AGENDA

Three Rivers Community Plan Update
Community Meeting
Monday May 11, 2015 7:00 P.M.
Arts Building
Three Rivers, CA

... *service with pride.*
Resource Management Agency

1. Welcome and Introduction.

2. Project Status/Brief Review of Community Meeting #15 April 13, 2015 Oak Woodland Management Summary Notes.

   (a) Oak Woodland Management Summary Notes (April 13, 2015 Three Rivers Community Plan Update Meeting).

3. Discussion of Oak Woodland Management Information.

   (a) Oak Woodland Management Background Materials.
   1. A Natural Resource Condition Assessment for Sequoia and Kings Canyon National Parks (National Park Service, June 2013).
   2. Forest Health Protection Survey (USDA Forest Service, April 2015).
   3. Modeled Regional Climate Change and California endemic oak ranges (UC Santa Cruz, November 2005).
   4. Climate Change Effects on Vegetation Distribution, Carbon and Fire in California (USDA Forest Service, September 2002).
   5. The Definition and Location of Central California Sycamore Alluvial Woodland (California Department of Water Resources, May 1997).
   6. Different fire–climate relationships on forested and non-forested landscapes in the Sierra Nevada ecoregion (International Journal of Wildland Fire 2015).

   (b) Sample Tree Inventory and Sampling.
   1. The Tree Inventory (University of Connecticut).
   2. California Native Plant Society/California Department of Fish and Wildlife Protocol for Combined Vegetation Rapid Assessment and Releve Sampling Field Form (April, 2014).
   3. Minimum Data Collection Attributes for CAL FIRE Grant-Funded Urban Tree Inventories (CAL FIRE 2014).

   (c) Urban Forest Practice Ordinance Guidelines.
   1. Guidelines for Developing Urban Forest Practice Ordinances (Oregon Department of Forestry, November 1999).

(d) CAL FIRE Urban and Community Forestry Program Grants.

1. Urban Forest Management For GHG Reduction Grant Program Information).

4. Other Topics as Related.

5. Topics for the Next Meeting.

6. Next Steps.

7. Adjournment: Next Meeting June 8, 2015 at 7:00 P.M.

Three Rivers Community Plan Website address:
http://www.tularecounty.ca.gov/rma/index.cfm/planning/three-rivers-community-plan-update/

2. Project Status/Brief Review of Community Meeting #15 April 13, 2015 Oak Woodland Management Summary Notes.

(a) Oak Woodland Management Summary Notes (April 13, 2015 Three Rivers Community Plan Update Meeting).

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THREE RIVERS COMMUNITY PLAN UPDATE
Oak Woodland Management Discussion Summary Notes
(April 13, 2015)

I. Oak Woodland Management Plan Approach

- Focus on Plan and then Implementation.
- Collect Background Materials Including Threats to Oak Woodland Communities.
- Mapping and Inventory Protocol/Strategy should be developed to Determine Baseline/Existing Conditions.
- Plan Strategy.
- Degree of Regulation consistent with Threat of Harm.
- Study Area should focus on development footprint areas within the UDB (Attachment A).

