Mapping Departure from Historic Fire Return Intervals in the Lassen Foothills of Eastern Tehama County, California

Report to Tehama County Resource Conservation District

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SUMMARY

The Lassen Foothills of eastern Tehama County in northern California represents important vegetation and wildlife habitat that has been largely lost where it occurred elsewhere in the state. We analyzed pre-settlement and current fire return intervals in a roughly 180,000 ha area to determine how fire regimes have changed since the pre-settlement era. Vegetation is primarily fire-adapted grasslands, blue oak woodlands, and chaparral, although non-native species have largely replaced native grasses and forbs. Fire has played an important ecological role in these vegetation types for thousands of years. We found that fire return intervals have been dramatically lengthened by fire suppression and the loss of intentional Native American ignition, although some chaparral-dominated areas are burning more frequently than expected. This information can be used to support vegetation management for improved wildlife habitat and watershed health in the Lassen Foothills.

INTRODUCTION

Fire Regimes

Fire is an ecological process that plays a critical role in the vegetation dynamics of the Lassen Foothills of northern California. Fire regimes are determined by temporal and spatial ignition patterns, physical factors such as topography and local climate, and vegetative attributes such as biomass accumulation, horizontal and vertical fuel distribution, and seasonal fuel moisture fluctuations (Brown and Smith, 2000). These vegetative attributes, including others such as floristic composition and population density, are in turn influenced by the associated fire regime. Although fire seasonality, intensity, size, and pattern are all important components of a fire regime, we chose to focus on mean fire return interval (FRI). Mean FRI is the average of data from several fires within the same stand and can be either a point or area value (Agee, 1993). Point mean FRI addresses the frequency at which fires have burned a particular location (often with considerable variability) and are usually compiled from fire scars on single or nearby trees. Area mean FRI is derived for a given landscape from the ages of multiple stands when there are no fire scars from which to derive a point FRI. FRI is particularly important due to its role in determining the distribution of plant species.

Fire regimes in California have been dramatically altered since European-American settlement (Skinner and Chang, 1996), often leading to increased fire severity and fire suppression costs (e.g., Miller *et al.*, 2008) as well as detrimental ecological effects on various plant communities (e.g., Arno and Fiedler, 2005). Fire regimes in large part regulate species composition, nutrient cycling, and vegetation structure. One useful way to frame the ecological impact of altered FRIs, particularly for chaparral, is the concept of "senescence risk" and "immaturity risk" (Zedler, 1995). Senescence risk describes how local regeneration is threatened when 1) FRI exceeds the duration of the individual plant life plus the duration of seed viability of post-fire re-sprouting species (e.g., *Cercocarpus betuloides*) or 2) FRI exceeds the duration of seed viability plus the age at last reproduction for obligate seeding species (e.g., many *Ceanothus* and *Arctostaphylos* species). On the other hand, immaturity risk describes the situation in which FRIs are so short that obligate seeders are unable to replenish the seed bank (FRI < age at first reproduction) or obligate sprouters are unable to rebuild energy reserves or dormant buds in sufficient quantities to re-sprout.

Fire Suppression and Its Effects on Lassen Foothills Vegetation

Federal land management policy generally favored complete fire exclusion from the early 20th century until the early 1960s when the Park Service began its prescribed burning program in California (Stephens and Ruth, 2005). Most pre-settlement low-elevation fires in the Lassen Foothills region were thought to have been frequent and of low intensity, although low fuel connectivity due to prominent volcanic landscape features produced locally variable fire regimes (Skinner and Taylor, 2006). Fire regimes in much of this area were intact until about 1905 when the national forest reserves were established (Skinner and Taylor, 2006). Taylor (1990) estimated that organized fire suppression in the Lassen National Forest (LNF) began in the early 1920s and became effective in the mid-1930s. His evidence indicates that until then, however, low-intensity fires in forests were common and probably encroached into meadows. Native American burning and lightning ignitions resulted in low- to moderate-intensity fires whose frequency decreased with elevation (Skinner and Taylor, 2006). Forests and meadows in LNF were also burned for sheep grazing purposes from the mid- to late-1800s until widespread grazing was regulated in 1905 (Taylor, 1990).

Skinner and Taylor (2006) point out that state and federal fire suppression in foothill and mid-montane areas has led to the replacement of a frequent, low- to moderate-intensity fire regime with infrequent but higher-intensity large fires that escape suppression because of the area’s remoteness and inaccessibility. These fires include the 1990 Campbell and Finley Fires, the 1994 Barkley Fire, and the 1999 Gun II Fire, all of which were more than 10,000 ha. The Antelope, Mill, and Motion Fires together burned almost 7,000 ha in 2008.

Grasslands. More than 9 million ha of California's Central Valley is estimated to have been grasslands or vernal pools before European-American settlement (Wills, 2006). Today this area contains possibly the most altered bioregion in California, primarily due to agricultural conversion, altered hydrologic regimes, non-native invasive species, and development. Little is directly known about pre-settlement vegetation and its fire regimes, although past fire frequency can be inferred from Native American burning practices (Stephens *et al.*, 2007). Native Americans burned grasslands for a variety of reasons whenever fuels were dry enough (Wills, 2006). In part because Native American population density in the Central Valley was among the highest west of the Mississippi River, it is likely that FRIs were the shortest in the state- estimated at from one to eight years (Wills, 2006; Reiner, 2007; Stephens *et al.*, 2007). This is in spite of an extremely low lightning strike density (Wills, 2006). Another important influence on fire regimes was flat, open topography (characteristic of only the lowest elevations of our study area) that allowed fires to spread easily (Wills, 2006). However, the majority of grassland fires today are suppressed at less than 4 ha (Reiner, 2007). Most of California's grasslands are capable of burning between May and October with local variation determined in part by topography and plant species (Reiner, 2007). Non-native species, typically annuals, now comprise from 50% to more than 90% of the plant cover and all but replaced the native perennials by the early- to mid-1800s, leading to a longer fire season, higher ignition probability, and more continuous fuels (Biswell, 1956; Bartolome, 1987; Brooks *et al.*, 2004; Wills, 2006). Many of the detrimental effects of non-native plant species on fire regimes cascade through whole ecosystems (Brooks *et al.*, 2004).

One management goal of The Nature Conservancy (TNC) in the Lassen Foothills is to treat more than 4,000 ha per year with prescribed fire to control the particularly invasive non-natives medusahead (*Taeniatherum caput-medusae*) and yellow star-thistle (*Centaurea solstitialis*) (Reiner *et al.*, 2002). The remaining native perennial grasses- purple needlegrass (*Nassella pulchra*) and *Aristida* species- occur in small patches. The results of prescribed fire on the presence and relative abundance of native vs. non-native species, grass vs. forb species, and annual vs. perennial species tend to be mixed (Wills, 2006). Without fire, most grasslands would likely be invaded by woody plant species within a few decades (Keeley, 2005). Vernal pools have been less impacted by invasive species and continue to be characterized by very low fuel loads and limited fire spread (Wills, 2006).

Oak Woodlands. Fire history and pattern in the Lassen Foothills oak woodlands are similar to descriptions above for grasslands. Large blue oaks (*Quercus douglasii*), the dominant oak species, are relatively safe from fire unless accumulated ladder fuels are able to carry fire into their canopies, a situation becoming increasingly common due to fire suppression. Even then, blue oaks will readily re-sprout following top-kill (Horney *et al.*, 2002). Like the grasslands, understory biomass in oak woodlands is often comprised of up to 95% non-native herbaceous plants (Wills, 2006), although understory species composition is not necessarily the same as in adjacent grasslands (Bartolome, 1987).

Fire regimes are thought to have been low-intensity and frequent, although oaks typically leave poor fire scar evidence (Wills, 2006). Stephens et al. (2007) estimated pre-settlement FRI to be between three and eight years- the same as grasslands- mainly due to Native American burning. Like the grasslands and chaparral, oak woodlands likely experienced an increase in fire frequency from the onset of European-American settlement until effective fire suppression. McClaran and Bartolome (1989) report that fire in oak woodlands was much more frequent (mean FRI of 7.4 years) during the hundred year period starting in 1848 than before or after. Stephens (1997) states that ranchers often burned oak woodlands for forage at 8 to 15 year FRIs and also found that, despite low lightning ignition probability, mean FRI in El Dorado County blue oak was 7.8 years (range 2-17 years) between 1850 and 1952. Blue oak regeneration in many locations is insufficient to maintain current stands (Bartolome, 1987). Hypothesized causes include livestock grazing, invasive plant species, firewood cutting, seed predation by wildlife, and fire (Swiecki and Bernhardt, 1998). Blue oak establishment and survival seem to be little affected by fire (Bartolome *et al.*, 2002; Wills, 2006). Fry (2008) found that prescribed fire led to sprouting and damaged few mature trees. Fire-free periods of up to 14 years may be required to allow young blue oaks to grow tall enough to withstand grazing and fire damage that would prevent recruitment into the overstory (Bartolome *et al.*, 2002; Fry, 2008).

