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Using Fire Return Interval Departure (FRID) Analysis to Map Spatial and Temporal Changes in Fire Frequency on National Forest Lands in California

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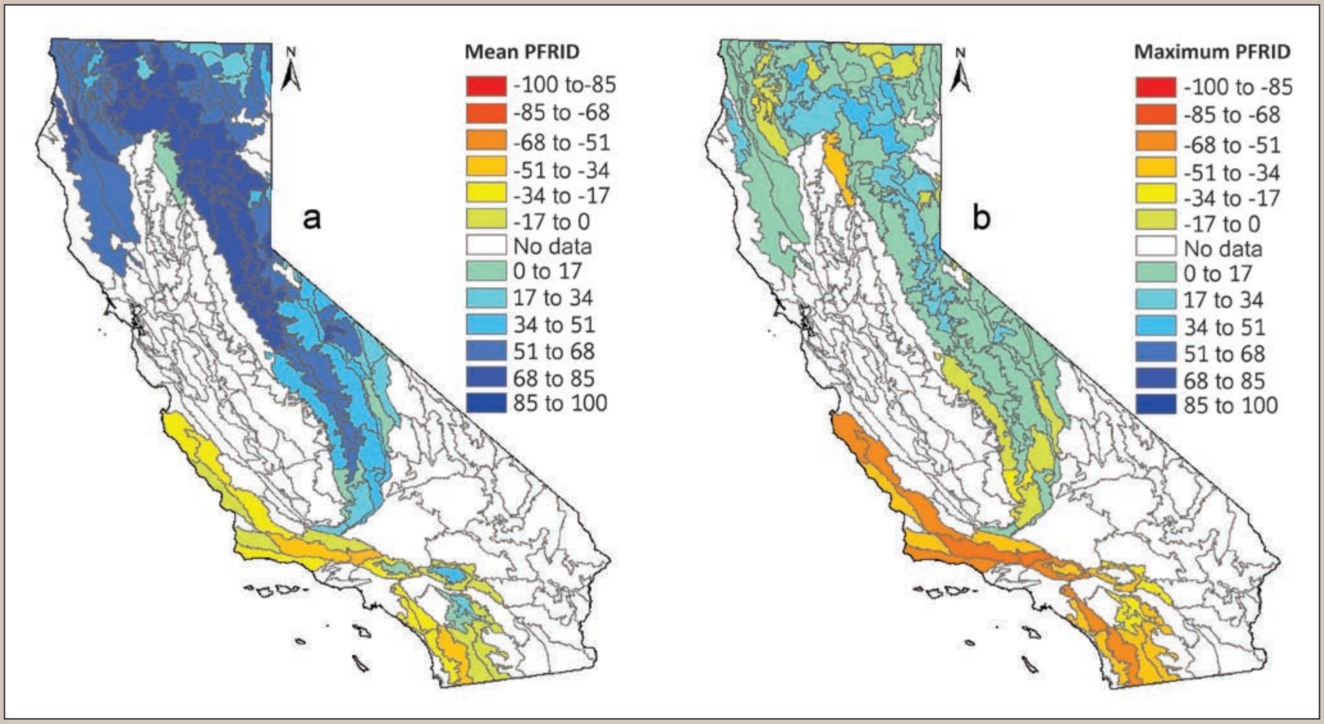

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Summary

In the state of California, fire regimes and related ecosystem processes have been altered by land use practices associated with Euro-American settlement, and climate warming is exacerbating the magnitude and effects of these changes. Because of changing environmental baselines, restoration of narrowly defined historical conditions may no longer be an attainable or sustainable long-term management goal, but comparisons between historical and current fire regimes can assist managers in prioritizing areas for ecological restoration and other management actions. Fire return interval departure (FRID) analysis quantifies the difference between current and presettlement fire frequencies, allowing managers to target areas at high risk of threshold-type responses owing to altered fire regimes and interactions with other factors. We assessed FRID variability along geographic, climatic, and vegetation gradients in California on lands managed by the U.S. Department of Agriculture Forest Service and three forest-dominated national parks, using two types of FRID metrics: percent FRID, and the NPS-FRID index. Percent FRID (PFRID) quantifies the extent in percentage to which contemporary fires (i.e., since 1908) are burning at frequencies similar to those that occurred prior to Euro-American settlement. The NPS-FRID index represents the number of intervals missed since the last fire relative to the central tendency of presettlement fire return interval (FRI) distributions. Much of northwestern (NW) California and the Sierra Nevada sensu lato (including the southern Cascades, Modoc Plateau, and White and Inyo Mountains) has missed multiple fire cycles owing to fire suppression, while southern California is characterized by large areas burning at higher frequencies than under presettlement conditions. Ecologically speaking, fire suppression is a management necessity in much of southern California, but it is a major contributor to the growing forest fuels problem in NW California and the Sierra Nevada region. The PFRID exhibited a unimodal (hump-shaped) relationship to elevation in all three regions. The PFRID showed little relationship to precipitation in NW California or the Sierra Nevada region, but it decreased with precipitation in southern California. PFRID trends with temperature were unimodal, reaching a maximum at temperatures that approximate the elevation of the mean freezing line in winter storms, which is also the transition between moist mixed conifer and red fir in most of northern California. Low- and middle-elevation vegetation types supported the greatest departures from presettlement fire frequencies, with oak woodlands, yellow pine, and mixed-conifer forests missing the most fire cycles, and coastal fir, coastal sage scrub, and chaparral tending to experience shorter FRIs than under presettlement conditions. We provide examples of how FRID data may be used in resource management in an age of global change. Our results help refine our understanding of departures from presettlement fire regimes across California, and provide a spatial basis for resource management and planning focused on ecological restoration and adaptation to climate change in a fire-prone region.

Abstract

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In California, fire regimes and related ecosystem processes have been altered by land use practices associated with Euro-American settlement, and climate warming is exacerbating the magnitude and effects of these changes. Because of changing environmental baselines, restoration of narrowly defined historical conditions may no longer be an attainable or sustainable long-term management goal, but comparisons between historical and current fire regimes can assist managers in prioritizing areas for ecological restoration and other management actions. Fire return interval departure (FRID) analysis quantifies the difference between current and presettlement fire frequencies. We assessed FRID variability along geographic, climatic, and vegetation gradients in California on lands managed by the U.S. Department of Agriculture Forest Service and three forest-dominated national parks, using two types of FRID metrics: percent FRID (PFRID), and the NPS-FRID index. Much of northern California north of the Tehachapi Mountains has missed multiple fire cycles owing to fire suppression, while southern California is characterized by large areas burning at higher frequencies than under presettlement conditions. PFRID exhibited a unimodal (hump-shaped) relationship to elevation across our study area. PFRID showed little relationship to precipitation in northwest California or the Sierra Nevada region, but it decreased with precipitation in southern California. PFRID trends with temperature were unimodal, reaching a maximum at temperatures that approximate the elevation of the mean freezing line in winter storms, which also marks the transition between moist mixed conifer and red fir in most of northern California. Low- and middle-elevation vegetation types supported the greatest departures from presettlement fire frequencies, with oak woodlands, yellow pine, and mixed-conifer forests missing the most fire cycles, and coastal fir, coastal sage scrub, and chaparral tending to experience shorter FRIs than under presettlement conditions. Our results help refine our understanding of departures from presettlement fire regimes across California, and provide a spatial basis for resource management and planning focused on ecological restoration and adaptation to climate change in a fire-prone region.

Keywords: Ecological restoration, fire history, presettlement fire regime, Sierra Nevada, time since last fire.

Contents

Introduction

Fire is a keystone ecological process in most of the world's Mediterranean-climate regions (Keeley et al. 2011). In the state of California, which comprises most of the North American Mediterranean-climate region, fire regimes (including fire frequency, severity, extent, spatial patterning, etc.) and related ecosystem processes have been profoundly altered by land use practices associated with Euro-American settlement, especially since American settlement began in earnest after 1849. These changes have in turn led to major modifications in vegetation distribution, structure, and composition (Agee 1993, Barbour et al. 2007, Skinner and Chang 1996, Sugihara et al. 2006). Climate variability at different temporal scales has also been shown to be associated with past, current, and projected changes in fire regimes, vegetation, and other ecosystem properties across California (Lenihan et al. 2003; Miller et al. 2009, 2012; National Research Council 2011; Swetnam 1993; Westerling et al. 2006, 2011). In a drought- and fire-prone region like California, ecological restoration efforts intended to increase ecosystem resilience to global change should consider fire and climate as central organizing principles (Keeley et al. 2011, North et al. 2009).

Practices of ecological restoration traditionally depend on the characterization of reference conditions, which can provide management targets and a means to measure management success (Egan and Howell 2001). Because modern human alteration of many ecosystems has been so profound, reference states must often be derived from historical information from before the onset of anthropogenic change. Maintaining managed ecosystems within the bounds of the "historical range of variation" (HRV) for key ecosystem patterns or processes has traditionally been seen as the best hope for preserving species and landscapes and ensuring long-term ecological sustainability (Egan and Howell 2001, Landres et al. 1999). Our trust in history as a dependable guide to the future has been tempered, however, by the revelation that many key ecosystem processes are not stationary, and that historical environmental baselines may or may not represent conditions that are particularly germane to either contemporary or future circumstances (Millar et al. 2007, Safford et al. 2012, Stephenson et al. 2010). At the same time, there is widespread recognition that the real problem lies not in history itself, which provides our only window into ecological processes operating at longer temporal scales, but rather in how historical information is applied to resource management (Stephenson et al. 2010, Wiens et al. 2012).

Because of the uncertainty surrounding future effects of climate and land use change on ecological processes such as fire, myopic focus on restoration of narrowly defined and static snapshots of historical conditions is probably not a sustainable management option in most California ecosystems (Millar et al. 2007, Safford et al. 2012). Nevertheless, information on fire regimes and ecosystem response to fire before Euro-American settlement is of elementary importance to current and future resource management (Fulé 2008, Millar et al. 2007, North et al. 2009, Van de Water and Safford 2011, Wiens et al. 2012). Such historical information can provide a foundation for understanding status of and trends in fire activity and its ecological effects over time; improve our understanding of the mechanisms that drive ecosystem response to climate and fire, their variability and their interactions with the landscape; furnish data upon which models of "properly functioning" or "resilient" ecosystems might be built; and determine to what extent current conditions may be historically anomalous and worthy of management intervention (Safford et al. 2012, Wiens et al. 2012).

The most commonly used fire regime attribute in reconstructions of historical fire regimes is fire frequency (Agee 1993, Johnson and Gutsell 1994). Disturbance frequency is a major driver of ecological and evolutionary response (Connell 1978, Huston 1994, Pickett and White 1985), and although frequency is only one component of the fire regime, the dependence of fire occurrence and behavior on the growth of vegetation produces a broadly inverse relationship between fire frequency and intensity (within a given ecosystem type, and assuming a constant climate) (Huston 2003, Turner et al. 1989). This relationship has permitted the development of simplistic but useful frequency-based and severity-based (a measure of the effect of fire intensity on the ecosystem) fire regime classifications that underlie mapping and management of wildland fire and fuels in the United States (e.g., Hardy et al. 1998, Heinselman 1978, Kilgore 1981). Within ecosystem types, this relationship also allows some (cautious) inference to be made about the effects of changing fire frequency on other fire regime attributes.

Drawing comparisons between past and current fire frequencies can assist resource managers in prioritizing areas for ecological restoration, fuels reduction, certain fire or habitat management practices, and other activities. Fire return interval departure (FRID) analysis is a method for quantifying the difference between current and presettlement fire frequencies on a management landscape (Caprio et al. 1997, Caprio and Graber 2000, van Wagtendonk et al. 2002). By comparing current fire return intervals (FRIs) with the range of reported pre-Euro-American settlement FRIs from the literature, a sort of rudimentary HRV analysis can be conducted. In such an analysis, quantified current departures from the reference conditions provide a basis to identify areas on the management landscape that are at high risk of type conversion or threshold-type responses owing to either greatly accelerated or greatly decelerated fire frequencies; areas that are within HRV can also be identified and targeted for maintenance management or study.

Several FRID assessments have been conducted in California, focused on individual national parks in the Sierra Nevada (Caprio et al. 1997, Caprio and Graber 2000, van Wagtendonk et al. 2002). These studies are enlightening, but they are of limited use in regional-scale restoration planning applications. In addition, the national park FRID analyses have been focused only on the time since the most recent fire, rather than on the complete record of fire location and size that has been collected since the early 20th century. Restoration of fire as an ecological process, and restoration of other ecosystem properties dependent on fire, will require more than a single application of prescribed fire or the occurrence of a single wildland fire. We therefore developed a complementary set of different FRID measures based on spatial fire records from throughout the last century. These percentage-based measures are less sensitive to the incidence of a single fire, and are more suitable to comparisons of fire frequencies over time between the current and pre-Euro-American settlement periods.

In this study, we determined time since last fire (TSLF) and calculated two sets of FRID measures (percent-based and National Park Service [NPS] calculations) for the approximately 8.1 million ha of land managed by the U.S. Forest Service in California. Except in some wilderness areas, most fires on Forest Service lands in California are subject to fire-suppression efforts, although indirect attack techniques can allow for significant fire spread under some circumstances. For comparison, we also include analyses of three of the largest national parks in California (Sequoia, Kings Canyon, and Yosemite national parks (NPs), 1.6 million ha in total), which encompass large areas where naturally ignited fires are allowed to burn under certain conditions for ecological benefit (van Wagtendonk 2007). In our analysis, we divided the state into three large geographic regions, which exhibit notable differences in climate, geography, and human land use that we expected to affect FRID: northwestern (NW) California; the Sierra Nevada, southern Cascades, Modoc Plateau, and White and Inyo Mountains (the combination of which we refer to as the "Sierra Nevada"); and southern California. Our focus was on identifying and interpreting major patterns in FRID across gradients of geography, climate, vegetation, and management, so as to provide a basis for broad-scale decisionmaking in resource management and planning on Forest Service and neighboring lands across California.

Methods

Study Area

The analysis area for this study, which consisted of the 19 national forests (NFs) and three NPs in California, was divided into three geographic regions: (1) NW

California (Klamath, Mendocino, Shasta-Trinity, and Six Rivers NFs); (2) the Sierra Nevada, including the southern Cascades, Modoc Plateau, and White and Inyo Mountains (El Dorado, Humboldt-Toiyabe [California portion only], Inyo, Lassen, Modoc, Plumas, Sequoia, Sierra, Tahoe, and Stanislaus NFs); the Lake Tahoe Basin Management Unit; and Yosemite, Sequoia, and Kings Canyon NPs; and (3) Southern California (Angeles, Cleveland, Los Padres, and San Bernardino NFs) (fig. 1). Most of California and almost all Forest Service lands in the state (except the eastern Inyo and Modoc NFs) are found in the Mediterranean-climate zone. In this paper, we refer collectively to the NW California and Sierra Nevada regions as “northern California.” In northern California, winters are cool and wet, and summers are warm and dry. In most of southern California, winters are cool but not as wet (except for the northern and central maritime portions of ecological section 261A (Miles and Goudey 1997) (fig. 1), and summers are warmer and drier than in the north. See Major (1988) and Minnich (2007) for information on temperature and precipitation in each region. Elevations in the NW California region range from near sea level to 4320 m; in the Sierra Nevada region, elevations range from 50 to

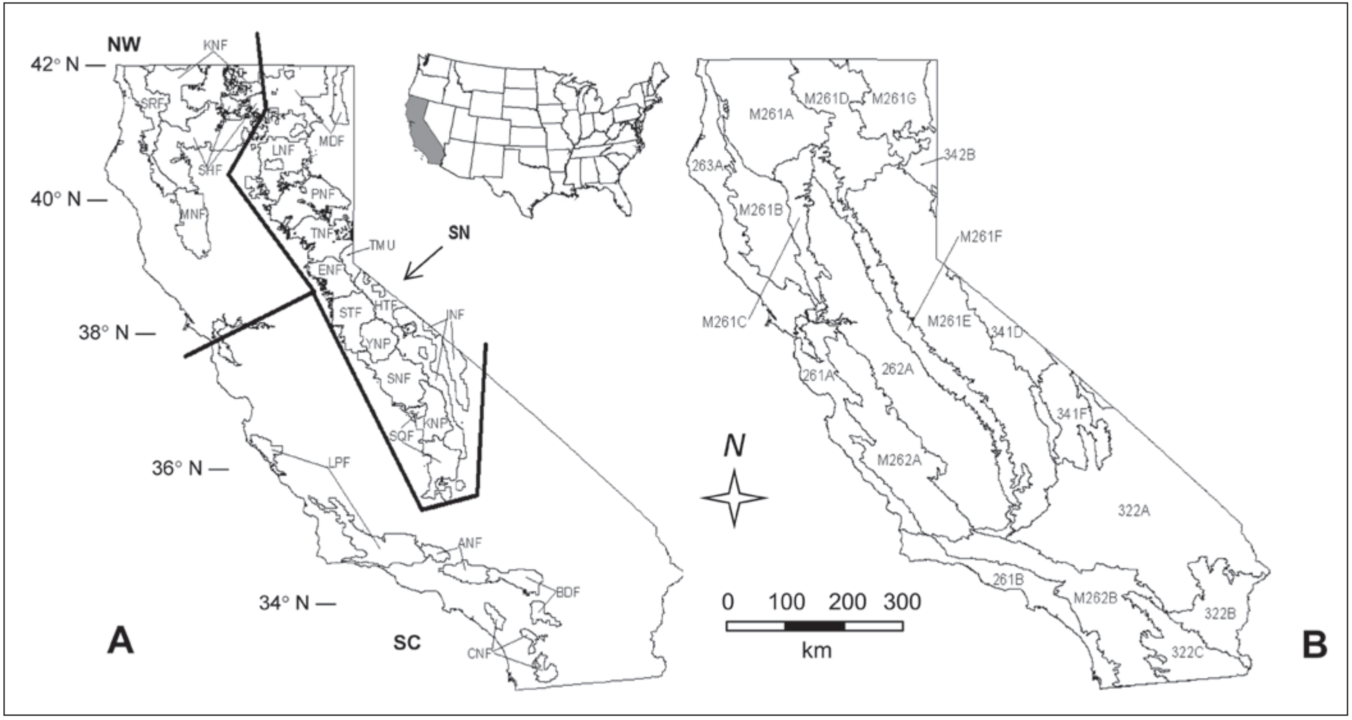

Figure 1—The study area. (A) Federal land management units included in the study area, segregated by geographic region (see text): NW = northwest California region; SN = Sierra Nevada region; SC = southern California region. National forests, clockwise from NW to SC: MNF = Mendocino, SRF = Six Rivers, SHF = Shasta-Trinity, KNF = Klamath; MDF = Modoc, LNF = Lassen, PNF = Plumas, TNF = Tahoe, TMU = Lake Tahoe Basin Management Unit, ENF = Eldorado, STF = Stanislaus, HTF = Humboldt-Toiyabe, SNF = Sierra, INF = Inyo, SQF = Sequoia; BDF = San Bernardino, CNF = Cleveland, ANF = Angeles, LPF = Los Padres. National Parks, in the Sierra Nevada: YNP = Yosemite, KNP = Sequoia-Kings Canyon. (B) Ecological sections in California, from Miles and Goudey (1997), and defined in table 2 on p. 12.