II. Focus on Plan and then Implementation

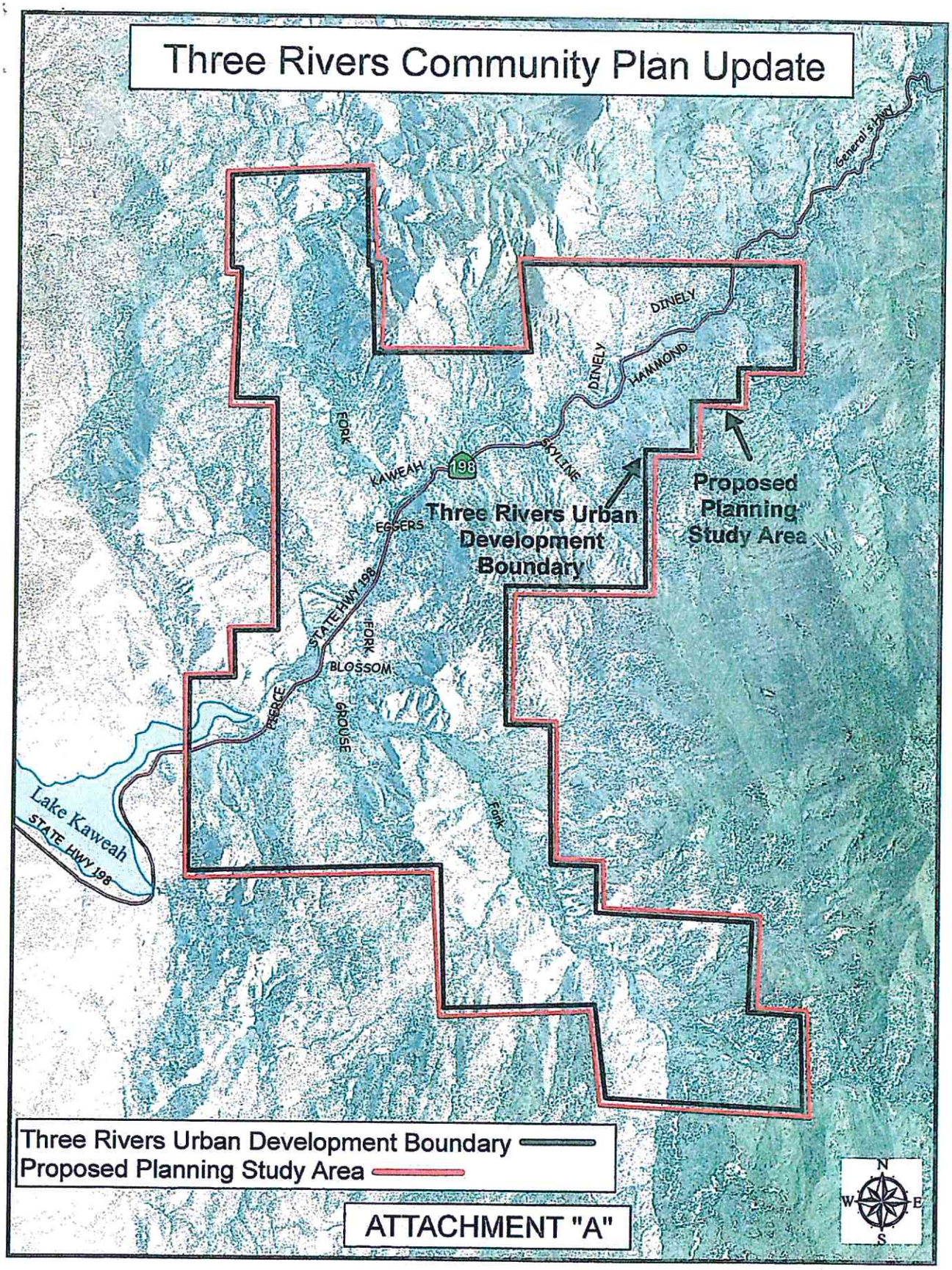
- Determine Plan Elements, Components, Design Guidelines, and Incentives.
- Consider description native oak species, estimates of the current and historical distribution of oak woodlands, existing threats, status of natural regeneration and growth trends. To the extent possible, prepare maps displaying the current distribution of oak woodlands.
- Review Importance of Oak Woodlands for economic value, natural resource values of oak woodlands, review importance of oak woodlands as benefits to wildlife habitat, retention of soil and water, aesthetics, and that planning decisions for oak woodlands should take into account potential effects of fragmentation of oak woodlands, support for landowners that participate in the Oak Woodlands Conservation Program, future funding, education and public outreach programs, implementation and update of the plan.

III. Collect Background Materials Including Threats to Oak Woodland Communities

- Review existing studies and materials, National Park Service, California Department of Fish and Wildlife, Academic Studies, California Native Plant Society, Caltrans.
- Oak Woodland Conditions.
- Threats to Oak Woodland Communities, Fire, Disease, Climate Change, Urban Development including infrastructure, tree harvesting.
- Collect Samples of Existing Plans, Community to Review Materials and Provide recommendations.

IV. Mapping and Inventory Protocol/Strategy should be developed to Determine Baseline/Existing Conditions

- Determine Approach, consider tree canopy study.
- Accurate, Reasonable, and Efficient.
- Inventory should consider average rainfall.
- Use Aerial Photos, Determine Historical Trends if possible.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ATTACHMENT "A"
N
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3. Discussion of Oak Woodland Management Information.

(a) Oak Woodland Management Background Materials.

1. A Natural Resource Condition Assessment for Sequoia and Kings Canyon National Parks (National Park Service, June 2013).