Chaparral. Fires in chaparral tend to be stand-replacing and leave no fire scars from which to estimate pre-settlement FRIs. Stephens et al. (2007) estimated pre-settlement chaparral FRI to be between 30 and 70 years. Beginning in the mid-1800s, European-American settlers increased fire frequency in foothill chaparral to extend grazing range (Keeley and Fotheringham, 2003). Chaparral is not prone to regeneration failure via senescence risk, but is quite prone to failure via immaturity risk (Keeley *et al.*, 2005). Today much of California’s chaparral is threatened by fires burning too frequently (Keeley and Fotheringham, 2003). Most of the dominant shrubs in the Lassen Foothills re-sprout following fire (Skinner and Taylor, 2006). There appears to be an FRI threshold of roughly one decade below which non-sprouting chaparral species have difficulty persisting and are replaced by non-native grasses and forbs (Keeley *et al.*, 2005). In addition to the effects of invasive species on fire regimes listed above, the conversion of chaparral to non-native grasses and forbs adds a lower-intensity surface fire component that allows more annual seeds to survive and provides greater horizontal fuel connectivity, thus accelerating the type conversion (Keeley and Fotheringham, 2003).

Project History

The Nature Conservancy has maintained an active prescribed burning and rotational grazing program in the Lassen Foothills since the 1990s to preserve native plant species. This region is fortunate in that it has largely escaped the wildland-urban interface issues of southern and coastal California, although rural growth is expected to exceed urban growth in the future (Bradshaw, 1987). Conservation easements help slow land use conversion to rural development in the Lassen Foothills while facilitating beneficial fire management (Byrd *et al.*, in press). Although the original idea goes back more than 5 years, this project formally started in 2007 with the objective of informing the Tehama County Watershed Assessment and Tehama County Watershed Management Plan as well as providing information to guide fire management. To our knowledge, no study has looked at departure from pre-settlement FRI in the Lassen Foothills. We extend condition class mapping methodology used by federal land management agencies for reporting and planning fuel treatments.

METHODS

Study area

Our study area consists of about 182,000 ha in the far northeastern corner of the Sacramento Valley, mostly in eastern Tehama County (Fig. 1). It is essentially the western half of TNC's 364,000 ha Lassen Foothills Project which encompasses one of California's largest remaining unfragmented and biologically diverse landscapes. TNC and its partners, including the Tehama County Planning Department, are primarily interested in the Lassen Foothills to protect the oak woodlands while preserving the economic viability of its working cattle ranches (Reiner *et al.*, 2002). The study area is comprised of lands managed by Denny Land and Cattle Company, Tehama Wildlife Management Area, Dye Creek Preserve, Lassen National Forest, and other private entities.

Elevations range from < 100 m along the western boundary to > 1500 m along the eastern boundary. The study area lies almost entirely within the Tuscan Flows ecological subsection (Sierra Nevada Foothills section; 94.6% of the area) while the lowest elevations lie within the North Valley Alluvium subsection (Great Valley section; 3.9%) and Tehama Terraces subsection (Northern California Interior Coast Ranges section; 1.5%). Terrain is generally gentle in the northwest and far west but deeply incised by drainages to the east and south. Volcanic buttes are present in the northern portion of the study area.

The climate consists of hot, dry summers and cool, wet winters. The Tuscan Flows and Tehama Terraces subsections average 51-102 cm of precipitation annually, mostly in the form of rain, while the North Valley Alluvium subsection receives 41-61 cm of precipitation annually, almost all of which is rain (Miles and Goudey, 1998). Mean annual temperatures are between 13 and 18 °C.

The Lassen Foothills is an important wildlife corridor from the Lassen Peak area down to the Sacramento Valley. The state's largest migratory deer herd winters in the Foothills because of its abundance of acorns. According to Moyle and Randall (1996), aquatic communities in Antelope, Deer, and Mill Creeks are in "very good to excellent" condition. These creeks and others provide spawning habitat for salmon, steelhead, and sturgeon coming up the Sacramento River from the Pacific. Vernal pools provide habitat for the endangered fairy shrimp (*Branchinecta conservatio* and *B. lynchi*) and tadpole shrimp (*Lepidurus packardii*) while riparian forests support migratory songbirds. More than half of California's 673 terrestrial vertebrate species are dependent on oak woodland habitats which are also home to roughly 150 bird species (Tietje and Vreeland, 1997). Although this area has been largely preserved through public lands and large-scale cattle ranching, development continues to be a threat, as are non-native invasive weeds and altered fire regimes.

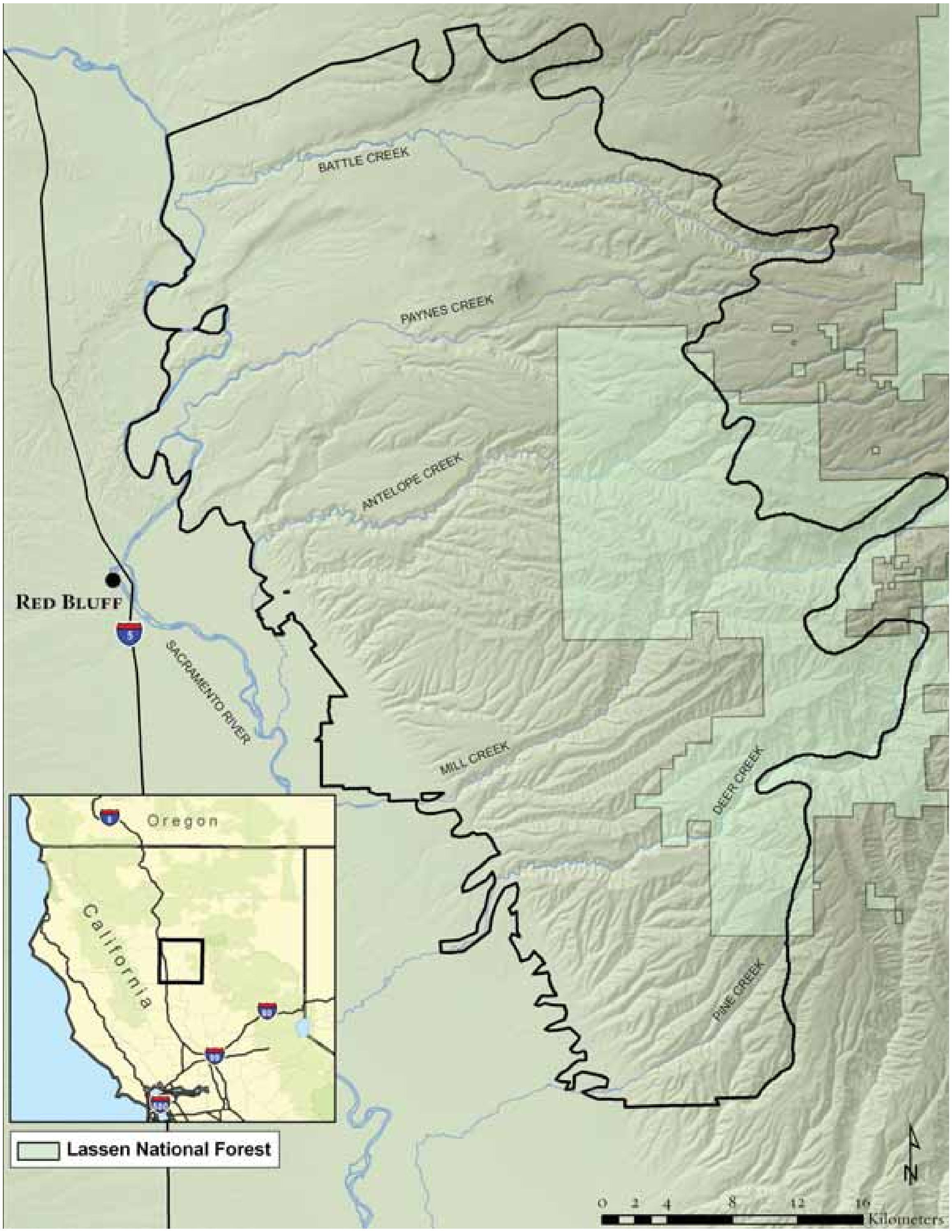

Figure 1. Study area.

Vegetation Mapping

This analysis does not attempt to estimate what vegetation may have been present before European-American settlement. The comparison is strictly based on the pre-settlement and current fire return intervals of the present vegetation. See the separate California Native Plant Society report for vegetation mapping methods and detailed results.

Pre-settlement Fire Return Intervals

We compiled estimates of pre-settlement fire return intervals for the major vegetation types in the Lassen Foothills from the following sources: the LANDFIRE project (Rollins and Frame, 2006), the Manual of California Vegetation 2nd edition, and LANDFIRE-based models developed jointly by the U.S. Forest Service and TNC (see Table 1). We also referred to Stephens *et al.* (2007). These estimates were assigned as attributes to the vegetation map.