4420 m; in the southern California region, elevations range from near sea level to 3500 m. Vegetation in the analysis area in northern California is dominated by conifer forest, with substantial hardwood presence in lower and middle elevation areas with sufficient precipitation. Vegetation in the analysis area in southern California is dominated by hardwood forests/woodlands and shrublands (Barbour et al. 2007) with conifer forests of relatively small areal extent at high elevations.

Fire Regime Typing

Current existing vegetation types within the analysis area (as identified by the Forest Service's CALVEG classification) (Franklin et al. 2000; see http://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192) were organized into 28 presettlement fire regime (PFR) groups according to the similarity of their historical relationships with fire (Van de Water and Safford 2011). The PFRs were developed only for vegetation types dominated by woody plants, as our understanding of historical fire regimes in herbaceous vegetation is poor. For each PFR, we conducted an exhaustive review of the published and unpublished literature pertaining to mean, median, minimum, and maximum FRIs that occurred prior to significant Euro-American settlement (i.e., the middle of the 19th century), and the average was taken of all mean, median, minimum, and maximum FRI values to yield a single mean, median, mean minimum, and mean maximum FRI estimate for each PFR (Van de Water and Safford 2011) (table 1). Most of the data used came from composite dendrochronological fire histories including records from multiple trees in a defined area. Our reference period is thus primarily the c. 200 to 500 years before 1850, although some of the records we accessed go back over 2000 years (Van de Water and Safford 2011).

Polygons were created for each area dominated by a given PFR and its associated presettlement mean, median, minimum, and maximum FRIs using ArcGIS 9.3[1] (ESRI 2008). The mapping base was the Forest Service existing vegetation (EVEG) geodatabase (available at http://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327836), which uses the CALVEG classification. We chose to use existing-vegetation polygons instead of potential natural vegetation (PNV) types because Forest Service PNV mapping was never completed in California and completed PNV mapping (mostly) disregarded disturbances like fire. The LANDFIRE Biophysical Settings (BpS) data are PNV types that incorporate disturbance (Rollins 2009), but the mapped accuracy of this modeled data layer varies across

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[1] Use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 1—Mean, mean minimum (min) and mean maximum (max) pre-Euro-American settlement fire return intervals (FRIs) for the presettlement fire regime (PFR) groups, and the current FRIs associated with the boundaries between condition classes (CCs)

PFR	Mean min FRI	CCs-2 and-3	CCs-1 and-2	Mean FRI	CCs 1 and 2	CCs 2 and 3	Mean max FRI
	Years						
Aspen	10	6.3	12.7	19	28.4	57.6	90
Big sagebrush	15	11.6	23.5	35	52.2	106.1	85
Bigcone Douglas-fir	5	10.2	20.8	31	46.3	93.9	95
Black and low sagebrush	35	21.8	44.2	66	98.5	200.0	115
California juniper	5	27.4	55.6	83	123.9	251.5	335
Chaparral and serotinous conifers	30	18.2	36.9	55	82.1	166.7	90
Coastal fir	90	32.7	66.3	99	147.8	300.0	435
Coastal sage scrub	20	25.1	50.9	76	113.4	230.3	120
Curl-leaf mountain mahogany	30	17.2	34.8	52	77.6	157.6	130
Desert mixed shrub	120	201.3	408.7	610	910.4	1,848.5	1,440
Dry mixed conifer	5	3.6	7.4	11	16.4	33.3	50
Fire-sensitive spruce or fir	90	38.6	78.4	117	174.6	354.5	250
Lodgepole pine	15	12.2	24.8	37	55.2	112.1	290
Mixed evergreen	15	9.6	19.4	29	43.3	87.9	80
Moist mixed conifer	5	5.3	10.7	16	23.9	48.5	80
Montane chaparral	15	8.9	18.1	27	40.3	81.8	50
Oak woodland	5	4.0	8.0	12	17.9	36.4	45
Pinyon-juniper	50	49.8	101.2	151	225.4	457.6	250
Port Orford cedar	10	9.9	20.1	30	44.8	90.9	160
Red fir	15	13.2	26.8	40	59.7	121.2	130
Redwood	10	7.6	15.4	23	34.3	69.7	170
Semidesert chaparral	50	21.5	43.6	65	97.0	197.0	115
Shore pine	190	82.5	167.5	250	373.1	757.6	1,025
Silver sagebrush	15	11.6	23.5	35	52.2	106.1	65
Spruce-hemlock	180	90.8	184.3	275	410.4	833.3	550
Subalpine forest	100	43.9	89.1	133	198.5	403.0	420
Western white pine	15	16.5	33.5	50	74.6	151.5	370
Yellow pine	5	3.6	7.4	11	16.4	33.3	40

Note: Mean, mean minimum, and mean maximum FRIs are from Van de Water and Safford (2011).

Forest Service lands in California. We believe the BpS maps are of reasonable accuracy at the regional (e.g., NW California, Sierra Nevada, southern California) or statewide scale, especially when similar vegetation types are pooled (see, e.g., Miller and Safford 2012), but our FRID geodatabase is intended to support planning and management at all spatial scales. Local inaccuracies in the BpS maps make use at or below the scale of a national forest or national park unit challenging. Note that our use of an existing-vegetation map from the 2000s as our base layer means that major changes in vegetation that have occurred since Euro-American settlement will affect the accuracy of our results. We elaborate on this issue in the "Discussion" section.

We carried out a union between the PFR geodatabase and CalFire's Fire Perimeters database (FRAP 2011), which tracks California fire history. The Fire Perimeters database is considered more or less complete for fires larger than 40 ha after 1908, and over 4 ha after 1950 (Miller et al. 2009); many smaller fires are also reported. The resulting geodatabase split the PFR polygons into smaller polygons based on the number of fires that had occurred in each PFR polygon since 1908.

FRID Mapping

Time since last fire was calculated by subtracting the year of the last fire in each polygon from 2010 (the most recent year included in the Fire Perimeters database when we conducted our analysis). Any polygon that had not had a fire since prior to 1908 was assigned a default TSLF value of 103 years; in many cases, TSLF will thus be a conservative measure of the time since last burn. Current FRI was calculated by dividing the number of years in the fire record (i.e., 2010–1908 = 103 years inclusive) by the number of fires occurring in each polygon (according to the Fire Perimeters database) plus one (current FRI = 103/number of times burned + 1). This calculation of current FRI is generally conservative because small fires (<40 ha prior to 1950, <4 ha after 1950) are not included in the Fire Perimeters database (FRAP 2011), prescribed fires are rarely included, and some parts of California have poor fire records for the period before World War II.

Five FRID metrics were calculated for each polygon. Four of them—mean, median, mininum, and maximum percent FRID (PFRID)—were calculated using the following equation when current FRI is longer than presettlement FRI (Hann and Strohm 2003):

PFRID = [1 – (presettlement FRI/purrent FRI)] × 100,

or, when current FRI is shorter than presettlement FRI:

PFRID = – [1 – (current FRI/presettlement FRI)] × 100

where presettlement mean, median, mean minimum, and mean maximum FRI are each substituted for their respective PFRID metrics. These PFRID metrics quantify the extent in percent to which contemporary fires (i.e., since 1908) are burning at frequencies similar to the frequencies that occurred prior to Euro-American settlement. To use an example: assuming a presettlement mean FRI of 10 years for some theoretical PFR, a current FRI of 30 years would be a +67 percent departure ([1 – (10/30)] × 100); for the same PFR, a current FRI of 5 years would be a -50 percent departure (-[1 – (5/10)] × 100). PFRID considers the cumulative fire history of each polygon since 1908 and does not return to zero when a fire occurs. For areas dominated by PFRs with a presettlement FRI greater than 103 years and that have not burned in the period of historical record considered in this analysis (i.e., since 1908), PFRID is assumed to equal zero.

Plotted against current FRI, the underlying distribution of the PFRID metric appears approximately linear between -99.9 percent and about +40 percent departure, but above +40 percent departure, increasingly larger leaps in current FRI are required to move the departure statistic (fig. 2), This is because the metric is actually asymptotic (see plot of PFRID against a logarithmic scale of current FRI, fig. 2 inset), owing to the behavior of the PFRID formulas, which divide presettlement FRI by current FRI in cases of positive PFRID and divide current FRI by presettlement FRI in cases of negative PFRID (Hann 2004, Hann and Strohm 2003). This property of the PFRID equations makes them particularly well suited to the analysis of fire frequency distributions where the mean and median FRIs are similar but a small number of high values results in a long tail to the right. This is not an uncommon situation with discrete data sets (Von Hippel 2005) and is the case with many of our nonmaritime forested PFRs (see fig. 1 in Van de Water and Safford 2011).

Mean and median PFRID measure the departure of current FRIs from the central tendency of presettlement FRIs, with median PFRID perhaps better representing the skewed nature of FRI distributions in some vegetation types (i.e., more short or long intervals, depending on the fire regime). Mean PFRID is the standard measure used by the Forest Service in California to spatially map contemporary departure from presettlement fire frequencies (Safford et al. 2011). Mean minimum and mean maximum (hereafter min and max) PFRIDs represent liberal and conservative estimates, respectively, of the departure of current from presettlement FRIs. Min and max PFRIDs are important variables, as they (hypothetically) provide us with approximate lower and upper bounds of sustainability/resilience for the ecosystems represented by our PFRs. Landscapes that are characterized by negative min PFRID values are burning much more frequently today than under presettlement conditions; these landscapes may have undergone or may be undergoing vegetation type conversion and should be focus areas for enhanced fire suppression and public education efforts. In contrast, landscapes that are characterized by positive max PFRID values are usually those that were historically characterized by frequent fire but have not experienced fire for a half century or more. These areas may have experienced major changes in vegetation composition and fuels and should be focus areas for fuel reduction by fire restoration or fire surrogates.

We categorized mean PFRID values into “condition classes” (CCs) (see Safford et al. 2011), where values from 0 to 33 percent and 0 to -33 percent are classified as

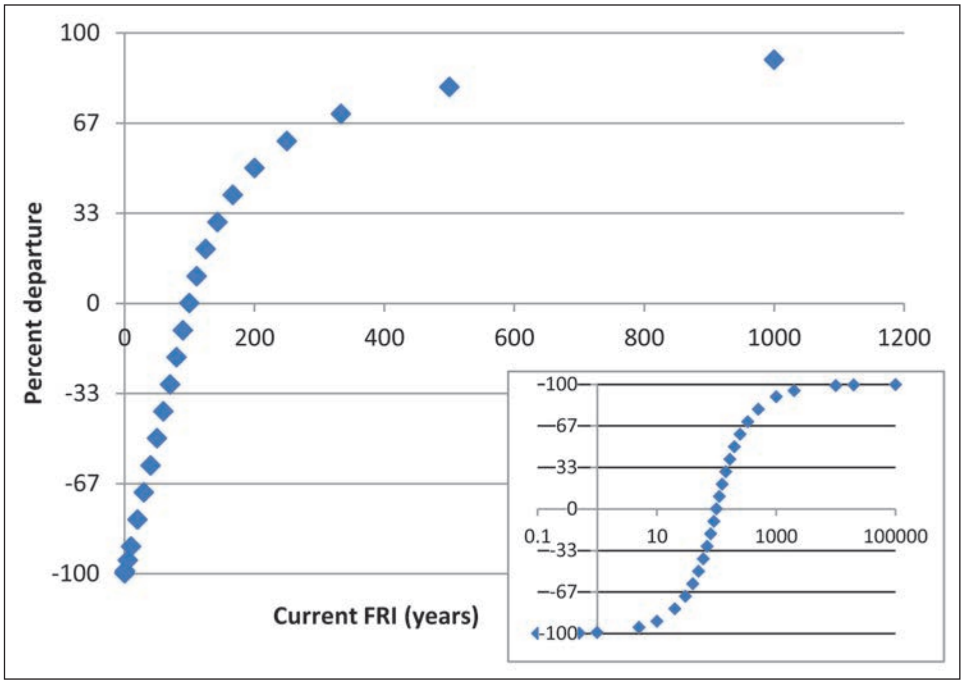

Figure 2—Percent departure versus current fire return interval (FRI) for a presettlement fire regime with a mean presettlement reference FRI of 100 years. The inset plots the departure from -99.9 percent to +99.9 percent against a Log FRI scale.

CC 1 and CC -1 ("low departure"), respectively, while values from 33 to 67 percent and -33 to -67 percent are CC 2 and CC -2 ("moderate departure"), and values greater than 67 percent and more negative than -67 percent are CC 3 and CC -3 ("high departure"). This CC categorization, which simply divides the 0 to 100-percent departure scale into thirds, was developed by the interagency Fire Regime Condition Class (FRCC) program (Hann 2004, Hann and Strom 2003). Positive CCs apply where contemporary fire frequencies are less than presettlement frequencies (Hann and Strohm 2003); negative CCs apply where contemporary fire frequencies are greater than presettlement frequencies (Safford et al. 2011).

Table 1 provides background information to help in the interpretation of the PFRID statistics. Table 1 expands on Van de Water and Safford (2011) to provide the current FRIs associated with the boundaries between the CCs for each PFR. It can be appreciated from table 1 that CC 1 and CC -1 occupy the area between current FRIs that are one-half the frequency of the presettlement FRI and 1.5 times the presettlement FRI. Condition class 2 is found in the area where current FRI is between 1.5 and three times the presettlement FRI; CC 3 is thus defined as any current FRI that is more than three times the presettlement FRI. The boundary between CCs -2 and -3 is found where current FRIs are one-third the presettlement FRIs (i.e., current fires are three times as frequent as the presettlement mean).

The fifth FRID metric we calculated was the NPS FRID index, which represents the number of intervals missed since the last fire relative to the central tendency of presettlement FRI distributions. The NPS-FRID index was calculated using the following equation:

NPS-FRID index = -[(presettlement mean FRI-TSLF)/presettlement mean FRI].

Note that the sign of the equation used in this analysis has been reversed from the original formula (see van Wagtendonk et al. 2002) to facilitate interpretation of FRID trends that is consistent with the sign of our other PFRID metrics. The NPS-FRID metrics were developed by the NPS for the southern Sierra Nevada and do not consider the cumulative fire history of each polygon, but only the time since the last fire (Caprio et al. 1997, Caprio and Graber 2000, Keifer et al. 2000, van Wagtendonk et al. 2002). The NPS-FRID metrics measure the number of presettlement FRIs missed since the first missed cycle, and are thus not helpful in identifying areas where current FRI is shorter than presettlement FRI. The NPS-FRID index values less than 0 are classified as low departure, while values from 0 to 2 are moderate, values from 2 to 5 are high, and values greater than 5 are extreme (van Wagtendonk et al. 2002). Note that the interpretive differences between the two metrics notwithstanding, the numerical boundary between moderate and high NPS-FRID (three missed fires) is equivalent to the boundary between moderate (CC 2) and high (CC 3) departure in the PFRID measure (current FRI = three times the reference FRI).

Fire return interval departure mapping products described above (including PFR, number of fires since 1908, TSLF, and all FRID values) were developed by the Forest Service's Pacific Southwest Region Ecology Program and Remote Sensing Lab (Safford et al. 2011) and are available online at http://www.fs.usda.gov/main/r5/landmanagement/gis.

To provide some geoecological context for our spatial patterns of departure, FRID GIS layers were intersected with a layer consisting of the ecological sections and subsections in California (figs. 1 and 3) (Miles and Goudey 1997). The subsection descriptions in Miles and Goudey (1997) provide information on prevalent environmental conditions in each subsection, including elevations, temperature and precipitation, soils, geology, vegetation, and human uses. The area-weighted average of TSLF and FRID values within each subsection was calculated, using only those Forest Service or analyzed NPS lands that occurred within each subsection, and then TSLF and FRID values were mapped by subsection; the section summaries in table 2 are the summed results from the subsection area-weighting and likewise represent only analyzed federal lands. We report results only for subsections that contained at least 5 percent Forest Service or NPS lands. Figure 3

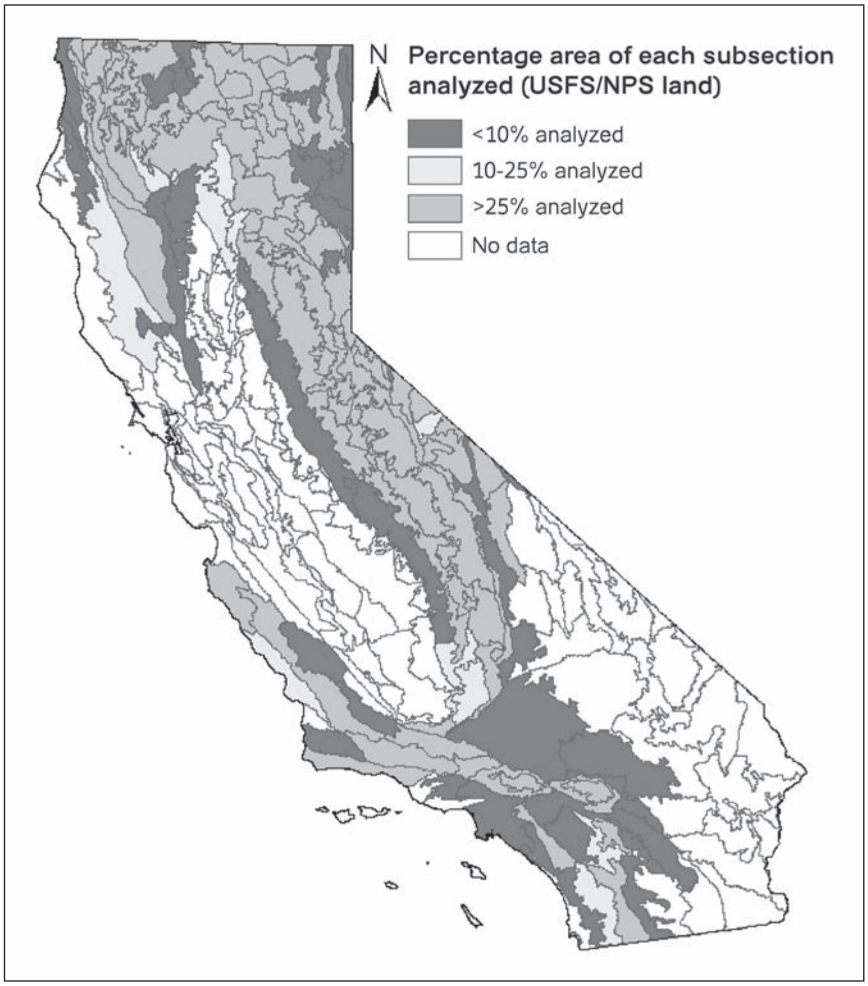

Figure 3—Ecological subsections intersecting with the national forests and national parks analyzed in this study. Dark gray subsections are those where >25 percent of the land base is found within analyzed management units; light gray = 10 to 25 percent of the land base is within analyzed management units; black = ≤ 10 percent of the land base is within analyzed management units. USFS = United States Forest Service, NPS = Natioinal Park Service.

