Fire Management and GIS: A Framework for Identifying and Prioritizing Fire Planning Needs [1]

Anthony Caprio, Corky Conover, MaryBeth Keifer, and Pat Lineback [2]

Abstract

With more funding becoming available for prescribed fire, it will be increasingly important to optimize selection of critical areas most in need of burning, on the basis of value, hazard, and risk criteria. A process under development by Sequoia and Kings Canyon National Parks integrates these criteria within a geographic information system (**GIS**) framework. Our goal is to identify high priority areas for prescribed burn treatment to optimize use of funding and resources. This use of GIS merges natural resource data with fire management planning information. We developed three major models that were integrated within a GIS: **Value**, **Hazard**, and **Risk**. The **Value** model consisted of two major parts: ecological need and infrastructure and human life/safety. For ecological need, we considered burn rotations on the basis of historic fire-return intervals (pre-1860) within major plant communities. The longer that the current time interval without a fire exceeded the maximum historic fire return interval, the greater the priority rating for returning fire to an area. For infrastructure and human life and safety, we gave greater weight to areas of high visitation and areas with buildings or other facilities when developing the GIS data. The **Hazard** model considered key factors (fuel model, slope, aspect, elevation) that affected management's ability to control fires, or a fire's resistance to control once ignited. Finally, the **Risk** model considered historic wildfire occurrence from both human and lightning causes. We aggregated these models in various ways depending on the specific questions we were attempting to answer, although each model could be output as a separate analysis. As severe wildfires continue to increase in North America due to continuing fuel accumulation, the use of fire as an option for fuel reduction and ecosystem management will become more important. In addition, the use of GIS will be an essential tool for planning and implementing such landscape-scale management programs.

Introduction

Project Area

Sequoia and Kings Canyon National Parks (SEKI), located in the southern Sierra Nevada, are topographically rugged with elevations ranging from 1,600 to 14,495 feet. Major drainages are the Kern, Kaweah, Kings, and San Joaquin Rivers. The Parks encompass about 864,383 acres. Three broad vegetation zones dominate the Parks: the *foothills* (1,600 to 5,000 ft) composed of annual grasslands, oak and evergreen woodlands, and chaparral shrubland; the *mixed-conifer*

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[2] Ecologist, Ecologist, Ecologist, GIS Coordinator, respectively, Sequoia & Kings Canyon National Parks, Three Rivers, CA 93271; email: tony_caprio@nps.gov; corky_conover@nps.gov; marybeth_kiefer@nps.gov; pat_lineback@nps.gov.

forest (5,000 to 10,000 ft) with ponderosa pine and white and red fir forests, and the *high country* (10,000 to 14,000 ft) composed of subalpine and alpine vegetation, and unvegetated landscapes. Within the mixed-conifer zone, well-defined groves of giant sequoia are found.

The climate is distinctly Mediterranean with cool moist winters and warm summers with little rainfall (seasonal summer thunderstorms occur sporadically at higher elevations). Precipitation increases as elevation increases, to about 40 inches annually from 5,000 to 8,000 feet on the west slope of the Sierra, and then decreases as one moves higher and to the east. Substantial snow accumulations are common above 5,000 feet during the winter.

European settlement of the area began in the 1860's 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.

Historic Fire Regimes

Historically, fire played a key ecological role in most Sierra Nevada plant communities. At the landscape level, fire history research shows an inverse relationship between fire frequency and elevation in areas of conifer forest (Caprio and Swetnam 1995). Currently, fire history information is lacking for the foothills area of the park. The cause of fires prior to European settlement is usually attributed to ignitions by lightning or Native-americans. However, since the actual source of these fires cannot be determined, the specific cause(s) remain largely unknown. The seasonal occurrence of pre-settlement fires was similar to the contemporary late summer-early fall fire season (Caprio and Swetnam 1995). Historic fire size ranged from large fires burning across multiple watersheds[3], to fires restricted to a few or a single trees. Fire intensity was variable both spatially and temporally (Caprio and others 1994, Stephenson and others 1991). In much of the mixed-conifer zone, fires were primarily non-stand replacing surface fires, although many exceptions exist (Caprio and others 1994). Specific regional fire years have also been identified (years in which fires have been recorded at sites from throughout the southern Sierra Nevada where pre-European fire history has been reconstructed), usually occurring during dry years (Swetnam and others 1992), along with long-term variation (1,000-2,000 years) in the fire regime associated with climatic fluctuations (Swetnam 1993).

Fire regimes in the Sierra Nevada changed dramatically beginning with European settlement around 1850-1870 (Caprio and Swetnam 1995, Kilgore and Taylor 1979, Warner 1980). Factors that contributed to this decline in fires during the latter portion of the 19th century include the loss of Native-merican populations that used fire and heavy livestock grazing that reduced herbaceous fuels available for fire spread (Caprio and Swetnam 1995). The occurrence of fires of large size decreased dramatically during the 20th century because of active fire suppression. This change in fire regime has lead to unprecedented fuel accumulations in many plant communities, structural and composition changes, and has resulted in an increased probability of widespread severe fires (Kilgore 1973).

[3] Unpublished data on file at ___________________________

Fire as a Tool

Most land management agencies classify fires as either "suppression fire" or "prescribed fire". The prescribed fire category is further broken down into prescribed natural fires (PNF), ignited naturally by lightning (unplanned ignitions), or management ignited prescribed fires (MIPF; planned ignitions). This paper focuses on the use of planned ignitions to achieve land management goals.