In addition to estimates of mean pre-settlement FRIs, we included estimates of minimum and maximum mean FRI to allow for the natural variability inherent in fire regimes and provide rough brackets of condition class. Minimum mean FRI was set to 50% of mean FRI while maximum mean FRI was set to 150% of mean FRI. Because so much of this area experienced extremely frequent fire, we only report results based on the mean and maximum pre-settlement FRIs which represent a more plausible situation for active management today.

Current Fire Return Interval

The California Department of Forestry and Fire Protection's Fire and Resource Assessment Program (FRAP; http://frap.cdf.ca.gov/) maintains a spatial database of fire perimeters for California with assistance from the U.S. Forest Service, Bureau of Land Management, and National Park Service. The database is updated annually to include the most recent fire perimeters as well as older fires that have been newly digitized. Generally fires since 1950 that are greater than about 121 ha (CDF) and 4 ha (U.S. Forest Service) are included, although in many areas records extend significantly farther back (approximately 1910). We took the fire perimeters in this database and calculated a mean FRI for the period 1910-2008 as:

mean FRI = [length of period]/(1+number of times burned)

For example, if a given point on the landscape has burned three times since 1910 its mean FRI is 98/(1+3) = 24.5 years. If the point has not burned, we get 98 which we interpret as "unburned". Where prescribed fire perimeter maps within the study area were available, they are included in our count of times a point has burned.

Condition Class

As originally conceived, "fire regime condition class" (FRCC; www.frcc.gov) referred to departure from pre-settlement fire regimes across a landscape as inferred from observations of species composition and structure (Hann and Bunnell, 2001). This definition of FRCC has been mapped across the U.S. by the LANDFIRE Project which developed and distributes national mapping products including fuels data and FRCC (available at www.landfire.gov). National projects such as LANDFIRE cannot map departure from pre-settlement FRIs because such data are not available for every state. We utilized California's spatial fire history database to map condition class (CC) based on the following FRCC definitions: CC 1 = within historic range of variability (up to 33% departure from pre-settlement conditions), CC 2 = moderate departure (34-66%), and CC 3 = severe departure (> 66%). We added corresponding negative condition classes to indicate where current FRIs are now shorter than before settlement (CC -1 is combined with CC 1). These classes broadly indicate the integrity of fire as an ecological process. We calculate this as a percent:

```
if (current FRI >= pre-settlement FRI)
        departure = (1-(pre-settlement FRI/current FRI))*(100%)
else if (current FRI = unburned and pre-settlement FRI >= period)
        departure = 0%
else
        departure = (1-(current FRI/pre-settlement FRI))*(-100%)
```

For example, if the current FRI has been determined to be approximately 20 years (four fires since 1910) for a given point whose pre-settlement mean FRI was 12 years (e.g., interior live oak), we would calculate the departure as (1-12/20)*100% = 40% = CC 2. If, however, the current FRI is approximately 25 years (three fires) for a point whose pre-settlement mean FRI was 100 years (e.g., juniper), we would have (1-25/100)*(-100%) = -75% = CC –3. Finally, for an area that has not burned in the period of record (current FRI is undefined) and its vegetation has been assigned a mean pre-settlement FRI greater than that period (such as mesic chaparral whose mean pre-settlement FRI is 100 years), we are unable to say if it is burning more or less often than before settlement, and therefore leave it at 0% departure (CC 1).

RESULTS

Vegetation

Approximately 95% of the study area is covered by the broad aggregated vegetation types listed in Table 1 below. The remainder of the landscape is composed of vegetation types which we did not analyze (e.g., irrigated pastures, rock and barren areas, development, and riparian areas). Over 60% of the area is dominated by grasslands or blue oak woodlands while chaparral covers another 16%. The grasslands and blue oak woodlands are interspersed and dominate large continuous areas of the landscape. Chaparral on the other hand (mostly *Arctostaphylos* spp., *Ceanothus cuneatus*, and *Quercus* spp.) tends to be patchier in its distribution and increases in dominance with elevation. Much of the blue oak occurs on rocky volcanic soils that only support sparse vegetation.

Name	% of Area	Mean FRI	Source
7100 - CA Mixed Grassland (Native)	22.9%	4	LANDFIRE
1311 - Quercus douglasii (Blue Oak)	22.4%	12	MCV, LANDFIRE
7101 - Med. CA Naturalized Grasslands	13.2%	4	LANDFIRE
4410 - Quercus wislizeni shrub	6.7%	40	MCV, J. Evens, LANDFIRE
4113 - Ceanothus cuneatus (Buckbrush)	6.5%	*	MCV, LANDFIRE
2211 - Quercus douglasii / Herbaceous (Lassen code)	5.5%	8	MCV, LANDFIRE
7401 - Med. CA Grassland & Forb Meadow Division	5.2%	4	LANDFIRE
1111 - Quercus wislizeni (Interior Live Oak Tree)	4.7%	12	MCV, LANDFIRE
1410 - Quercus chrysolepis (Canyon Live Oak)	2.6%	15	USFS-TNC model
1312 - Quercus kelloggii (Black Oak)	2.5%	7	MCV, LANDFIRE
6111 - Quercus garryana/ var. breweri (Brewer Oak)	1.2%	80	LANDFIRE
1210 - Pinus sabiniana (Foothill Pine)	1.2%	100	H. Safford, MCV, LANDFIRE
6110 - Ceanothus integerrimus (Deerbrush)	0.8%	45	MCV, LANDFIRE, FEIS
4115 - Arctostaphylos manzanita	0.7%	*	MCV, LANDFIRE
4112 - Arctostaphylos viscida (Sticky Whiteleaf Manz.)	0.6%	*	MCV, LANDFIRE
4200 - California Mesic Chaparral	0.5%	**	LANDFIRE
1212 - Juniperus californica (California Juniper)	0.5%	100	MCV/CNPS
4114 - Eriodictyon californicum (Yerba Santa)	0.5%	20	MCV
1313 - Quercus lobata (Valley Oak)	0.4%	10	MCV, blue oak/grassland FRIs
4211 - Cercocarpus montanus (birchleaf mtn mahog)	0.3%	**	LANDFIRE
2200 - California Montane Conifer Forests	0.3%	12	USFS-TNC model
2210 - Pinus ponderosa (Ponderosa Pine)	0.2%	12	USFS-TNC model
1211 - Pinus attenuata (Knobcone Pine)	0.1%	65	H. Safford, MCV
2110 - Pseudotsuga menziesii (Douglas-fir)	0.1%	15	USFS-TNC model
4210 - Quercus berberidifolia (scrub oak)	0.1%	75	MCV, LANDFIRE
1110 - Umbellularia californica (California Bay)	0.1%	30	MCV/CNPS
2212 - Pinus ponderosa - Calocedrus decurrens	0.02%	12	USFS-TNC model
		*45 or 100	100 years where shrub density is low
		**75 or 150	150 years where shrub density is low

Table 1. Vegetation types, the percent of area each covers, and the pre-settlement mean FRI of each. (FEIS = Fire Ecology Information System; www.fs.fed.us/database/feis/)