Table 2—Differences in time since last fire (TSLF) and fire return interval departure (FRID)[a] among ecological sections[a], averaged from subsections within the section that contains lands under Forest Service or National Park Service (NPS) (Yosemite or Sequoia-Kings Canyon National Parks) administration

Ecological section	Code	n	Analyzed area	Section area	Percentage of section analyzed	TSLF	Min. PFRID	Mean-PFRID	Median PFRID	Max. PFRID	NPS-FRID Index[b]
			Hectares			*Years*					
Central Coast	261A	2	137 055	1 375 722	10.0	16	25	-19	-7	-57	-0.6
Southern Coast	261B	5	75 765	1 449 424	5.2	33	30	-20	-25	-49	-0.4
Northern Coast	263A	3	11 637	1 722 125	0.7	101	85	71	83	18	3.3
Mojave Desert	322A	3	26 074	6 683 237	0.4	79	16	-1	-4	-17	-0.3
Colorado Desert	322C	1	229	1 185 242	0.0	19	-65	-91	-92	-95	-1.0
Mono	341D	14	402 040	798 345	50.4	98	65	39	39	8	1.0
Southeastern Great Basin	341F	4	83 116	1 103 764	7.5	103	38	21	21	5	0.2
Northwestern Basin and Range	342B	5	3 776	522 403	0.7	94	78	53	51	6	1.8
Klamath Mountains	M261A	16	1 755 085	2 256 796	77.8	77	84	67	79	10	3.3
Northern Coast Ranges	M261B	3	614 783	1 552 449	39.6	77	82	64	70	9	3.3
Northern Interior Coast Ranges	M261C	2	4267	749 443	0.6	69	74	52	60	3	2.3
Southern Cascades	M261D	9	958 842	1 702 525	56.3	90	86	70	73	18	4.6
Sierra Nevada	M261E	21	4 116 267	5 159 316	79.8	84	78	61	66	11	3.3
Sierra Nevada Foothills	M261F	5	152 857	1 819 108	8.4	58	62	31	39	-18	1.8
Modoc Plateau	M261G	11	711 801	1 430 882	49.8	90	75	51	56	13	2.9
Central Coast Ranges	M262A	3	190 822	2 485 244	7.7	22	0	-41	-45	-63	-0.6
Southern Mountains and Valleys	M262B	16	1 193 734	2 755 093	43.3	43	34	-6	-5	-40	0.3

n = Number of analyzed ecological subsections within each section.

[a] Percentage fire return interval departure (PFRID) data are read as percentage departure.

[b] Sign of NPS-FRID Index values reversed to allow consistent interpretation with other FRID measures.

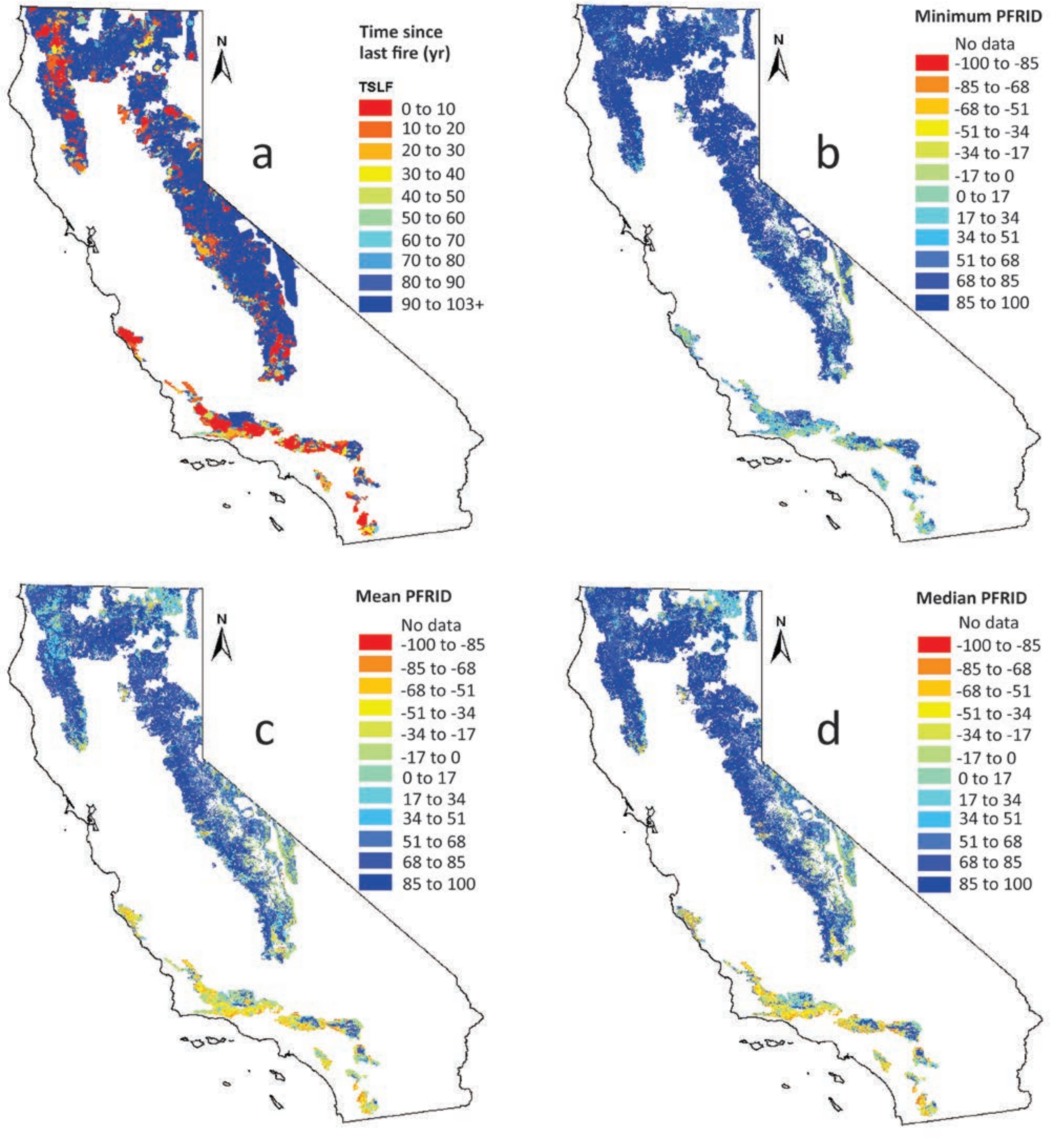

Figure 4—Time since last fire and the five fire return interval departure metrics for federal lands analyzed in this study. Negative percent FRID (PFRID) measures (warm colors) identifies places where current fire return interval (FRI) is shorter than the presettlement FRI; positive PFRID (cool colors) identifies places where current FRI is longer than the presettlement FRI. The PFRID measures are grouped into categories that approximately correspond to the standard condition classes from Hann and Strohm (2003) (see “Methods”). For the National Park Service FRID Index, see “Methods” for interpretation of the index values.

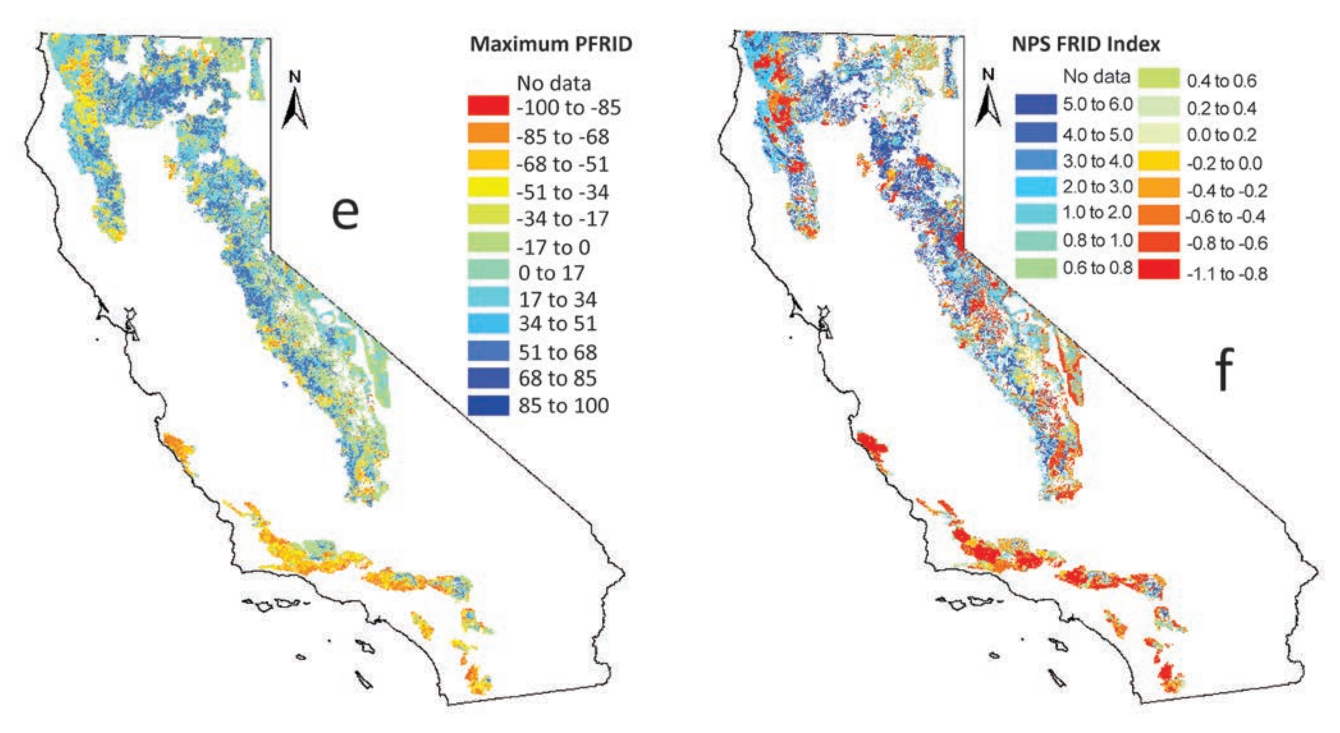

Figure 4—Continued.

identifies those ecological subsections where these federal lands account for < 25 percent and < 10 percent of subsection area. Be careful to avoid overinterpretation of our results in these subsections.

We selected those ecological subsections with the highest positive departure (greater than 17 percent departure, n = 25; the "P" group) as determined by max PFRID (see fig. 4), and those subsections with the most negative departure (more than 33 percent negative departure, n = 17; the "N" group), and used data from Miles and Goudey (1997) to characterize each of the 42 subsections with respect to lowest elevation, mean annual precipitation (from the range given); low mean annual temperature; high mean annual temperature; mean annual frost-free period in days (from the range given); dominant precipitation type (rain = 1, snow = 2, mix = 1.5); soil temperature (thermic = 4, mesic = 3, frigid = 2, cryic = 1; intermediate values given for mixes); and soil moisture (udic = 3, xeric = 2, aridic = 1; intermediate values given for mixes). Each of the 42 subsections was assigned a predominant pre-Euro-American settlement FRI using the predominant vegetation types described by Miles and Goudey (1997) and crosswalking these to the PFRs in Van de Water and Safford (2011). We also assigned each subsection a human population density from the California county that the subsection was found in; in cases of multiple counties, we averaged the densities (data from http://www.csac.counties.org/). The above data were entered into a Principal Components Analysis (PCA) ordination using PC-ORD v. 5 (McCune and Mefford 2006). Before analysis, the input data were relativized by their maximum values. Monte Carlo permutations of the data were carried out 1,000 times in order to calculate correlations of the environmental data with the ordination axes. We also statistically compared the P and N group means for the environmental and population data listed above using the univariate nonparametric Mann-Whitney U test.

In the southern Sierra Nevada, we compared differences in FRID between three large national parks (Yosemite, Sequoia, and Kings Canyon, all of which include large areas where naturally ignited fires are allowed to burn for ecological benefit) and the five adjacent national forests by calculating the area-weighted average of TSLF and FRID values in the two jurisdictions.

Elevational trends in departure were explored using the zonal statistics function of ArcGIS 9.3 (ESRI 2008), which averaged the TSLF and FRID values of all cells of identical elevation in a 100-m digital elevation model. Trends in departure along precipitation, mean, minimum, and maximum temperature gradients were also explored using zonal statistics on averaged annual PRISM climate normal grids, 1971–2000 (PRISM Group 2004).

Results

Geographic Patterns

Geographic patterns of FRI departure on the analyzed Forest Service and NPS lands generally showed positive FRID and longer TSLF in NW California and Sierra Nevada, and negative FRID and shorter TSLF in southern California; trends were relatively consistent across all metrics (table 2, figs. 3 through 6). TSLF strongly reflected the fire seasons of 2003 and 2005–2008 and resulted in very low departure according to the NPS-FRID Index (which is based only on the most recent fire) for much of southern California and scattered portions of the North Coast Ranges, Klamath Mountains, and Sierra Nevada (figs. 4a–4f).

The PFRID measures, which consider fire history across the entire 103-year study period, were much less affected by recent fire seasons (figs. 4b–4e). Min PFRID, which is based on the mean minimum presettlement FRI for the mapped PFRs (Van de Water and Safford 2011), classified most of the study area at high positive departure (fig. 4b). Lower elevation PFRs in the southern California national forests were an exception: some areas in the southern California foothills mapped as high negative departure even using the min PFRID measure, which means they have burned much more frequently over the last century than during any comparable (average) presettlement period in our reference period. Mean and median PFRID were nearly indistinguishable: both showed very high positive departure from presettlement fire frequencies throughout most of NW California and the Sierra Nevada (with some exceptions of low to moderate departure in the central Klamath Mountains, parts of the Modoc Plateau, and the southeastern Sierra Nevada), and a belt of moderate to high negative departures through most of lower and middle elevation southern California (figs. 4c–4d). Max PFRID, based on the mean maximum presettlement FRI, is a more conservative measure of departure for places that are lacking fire and a more liberal measure for places that are seeing much more fire (fig. 4e). Places identified as high positive departure using max PFRID have missed a greater than average number of fire cycles; these tended to be centered in the eastern Klamath Mountains, the southern Cascades, and middle elevations in the main Sierra Nevada. As would be expected, most of southern California is mapped as very large negative departure using the max PFRID measure (fig. 4e).

Figure 5 compares the three major geographic regions by the proportion of area in Forest Service and (in the Sierra Nevada) NPS jurisdiction that falls in each of the CCs, based on the standard mean PFRID measure. It can be readily seen how different southern California is from the northern California regions. Forty-three percent of Forest Service lands in southern California are burning more (CC -2) or much more (CC -3) frequently currently than under the pre-Euro-American settlement fire regime; only 2 percent of the Sierra Nevada and 1 percent of NW California lands fall into this category (fig. 5). About one-third of southern California falls into CCs 1 and -1, within +/- 33 percent of the presettlement mean fire frequency, versus 16 percent in the Sierra Nevada and 9 percent in NW California. More than 85 percent of Forest Service lands in NW California is burning either less frequently (CC 2) or much less frequently (CC 3) currently than under presettlement conditions, compared with 67 percent of Forest Service and NPS lands in the Sierra Nevada and 19 percent in southern California.

Table 2 averages results of the area-weighting procedure among the ecological sections (see fig. 1 for map); figure 6 portrays the geographic results by ecological subsection for mean and max PFRID. After rounding, only seven ecological sections contained more than 40 percent Forest Service or NPS lands (table 2). It is important to remember that our results summarized by ecological units (sections and subsections) are only valid for the Forest Service and NPS lands within those units. As noted above, the highest positive FRID values were consistently on Forest

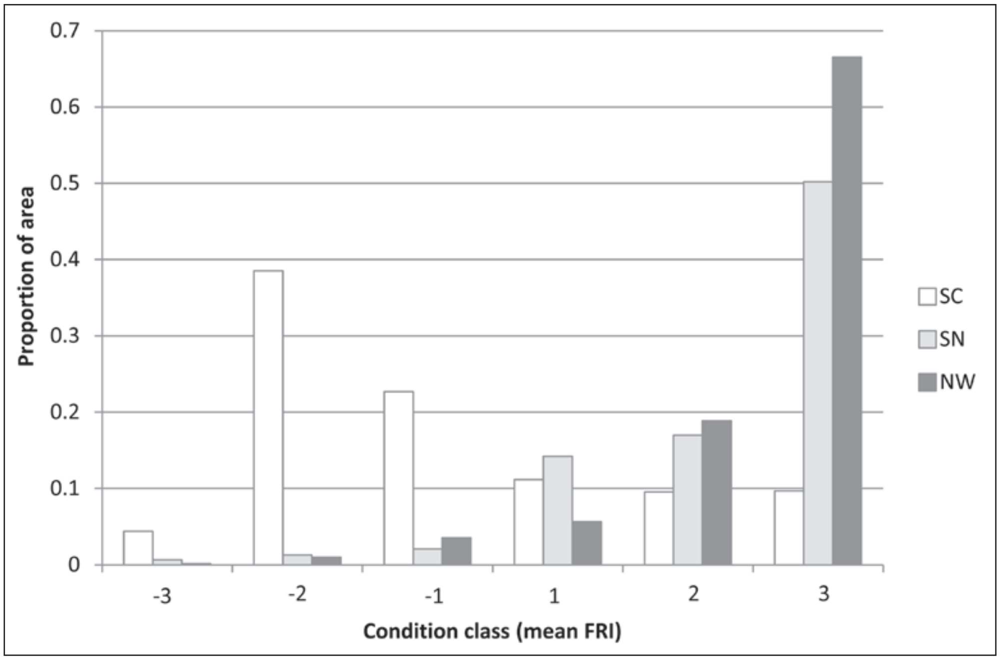

Figure 5—Proportion of total analyzed area in the three geographic regions falling into each of the six condition classes (CCs). Negative CCs represent places where the current fire return interval (FRI) is shorter than the presettlement FRI; positive CCs identify places where current FRI is longer than the presettlement FRI. SC = Southern California, SN = Sierra Nevada, NW = Northwestern California.