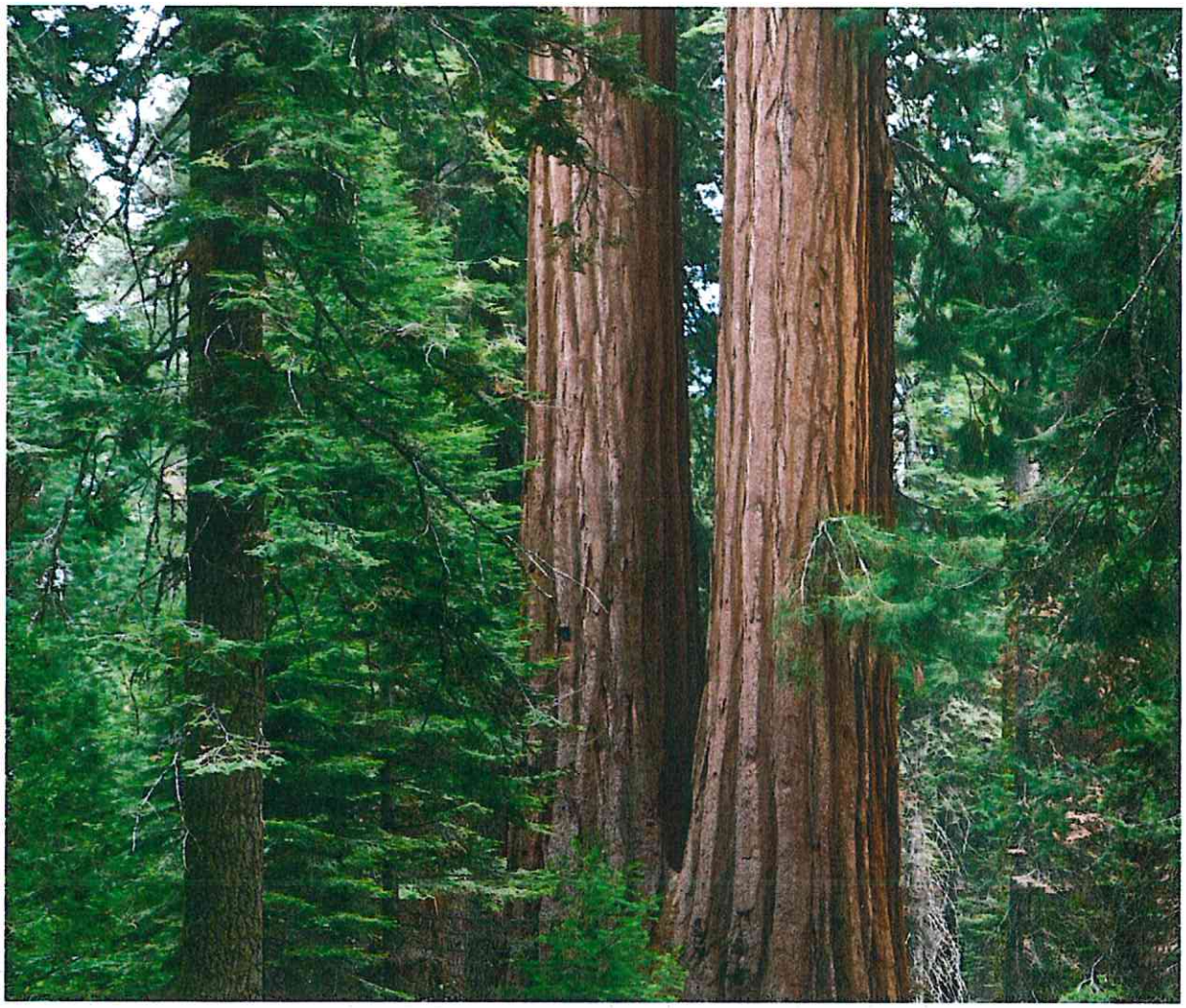
National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

A Natural Resource Condition Assessment for Sequoia and Kings Canyon National Parks

Appendix 10 - Foothills Vegetation

Natural Resource Report NPS/SEKI/ NRR—2013/665.10



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Rodriguez-Buritica S and Suding K. 2013. A natural resource condition assessment for Sequoia and Kings Canyon National Parks: Appendix 10 – foothills vegetation. Natural Resource Report. NPS/SEKI/NRR—2013/665.10. National Park Service. Fort Collins, Colorado. Published Report-2195590.