Land management agencies use fire for a variety of reasons, including: fuel reduction for protection of human safety and developments, resource protection, site preparation, thinning, elimination of undesirable species, protection of desirable species, and reintroduction of fire as a natural process. Agencies with large land areas are interested in restoration of fire as a natural process. 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 will not be 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, planned ignitions will be a key tool for putting fire back into the ecosystem (Federal Wildland Fire Management Policy and Program Review 1995).

Results and Discussion

Value Model

The **Value Model** was divided into two components: ecological need and human life safety/infrastructure. The motivation for an ecological need component was based on the National Park Service's mission statement to "protect and preserve" natural resources. Fire is an important process and component for working towards this goal.

The ecological need component provided a rating index to rank areas on the need for fire. All areas within the Parks' 11 broad vegetation classes were rated based on *fire return interval departures* (FRID). This rating permitted us to assign priorities based on ranks for all areas in our model. A specific value for each area's FRID was based on the *time since the last fire* (TSLF), relative to the maximum average fire return interval (RI_{max}) prior to European settlement for each vegetation type. The historic fire regime return interval values (**table 1**) were based on reconstructed fire history chronologies derived from tree-ring samples obtained from fire-scarred trees in the vicinity of Sequoia and Kings Canyon National Parks. If information for a vegetation type did not exist from within or near the Parks, the information was obtained from the literature (Caprio and Lineback in prep.). To provide a conservative estimate, we used the RI_{max} for each vegetation class. The TSLF was derived from historic fire records (started in 1921) or was based on the last widespread fire date recorded by the fire history reconstructions. On the basis of history chronologies, the year 1899 was chosen as a conservative base year for the occurrence of the last fire for all areas where no recent historic fires (since 1921) have occurred (**fig. 1**).

Table 1. Maximum average fire return intervals (Rimax) for vegetation classes (Caprio and Lineback in prep.).

Vegetation classification	RI_{max}
1 - Ponderosa mixed conifer	6
2 - White fir mixed conifer	16
3 - Red fir mixed conifer	50
4 - Lodgepole pine forest	163
5 - Xeric conifer forest	50
6 - Subalpine conifer	508
7 - Foothills hardwood and grassland	17
8 - Foothills chaparral	60
9 - Mid-elevation hardwood	23
10 - Montane chaparral	75
11 – Meadow	65

By using these inputs, a derived index was calculated to quantify the departure of the vegetation type from its pre-European settlement fire return interval. The equation for the index is:

$$\textit{Fire Return Interval Departure}\ \text{(FRID)} = \frac{RI_{max} - TSLF}{RI_{max}}$$

in which,

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

and,

TSLF (time since last fire) = time that has passed since the most recent fire from historic fire records or using the baseline date of 1899 derived from the fire history chronologies.

The departure index ranged from -16 to 1 given our data set with a beginning TSLF of 1899 and a minimum RI_{max} value of 6. We reclassed the index values into four rating categories that were likely to capture current forest conditions and the need for burning based on historical fire intervals (**table 2**).

Table 2. Fire return interval departure index for each ecological need category.

Extreme	High	Moderate	Low
≤-5	>-5 and ≤-2	>-2 and ≤0	>0

By using this component of the model, these categories were mapped spatially across the Parks by using a geographic information system (GIS) (**fig. 2**). While the dominant ecological need category was "moderate" (**fig. 3**), the "extreme" and "high" categories were most important in the lower and mid-elevation conifer forests. These areas have the highest visitor use and are consequently the greatest human safety concern to park managers.

In the infrastructure and life/ safety component of the **Value Model**, we addressed the anthropogenic and natural resources on the landscape that could potentially be impacted by fire. Each factor was divided into three categories: high, moderate, or low, based on a number of criteria (**table 3, 4**).

Table 3. Infrastructure values: criteria as they relate to replacement costs or disruption of services caused by fire.

High	Moderate	Low
developed sites, power/phone lines, electronic sites, pipelines	campgrounds, picnic areas, maintained roads	trails, vistas, overlooks, fences, backcountry camp sites

Table 4. Life/safety values: categories for developed areas as they relate to the potential threat to human life from fire.

High	Moderate	Low
Bearpaw High Sierra Camp, Oriole Lake, Atwell Area, Cabin Cove Area, Silver City Area, Giant Forest Area, Ash Mountain Area, Crystal Cave Area, Crystal Cave Road, Mineral King Road, General Hwy from Hospital Rock to Eleven Range	Grant Grove Area, Red Fir Area, Lodgepole Area, Wuksachi Area, Dorst Campground, Faculty Flat Area, Generals Hwy from Eleven Range to Grant Grove	Cedar Grove Area, Mineral King Valley Area

Hazard Model

In the **Hazard Model** we examined key parameters that affect a manager's ability to control a fire (i.e., resistance to control). The four parameters were fuel model, slope, elevation, and aspect. Slope, aspect, and elevation were derived from a digital elevation model (DEM). The fuel models used were the 13 standard fuel models for fire behavior estimation (Albini 1976) and "custom models" (Burgan and Rothermel 1984) developed from Park fuels surveys by the Park's fuels specialist (**table 5**). Custom models were developed because standard fuel models were not representative of the actual fuel conditions found within some vegetation types within the Parks.

Table 5. Custom fuel model descriptions ("low elevation"≤ 6,500 ft, "mid elevation" = 6,500-8,000 ft, and "high elevation" ≥ 8,000 ft).