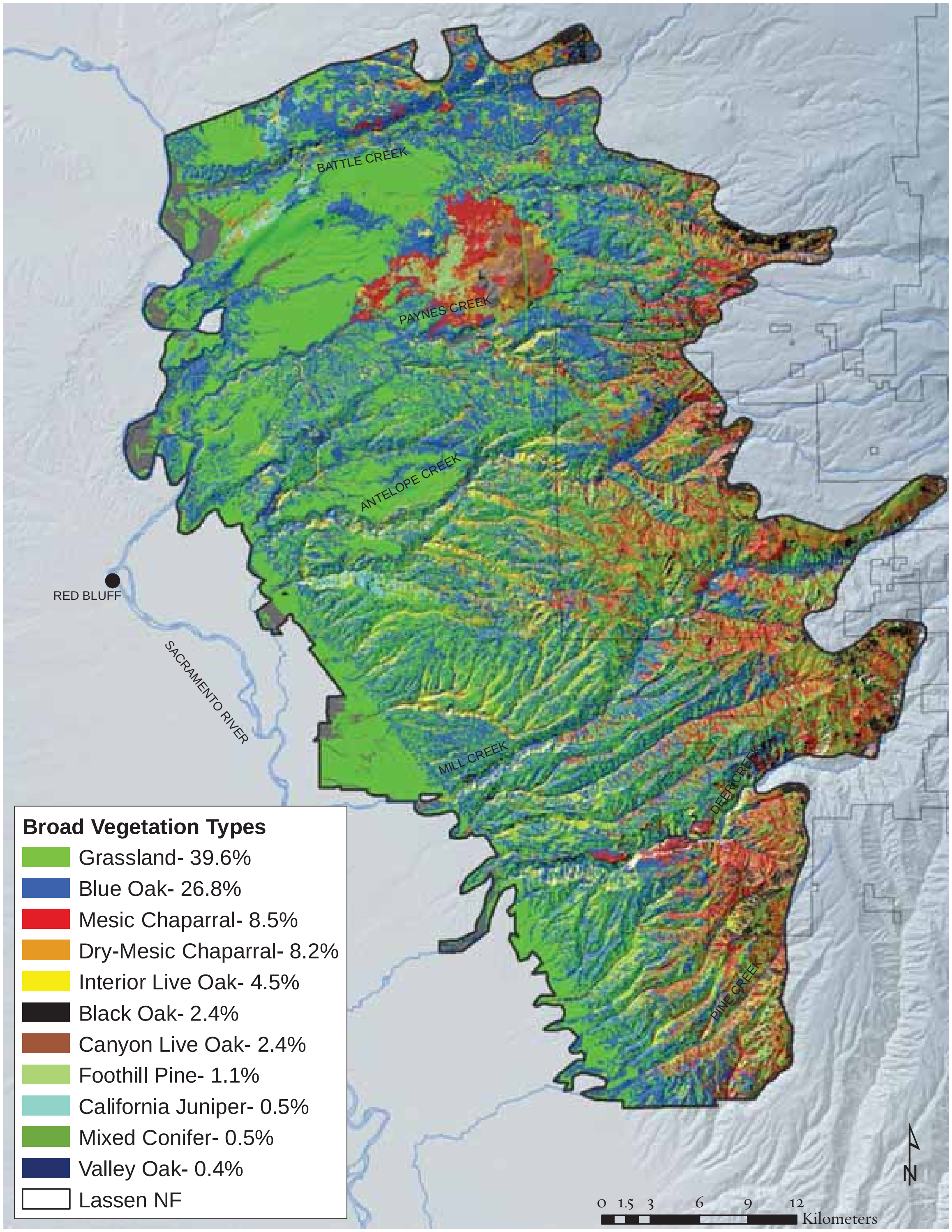

Figure 2. Aggregated vegetation types ordered by decreasing presence in study area.

Mean Pre-settlement Fire Return Interval

Mean pre-settlement FRIs as well as the percent of the area represented by each FRI are listed above in Table 1 and mapped below in Figure 3. Approximately 76% of the landscape historically burned with a fire return interval of 12 or fewer years on average.

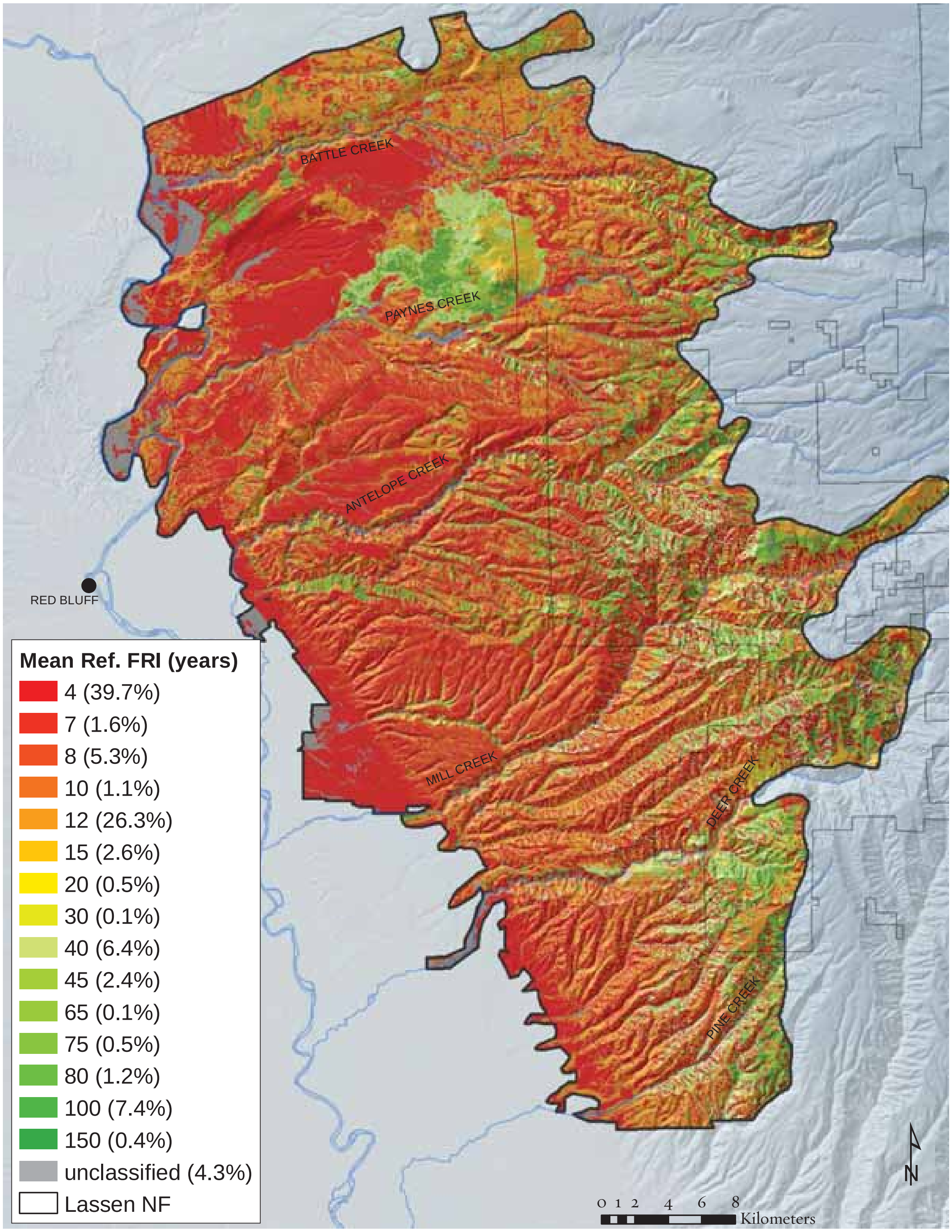

Figure 3. Mean pre-settlement fire return interval listed with percent of area represented.

Maximum Pre-settlement Fire Return Interval

Maximum reference FRI is also included (Fig. 4) to represent the more conservative case of 50% less frequent fires. The color scale is the same as Figure 3. In this case approximately 76% of the landscape historically burned with a fire return interval of 18 or fewer years on average.

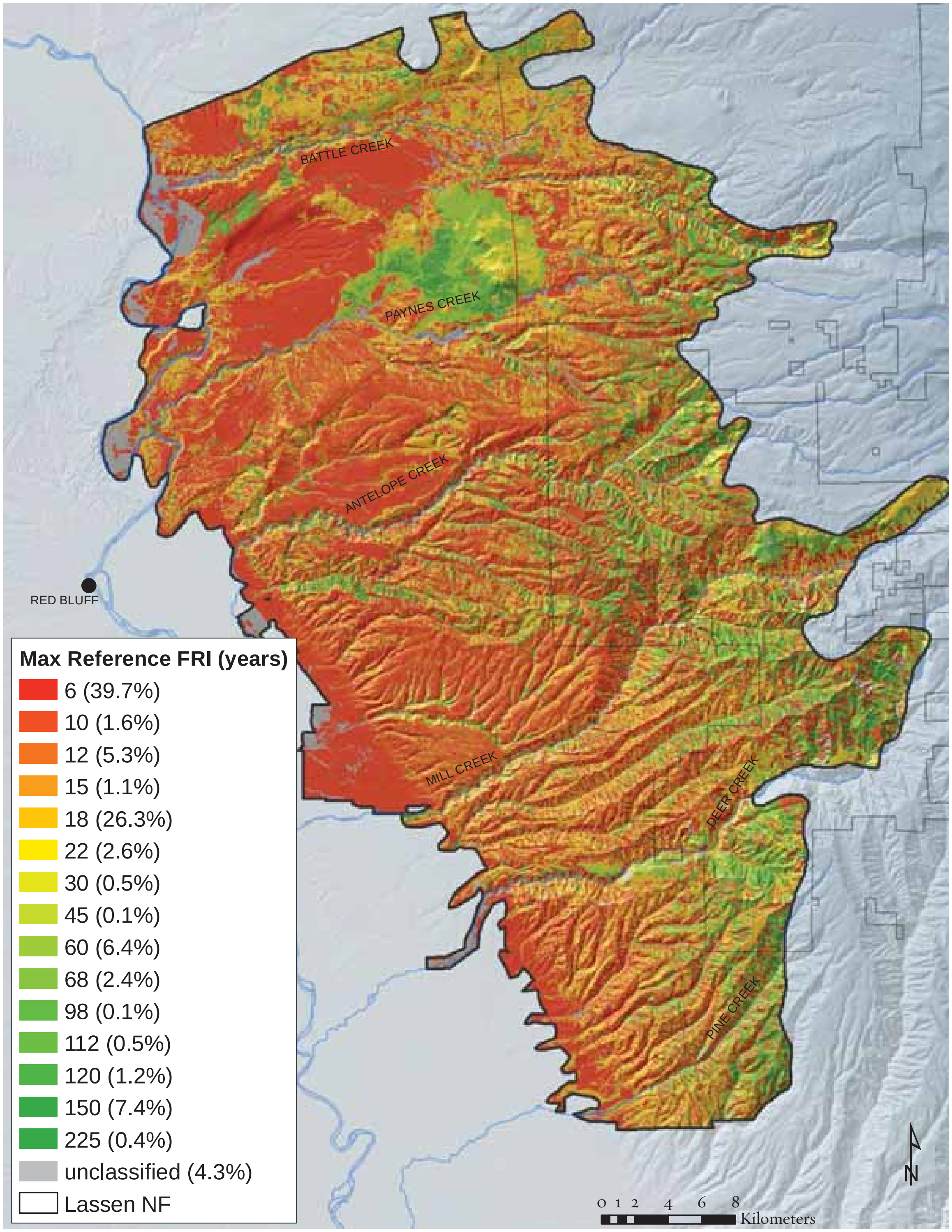

Figure 4. Maximum pre-settlement fire return interval listed with percent of area represented.