Published Report

Reference Code: 2195590
Reference Status as of 08/20/2013: Active
Visibility: Public

Core Information

Report Series

View Profile

Report Series Title	Natural Resource Report
Report Series Description	The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.
Publisher	National Park Service

Published Report

Report Title	A natural resource condition assessment for Sequoia and Kings Canyon National Parks: Appendix 10 – foothills vegetation
Brief Description	A natural resource condition assessment for Sequoia and Kings Canyon National Parks: Appendix 10 – foothills vegetation
Date of Issue	June, 2013
Content Begin Date	-
Content End Date	-
Place of Issue	Fort Collins, Colorado
Abstract/Full Description	The foothill zone in the Sequoia and Kings Canyon National Parks (SEKI) encompasses areas between 460 and 1830 meters above sea level (m.a.s.l.) along the watershed of the Kaweah and Kings rivers (Parsons et al. 1981). Foothill vegetation is typically oak woodlands, hardwood forests, and shrublands. Hardwood forests cover most of the foothills (60% of the total area), most of which (42%) corresponds to evergreen forest dominated by canyon live oak (Quercus chrysolepsi) associations. Shrublands, the second most abundant cover type (27%), are particularly characterized by chamise (Adenostoma fasciculatum)-chaparral associations (17%). Mixed coniferous forests are minimally represented at this elevation range (9%). Foothill plant communities are influenced by several potential stressors that may affect their stability and conservation status. In SEKI as a whole, these potential stressors include air pollution, climate change, altered fire regimes, invasive species, and infectious diseases. In the particular case of the foothills, some of these stressors represent a more immediate threat. In the foothill shrublands, for instance, more frequent fire regimes favor invasion of non-native annual grasses and limit canopy closure of the native vegetation (Keeley et al. 2003). We also add cattle grazing to the list of potential stressors in foothill communities. While still a subject of some debate, it is generally thought that frequent fire and increased non-native grasses, in combination with severe climatic events and cattle grazing, can interfere with regeneration of oak species in foothill oak woodlands. Of all the foothill vegetation types at SEKI, we play particular attention to blue oak (Quercus douglasii) woodlands. Blue oak woodlands are unique and valuable areas in California (Standiford et al. 2001). Over the past several decades, the future vitality and existence of blue oaks have become the focus of extensive research. Blue oak woodlands are anticipated to diminish further in the coming years given that several oak species, including blue oaks, appear to be regenerating at levels below what is necessary for self-replacement. In this chapter, we evaluated existing information on factors affecting persistence of two different vegetation types in the foothills—hardwood forests and shrublands—and specifically evaluated the current status of blue oak populations in the park. To do this, we compiled and evaluated vegetation information pertinent to the foothills using five available datasets. Each dataset was generated as part of independent studies conducted throughout SEKI between 1960 and 2004, and they cover most of the foothill area. To focus on the conservation status of oak woodlands in particular, we conducted a more in-depth literature review on the current state of knowledge of blue oak populations in the park.
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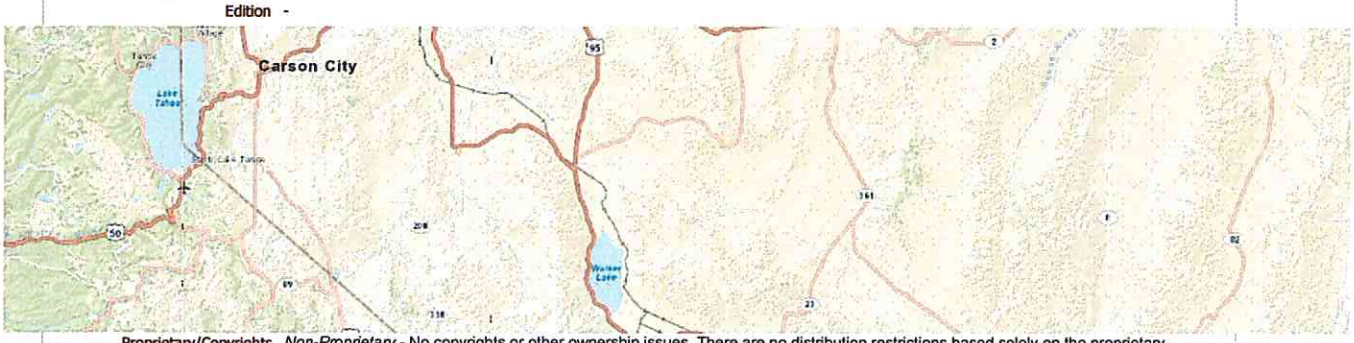
Report Number/ID	NPS/SEKI/NRR—2013/665.10
Edition	-