Custom model description	Custom model number

Low elevation short needle conifer	14
Low elevation pine	15
Mid-elevation short needle conifer	16
Mid-elevation pine	17
High elevation short needle conifer	18

Each of the four parameters was divided into three categories: high, moderate, or low hazard, based on specific elements within each parameter (**table 6**). Applying this model using GIS (**fig. 4**) indicated that the largest portion of the Parks was in the low hazard category and the smallest portion was in the high category (**fig. 5**).

Table 6. **Hazard Model** parameters, ratings, and individual elements within each parameter.

Parameter	High	Moderate	Low
Fuels	4, 9,10,15	1, 2, 3, 5, 6, 14,16,17	8, 18
Slope	40 pct.+	11-39 pct.	0-10 pct.
Elevation	0-5000 ft.	5001-8000 ft.	8000+ ft.
Aspect	S, SW	SE, E, W	N, NE, NW

Risk Model

In the **Risk Model**, we identified the risk of potential ignitions by examining the historic occurrence of both human and naturally (lightning) caused fires. We divided the Parks into watersheds and plotted the occurrence of reportable fires over the past 10 years of record (**fig. 6**). We compared the number of fires with the ratio of fires per 1,000 acres for the 13 watersheds within the Parks. The watershed with the greatest risk of a non-management ignition (an ignition due to lightning or human-caused wildfire) was the South Fork of the Kings (135 unplanned fires). The watershed with the largest number of human caused wildfires was the Marble Fork of the Kaweah, followed by the South Fork of the Kings and the Middle Fork of the Kaweah (**fig. 7**). All three of these watersheds are areas of high visitor use. The ratio data showed that the watershed with the greatest risk per acre was Kings Tributaries (Grant Grove), followed by the Marble Fork of the Kaweah, with most of the risk attributable to human-caused fires. The risk from natural lightning fires varied to a lesser degree among watersheds and appeared to be related to the proportion of a watershed that was vegetated. The ratio data for the Kings Tributaries watershed was somewhat misleading because of the small size of the area (3701 ac). These two analyses indicate that the greatest risks were located in the Marble Fork of the Kaweah watershed, followed by the Kings Tributaries. A key assumption in the **Risk Model** was that locations where fire ignitions have historically occurred will continue to be sources of ignition.

Model Summary

The framework presented for the development of GIS models for prioritizing fire planning needs produce simple, color-coded ratings on park maps for each of the model components. The areas with the highest priority ratings based on either **Value**, **Hazard**, or **Risk** can be viewed spatially when determining which areas to focus planned ignition efforts. Depending on the program goals and questions asked, the models can be used separately or merged, by using either overlays or by combining model algorithms to produce integrated maps of a combination of models. Other applications for this framework include: fire prevention planning, fire preparedness planning, and use in National Environmental Policy Act (NEPA) compliance documents.

Future Model Considerations

As these models evolved and developed, potential improvements were identified in the form of model validation, improved source data, and model refinement. Some of the planned changes include:

- The fuels and vegetation data will be improved. Some modification and customization of these themes will occur as we add to our information base.
- The ecological need component of the **Value Model** should incorporate the importance of repeated burns in areas that have been burned for fuel reduction. These areas will then have a higher priority than similar unburned areas since there is value in not letting fuel conditions deteriorate into the severe classes again. The secondary or re-burns are also usually less costly than the primary fuel reduction burn.
- The ecological need component should also incorporate vegetation fire return intervals that are more sensitive to local landscapes. This refinement will result in historic fire return intervals that more fully consider landscape differences such as aspect, elevation, slope, and watershed.
- Additional inputs into the ecological need component could include a weighting for our confidence about the input data. For example, vegetation types for which we have a poor understanding of pre-European fire history might be given a weighting that would reflect the uncertainty of our knowledge. Another potential input into this component could be the identification of critical areas or habitats that would either be a target for fire or protected from fire because of specific ecological reasons.

Acknowledgments

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Figure Captions

Figure 1. Fire history dates (before 1920) for sites in or near Sequoia and Kings Canyon National Parks.

Figure 2. Spatial extent of extreme and high categories derived of the fire return interval departure (FRID) analysis from the ecological need component of the **Value Model** for Sequoia and Kings Canyon National Parks.

Figure 3. Acreage within each of the fire return interval departure (FRID) classes for the total vegetated area in Sequoia and Kings Canyon National Parks.

Figure 4. Spatial extent of the two **Hazard Model** categories of Sequoia and Kings Canyon National Parks.

Figure 5. Acreage within each of the **Hazard Model** classes for the total vegetated area of Sequoia and Kings Canyon National Parks.

Figure 6. Human-caused fire ignition points from 1987 to 1996 used in part for developing the **Risk Model**.

Figure 7. Ignition risk by watershed for human caused wildfires. The figure gives total number of human-caused fires and proportion of these relative to all unplanned fires within each watershed of Sequoia and Kings Canyon National Parks. See figure 6 for watershed abbreviations.