Current Fire Return Interval

Current FRI is displayed in Figure 5. A current FRI value of 14 means that particular area has burned 6 times (98/(1+6)), a value of 16 means it has burned 5 times (98/(1+5)) and so forth. The same color scale shown in Figures 3 and 4 is used here to allow direct visual comparison. Table 2 shows the total area burned within the study area for every decade since 1910. Much of the area burned in the 1990s comes from the Gun II Fire. More than a quarter of this landscape has not burned since 1910 and almost a third has only burned once in the same period. Although roughly 2,969 ha of prescribed burning have been accomplished since 1996 (some areas up to three times), changes to current FRI are minimal (Fig. 6). When prescribed fire is included, unburned area dropped from 28.5% to 27.0% of the landscape. Most of the area burned with prescribed fires had not previously burned. What had been burned by wildfires previously was in 1976 or 1980. TNC has also done extensive burning within the Lassen Foothills but outside the bounds of this particular study area.

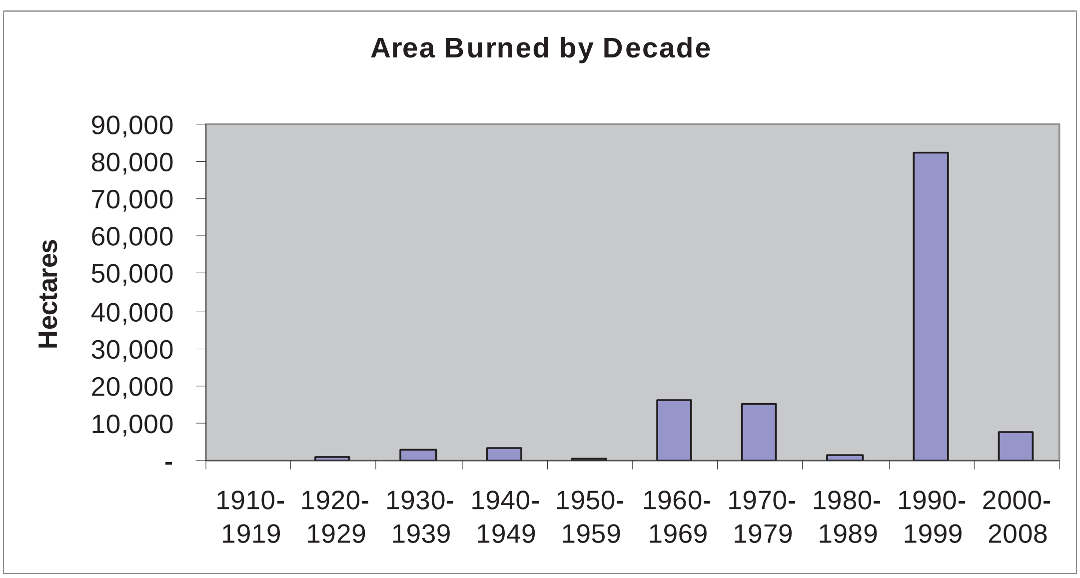

Table 2. Total area burned by decade.

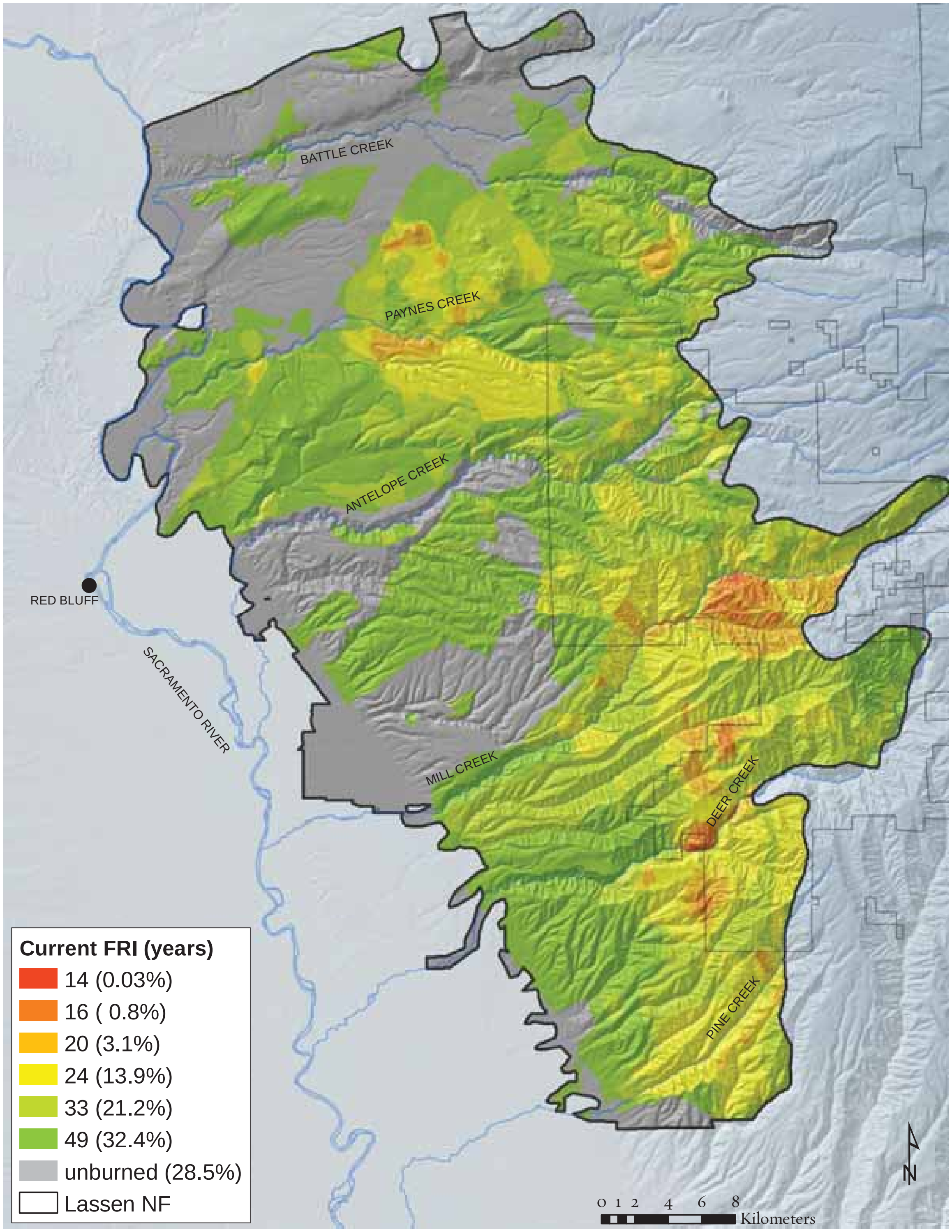

Figure 5. Current mean fire return interval (1910-2008) with percent of landscape represented.