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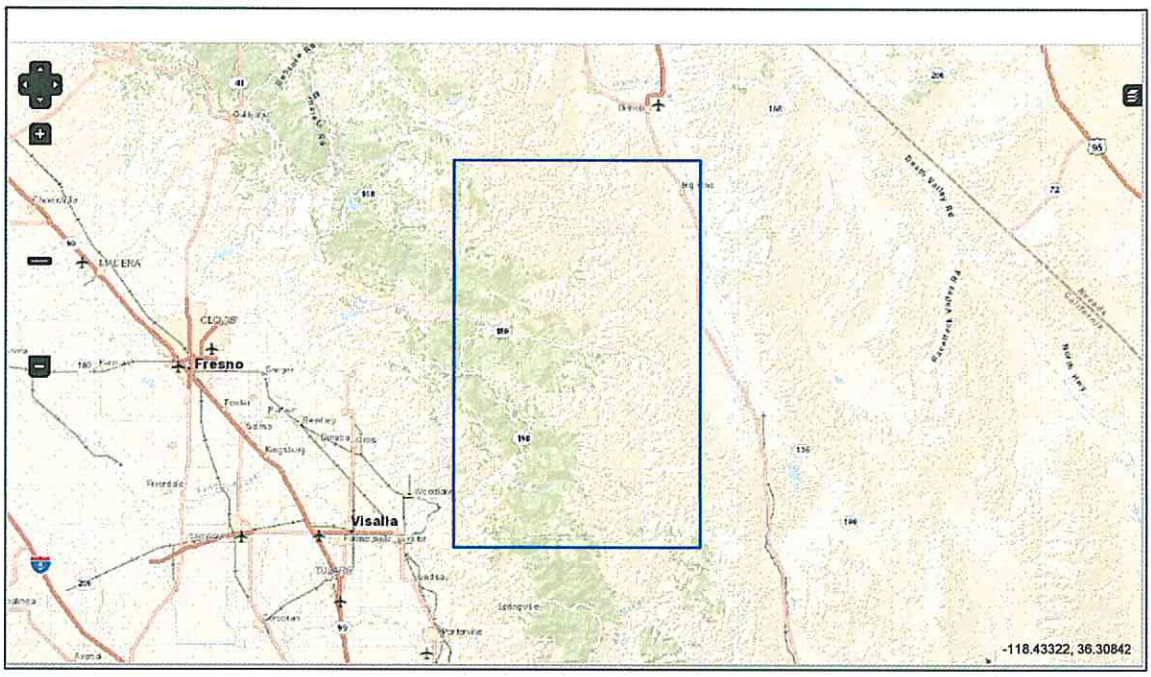
Quality	*High* - The Information Resource is not known to be missing or contain misleading information AND adequate documentation on its generation is present. Generally, peer-reviewed materials (e.g., from published journal articles or rigorous monitoring programs) fall into this category.

Originating Project

Bounding Boxes Sequoia and Kings Canyon National Parks (SEKI). Default Bounding Rectangle: xmin, ymin: -118.9832, 36.29138 xmax, ymax: -118.2348, 37.23762



Keywords

Subject Categories Ecological Framework: Biological Integrity | Invasive Species | Invasive/Exotic plants
Ecological Framework: Biological Integrity | Focal Species or Communities | Grassland/Herbaceous Communities
Ecological Framework: Biological Integrity | Focal Species or Communities | Shrubland Communities
Ecological Framework: Biological Integrity | Focal Species or Communities | Forest/Woodland Communities
Ecological Framework: Landscapes | Fire and Fuel Dynamics | Fire and Fuel Dynamics

Biological Taxa -

Freeform Keywords Blue oak woodlands, Chaparral, native California grasslands, invasive grasses, FIRE, SEKI, NRCA

Version History

ON THE COVER
Giant Forest, Sequoia National Park
Photography by: Brent Paull

A Natural Resource Condition Assessment for Sequoia and Kings Canyon National Parks

Appendix 10 - Foothills Vegetation

Natural Resource Report NPS/SEKI/ NRR—2013/665.10

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June 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This document contains subject matter expert interpretation of the data. The authors of this document are responsible for the technical accuracy of the information provided. The parks refrained from providing substantive administrative review to encourage the experts to offer their opinions and ideas on management implications based on their assessments of conditions. Some authors accepted the offer to cross the science/management divide while others preferred to stay firmly grounded in the presentation of only science-based results. While the authors' interpretations of the data and ideas/opinions on management implications were desired, the results and opinions provided do not represent the policies or positions of the parks, the NPS, or the U.S. Government.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

Please cite this publication as:

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NPS 102/121027, June 2013

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Scope of Analysis

The foothill zone in the Sequoia and Kings Canyon National Parks (SEKI) encompasses areas between 460 and 1830 meters above sea level (m.a.s.l.) along the watershed of the Kaweah and Kings rivers (Parsons et al. 1981). Foothill vegetation is typically oak woodlands, hardwood forests, and shrublands. Hardwood forests cover most of the foothills (60% of the total area), most of which (42%) corresponds to evergreen forest dominated by canyon live oak (*Quercus chrysolepsi*) associations. Shrublands, the second most abundant cover type (27%), are particularly characterized by chamise (*Adenostoma fasciculatum*)-chaparral associations (17%). Mixed coniferous forests are minimally represented at this elevation range (9%) (Table 1).