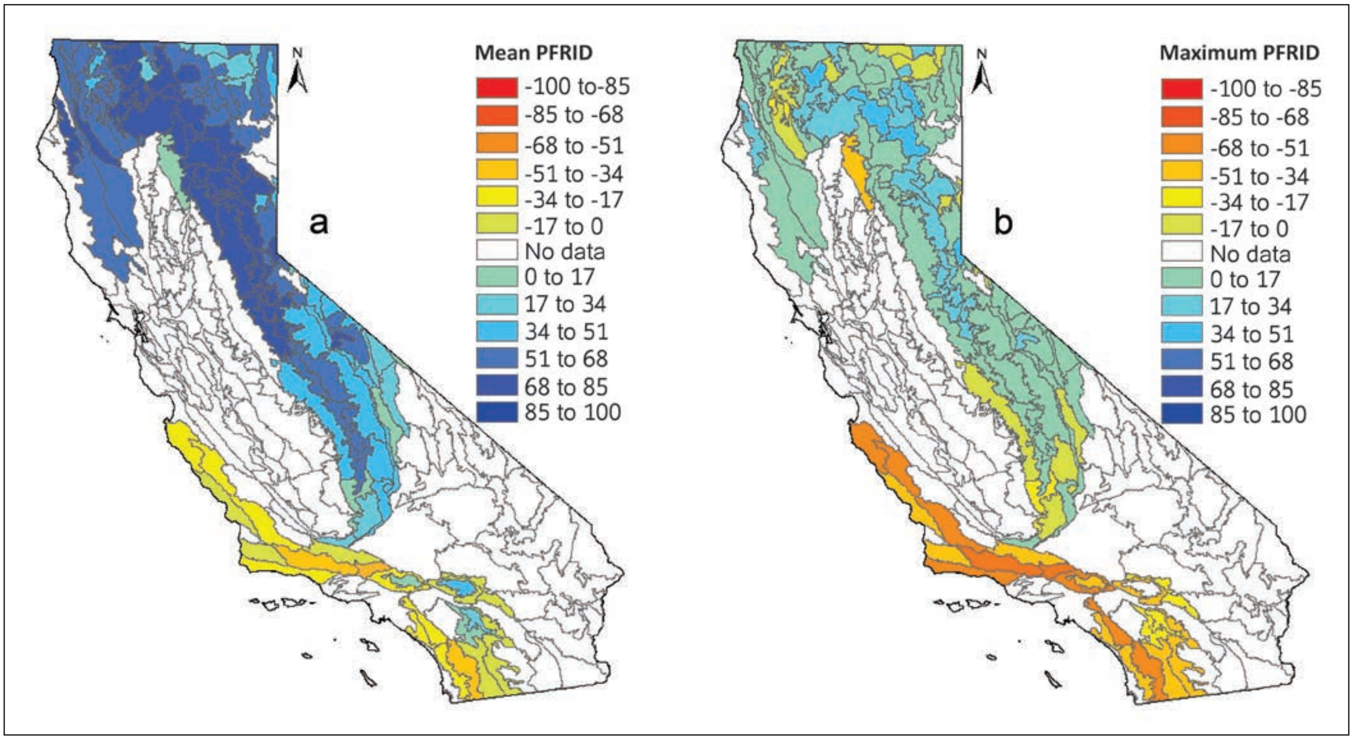

Figure 6—Mean and max percent fire return interval departure (PFRID), with the results of figure 4 extrapolated to the ecological subsection boundaries (Miles and Goudey 1997). See figure 3 for percentages of subsections analyzed; in this figure, subsections with < 5 percent analyzed land have been removed.

Service lands in the eastern Klamath Mountains and the southern Cascades (fig. 6). Mean TSLF averaged 68 years, ranging from 16 years in the Central Coast Ecological Section to 103+ years in the Southeastern Great Basin Section (table 2). The min PFRID measure averaged 50 and ranged from -65 in the very small area of Forest Service land in the Colorado Desert Section to 86 in the Southern Cascades Section (table 2). Mean PFRID averaged 24 across the analyzed subsections, which is high CC 1. Mean PFRID varied from -91 in the Colorado Desert Section to 70 in the Southern Cascades and 71 in the North Coast Section (table 2, fig. 6a). The median PFRID measure averaged 27 and varied from -92 in the Colorado Desert Section to 83 in the North Coast Section (table 2). Max PFRID averaged -14, and ranged from -95 in the Colorado Desert Section to 18 in the Northern Coast and Southern Cascades Sections (table 2, fig. 6b). The NPS-FRID index averaged 1 (moderate departure), ranging from -1.0 in the Colorado Desert Section to 4.6 in the Southern Cascades Section; many northern California Sections fell between 2.9 and 3.3, which fall in the “high” departure category (table 2).

The results of the Principal Components Analysis (PCA) on the subsection environmental data are shown in figure 7. Axis 1 explained 51.3 percent of the variance in the data matrix, axis 2 explained 17.8 percent, and axis 3 explained 11 percent. The subsections supporting strongly positive FRIDs (as determined using max PFRID) were clearly segregated from the subsections supporting strongly negative FRIDs. Of the 25 subsections in the positive FRID (P) group, all but three were from NW California and the Sierra Nevada (the exceptions being P23–25, which are the Upper San Gabriel, Upper San Gorgonio, and San Jacinto Mountains in southern California). Of the 17 subsections in the negative FRID (N) group, all but one (N17—Tuscan Flows [Miles and Goudey 1997]) were from southern California. Along axis 1, all but one of the subsections in the N group were clustered to the right of the ordination center; all but three of the subsections in the P group were grouped to the left of center (fig. 7). Axis 1 was most strongly correlated with environmental variables related to temperature and elevation, with the warmest and lowest subsections (excepting P6) all in the N group. The most strongly correlated variables with axis 1 were: high mean temperature ($r = 0.924$); lowest elevation ($r = -0.919$); and mean frost-free period ($r = 0.894$). Soil temperature was a categorical variable and an r value could not be determined, but it was the most closely associated variable with axis 1. Axis 2 was most closely correlated with moisture (mean annual precipitation [$r = -0.745$] and soil moisture [categorical variable]) and presettlement FRI ($r = 0.542$). Along axis 2, the P subsections were evenly distributed above and below the ordination center, but most of the N sites were near or below the center (i.e., N sites tend to be drier and support longer presettlement

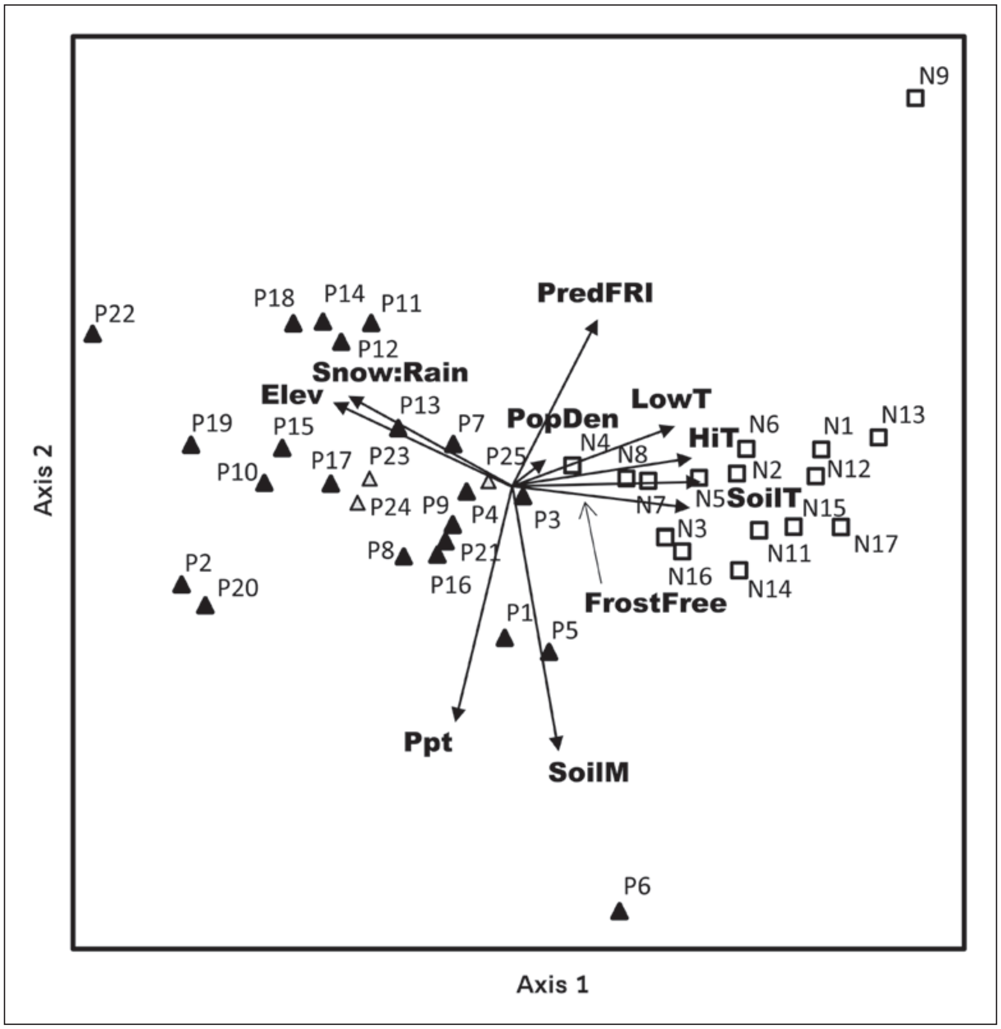

Figure 7—Principal Components Analysis ordination of highly positively ("P," triangles) and highly negatively departed ("N," squares) subsections (see "Methods"). The gray triangles are three southern California sites belonging to the P group.

FRIs). Population density was correlated with axis 3 at $r = 0.960$, which was the strongest correlation overall between the environmental variables and any axis; the arrow representing population density in the ordination diagram seems very short because the effect of population density is nearly orthogonal to axes 1 and 2. Along axis 3, the N sites were characterized by high population densities (and are in the distance along axis 3) and the P sites (which are nearer to the observer along axis 3) by low population densities (fig. 7).

We compared the means for the environmental data entered into the PCA for the N and P groups using Mann-Whitney U tests. The results are shown in figure 8. Based on figures 7 and 8 and Miles and Goudey (1997), we can describe the P group as predominantly northern California (plus a few small areas

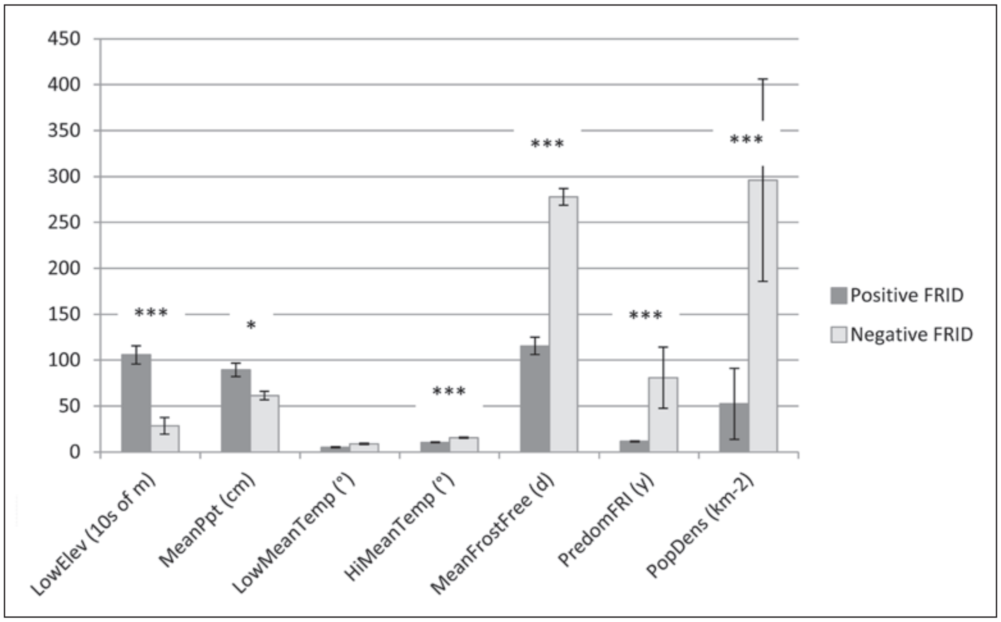

Figure 8—Means comparisons for six environmental variables and human population density between the positive (P) and negative (N) subsection groups from the Principal Components Analysis ordination. LowElev = lowest listed elevation; MeanPpt = mean annual precipitation; LowMeanTemp = lowest listed mean annual temperature; HiMeanTemp = highest listed mean annual temperature; MeanFrostFree = mean length of annual frost free period, in days; PredomFRI = mean presettlement fire return interval (FRI) for the predominant vegetation type in the subsection; PopDens = mean human population density. See “Methods” for data sources. Comparison made with nonparametric Mann-Whitney U-test; * = significantly different at $P < 0.05$; *** = significantly different at $P < 0.001$.

of high-elevation southern California); higher elevation, wetter and cooler, with most precipitation arriving as snow; growing season of 3 to 4 months; conifer forest-dominated vegetation with short presettlement FRIs; mesic to frigid soil temperature regime; and in areas of low population density. The N group can be characterized as predominantly southern California; lower elevation, warmer and drier, with precipitation arriving as rain; growing season of 8 to 10+ months; shrub-dominated vegetation with longer presettlement FRIs; thermic to mesic soil temperature regime; and in areas of high population density.

Differences Among Management Units

Using mean PFRID and considering only those lands for which FRID was calculated (i.e., ignoring barren and rocky areas, lakes, herbaceous vegetation, etc.), the percentage of lands with negative FRI departures (CC -2 and -3) vs. lands within 33 percent of the mean presettlement FRI (CC -1 and 1) vs. lands with positive FRI departures (CC 2 and 3) is different in the three Sierra Nevada national parks (2, 30, and 68 percent) compared to Forest Service-managed lands in the Sierra Nevada (2, 18, and 80 percent). If only the five national forests adjacent to the parks are compared, however (Humboldt-Toiyabe, Inyo, Stanislaus, Sierra, and Sequoia NFs), the national forest percentages are very similar to the national parks (3, 27, and, 70 percent). Most other measures of fire frequency departure in the neighboring national forests are also relatively similar (table 3). Average TSLF is lower in the national parks, although Sequoia NF has the lowest overall TSLF (table 3). The NPS-FRID index is in the "moderate" range (0-2) in the national parks, while the national forests average in the "high" range of departure. Two national forests with large areas of high-elevation wilderness (Inyo and Humboldt-Toiyabe) also fall in the low range (table 3).

Table 3 also highlights the strong differences between NW California plus Sierra Nevada and southern California. The average TSLF in southern California is less than half of the value in the other two regions, and the average PFRID values are all negative in southern California, compared to highly positive numbers in NW California and the Sierra Nevada. The extensive 2008 fires result in a lower TSLF in NW California than the Sierra Nevada, but Min, Mean, and Median PFRID and the NPS-FRID index are all lower in the Sierra Nevada. Averaged across all national forest land, NW California is the region with the greatest FRI departures, but the individual national forest units with the greatest departures are found in the central and northern Sierra Nevada (table 3).

We can also compare management units on the basis of the CC measures derived from mean PFRID. On three national forests in the Sierra Nevada (Lassen, Plumas, and Tahoe), over 70 percent of the landscape falls in CC 3, which is to say that on 7/10 of these lands there has been a greater than 67 percent decrease in fire frequency (i.e., at least three FRIs have been missed) over the last century as compared to the pre-Euro-American settlement period (fig. 9a). The Shasta-Trinity NF in NW California is nearly as extreme. In terms of overall area, the Shasta-Trinity is the only management unit with over 500 000 ha of CC 3 lands; the Klamath, Lassen, Plumas, and Six Rivers NFs all manage more than 300 000 ha of CC 3 lands (fig. 9b).

The lowest percentage and area of CC 3 lands are found in the shrub and hardwood-dominated southern California national forests. At the same time, these four national forests (Angeles, Cleveland, Los Padres, and San Bernardino) contain the only substantial areas of negative CCs (where fire frequencies are currently greater than in presettlement conditions) in California (figs. 4, 6, and 9). In management units dominated by conifer forests, only Yosemite and Sequoia-Kings Canyon National Parks and the Inyo NF have less than one-third of their area in CC 3. Three other national forests in the Sierra Nevada region (Sequoia, Sierra, and Modoc) are 40 to 44 percent CC 3 (fig. 9).

Table 3—Differences in time since last fire (TSLF) and fire return interval departure (FRID) measures between national park (NP) and adjacent national forest (NF) lands in the southern Sierra Nevada, followed by TSLF and FRID measures for the remaining NFs analyzed

Unit	TSLF	Min PFRID	Mean PFRID	Median PFRID	Max PFRID	NPS-FRID Index[a]	Analyzed area[b]	
	Years						*Hectares*	
National parks:								
Sequoia-Kings Canyon NPs	80	60	43	48	-2	1.3	222 045	
Yosemite NP	77	70	51	57	1	1.7	237 318	
National park mean	78	65	47	52	-1	1.5	459 363	Total
Adjacent national forests:								
Humboldt-Toiyabe NF	91	73	50	50	7	1.9	339 646	
Inyo NF	98	55	35	35	7	1.0	766 030	
Sequoia NF	71	71	46	51	-1	2.3	538 316	
Sierra NF	89	71	56	63	10	3.4	529 756	
Stanislaus NF	81	83	68	74	17	4.2	395 477	
Adjacent national forest mean	87	68	49	52	8	2.4	2 569 225	Total
Northwest (NW) California:								
Klamath NF	82	83	65	74	11	3.6	803 959	
Mendocino NF	73	79	60	64	6	3.3	435 526	
Shasta-Trinity NF	81	87	73	80	17	4.3	1 219 109	
Six Rivers NF	79	82	63	79	4	2.4	546 924	
NW California mean	80	84	67	76	11	3.6	3 005 517	Total
Southern California:								
Angeles NF	34	27	-16	-14	-50	0.0	264 271	
Cleveland NF	31	23	-21	-22	-52	-0.2	221 536	
Los Padres NF	35	33	-13	-11	-45	-0.2	753 572	
San Bernardino NF	56	46	13	15	-24	1.1	310 261	
Southern California mean	39	33	-9	-8	-43	0.1	1 549 640	Total
Sierra Nevada:								
El Dorado NF	91	90	76	82	22	4.8	325 558	
Modoc NF	89	75	50	55	11	2.9	835 343	
Lassen NF	86	87	72	76	17	4.4	609 661	
Plumas NF	79	91	77	82	16	4.4	559 398	
Tahoe NF	86	89	75	80	16	4.4	447 880	
Lake Tahoe Basin management unit	99	83	71	74	23	4.0	53 218	
Sierra Nevada mean[c]	87	77	59	63	12	3.2	5 400 282	Total

PFRID = percentage of FRID.

[a] Sign of NPS FRID values reversed for consistent interpretation.

[b] Areas refer only to lands for which FRID was calculated, i.e., they exclude rocky and barren areas, herbaceous vegetation, lakes, etc.

[c] Sierra Nevada means values and local area calculated from 11 Sierra Nevada region forests.