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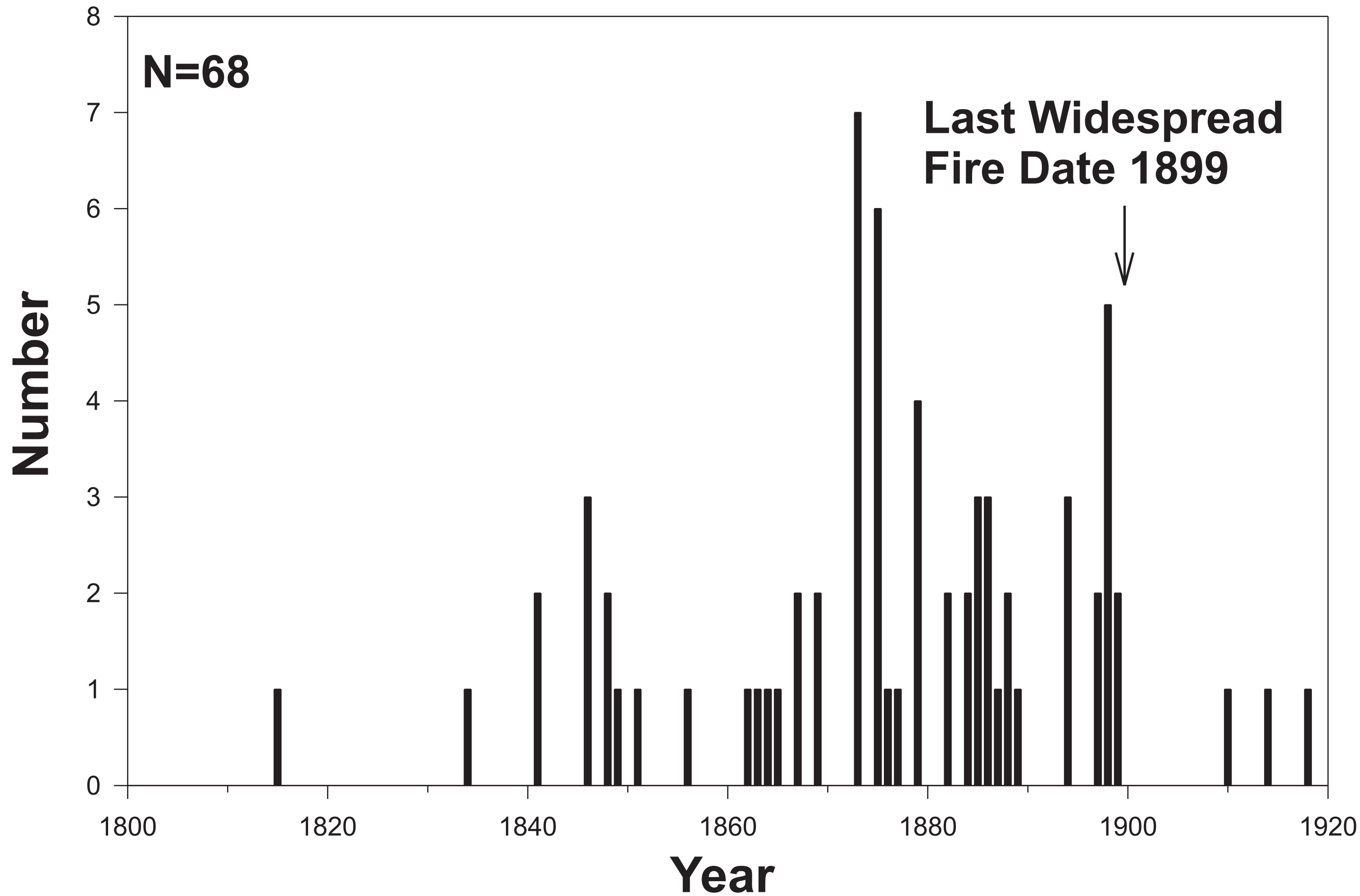
Figure 1.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Last Widespread
Fire Date 1899
Number
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1820
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1880
1900
1920
Year

Figure 2.

