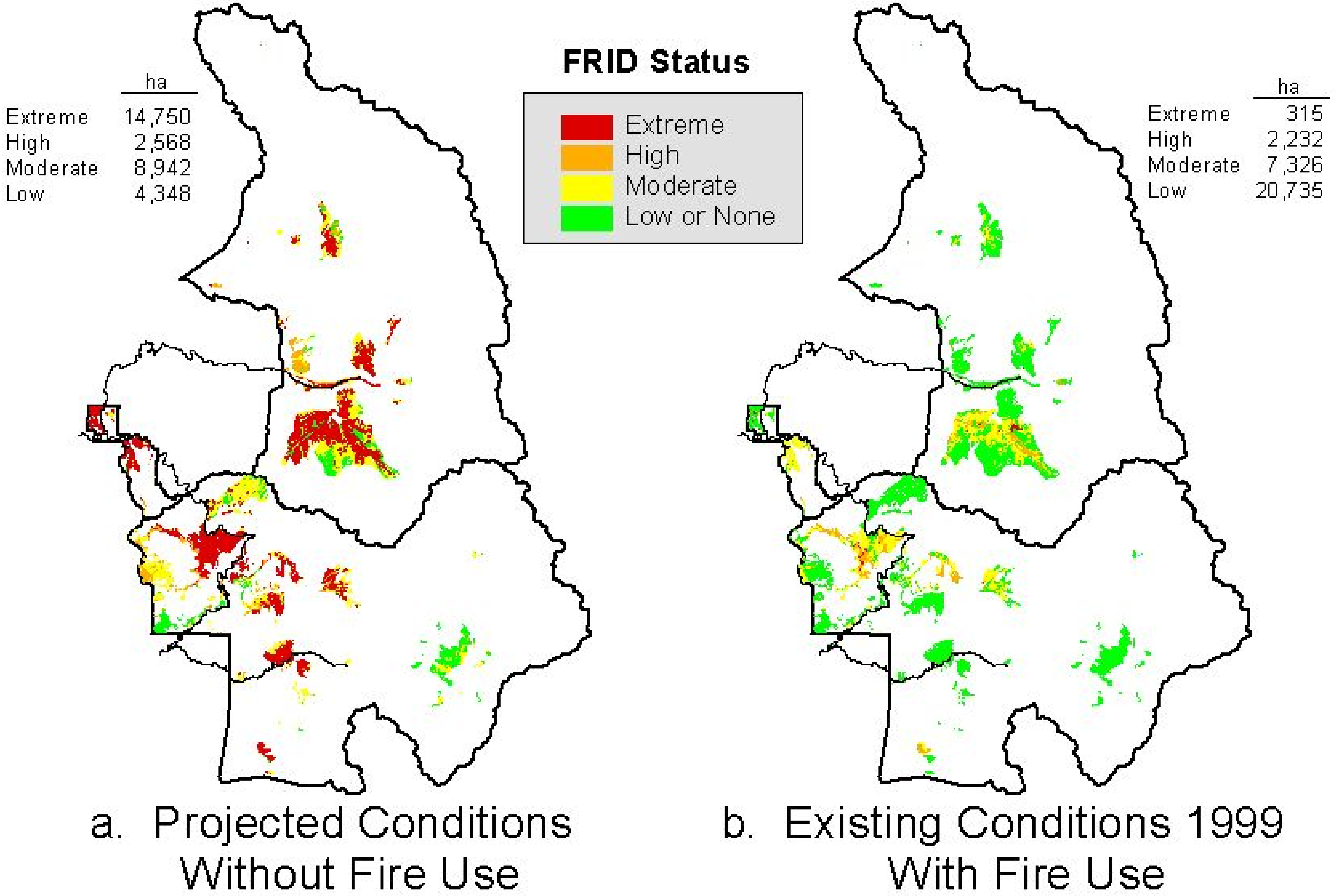

Figure 6. Fire Return Interval Departure (FRID) for areas of Sequoia and Kings Canyon National Parks where fire restoration activities (prescribed fire or wildland fire used for resource benefit) have occurred over the last 30 years: a) projected FRID without fire use; b) existing FRID with fire use.