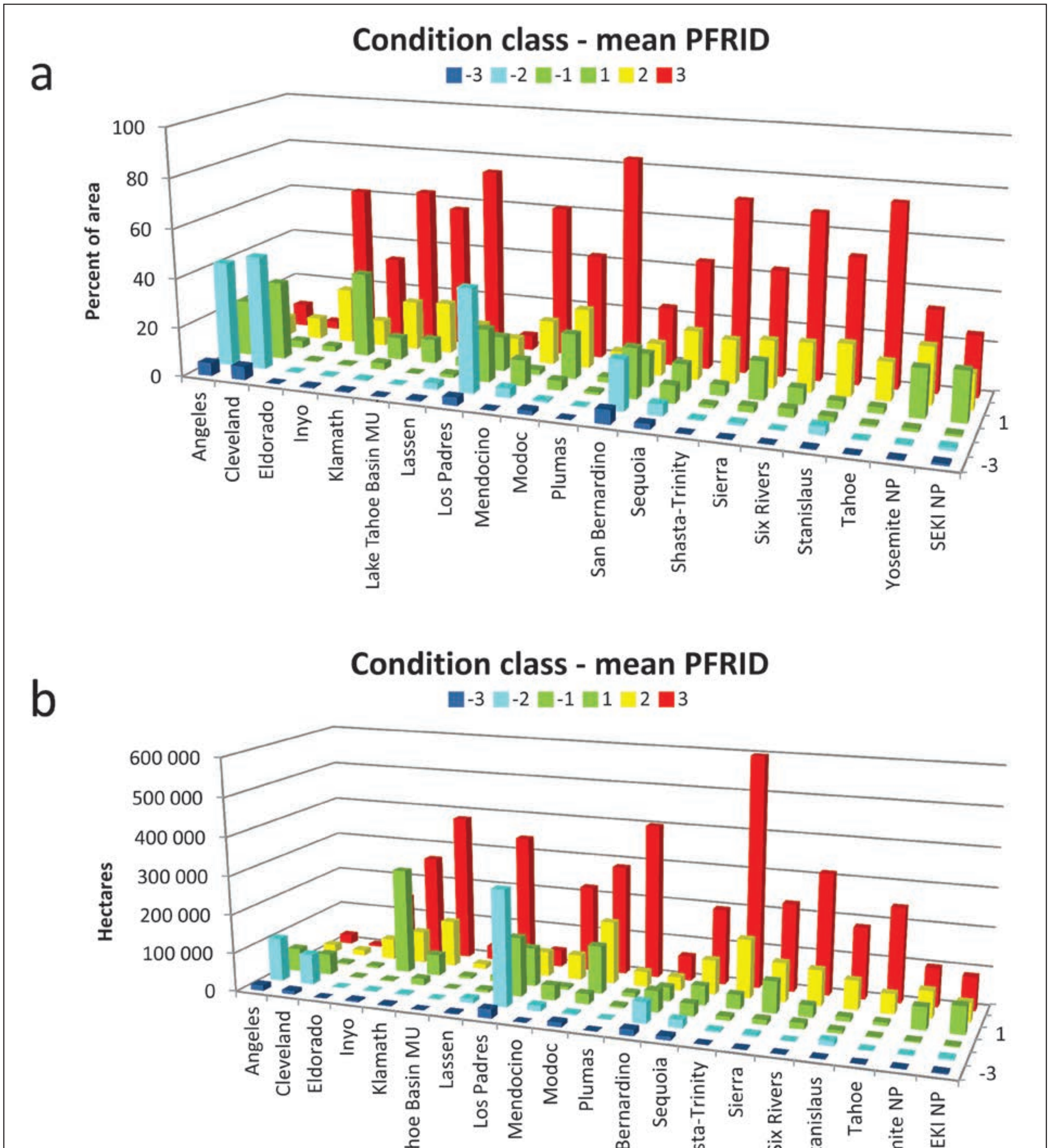

Figure 9—Comparison of condition class (CC) measures (from the mean percent fire return interval departure [PFRID] metric) for the 18 California national forests managed by the Pacific Southwest Region, and Yosemite and Sequoia-Kings Canyon National Parks (NPs); (a) percentage of area; (b) total area. Total area of each management unit includes lands not in woody vegetation (grassland and meadows, barren lands, rocks, etc.), so totals do not add up to 100 percent. Colors are reversed from figures 3 and 5 to correspond to the nationally standard color scheme for CCs 1 through 3 (green-yellow-red).

Elevational Trends

Above 700 m, TSLF rose in all three regions when plotted against elevation (fig. 10). Fire return interval departure measures were mostly unimodally related to elevation, but they rose over most of the elevational gradient in southern California, and dropped over the upper half of the gradient in NW California and the Sierra Nevada. In NW California, the 100-m moving average of TSLF decreased as elevation increased from sea level to 400 m, then increased again at higher elevations (fig. 10a). The 100-m moving averages of mean, median, min, and max PFRID and the NPS-FRID index rose slightly between sea level and 1500–1700 m, then decreased to a minimum at 2900 m. Mean, median, and min PFRID, and NPS-FRID index remained largely positive over the entire elevational range, while max PFRID transitioned from positive to negative at approximately 2400 m. In the Sierra Nevada, TSLF decreased between sea level and 700 m, then increased again at higher elevations (fig. 10b). Mean, median, min, and max PFRID, and the NPS-FRID index decreased between sea level and 700 m, increased until 1750 m, then decreased to a minimum at 3700 m. Mean, median, and min PFRID remained positive over the entire elevation range, while max PFRID was negative from 450 m to 1000 m, and the NPS-FRID index was negative from 3050 m to 3700 m. As elevation increased in southern California, TSLF decreased from sea level to approximately 700 m, then increased again at higher elevations (fig. 10c). Mean, median, min, and max PFRID, and the NPS-FRID index also decreased between sea level and approximately 750 m, then increased to a maximum at around 2500 m before decreasing again. Mean and min PFRID remained largely positive over most of the elevational range. Median PFRID transitioned from negative to positive at approximately 1400 m, max PFRID transitioned at 1800 m, and the NPS-FRID index transitioned at 1600 m.

Using the standard mean PFRID measure as an index of central tendency, the southern California landscape is mostly in CC 2 from about 1500 m to 2900 m elevation (fig. 10c). Averaged across the NW California area, mean PFRID remained above CC 1 throughout the elevational profile until about 2200 m; mean PFRID was in CC 3 between 1200 and 1800 m elevation (fig. 10a). In the Sierra Nevada, mean PFRID showed similar patterns to NW California: it was greater than CC 1 throughout the elevational gradient and in CC 3 between 1600 and 2000 m. Mean PFRID fell to CC 1 values above about 2700 m (fig. 10b). The NPS-FRID index never reached “high” (>2) values in southern California, was >2 between 1000 and 1600 in NW California, and >2 between 900 and 2200 m in the Sierra Nevada.

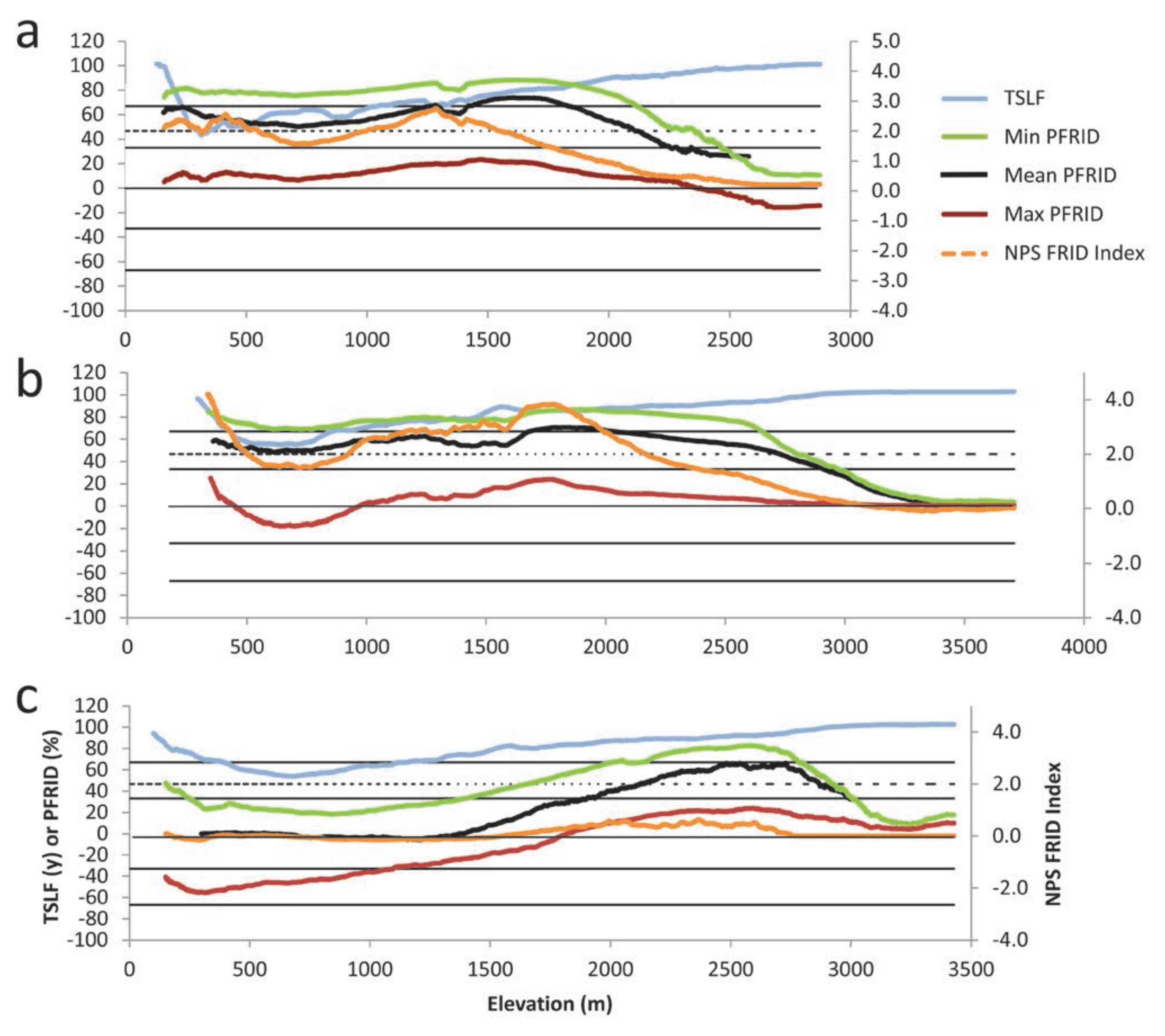

Figure 10—100-m moving averages of time since last fire (TSLF) and fire return interval departure (FRID) versus elevation in (A) northwest California region, (B) Sierra Nevada region, and (C) southern California region. Median percent FRID (PFRID) closely corresponds to mean PFRID and was removed for clarity. For figures 10 through 14, solid horizontal reference lines are provided for PFRID values of -67 (transition from CC -2 to CC -3), -33 (CC -1 to CC -2), +33 (CC 1 to CC 2), and +67 (CC 2 to CC 3). Dotted reference line refers to the National Park Service (NPS) FRID Index value of 2, which is the transition from “moderate” departure to “high” departure.

Precipitation Trends

The TSLF in NW California fluctuated considerably but generally increased with increasing annual precipitation, from 55 years at 25 cm to 103+ years at 420 cm (fig. 11a). As precipitation increased in the Sierra Nevada, TSLF decreased between 10 and 85 cm, increased until 130 cm, decreased until 250 cm, and then increased to a maximum at 300 cm (fig. 11b). Annual precipitation had little relationship to the different FRID measures in either NW California or the Sierra Nevada. In both regions, most FRID measures rose almost imperceptibly across the precipitation gradient (except below 50 cm), although max PFRID decreased gradually with precipitation in NW California. The TSLF and the FRID measures in southern California decreased with precipitation, except between 50 and 100 cm, where they leveled off (fig. 11c). Mean PFRID decreased as precipitation increased from 20 to 50 cm, rose slightly to 100 cm, and then dropped again; the NPS-FRID index stayed near zero, except at the highest precipitation values. Min PFRID remained positive over the entire precipitation gradient, whereas max PFRID remained negative.

In both NW California and the Sierra Nevada, mean PFRID tracked the boundary between CC 2 and 3 across most precipitation values. In southern California, areas with precipitation over 110 cm generally fell in the CC 1 to CC -1 belt (within +/-33 percent of presettlement fire frequency) (fig. 11).

Temperature Trends

Fire return interval departure trends with temperature in NW California and the Sierra Nevada were broadly similar. In both regions, FRID measures were (generally) low at low temperatures, gradually rose to a maximum, then gently declined (figs. 12 and 13). In both regions, the maximum departure between contemporary and presettlement fire frequency was generally reached between -4 and -2 °C mean minimum temperatures, 9 to 11 °C mean temperatures, and 25 to 27 °C mean maximum temperatures. In the Sierra Nevada, a rise in all of the FRID values also occurred again at the highest temperatures (fig. 13). In NW California, mean PFRID exceeded CC 1 along most of the temperature gradient, beginning at about -7 °C mean minimum temperature, 4 °C mean temperature, and 19 °C mean maximum temperature (fig. 12). In the Sierra Nevada, mean PFRID exceeded CC 1 above -10 °C mean minimum temperature, 3 °C mean temperature, and 19° mean maximum temperature; it fell back within CC 1 above 4 °C mean minimum temperature.

In southern California, FRID measures rose with increasing temperature until approximately -6 °C mean minimum temperature, 7 °C mean temperature, and 25 °C mean maximum temperature (fig. 14). Thereafter all measures dropped strongly

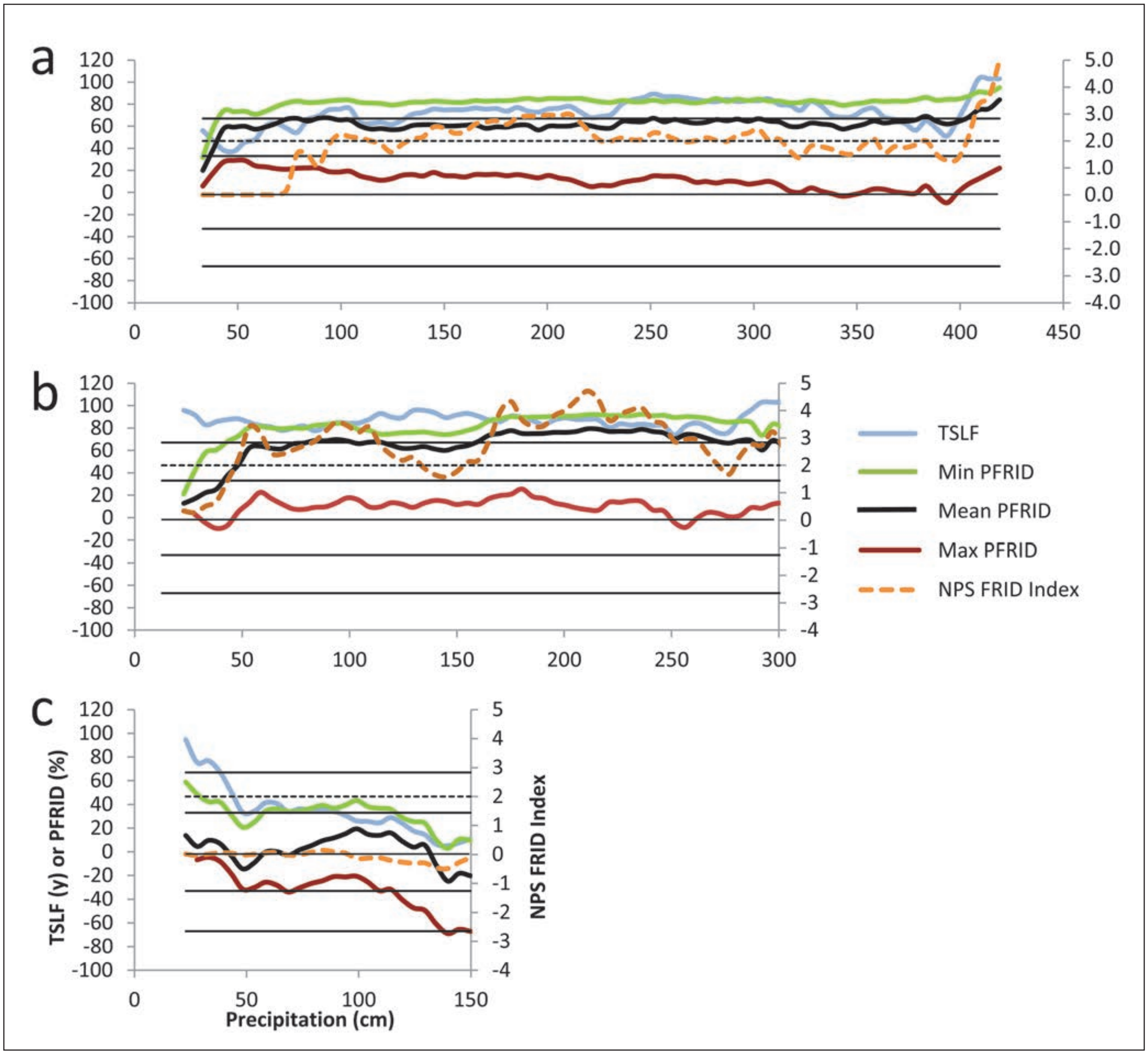

Figure 11—Time since last fire (TSLF) and fire return interval departure (FRID) versus precipitation in (A) northwest California region, (B) Sierra Nevada region, and (C) southern California region. Median percent FRID (PFRID) closely corresponds to mean PFRID and was removed for clarity. See figure 10 for explanation of horizontal reference lines. NPS = National Park Service.