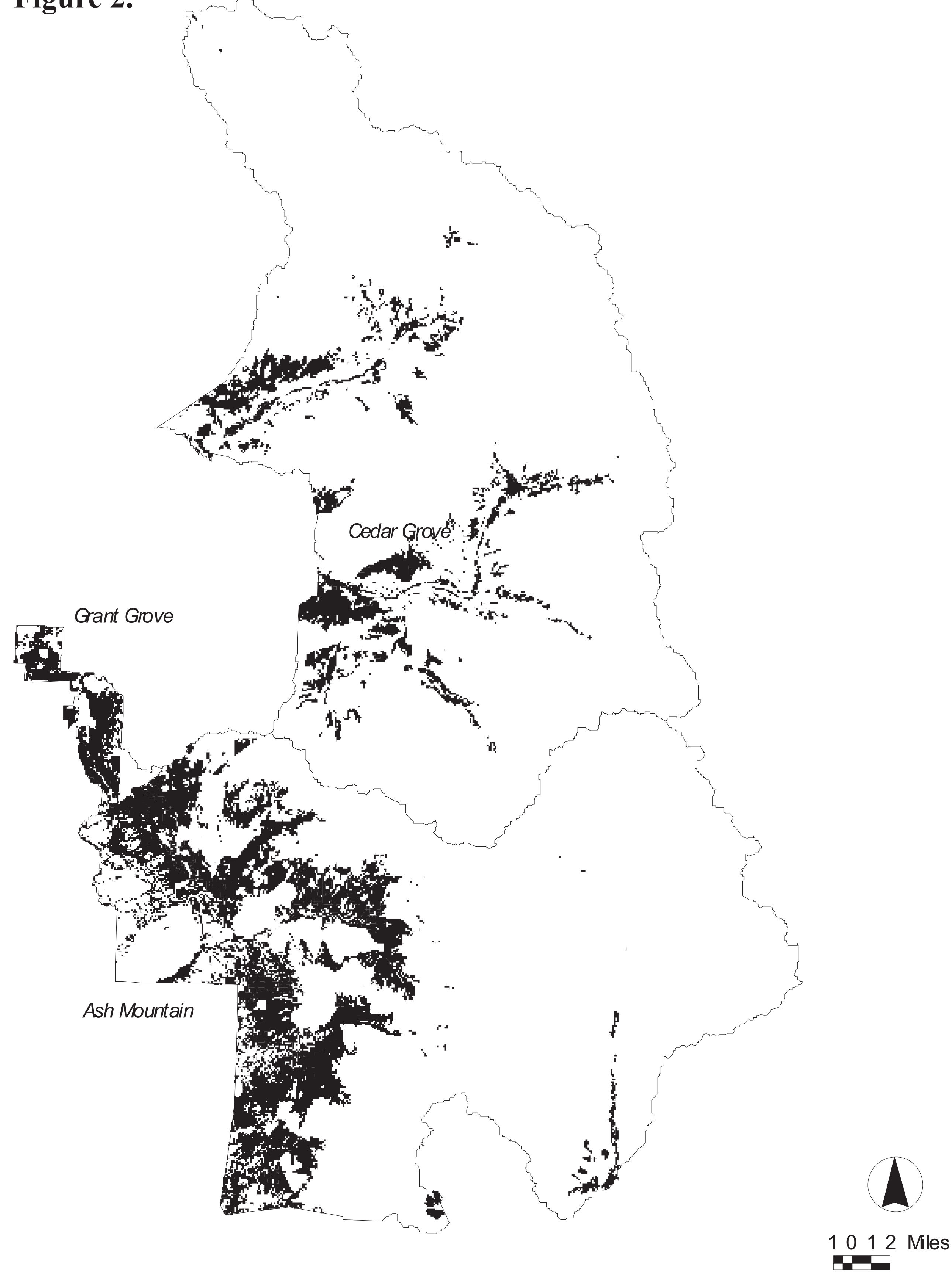
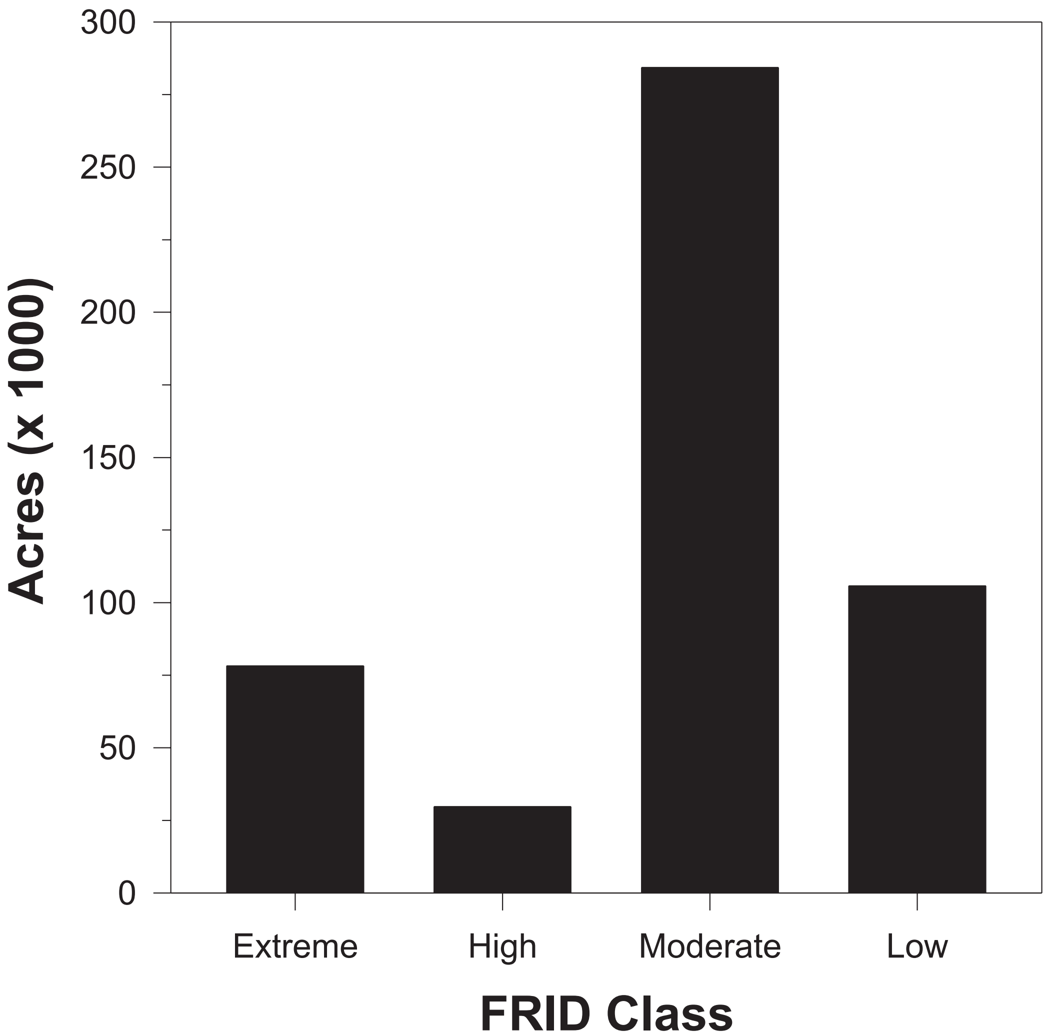


Figure 3.