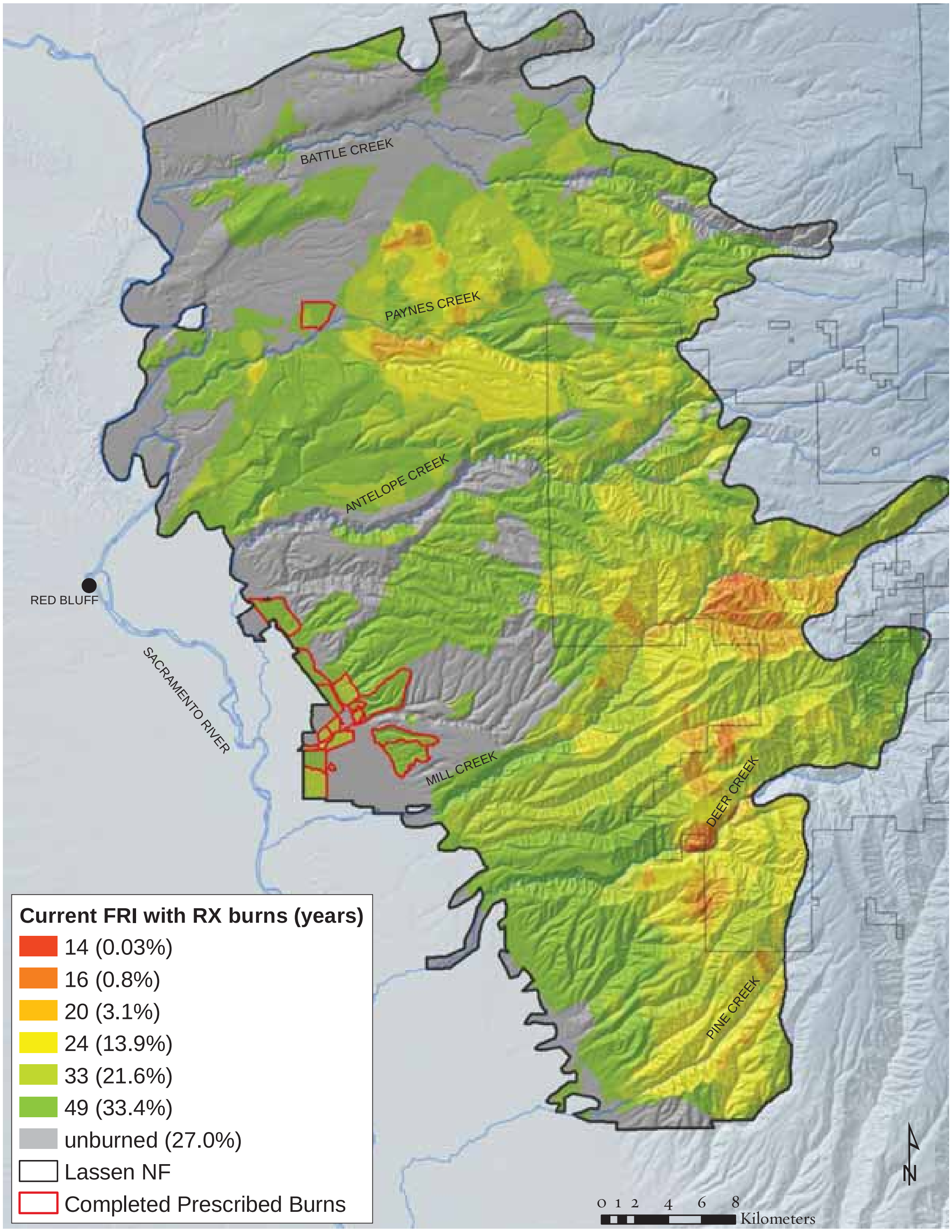

Figure 6. Current mean fire return interval (1910-2008) with percent of landscape represented, including prescribed fire.

Condition Class Maps

Figure 7 shows departure from historic range of variability summarized into condition classes based on mean pre-settlement FRI. The majority of the landscape (77%) has fire interval returns that are more than 66% longer than are predicted in the pre-settlement period. Fire has been essentially lost as an ecological process in these areas. Only 7% of the landscape has fire return intervals that are more or less intact. Areas mapped in blue (about 12% of the landscape) are currently burning more frequently than they did before settlement. These areas are generally chaparral with relatively long FRIs that have been burned 2-3 times by wildfires.

Figure 8 shows departure from pre-settlement maximum FRI. Using this measure results in a slight increase in the area mapped as burning more often than historically, while the area classified as within the range of natural variability also slightly increased to almost 9% of the landscape.

Unfortunately the prescribed burning was not extensive or frequent enough to change condition class.

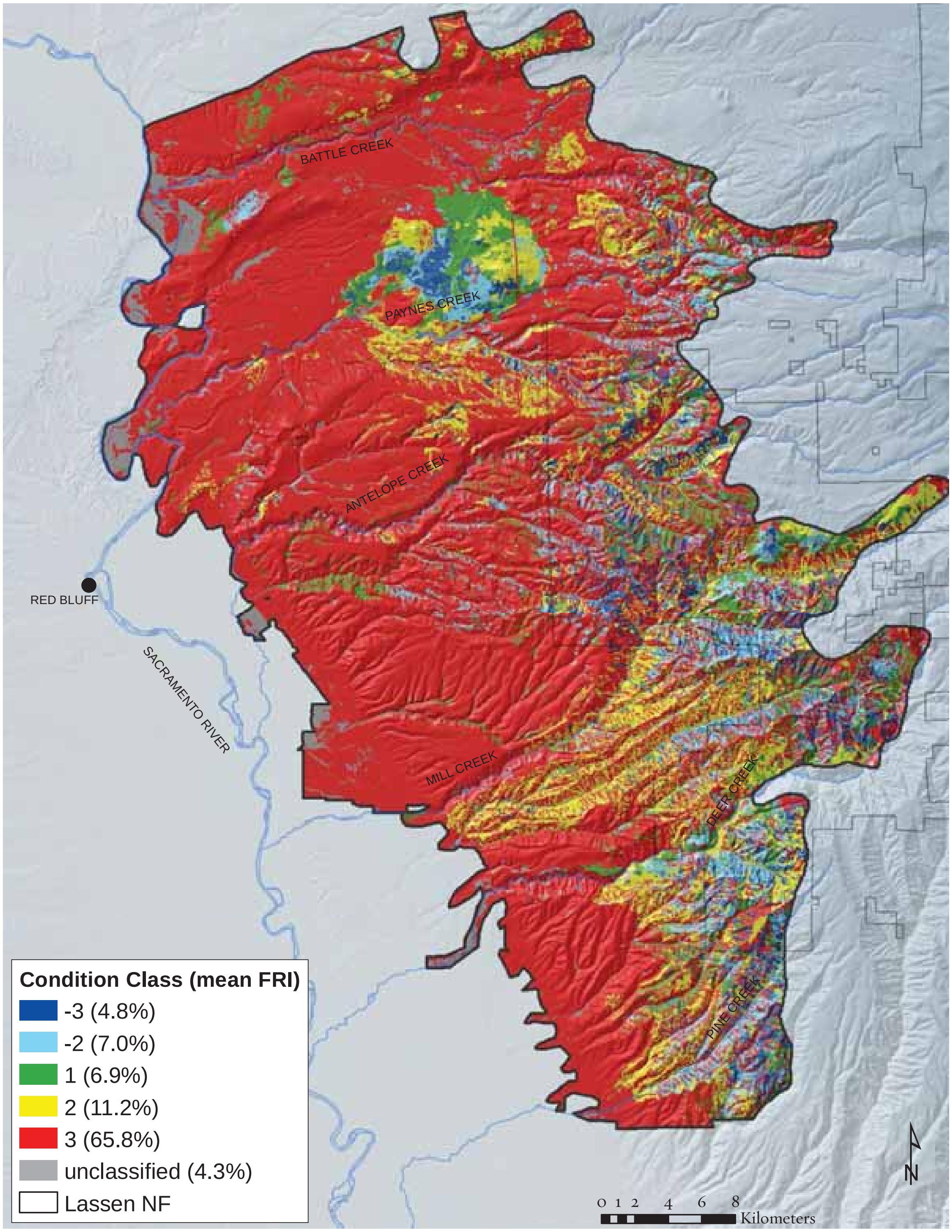

Figure 7. Departure from pre-settlement mean FRI and percent of landscape represented.