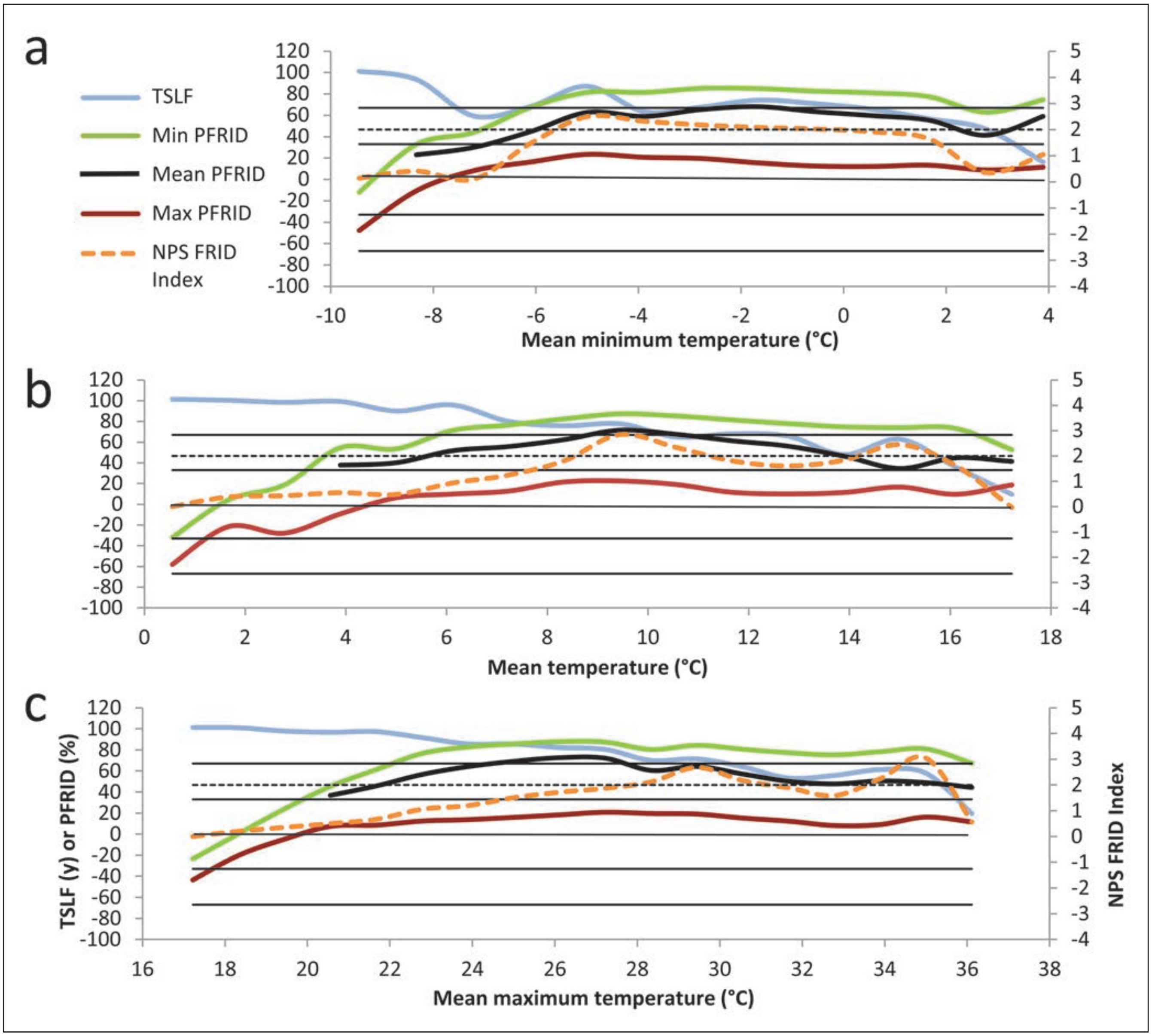

Figure 12—For the northwest California region, time since last fire (TSLF) and fire return interval departure (FRID) versus (A) mean minimum annual temperature, (B) mean annual temperature, and (C) mean maximum annual temperature. Median percent FRID (PFRID) closely corresponds to mean PFRID and was removed for clarity. See figure 10 for explanation of horizontal reference lines. NPS = National Park Service.

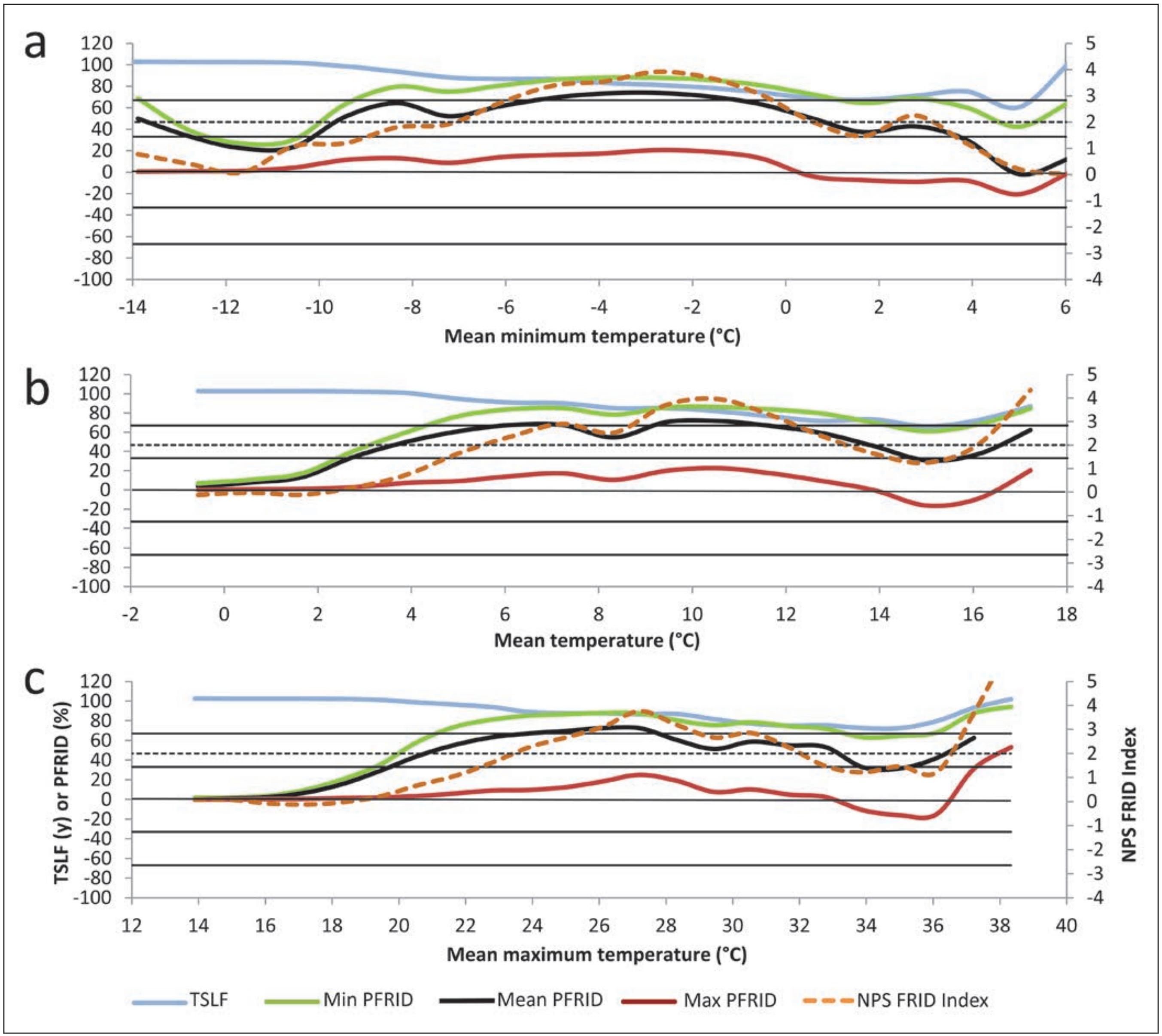

Figure 13—For the Sierra Nevada region, time since last fire (TSLF) and fire return interval departure (FRID) versus (A) mean minimum annual temperature, (B) mean annual temperature, and (C) mean maximum annual temperature. Median percent FRID (PFRID) closely corresponds to mean PFRID and was removed for clarity. See figure 10 for explanation of horizontal reference lines. NPS = National Park Service.

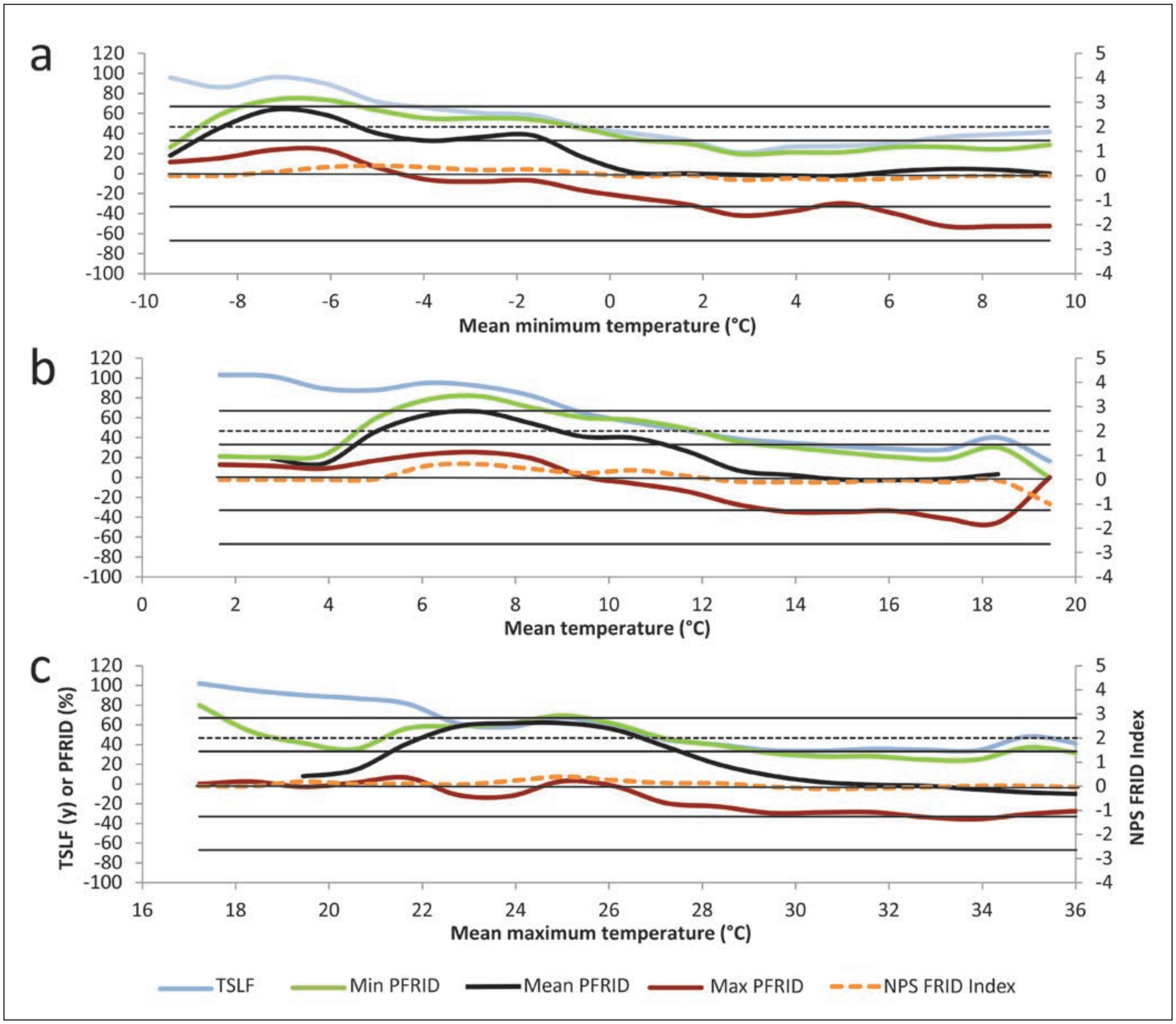

Figure 14—For the southern California region, time since last fire (TSLF) and fire return interval (FRID versus (A) mean minimum annual temperature, (B) mean annual temperature, and (C) mean maximum annual temperature. Median percent FRID (PFRID) closely corresponds to mean PFRID and was removed for clarity. See figure 10 for explanation of horizontal reference lines. NPS = National Park Service.

with increasing temperature. In southern California, mean PFRID (and most other indices) fell in the CC 1 to CC -1 belt above -1 °C mean minimum temperature, 11 °C mean temperature and 27 °C mean maximum temperature (fig. 14).

Differences Among Presettlement Fire Regime (PFR) Types

There were notable differences in departure statistics among the 28 major PFR types (table 4). With respect to PFRs experiencing missed fire events, the most extreme departures (CC 3) were in lower montane and montane forest and woodland types, with the degree of departure decreasing broadly with increasing elevation, precipitation and the snow:rain ratio, and decreasing temperature: yellow pine (*Pinus ponderosa* Dougl. ex Loud. and *P. jeffreyi* Balf.) and dry mixed conifer > moist mixed conifer (all CC 3) > lodgepole pine (*P contorta* Douglas ex Louden) > red fir (*Abies magnifica* A. Murry bis) > western white pine (*P. monticola* ex D. Don) (all CC 2) > subalpine (CC 1) (table 4). Aspen (*Populus tremuloides* Michx.) was another PFR type with mean PFRID in CC 3. With respect to PFRs experiencing enhanced fire activity, there were two groups with high departures: coastal fir and fire-sensitive spruce/fir (both CC -2), which are primarily ± maritime or in areas of higher precipitation; and coastal sage scrub (also CC -2 on average), a shrub type in coastal and near coastal southern California. Much chaparral in southern California is also in CC -2 or -3, but northern California stands are not as prone to anthropogenic fire, and statewide averaging results in an overall mean PFRID of only -19 (CC -1). With respect to Great Basin PFRs, the three sagebrush types were ranked thus: silver sagebrush (*Artemisia cana*; almost CC 3) > big sagebrush (*A. tridentata*; high CC 2) > black and low sagebrush (*A. nova, A. arbuscula*; CC 1). The pinyon-juniper PFR was ranked CC -1 (table 4). Both desert shrubland PFRs (desert mixed shrub and semidesert chaparral) were CC -1, with some geographic areas experiencing much higher current frequencies of fire than under presettlement conditions (e.g., the western Colorado desert), and others not.

Discussion

Our analysis highlights some broad dichotomies and notable gradients in the contemporary occurrence of wildland fire when viewed in the context of the probable "natural" fire frequencies experienced by the ecosystems over the centuries preceding Euro-American settlement. Geographically speaking, there are major differences between northern California and southern California, continental-climate California (Great Basin and desert) and Mediterranean-climate California, and wildland and suburban California. Elevation is unimodally related to most FRID measures, as are mean minimum, mean, and mean maximum temperatures.

Table 4—Total area and spatial averages of time since last fire (TSLF) and fire return interval departure (FRID) measures for the 28 presettlement fire regime (PFR)[a] groups analyzed in this study

PFR	Area	TSLF	Mean PFRID	Median PFRID	Min PFRID	Max PFRID	NPS-FRID Index
	Hectares	*Years*					
Aspen	24 533	96	80	79	89	7	4.0
Big sagebrush	1 105 857	89	57	50	82	5	1.5
Bigcone Douglas-fir	31 939	31	20	23	87	-51	0.0
Black and low sagebrush	336 888	99	32	45	63	-4	0.5
California juniper	7084	71	-4	1	93	-32	-0.2
Chaparral and serotinous conifers	1 575 973	38	-19	-23	24	-47	-0.3
Coastal fir	18 036	20	-57	-67	23	-72	-0.7
Coastal sage scrub	108 323	40	-33	-48	51	-53	-0.5
Curl-leaf mountain mahogany	64 907	96	43	32	67	-8	0.9
Desert mixed shrub	308 386	99	-4	-4	-3	-4	-0.9
Dry mixed conifer	1 398 610	85	85	88	93	35	6.7
Fire-sensitive spruce or fir	159	16	-63	-47	-38	-75	-0.8
Lodgepole pine	186 298	99	62	63	84	-5	1.7
Mixed evergreen	1 302 184	67	51	78	74	-11	1.3
Moist mixed conifer	2 090 128	85	80	85	94	7	4.3
Montane chaparral	519 106	73	61	64	77	27	1.8
Oak woodland	184 673	73	79	79	91	25	5.1
Pinyon juniper	650 199	95	-7	3	46	-8	-0.5
Port Orford cedar	8373	91	65	81	88	-12	2.0
Red fir	522 511	93	55	63	83	-8	1.4
Redwood	7585	60	51	68	78	-38	1.6
Semidesert chaparral	56 233	58	-2	-2	15	-35	-0.1
Silver sagebrush	7921	98	64	69	84	33	1.8
Spruce-hemlock	636	103	0	0	0	0	-0.6
Subalpine forest	335 339	100	-2	-2	1	-3	-0.5
Western white pine	35 066	99	48	57	84	-5	1.0
Yellow pine	1 279 302	80	84	90	93	43	6.3

Note: Results for the shore pine PFR are not reported as it does not occur in the analysis area. Percent fire return interval departure PFRID data are read as percentage departure.

[a] From Van de Water and Safford (2011).

In southern California, precipitation is negatively related to FRID, but elsewhere (both NW California and the Sierra Nevada) it shows little relationship above 50 cm. There are differences among management units and vegetation types as well. We discuss these patterns below.

Vegetation in "northern California" (NW California and Sierra Nevada regions) is dominated primarily by conifer forest and woodland, while shrublands and hardwoods dominate coastal southern California with dryland and desert vegetation covering interior southern California. For any given longitude, precipitation in northern California is generally higher than in southern California, and areas of similar elevation and topographic position are usually warmer and drier in southern California. The fire season in southern California is nearly year-round (compared to 4 to 6 months in most of northern California), and half of the year is characterized by periodic strong, dry easterly winds (e.g., "Santa Ana winds") that are rare north of latitude 35°. About two-thirds of California's human population lives in the southern one-fifth of the state, and fire ignition patterns strongly follow this pattern. The proportion of lightning to human ignitions (on Forest Service lands) is about 1:5 in southern California, but closer to 1:1 in the rest of the state (and 1.3:1 if the Lake Tahoe Basin is excluded) (Keeley 1982). These major ecogeographic differences between southern and "northern" California are key to understanding many of the geographic gradients we see in the FRID data.

Patterns in Southern California

Forest Service lands in 6 of 18 of the ecological sections had average mean and median PFRID values less than 0, and all of these are in southern California. Most of these averaged in the CC -1 range (0 to 33 percent departure), with the exception of Forest Service lands in the Colorado Desert section (a very small area in only one subsection analyzed), which were CC -3 or borderline by all of the PFRID measures, and the central Coast Ranges section, which were CC -2 (almost all Forest Service land in the section is in one subsection, the southern part of the interior Santa Lucia Range). In our analysis, the Colorado Desert section was represented by 521 ha of Forest Service land in the Coachella Valley subsection. Much of the valley is populated or converted to agriculture, and human ignitions are affecting Forest Service lands in areas that are (or were) dominated by the desert mixed shrub PFR, which has the longest reference mean FRI (610 years) of the 28 PFR types in our study (Van de Water and Safford 2011). The Anza-Borrego desert to its south (the Borrego-West Mesa subsection, not in our study area) is also subject to a regime of numerous ignitions by humans. In both subsections, invasion of drylands by exotic grasses and forbs (e.g., red brome [*Bromus madritensis* L. ssp. *rubens*], Mediterranean grass [*Schismus* spp.], Sahara mustard [*Brassica tournefortii* Gouan]) is widespread and leads to fuel continuity that abets fire spread (Brooks and Minnich 2006). Similar invasion by highly flammable exotic species is also occurring in areas of the Mojave Desert Section (which is also mapped predominantly in the mixed desert shrub PFR), but Forest Service lands in the Mojave Desert are only a very small proportion of the section area (fig. 3, table 2) and they are dominated by stands of California juniper (*Juniperus californica*), whose mean presettlement FRI (77 years) is very close to the average TSLF for the section (table 3).

Many areas in the Southern Coast and Southern Mountains and Valleys ecological sections have seen fire frequencies rise dramatically over the last century. Most of this increase in fire activity has occurred since the end of World War II, and temporal and spatial patterns in increasing fire frequency in southern California are strongly correlated with human population growth (Keeley and Fotheringham 2001, Syphard et al. 2007). Interactions between human populations and highly flammable vegetation types like coastal sage scrub and chaparral have led to major changes in fire regimes in and around southern California's urban areas. The ecological subsections surrounding the San Diego, Los Angeles, and Santa Barbara metropolitan areas are among the most negatively departed in the state (figs. 4 and 6; because they did not include Forest Service lands, the coastal subsections including the San Diego and Los Angeles metropolitan areas, Oxnard, and the Santa Monica Mountains were not analyzed in our study, but they have some of the highest fire frequencies in California). In these areas, extensive landscapes characterized originally by dense native shrublands have been converted to degraded, open stands of native shrubs and exotic annual grasses and forbs, which are easily reignited. These fire-mediated changes in vegetation lead to higher rates of erosion, increased exotic species invasion, and higher fire hazard as grass fuels replace shrubs (Merriam et al. 2006, Wells 1987, Zedler et al. 1983).