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200
150
100
50
0
Acres (x 1000)
Extreme
High
Moderate
Low
FRID Class

Figure 4.

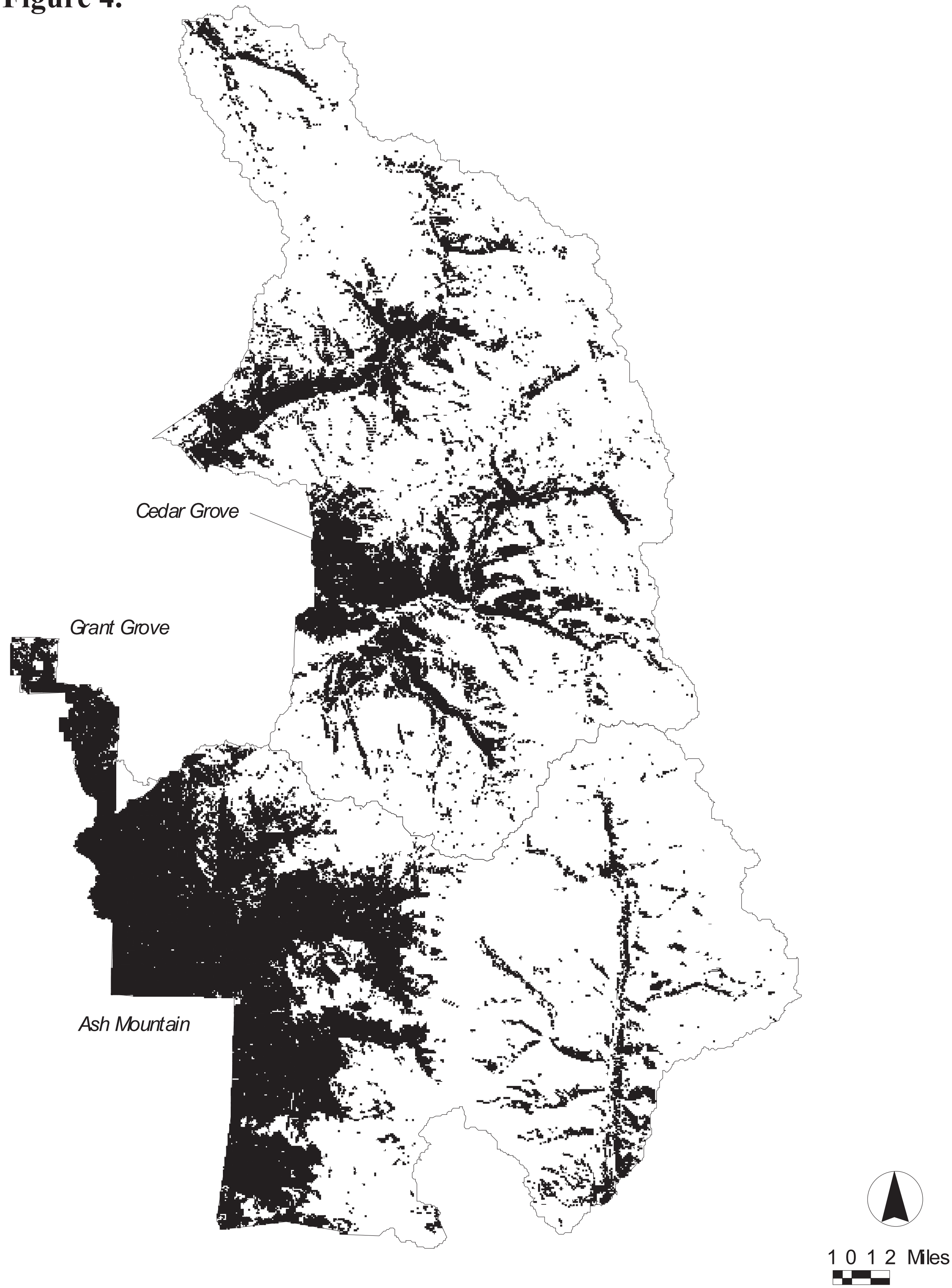
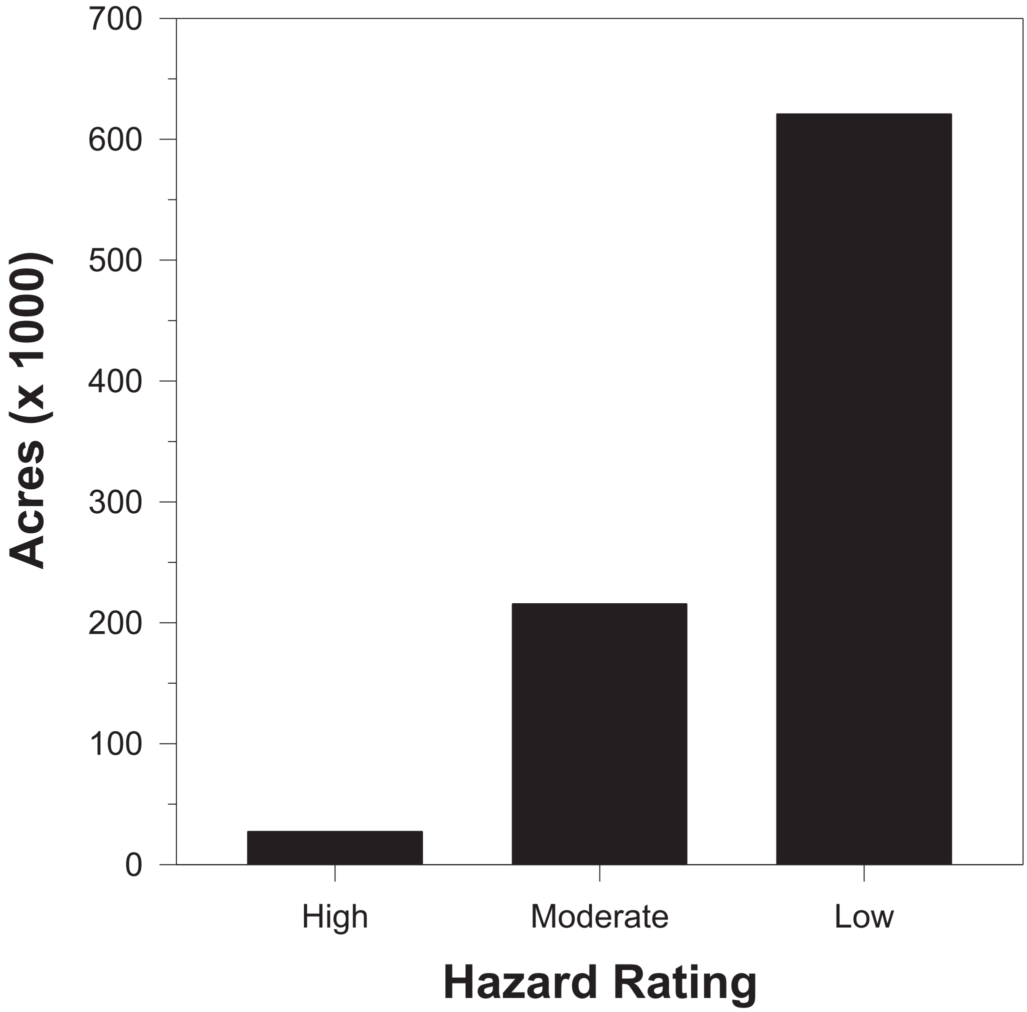