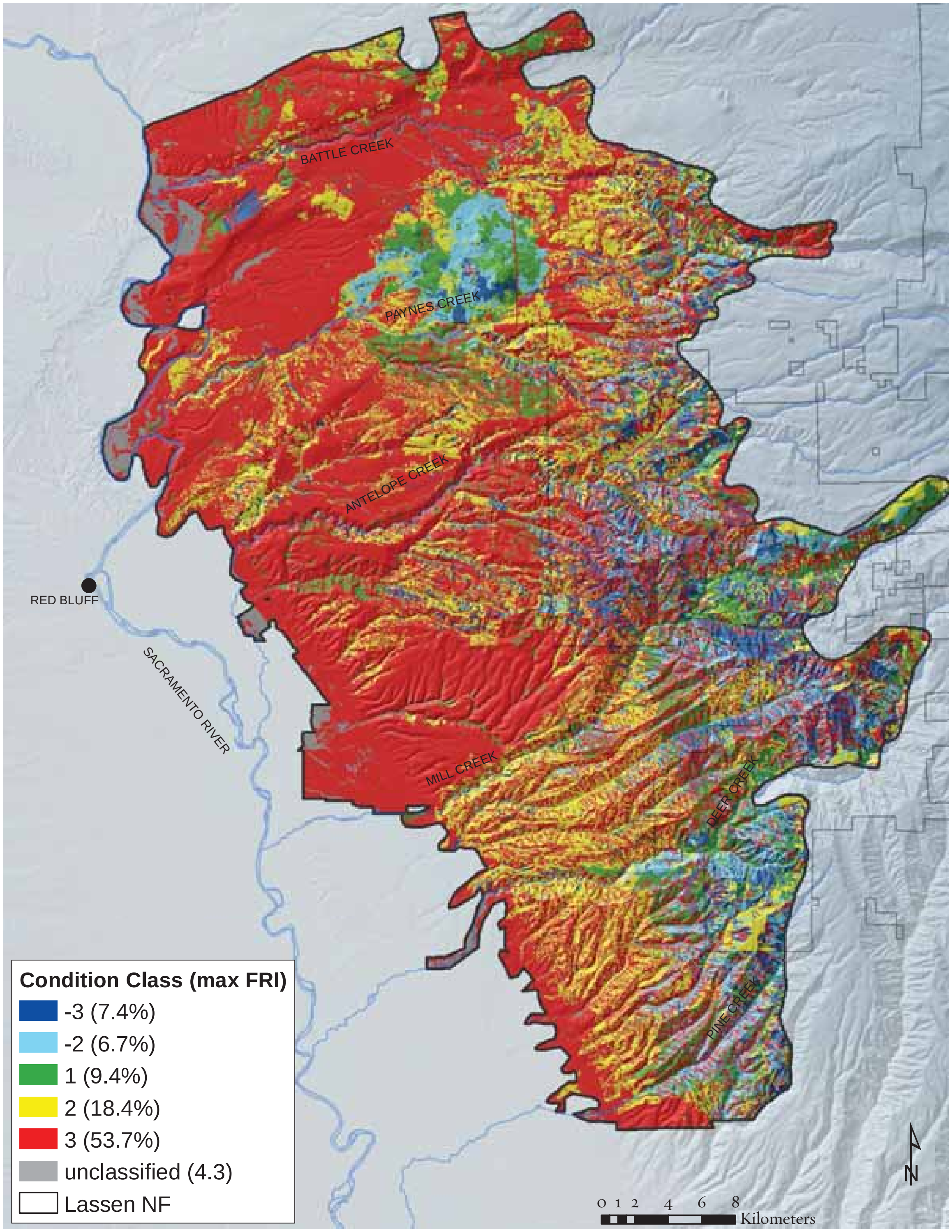

Figure 8. Departure from pre-settlement maximum FRI and percent of landscape represented.

Condition Class by Vegetation Type

I summarized condition class for the four major aggregated vegetation types present within the study area (blue oak woodlands, grasslands, mesic chaparral, and dry-mesic chaparral; Fig. 9). The left side shows condition classes when the mean pre-settlement FRIs are used, while the right side is based on maximum pre-settlement FRIs. In both cases blue oak is moderately to severely departed from pre-settlement fire return intervals, although assuming a more conservative pre-settlement FRI improves the situation slightly. In both mean and maximum cases 100% of the grassland has severely departed FRIs. On the other hand, the majority of the two chaparral types are currently experiencing significantly more frequent fire than in the past. This situation worsens given maximum pre-settlement FRIs.

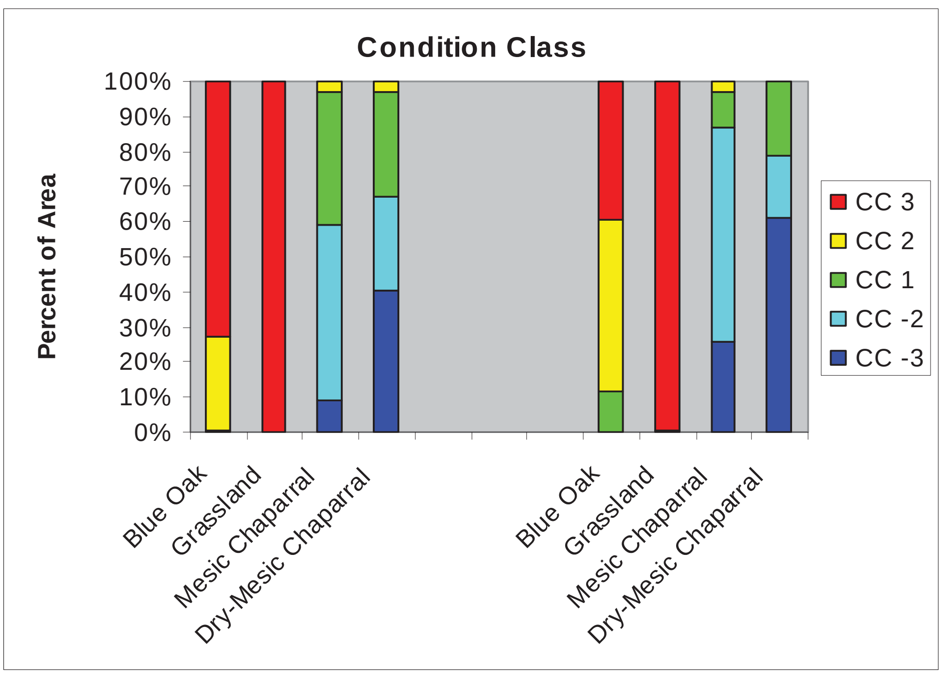

Figure 9. Condition classes for the four dominant vegetation types (mean pre-settlement FRI on the left, maximum pre-settlement FRI on the right).

DISCUSSION

The use of condition class in grasslands is complicated by the lack of reference conditions and the wide-spread presence of non-native species and should be therefore be approached with caution (Reiner, 2007). It is also important to note that pre-settlement FRIs likely varied considerably with topography, which we do not attempt to account for here.

Although we did not attempt to estimate pre-settlement vegetation types, it is likely that annual wildflowers and perennial forbs were common in areas that are now dominated by invasive annual grasses. On the other hand, some of what is now grassland may have been chaparral in the past (Keeley and Fotheringham, 2003).

These results show a dramatic decrease in fire frequency for most of the study area, even with a vigorous prescribed burning program and even when the maximum pre-settlement FRI is assumed. Prescribed burning only changed condition class from CC 3 to CC 2 on a few hectares and did not create enough change to show up in the mapping. The situation is made more complex due to the chaparral areas that are currently burning more frequently than they did before settlement.

Is it possible or even desirable to return to historic FRIs? Native American burning for resource benefit was likely the driver of extremely short FRIs in grasslands and oak woodlands. The Lassen Foothills may be one of the few remaining large landscapes in California where the lack of human development could allow such large-scale prescribed burning today. However, attempting to replicate the extremely high fire frequency that characterized vast areas of the Lassen Foothills is all but impossible due to constraints such as air quality, liability, and logistical issues. A more realistic approach would be to prioritize areas where repeated prescribed burning can be accomplished.

Mediterranean-type landscapes such as the Lassen Foothills have always been dynamic. Fire and other disturbances ensured that the boundaries between grassland, woodland, and chaparral constantly shifted. This dynamism will continue into the future, requiring that management be based on more than our incomplete understanding of the influence of past disturbances in this landscape. Climate change may play an important role by further altering fire regimes. Projections of maximum temperature for the period 2041-2060, based on IPCC4 emissions scenario A1B (medium) and an ensemble of the CSIRO-MK3.0, MIROC3.2, and UKMO-HadCM3 general circulation models, are about 5 ºF warmer than today's climate (Fig. 10; http://climatewizard.org). Annual precipitation, using the same parameters, is expected to decrease by between 2 and more than 3 in (Fig. 11; http://climatewizard.org). A warmer, drier future would also likely result in longer, more frequent, and more severe wildfires. Although in the case of chaparral, climate change predictions are not especially useful as fire regimes are driven by extreme events not currently well-described by the models (Keeley and Fotheringham, 2003). Maintaining the relatively undeveloped nature of the Lassen Foothills may be the biggest priority for the future.