For its size, southern California between Santa Barbara, San Diego, and San Bernardino is the national leader in average annual wildfire frequency and area, as well as fire-caused human mortality, home loss, and economic damages (Halsey 2004, Hammer et al. 2007, Safford 2007). Although the ecological consequences of the contemporary anthropogenic fire regime in southern California are significant, they receive comparatively little coverage in the popular press, and further degradation of the remaining natural landscapes in southern California will feed back into yet greater human exposure to natural hazards like debris flows, flash floods, and wildfires in suburban settings (Cannon and Gartner 2005, Halsey 2004). Continued high fire frequencies in southern California also threaten the viability of plant and animal species that require longer fire-free periods. High-profile examples of such species include the federally listed California gnatcatcher (*Polioptila californica*) and Tecate and Cuyamaca cypress (*Hesperocyparis forbesii, H. stephensonii*) (Bontrager et al. 1995, Gouvenain and Ansary 2006).

Three small areas of higher mountains (up to 3500 m) rise above southern California south of 35° N latitude. These are found within the Upper San Gabriel, Upper San Gorgonio, and San Jacinto Ecological Subsections. These three subsections can be clearly seen in the mean PFRID map in fig. 6a, where they appear as positive (blue) inclusions in the sea of negatively departed landscapes. These mountain "sky islands" support coniferous PFRs like dry mixed conifer, yellow pine, and lodgepole pine, as well as mixed evergreen forest and montane chaparral. To a great extent, plant communities inhabiting these higher mountains are southern extensions of montane communities in the Sierra Nevada, and their historical relationship with fire is similar (Sugihara et al. 2006). Lightning-ignited fires once burned frequently in these high-elevation forests, but—unlike in lowland chaparral—fire suppression policies have been successful in nearly eliminating wildfire as an ecological force (Keeley et al. 2009). This has resulted in a curious elevational schizophrenia in contemporary southern California fire regimes, where high-elevation forests that once experienced frequent, low- to moderate-severity fire now rarely experience it (and when they do, it is often high severity), while many areas of lower elevation shrublands that experienced relatively infrequent fire before Euro-American settlement (on average maybe every 50 to 80 years) (Van de Water and Safford 2011) are now seeing fire return intervals of 10 to 20 years or less (Safford 2007).

Although it is also part of our southern California block, Forest Service lands in the Central Coast Section are mostly within the probable HRV for fire frequency or are only moderately departed (table 2, figs. 4 and 6) (Moritz 1997). Although a spate of recent large fires in the northern Santa Lucia Range has brought attention to the area, presettlement mean FRIs for the dominant vegetation types in the area were between 23 years (redwood; but this was strongly anthropogenic [Greenlee and Langenheim 1990]) and 76 years (coastal sage scrub) (Van de Water and Safford 2011). Most Forest Service lands in the north and south Santa Lucia Range subsections have burned between two and four times since 1908, so FRIs over the last century are mostly between 25 and 50 years.

Great Basin

In similar fashion to the southern California deserts but to an even greater degree, the Great Basin is experiencing a rash of large fires in lower elevation ecosystems that are driven largely by invasive species (chief among them cheatgrass [*Bromus tectorum* L.] and red brome), which have altered fire regimes by increasing fine fuels, fuel connectivity, and the rate of fire spread (Link et al. 2006). Most PFRs mapped in the small portion of eastern California belonging to the Great Basin sensu lato (ecological sections include Mono, the Southeastern Great Basin, and the Northwestern Basin and Range) (table 2) had presettlement FRIs between 35 and 150+ years (Van de Water and Safford 2011). Some areas in the Great Basin of Nevada and southern Idaho are now burning at intervals of 3 to 5 years (Whisenant 1990). Such extremely high fire frequencies are not yet common in the Great Basin portion of our study area, because the wave of cheatgrass invasion only recently arrived in eastern California, but also because Great Basin lands contained in the California national forests tend to be higher elevation and are less subject to invasion by annual grasses (D'Antonio et al. 2004). Fire frequencies are very high in the Nevada counties east of Lake Tahoe and northeast of Mono Lake (between 38 and 40° N latitude, in Washoe, Douglas, and Lyon Counties and Carson City, just to the east of our study area), and many former stands of single-leaf pinyon pine (*Pinus monophylla* Torr. & Frém.), juniper (*Juniperus* spp.), sagebrush (especially subspecies of *Artemisia tridentate* Nutt.), and even Jeffrey pine have been eliminated and replaced by degraded landscapes of exotic grasses and scattered shrubs. Cheatgrass has recently become an issue in the Mediterranean part of California as well, and it is now a frequent invader of burned areas along the west slope of the Sierra Nevada, especially where the regenerating shrub layer is sparse (McGinnis et al. 2010).

Northwestern California and Sierra Nevada Regions

Unlike most of southern California, the NW California and Sierra Nevada Regions ("northern California") are experiencing major ecosystem impacts from a century of fire suppression. The effects of fire exclusion on fire frequencies in northern California are the most obvious large-scale pattern in figures 4 to 6 and table 2. Densities of ignitions by humans are much lower in northern California; northern California is less subject to extreme thermal winds than southern California; the northern California fire season is shorter; and fires in contemporary forests in northern California burn largely through woody coniferous fuels, in which relatively low vertical and horizontal continuity in fuel structure makes the occurrence and sustenance of crown fire much less likely than in the more homogeneous and continuous fuels found in southern California chaparral. As a result, the fire suppression policy has been effective in much of northern California, although recent trends in fire activity, burned area, and fire severity suggest that the situation is rapidly changing as climate warms and fuels continue to accumulate (Miller and Safford 2012, Miller et al. 2009, Westerling et al. 2011).

The ecological sections with Forest Service lands having the greatest FRI departures in California are the Southern Cascades, the North Coast (but only a very small part of the section analyzed), the Klamath Mountains, the Northern Coast Ranges and the Sierra Nevada (table 2). The NPS-FRID index, which focuses on the time since last fire, identifies the Southern Cascades as the section with the greatest departure—its 4.6 score is almost in the "extreme" range—while the other sections listed above all scored as 3.3, or "high" departure. There have been very few wildfires in the Southern Cascades section during the contemporary period, largely because—between the volcanoes—much of the landscape is comprised of forests on rolling lava beds and the road density is high, which combine to permit rapid firefighter access to and containment of fire starts (Skinner and Taylor 2006). Another factor contributing to high FRID in certain NW California and Sierra Nevada ecological sections is the high level of fragmentation of federal land ownership. The checkerboard ownership pattern across much of eastern NW California and the northern Sierra Nevada leaves little opportunity for creative fire management to serve ecological purposes, as private land is usually within a burning period of any ignition point.

The only large area of low CC 2 (in some cases CC 1) lands in the Sierra Nevada and NW California regions is found in the southern Sierra Nevada (fig. 6). Here, checkerboard ownership is rare, and Forest Service and NPS lands combine to form one of the largest contiguous blocks of federally managed forest lands in the lower 48 States. The core of this block is formed by Yosemite, Sequoia, and Kings Canyon NPs, all of which include large areas of wilderness managed to promote the occurrence of naturally ignited wildfires. Neighboring national forests (e.g., Sequoia, Sierra, Stanislaus, Inyo, and Humboldt-Toiyabe) also include large tracts of high-elevation wilderness, and wildfires are much more likely to be managed for ecological benefits here than on any other national forests in California. That said, it is noteworthy that the mean PFRID averaged across these southern Sierra Nevada management units still falls into CC 2 (in the case of the Stanislaus NF, CC 3) (table 3). The similarities in PFRID metrics between the adjacent national forest and NPS units are due to the fact that fire was suppressed in both land ownerships for the majority of the time period considered in our analysis (until the early 1970s, when the NPS embarked on a more aggressive wildland fire-use program [note that the term “wildland fire use” is no longer in use]), and relatively few areas have burned a sufficient number of times since 1908 to make up the long-term deficit in fire. If we had based our PFRID comparisons on current FRIs beginning in 1970 instead of 1908, the differences between the NPS units and the national forests would doubtless be much greater. A further consideration is that naturally ignited fires managed for ecological benefit tend to occur in higher elevation forests (e.g., high-elevation mixed-conifer, red fir, subalpine), where fire is more easily controlled owing to lower tree densities, low fuel loadings, and higher fuel moistures, but where FRIs are longer and FRID is generally lower than at lower elevations that are (or were once) dominated by yellow pine, oak, and dry mixed-conifer forests. Fire managers are much less comfortable allowing fires in lower elevation forests to burn, as high fuel loads, drier conditions, and the presence of human communities magnify the consequences of a fire escape. Such lower elevation forests are the core of the fuels problem however, and—at the landscape scale—the use of managed fire in high-elevation forests, while commendable, does nothing to resolve the growing potential for high-severity fire in the yellow pine and mixed-conifer belt (Miller et al. 2009, Miller and Safford 2012). Even under a much expanded managed fire program, it will take many decades of progressive wildfire use in these landscapes to restore them to a compositional and structural state that is reasonably resilient to the probably accelerated disturbance regimes of a warmer future (Overpeck et al. 1990).

The only ecological subsections in NW California and the Sierra Nevada with contemporary fire frequencies approaching presettlement frequencies are in the northern and southern ends of the Sierra Nevada Foothills, the mountain ranges and dry valleys of the Mojave/Southeastern Great Basin, and portions of the Modoc Plateau in the northeastern corner of the state (fig. 6). In the case of the Sierra Nevada Foothills, these are largely landscapes of grasslands and oak woodlands, where contemporary fire frequencies are high owing to intensive human land use and relatively high population densities. The Great Basin and Modoc Plateau subsections support dryland ecosystems (sagebrush, pinyon-juniper, etc.) with longer natural FRIs (35 to 151+ years), and fire frequencies have been relatively low over the last century. The ongoing invasion of cheatgrass into the Great Basin borderlands seems likely to increase fire activity in these subsections as the climate continues to warm (Billings 1994, Brooks and Minnich 2006).

FRID Trends Along Environmental Gradients

Fire return interval departure trends along the analyzed environmental gradients (elevation, precipitation, and temperature) underline the similarities between NW California and the Sierra Nevada, and the different nature of the fire situation in southern California. Along the west coast of North America at 90° W longitude and between 20° and 60° N latitude, the latitudinal gradient in monthly mean temperature averages about 5.6 °C per 1000 km (ranging from 8.7° January to 2.5° July; calculated from isotherms in FAA [1975]). Thus, on average, mean annual temperatures in interior NW California at latitude 41° N are about 1.8 °C cooler than at the same elevation in the central Sierra Nevada (latitude 38° N) and about 4.3 °C cooler than the same elevation in interior southern California (latitude 34° N). The latitudinal increase in warmth to the south results in an upward shift of the major forest types. The elevations and temperatures of the maximum mean PFRID values in NW California and the Sierra Nevada (elevations of 1500 to 1700 m in the former, 1700 to 1900 m in the latter; corresponding temperatures of -2 °C mean minimum, 10 °C mean, 27 °C mean maximum; figs. 10 through 13) correspond broadly to the average elevation of the transition from moist mixed-conifer ("lower montane") to red fir ("upper montane") forest. These elevations are slightly above the level of maximum annual precipitation (Armstrong and Stidd 1967, Barbour et al. 2007), and correspond approximately to the elevations at which the mean freezing level occurs during mid-winter storms (Barbour et al. 2002). Red fir-dominated forests above this transition receive the highest snowfall totals of any vegetation type in California, the growing season is short, and productivity is markedly lower than in lower montane forests (Barbour et al. 2002, 2007). This leads to lower levels of fuel accumulation, moister fuel beds in the early fire season, and lower fire hazard than in the mixed-conifer belt (Cope 1993, Kilgore 1981, Sugihara et al. 2006); the latter is also partly due to the enhanced component of fir needles in surface litter in red fir forest, as fir litter is substantially less flammable than pine litter (Fonda et al. 1998). Presettlement FRIs in the red fir belt averaged 40 years (range of means = 15 to 130), while moist mixed-conifer forests in the lower montane zone supported much more frequent fire (mean = 16 years, range = 5 to 80) (Van de Water and Safford 2011).

In southern California, the behavior of FRID metrics along the environmental gradients was substantially different than in the two northern California regions. The elevations of the maximum mean PFRID values were much higher than in northern California (2500 to 2700 m), and the temperatures much lower (-7 °C mean minimum, 7 °C mean, 25 °C mean maximum; these correspond to about 2600 m). Above these elevations, FRID dropped rapidly (fig. 10), suggesting a threshold type of response. We believe this is because there is no red fir in southern California, so there is no transitional fire regime between the mixed-conifer and subalpine forests, which begin above 2400 to 2700 m in southern California. According to Minnich (2007), the mixed-conifer/subalpine ecotone in southern California represents a shift from frequent surface burns to infrequent stand-replacing burns, and our data support this generalization. As in NW California and the Sierra Nevada, the elevation of the highest mean PFRID values in southern California corresponded broadly to the elevation of the mean freezing level during winter storms, which ranges from 2300 to 2500 m (Minnich 1986) in the San Bernardino Mountains.

The NPS-FRID index is almost invariant along the analyzed environmental gradients in southern California, remaining very near zero in almost all cases. The only slight rises in the NPS-FRID index in southern California are at about those temperatures or elevations that correspond to the maximum mean PFRID values. Because it was developed for assessing departure in fire-suppressed forests, the NPS-FRID index is insensitive to fire frequencies that are occurring at shorter intervals than under reference conditions, which is the case in most of the southern California lowlands that we analyzed. The fact that the NPS-FRID index remains near zero even in fire-suppressed montane forests underlines the recent increase in fire activity that has characterized southern California in general. The PFRID metrics, which depend on FRI information from the entire 103-year record of fire perimeters, show major departures from presettlement conditions and dilute the signal of recent rises in burned area and the incidence of large fires in southern California, which have been ascribed to the effects of increasing drought severities on fuel conditions (Keeley and Zedler 2009).

On its own, precipitation shows no obvious relationship to any of the FRID metrics or TSLF in northern California, but most of the FRID metrics and TSLF appear to decline with rising precipitation in southern California. The range of precipitation in NW California and the Sierra Nevada is at least twice as broad as the range in southern California (fig. 11). All of the regions include some areas with annual precipitation < 50 cm, but none of our southern California analysis area receives more than 150 cm annually, while many areas in the Sierra Nevada and NW California do (fig. 11) (Minnich 2007, Potter 1998). Working in the Sierra Nevada and NW California, Miller et al. (2009, 2012) found that for the period 1908–1910 to 2006–2008 (depending on the region), annual precipitation had no relationship to annual fire number, mean or maximum fire size, or total annual burned area in either region (only forest fires analyzed). However, different seasonal precipitation totals explained substantial variation in the response variables, with the season in question changing over the course of the study period; summer (June through August) or spring (March through May) precipitation had the strongest relationship over the last 20 to 25 years (Miller et al. 2009, 2012). We did not relate seasonal precipitation totals to FRID or TSLF, but Miller et al.'s results, where no single season of precipitation was related to fire number, size, or area measures through the entire study period, make us confident that we would have found no simple relationship. The lower PFRID and NPS-FRID index measures below 50 cm precipitation in NW California and the Sierra Nevada are driven partly by the longer reference FRIs in sagebrush-dominated habitats in the northeastern and southeastern Sierra Nevada regions, and partly by recurrent fires in drier lowland habitats around the Central Valley and elsewhere (fig. 6).

In southern California, the strong drop in TSLF and the PFRID metrics (and the slight dip in the NPS-FRID index) above 100 cm precipitation (fig. 11) is due to the very large 2008 and 2009 southern and central California fires, which burned over 160 000 ha in areas of relatively high precipitation, including the Monterey District of the Los Padres NF (which includes the only part of southern California with mean annual precipitation > 120 cm), and the San Gabriel Mountains around Mount Wilson. Higher PFRID values below 50 cm precipitation (fig. 11) are due primarily to the northeastern, transmontane part of the main body of the Los Padres NF (see figs. 1 and 4), which supports >100 000 ha of pinyon-juniper (presettlement FRI mean = 151 years, range 50 to 250), California juniper (mean = 83 years, range = 5 to 335), and related dryland vegetation and has largely escaped fire for the last century.

Using FRID Data in Resource Management

Using historical data to inform resource management is not simple, and a number of critical limitations must be surmounted. Important limitations include how to account for the roles of humans in reference ecosystems, mismatches in scale within the data and between the data and their application, the quality and quantity of available data, and the lack of stationarity in environmental baselines (Wiens et al. 2012). We discuss these complications below, and then finish with a few examples of how our FRID data can be used in resource management and restoration.

The role of human ignitions prior to Euro-American settlement—
A question that always arises when restoration of fire is discussed is, What role did humans have in the pre-Euro-American settlement regime, and should we be targeting that regime or some version of a fire regime driven only by “natural” (lightning, etc.) ignition sources? The presettlement fire record is derived primarily from fire-caused injury lesions in tree stems or charcoal in layers of sediment or peat, and we are mostly unable to discern lightning-ignited fires from anthropogenic fires. Although lightning occurrence differs temporally at multiple scales, contemporary lightning strike densities (LSDs) can provide some idea as to where on the landscape the ratio of lightning to anthropogenic ignitions was skewed one way or another. California is one of the least lightning-prone states in the United States, with most of the Mediterranean part of the state averaging only 0 to 0.25 strikes per square kilometer per year (compare to the Gulf Coast, with over six strikes per square kilometer per year, or the southeastern and Midwestern United States, with more than three strikes per square kilometer per year [Orville 2008]). The highest LSDs in California are in the deserts of southeastern California and the eastern and higher western slopes of the Sierra Nevada, where average annual LSDs range from 0.3 to 0.55 strikes per square kilometer per year. Highlands in the eastern Klamath Mountains, the southern Cascades, and the interior ranges of southern California average about 0.25 to 0.3 strikes per square kilometer per year (van Wagtendonk and Cayan 2008). Pre-Euro-American settlement fire frequencies in the California Coast Ranges were clearly due primarily to human use of fire, with redwood and

coastal oak woodlands being two of the best examples of ecosystems strongly shaped by human fire management. The relative magnitude of human inputs to the fire regime in the Sierra Nevada before Euro-American settlement is much less certain, although anthropogenic fire was certainly a significant factor within some radius of many Native American cultural sites and as California probably supported more Native Americans than any other Western State (Anderson 2005, Starr 2005), giving consideration to their role in molding California ecosystems seems both wise and justified. (Anderson 2005, Sugihara et al. 2006). Depending on desired conditions and the results of collaborative planning, restoration target conditions in California landscapes might focus on the cultural presettlement landscape, or on some vision of an ecosystem resilient to warming temperatures and higher fire hazard in the future, or even on some conception of how the landscape might have looked in the absence of anthropogenic fire. Whatever the location and the management situation, humans have been in California for more than 10,000 years.