Figure 5.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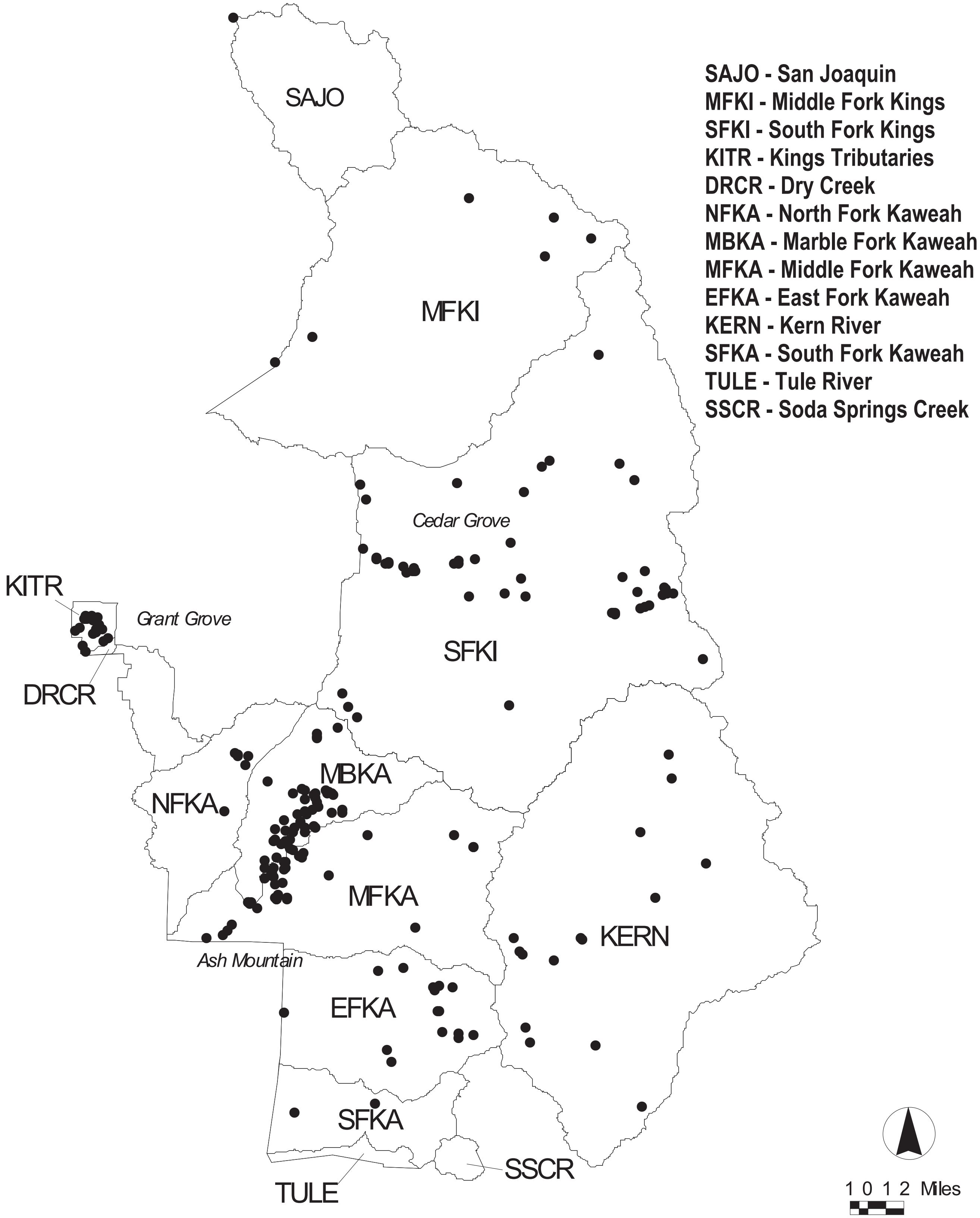
Acres (x 1000)
High
Moderate
Low
Hazard Rating

Figure 6.