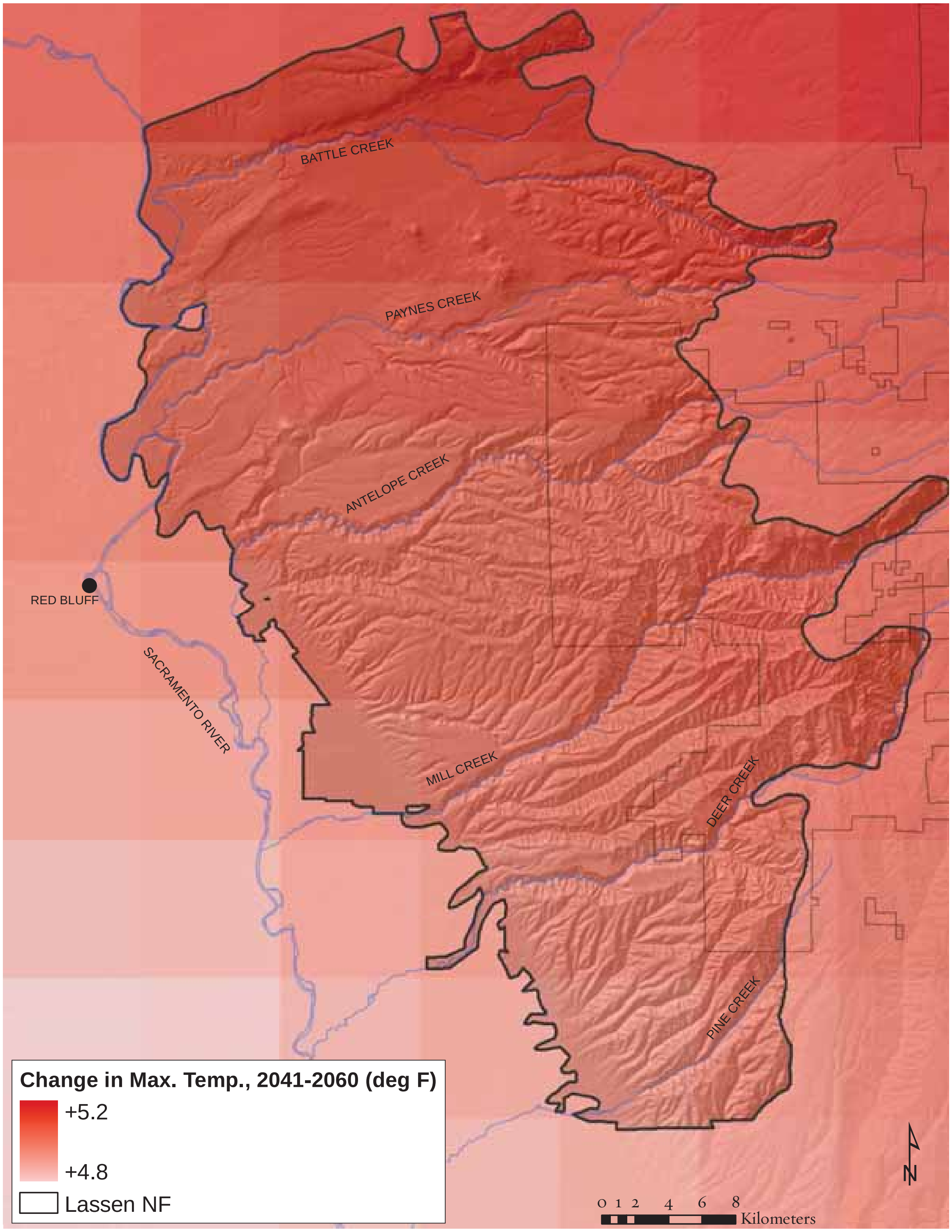

Figure 10. Projected change in annual maximum temperature for the period 2041-2060.

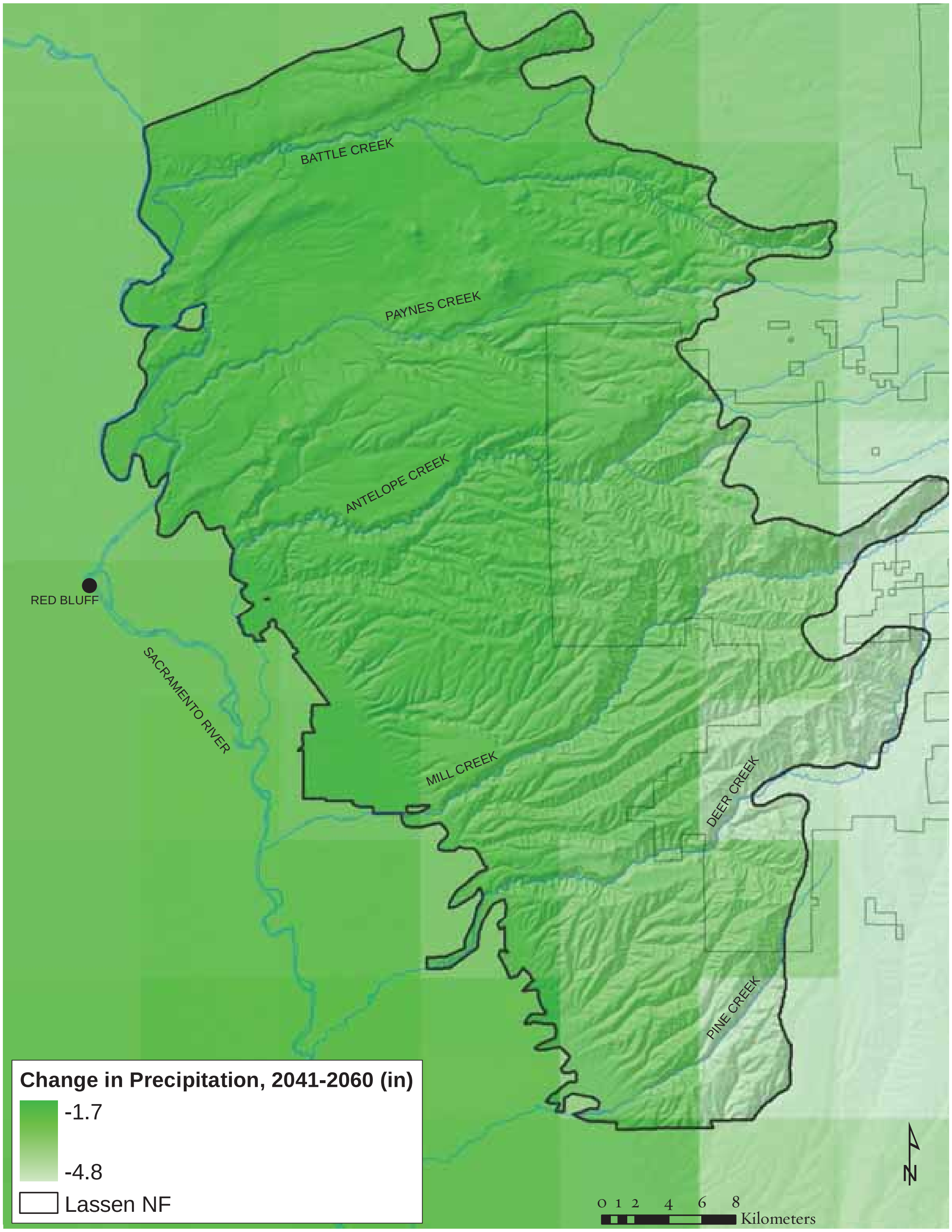

Figure 11. Projected change in annual precipitation for the period 2041-2060.

Recommendations

Grasslands. Late spring (typically June and July) prescribed fire is a common tool for increasing native species richness and cover (Wills, 2006). Several studies have found that non-native annual grasses decreased and forbs (both non-native and native) increased after multiple prescribed fires (Reiner, 2007). Fire in annual grasslands and shrublands tends to decrease woody species while increasing forbs and geophytes (Reiner, 2007). Variation in fire intensity may explain the mixed results of fire on grassland species, such as the tendency of high intensity fires to decrease perennial species abundance (Reiner, 2007).

Varying the season of burn produces species-specific results, although annual grasses generally tend to be reduced by spring-early summer fires (Reiner, 2007). Spring prescribed burning shows a number of benefits: decreased weeds and thatch, increased native grass and forbs, and improved blue oak and shrub regeneration due to decreased competition. On the other hand, burning in summer and fall tends to produce the opposite result (Reiner *et al.*, 2002). Spring and fall burning in the southern Sierra Nevada favored forbs over grass although non-native grasses quickly recovered when burning stopped (Parsons and Stohlgren, 1989). Although the timing of burning can be manipulated to eliminate weeds and increase natives, it may also result in a monoculture of fire-resistant invasive species. The timing and intensity of fire are crucial (Harrison *et al.*, 2003).

Restoring Lassen Foothills grasslands is more complex than reinstating short FRIs or a more natural grazing regime. Surrounding areas dominated by non-native species will continue to provide an outside seed source. Fire regimes within the Lassen Foothills are also dependent in large part on the fire management policies of the surrounding lands.

Oak Woodlands. Issues in the oak woodlands are similar to those of the grasslands. It may be beneficial to prioritize areas for prescribed burning where fuel conditions are such that wildfire intensity would threaten even mature oak stands. More research is necessary to explain the role of fire in blue oak regeneration.

Chaparral. Unlike the grasslands and oak woodlands, most of the chaparral-covered areas of the Lassen Foothills are currently experiencing too much fire. As noted, these shrublands will convert to invasive grass species if FRIs drop below the threshold of roughly one decade. Prescribed burning in chaparral is not recommended and would not reduce invasive species (Keeley and Fotheringham, 2003). A more suitable approach might be to work with managers of surrounding lands such the Lassen National Forest to institute policies to help maintain longer FRIs in the chaparral.

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