Issues of scale—

We conducted our assessment primarily at the state and regional level, which necessarily hides substantial variability at finer scales. For example, the Sierra Nevada sensu stricto is nearly 700 km long, and precipitation drops and temperature rises from north to south. Forest structure and composition also change. Tree densities and canopy cover decrease to the south, pine dominance increases, and shade tolerant tree species like Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), tanoak (*Notholithocarpus densiflorus* Hook. & Arn.) Manos, CH. Cannon & S. oh), and madrone (*Arbutus menziesii* Pursh) are rare or altogether absent south of 37° 30’ N latitude (Barbour et al. 2007). Other tree species, like giant sequoia (*Sequoiadendron giganteum* (Lindl.) J. Bucholz) and foxtail pine (*Pinus balfouriana* Balf.), are restricted primarily or completely to the southern Sierra Nevada. Such clinal changes can have major effects on the fire regime, even within a single vegetation or PFR type. As noted in Van de Water and Safford (2011), different FRI measures (mean, median, minimum, maximum) may be of more use in different parts of the PFR range. Where local data on pre-Euro-American settlement fire regimes are available, they should be consulted (see Van de Water and Safford [2011] for a comprehensive list of pre-2011 references). Spatial relationships between PFRs can also have a major impact on local fire regimes. For example, where vegetation types of very different flammabilities are juxtaposed, fire frequencies will be locally affected. Vegetation patch sizes are also important and can be an important determinant of the local fire regime (Agee 1998, Bond and van Wilgen 1996). Our FRID mapping products are available for all Forest Service units in California, so assessments at finer scales are possible.

Another scalar issue is related to the numerical resolution of the FRID data and the resolution at which they are applied. Condition classes based on some aspect of fire regime or its effects on ecosystem status (e.g., vegetation structure, such as in the FRCC program [Hann and Strohm 2003]) have become widely used measures of ecosystem status and management progress in reducing fuels or restoring forest structure. The green-yellow-red (good-poor-bad) color scheme of many condition class maps or graphics (e.g., fig. 9) is a useful and eye-catching method for highlighting areas in need of management intervention, but it can hide important variation in the analyzed ecosystems and landscapes, and it can suggest one-size-fits-all remedies for situations that require nuanced consideration. Our addition of the negative cc to the classic green-yellow-red (CC1-2-3) scheme for the mean PFRID metric (Safford et al. 2011) was an attempt to allow managers to recognize the very different ecological situations and management challenges created by departures caused by overly frequent fire. Broad categories like condition classes make wide generalizations possible, which may be useful for political, budgetary, and educational purposes. However, we recommend that the PFRID metrics be considered principally in their raw, unclassified form (e.g., 53 percent departure rather than "CC 2") and with a keen eye to local conditions and information that can provide a more reasoned and realistic assessment at scales that matter to on-the-ground management.

A third scalar issue pertains to the temporal scale of comparison between the reference FRI information and current FRIs. Our PFRID metrics are set up to compare two relatively long-term data sets: the current FRIs, which in this study are obtained from the 103 (inclusive) years between 1908 and 2010, and the pre-Euro-American settlement FRIs, which were primarily derived from the two to five centuries before 1850. Fire management in California has passed through a number of different philosophical and tactical phases (Stephens and Sugihara 2006), and the effects of these different management periods on fire occurrence are masked or diluted by a metric based on averages from 103 years of data. The best example of this effect is in the comparisons we made between Yosemite, Sequoia and Kings Canyon NPs and the adjacent Sierra Nevada national forests. Extensive management of natural ignited fires for resource benefits began in the national parks in the 1970s, and a PFRID comparison using only the current FRIs since that time would probably show much greater differences between the national parks and the national forests, which continue to suppress most wildfires.

Data quality considerations—

The PFR data provided in Van de Water and Safford (2011) are not infallible, and we know of a number of situations where future data collection and finer differentiation of fire regimes are recommendable. For example, Jeffrey pine was placed into the yellow pine PFR by Van de Water and Safford (2011), but it is very stress tolerant and often found in situations where low site productivity notably reduces growth and fuel accumulation. Such sites simply cannot support the very high fire frequencies associated with modal Jeffrey pine sites. Examples include ultramafic "serpentine" soils in NW California and the Sierra Nevada, where Jeffrey pine is often the dominant tree species (Safford and Mallek 2010). The high positive FRID found for the Upper and Lower Scott Mountains ecological subsections in the eastern Klamath Mountains, which are largely underlain by ultramafic substrates, is thus almost certainly an overestimate of departure. In the Sierra Nevada on nonserpentine sites, Jeffrey pine grows extensively on the east side of the range at moderate elevations and on the west side in upper montane forests, where it generally occupies rocky, exposed sites with California juniper and other stress tolerators. The reference FRI in these low-productivity west-side sites, nested in forest with mean presettlement FRIs ≥ 40 years, is likewise surely longer than the standard yellow pine PFR (Van de Water and Safford 2011). The many shrub and closed-cone conifer types grouped together under the huge PFR category "chaparral and serotinous conifers" by Van de Water and Safford (2011) also include variability in FRIs across climatic and edaphic clines that may be better incorporated into a number of groups.

The fire perimeter data upon which the FRID polygons are based are also far from perfect. Because the database focus is on the fire perimeter, many unburned inclusions within fires are missed. Older fire perimeters (pre-World War II) are notoriously inexact, and some fires are represented simply by circular polygons of the appropriate fire size centered on the approximate fire location. Some portions of California are missing records of most fires before 1950. Most prescribed fires are missing from the database, although we are currently working with the Forest Service and NPS to remedy this deficiency. With all of these problems, however, the California Fire Perimeters database (FRAP 2011) is the most extensive and complete data source for fire location, size, and shape in the world to our knowledge. It is considered approximately complete for fires over 4 ha in size back to 1950, and mostly comprehensive for Forest Service fires to about 1908, when the agency began to require the collection of data on fire location and size (see McKelvey and Busse 1996, Miller et al. 2009).

Optimally, we would base an assessment of current FRID from pre-Euro-American settlement conditions on a vegetation map of average presettlement conditions. Obviously such a map does not exist. We considered using potential vegetation maps such as the Küchler map of California from 1976 (Barbour and Major 1988) or the Biophysical Settings (BpS) map from the LANDFIRE project (Rollins 2009), but the former was drawn qualitatively on a very broad-scale map of the state before the advent of geographic information systems, and the latter has too many inaccuracies at the subregional scale. The Forest Service inventoried California's nondesert wildlands in the 1920s and 1930s, but this was 70 to 80 years after settlement (although only a few decades after the beginnings of federal fire suppression), and the project was halted after about 60 percent of the area had been mapped (Wieslander 1935). Our decision to go with the most accurate statewide map of existing vegetation means that any substantial changes in vegetation over the time since 1850 could have an impact on the accuracy of our metrics. One of the best documented widespread changes has been the decrease in pine dominance and the increase in fire-intolerant species in lower and middle elevation forests in northern California (and higher elevation southern California) owing to 19th- and 20th-century timber harvest and 20th century fire suppression (Barbour et al. 2007, Minnich et al. 1995, Sugihara et al. 2006, Thorne et al. 2008). Many forest stands mapped today as mixed conifer would probably have been mapped as yellow pine in the mid-19th century. In these cases, our FRID measures of current departure from presettlement FRIs understate the actual magnitude of change, as the FRID measures are being calculated based on the mixed-conifer reference FRIs, which are up to 45 percent longer (in the case of moist mixed conifer) than the yellow pine reference FRIs (Van de Water and Safford 2011). In other cases, the reverse may be true. For example, comparison of the 1930s Forest Service maps of the Sierra Nevada (Wieslander 1935) with the current EVEG maps suggests that some areas originally mapped as subalpine forest are now dominated by red fir, which would reduce the presettlement baseline mean FRI from 133 years to 40 years. In this case, our FRID measures are somewhat more difficult to interpret, as the vegetation change is more likely due to climate warming than human management (Dolanc et al. 2012), and management attempts to reverse the trend may be counterproductive.

Consideration of changing climate—
Ecosystem transformations caused by directional climate change form the basis for a recent wave of concern regarding the usefulness and applicability of historical data to contemporary and, more importantly, future management problems (Millar et al. 2007, Stephenson et al. 2010, Wiens et al. 2012). The traditional assumption that ecosystem patterns and processes vary about some long-term mean (i.e., that

they exhibit stationarity) was always untenable, but it has become even more so in the “Anthropocene” Epoch (Steffen et al. 2007). Changes in the environmental baseline resulting from climate change, or human land use, or invasive species, etc., make the uncritical use of historical data as a management target less and less defensible, but this does not reduce the value of historical data; indeed, the less we know about the future, the more we will have to rely on insight gained from our experiences with the past (Wiens et al. 2012). In the case of fire-suppressed forest types that historically burned at high frequency, human management has pushed the range of variation for fire occurrence far below the HRV. Modeled or inferred considerations of fire frequency over the next 50 to 100 years nearly unanimously project increasing potential for wildfire, perhaps even above levels that reigned when Euro-Americans settled California (see below). In this case, restoration of HRV conditions is a logical first step and might be treated as a waypoint toward the ultimate goal of increasing resilience to a much warmer future (Safford et al. 2012).

Management application of FRID data—
Fire return interval departure data can provide a template for assessing ecosystem conditions and evaluating landscapes for restoration need. Yosemite, Sequoia, and Kings Canyon NPs have used the NPS-FRID index for such purposes for over two decades (Caprio et al. 1997, Keifer et al. 2000, van Wagtendonk et al. 2002). At the simplest level, relationships between FRID and ecosystem type (as represented by our PFRs) can help direct broad landscape-level strategies. In northern California, high-elevation forests (red fir, western white pine, subalpine) are only moderately departed from historical conditions and—ecologically speaking—tend not to be high-payoff landscapes for fuels reduction, wildland fire use for ecological benefit, or other types of restoration management (Agee 2005). However, these are often the safest and easiest places to carry out such management (and climate warming is increasing concern for lower elevation red fir forests, which are transitional from the mixed-conifer belt). Areas of extreme departure, especially when evaluated against min or max PFRID, are probably at or beyond the HRV for fire frequency. These landscapes, mostly shrublands in southern California and low to middle elevation forests in northern California, may seem like logical places to focus ecological restoration efforts, but in some cases, they may be too difficult, too remote, too expensive, or too controversial to actively manage. The projected future environment of the restoration landscape will need to be considered in restoration planning, and management targets may need to be adjusted. The FRIs documented in the database do not need to represent the long-term target condition for the restored landscape, but they provide an idea of the range of fire frequencies that might best promote sustainability of the reference ecosystem type.

Future projections suggest even more ecological potential for wildfire in most Western U.S. forests than was the case during our pre-Euro-American settlement reference period (Lenihan et al. 2003, National Research Council 2011, Westerling et al. 2011), when fire was much more common than today. Climate-driven projections also suggest higher levels of drought and stress-related susceptibility to insect attack and disease (Evangelista et al. 2011, Sturrock et al. 2011). These projections suggest that a serious management effort will be required to increase the resilience of fire- and drought-prone landscapes to future environmental stressors. Our mean PFRID metric can be used in conjunction with the NPS-FRID index to identify recently burned locations that have experienced fire frequencies in the 20th century that are within or near HRV. Lydersen and North (2012) recently used a similar protocol to identify frequently burned mixed-conifer stands in the Sierra Nevada and conducted ground sampling to develop a picture of forest structure in fire-resilient stands. These are places to begin use of prescribed or managed wildland fire to ensure long-term maintenance of fire-resilient composition and structure. Such places could also be used as core areas around which to expand restoration efforts into the surrounding landscape.

As restoration efforts proceed, FRID data can be used to track progress and measure management success. Miller and Davis (2009) carried out fire modeling in two watersheds of Sequoia-Kings Canyon and Yosemite NPs based on suppressed lightning ignitions that had occurred during a previous 20-year period. At the end of their study period, they assessed the outcome of their exercise by generating a hypothetical map of the NPS-FRID index and comparing it to the actual FRID map that existed without the modeled fires. Tracking of fire restoration efforts at the broader landscape scale could be accomplished with a similar comparative protocol. For short-term monitoring, the NPS-FRID index may be the most useful performance measure, as it considers only the time since the most recent fire. In the end, repeated fires at appropriate levels of severity will be required to sufficiently restore the fire regime, vegetation structure and composition, wildlife habitat, and other ecosystem patterns and processes in frequent-fire forest types. In southern California shrubland ecosystems, on the other hand, the focus should be on reducing fire frequencies. Measures like mean, min, and max PFRID, which are better at evaluating the frequency of fire in an ecosystem over time, will be more helpful in targeting and tracking a long-term strategy to promote resilience. The final goal should not be a slavish adherence to the mean pre-Euro-American settlement fire frequencies listed in Van de Water and Safford (2011) and elsewhere. However, these values and their ranges can be used profitably as short- or medium-term targets for restoration efforts, in the understanding that the long-term goal is not some static picture postcard of a presettlement landscape, but a dynamic ecosystem that is more resilient to disturbance, a warming climate, and all of the other stressors that will come with global change.

When using the PFRID measures, managers may have the tendency to focus their restoration efforts on areas mapped as CCs 3 or -3, because current management policies are focused on highly departed lands. In most cases, this is probably a reasonable course of action, although—as noted above—for most situations we recommend use of the raw FRID data rather than the condition class categories. The extent to which the CC 2 and 3 or -2 and -3 boundaries might represent a reliable ecological warning bell can be gauged by the information provided in table 1. Table 1 compares the mean minimum and mean maximum pre-Euro-American settlement FRIs from Van de Water and Safford (2011) with the FRIs associated with the CC 2 and 3 (+67 percent departure) and CC -2 and -3 (-67 percent departure) boundaries. The 33 percent and 67 percent cutoffs used to identify CCs 1, 2, and 3 were based on simple division of the 100 percent maximum departure into thirds (Hann 2004, Hann and Strom 2003), thus there is no underlying statistical distribution of fire frequencies assumed. This leads to different relationships between the range of presettlement FRIs associated with each PFR and the FRIs represented by the CC 2 and 3 and CC -2 and -3 boundaries (table 1, fig. 15).

Looking at table 1, some generalizations can be made about these differences. For example, most tree-dominated PFRs show longer mean maximum FRIs than the FRIs associated with the CC 3 boundary (e.g., fig. 15), while shrub-dominated PFRs in table 1 universally show shorter mean maximum presettlement FRIs than the FRIs represented by the CC 3 boundary (table 1). These differences are probably due both to differences in sample size (there are many fewer studies of fire history in shrub vs. forest ecosystems) (Van de Water and Safford 2011), and inherent differences in the distributions of fire frequencies in the two ecosystem types (e.g., Grissino-Mayer 1999, Moritz 2003). For tree-dominated PFRs with longer mean maximum FRIs, managers might want to treat the mean maximum FRI as a higher class of departure (“extreme?”). For shrub PFRs with shorter mean maximum FRIs, CC 3 is a more conservative measure of departure than the mean maximum FRI. On the negative side of the PFRID scale, for most shrub PFRs the mean minimum presettlement FRI is longer than the FRI represented by the CC -3 boundary (table 1). In practical terms, this means that for PFRs like chaparral/serotinous conifers or semidesert chaparral, both with extensive distributions in southern California, use of the CC -3 category as an ecological alarm bell for overly frequent fire may actually underestimate the magnitude of the ecological departure.

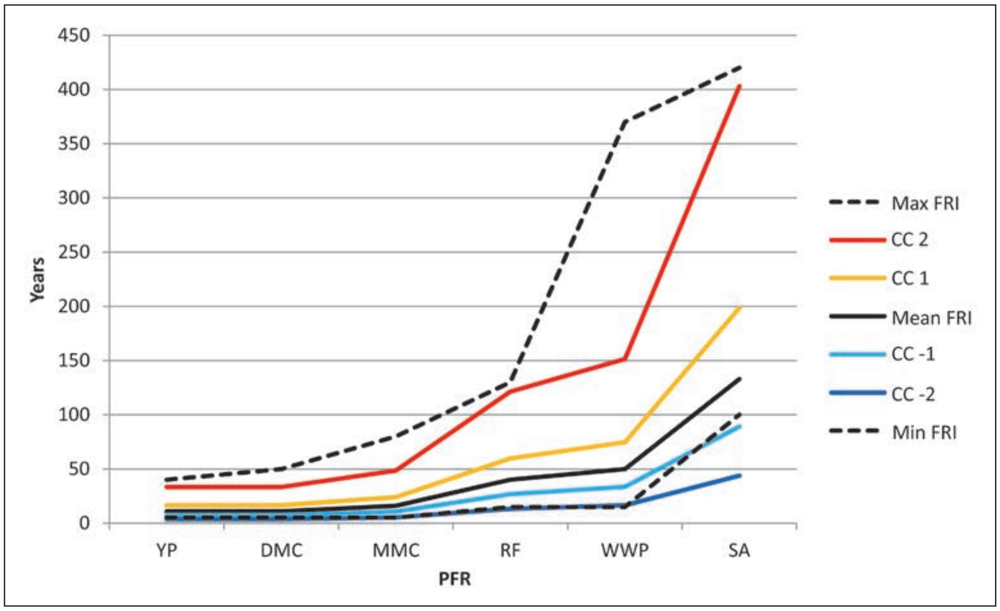

Figure. 15—Elevational gradient (left to right: low elevation to high) of six forest presettlement fire regimes (PFRs) on the west slope of the Sierra Nevada, comparing the condition class (CC) boundaries for each PFR with the approximate range of pre-Euro-American settlement fire return intervals (FRIs) (the area between mean maximum ["max FRI"] and mean minimum ["min FRI"]). Condition class color scheme corresponds to figure 9. YP = yellow pine, DMC = dry mixed conifer, MMC = moist mixed conifer, RF = red fir, WWP = western white pine, and SA = subalpine forest.

Fire return interval departure users should pay careful attention to the various limitations and caveats inherent to the tool. As discussed above, these include scalar issues, issues with data quality and extent, issues with the reference baseline, and issues with interpretation. We finish by reminding the reader that FRID analysis does not include information on aspects of the fire regime other than fire frequency calibrated by vegetation type. Fire occurrence and behavior are driven by such factors as topography, weather, and fuel conditions that were not directly considered in our analysis. FRID is a useful broad-scale planning tool, but proper interpretation at scales meaningful to resource managers will require concurrent consideration of other sources of information as well, such as site history, fuel loading and vegetation structure, topography, weather, and other components of the fire regime, including fire size, severity, and spatial pattern.

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English Equivalents

When you know:	Multiply by:	To find:
Millimeters (mm)	0.0394	Inches
Meters(m)	0.394	Feet
Kilometers (km)	0.621	Miles
Hectares (ha)	2.47	Acres
Square kilometers (km^2)	0.386	Square miles
Degrees Celsius (°C)	1.8 °C + 32	Degrees Fahrenheit

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