SAJO - San Joaquin
MFKI - Middle Fork Kings
SFKI - South Fork Kings
KITR - Kings Tributaries
DRCR - Dry Creek
NFKA - North Fork Kaweah
MBKA - Marble Fork Kaweah
MFKA - Middle Fork Kaweah
EFKA - East Fork Kaweah
KERN - Kern River
SFKA - South Fork Kaweah
TULE - Tule River
SSCR - Soda Springs Creek
SAJO
MFKI
Cedar Grove
KITR
Grant Grove
SFKI
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MBKA
NFKA
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KERN
Ash Mountain
EFKA
SFKA
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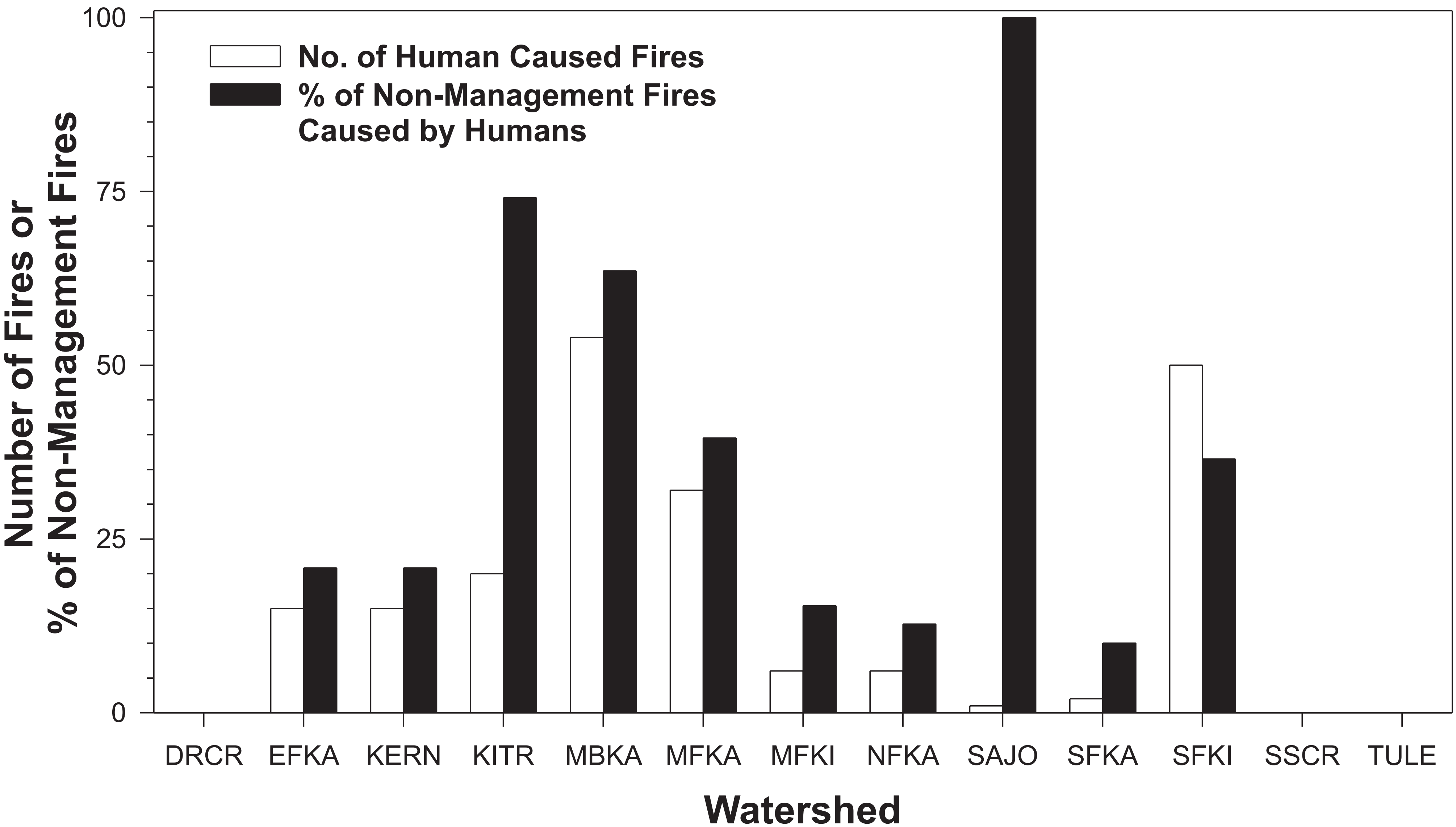
Figure 7.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% of Non-Management Fires Caused by Humans
Number of Fires or % of Non-Management Fires
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50
25
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DRCR
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KITR
MBKA
MFKA
MFKI
NFKA
SAJO
SFKA
SFKI
SSCR
TULE
Watershed