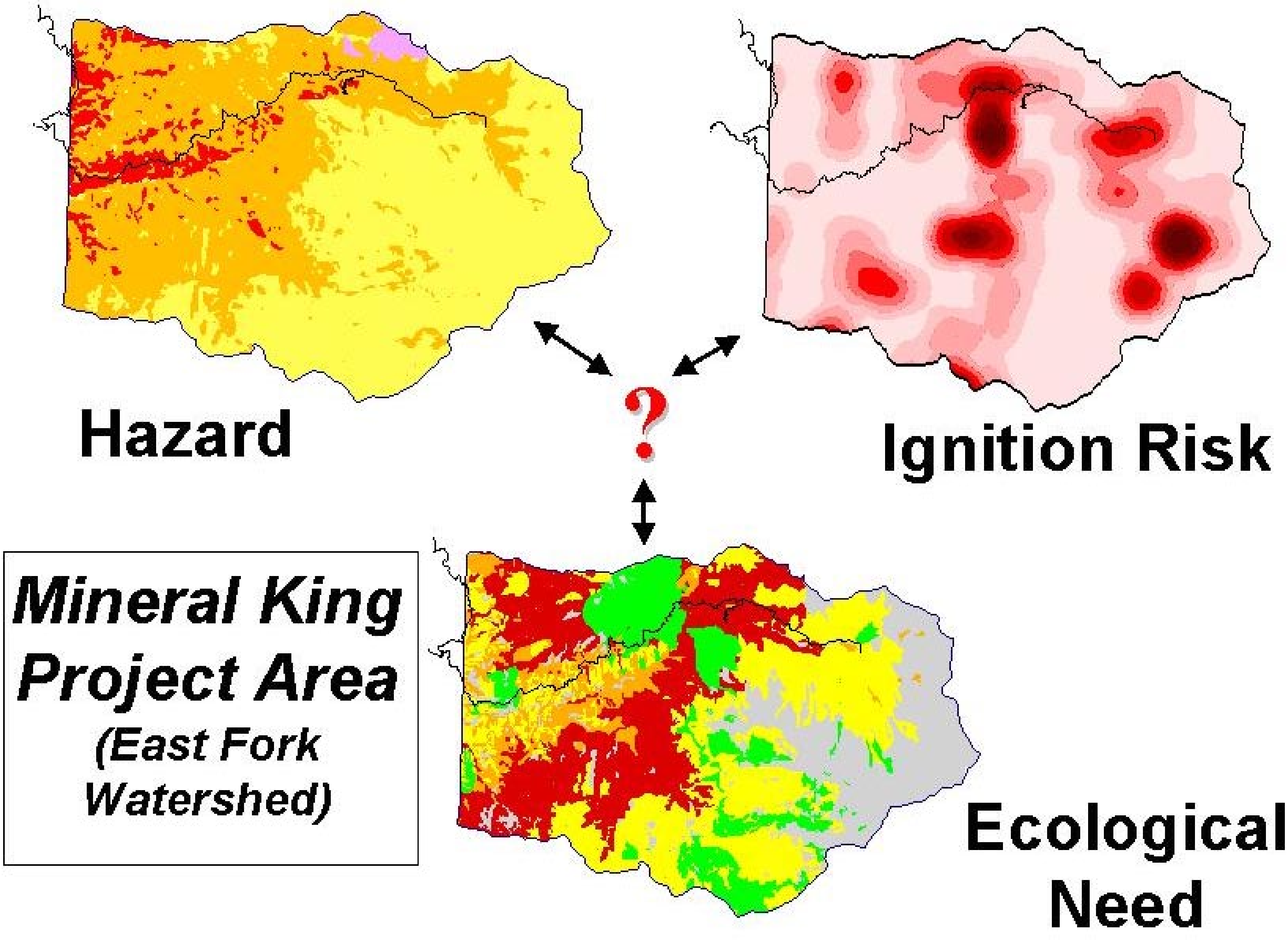

Figure 7. Three separate models developed for the Mineral King Risk Reduction Project area of the parks. Combining these models to optimize the treatment of areas of the highest hazard, ignition risk, and ecological need will increase the economic efficiency of the fire management program.

or merged using overlays or by combining model algorithms to produce integrated maps. In addition, incorporating the model into a performance-based management process will help insure accountability and demonstrate achievement of ecosystem goals.

The area of model application needs to be expanded beyond the park boundaries so that ecosystem-based, interagency fire management planning can be accomplished. This expansion will require development of standards and protocols across agency jurisdictions, as well as the creation of a user interface to facilitate use of the model by managers.

This type of analysis will assist fire managers in describing and justifying the results of their fuels and fire management programs to Congress. Fire managers can show how tax dollars are being spent with both numerical tables and maps that provide a simple and dynamic picture of their accomplishments.

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