Foothill plant communities are influenced by several potential stressors that may affect their stability and conservation status. In SEKI as a whole, these potential stressors include air pollution, climate change, altered fire regimes, invasive species, and infectious diseases. In the particular case of the foothills, some of these stressors represent a more immediate threat. In the foothill shrublands, for instance, more frequent fire regimes favor invasion of non-native annual grasses and limit canopy closure of the native vegetation (Keeley et al. 2003). We also add cattle grazing to the list of potential stressors in foothill communities. While still a subject of some debate, it is generally thought that frequent fire and increased non-native grasses, in combination with severe climatic events and cattle grazing, can interfere with regeneration of oak species in foothill oak woodlands.

Of all the foothill vegetation types at SEKI, we play particular attention to blue oak *(Quercus douglasii)* woodlands. Blue oak woodlands are unique and valuable areas in California (Standiford et al. 2001). Over the past several decades, the future vitality and existence of blue oaks have become the focus of extensive research. Blue oak woodlands are anticipated to diminish further in the coming years given that several oak species, including blue oaks, appear to be regenerating at levels below what is necessary for self-replacement.

In this chapter, we evaluated existing information on factors affecting persistence of two different vegetation types in the foothills—hardwood forests and shrublands—and specifically evaluated the current status of blue oak populations in the park. To do this, we compiled and evaluated vegetation information pertinent to the foothills using five available datasets. Each dataset was generated as part of independent studies conducted throughout SEKI between 1960 and 2004, and they cover most of the foothill area. To focus on the conservation status of oak woodlands in particular, we conducted a more in-depth literature review on the current state of knowledge of blue oak populations in the park.

Critical Questions

We had two objectives. First, we characterized the status of foothill vegetation and explored if spatial variability in community-level metrics such as diversity can be associated with potential stressors in the foothill zone (specifically, cattle grazing, fire and invasive species). We focused this analysis on overall community characteristics for the two most abundant vegetation types in the foothills: hardwood forests, which include blue oak woodlands and oak forests, and shrublands. Within each vegetation type, we estimated diversity and dominance for native herbaceous species, shrubs, and tree species. We focused on the spatial variation of community characteristics, emphasizing the relationships with spatial variation of topographic and climatic variability, history of fire and cattle grazing.

Second, we performed a comprehensive literature review on the factors affecting blue oak regeneration throughout California, and in light of this review, we evaluated the general condition of blue oak woodlands in SEKI. We focused on blue oak because it is the most extensive hardwood species in the state, encompassing an estimated 1.214 million ha (3 million acres) and representing nearly half of the oak-covered landscape in California (Bolsinger 1988; Allen-Diaz and Holzman 1991). In addition, blue oak has served as a case study species for over 60 years in studies on the low regeneration observed in oak communities; it is one of the most well studied species of oak.

Given these two objectives, we investigated three critical questions:

1. What is the status of native herbaceous, shrub, and tree communities throughout the foothill zone?
2. To what extent is the spatial variation of diversity metrics in the foothills explained by variability in local growing conditions, characterized by topography and climatic variation, and to what extent is it explained by past history of disturbance, mainly fire and grazing?
3. In the light of our current knowledge of factors affecting blue oak regeneration, what is the status of blue oak communities at SEKI?

Table 1. Vegetation types within foothills areas in each HUC-10 unit. The percentage of the foothill area of SEKI NPS land in each HUC-10 unit is listed in parentheses, followed by acronyms used for each unit (e.g., MFK for Middle Fork of Kings River); these acronyms are used throughout this chapter. Except for Middle and Marble Fork Kaweah units the HUC-10 delineation corresponds to watershed units; for this reason we refer to HUC-10 units rather than watersheds. Percentages do not add to 100% in each column due to rounding.

HUC 10 unit classification	Roaring River (0.13%)	Middle Fork Kings (4.8%) MFK	Lower South Fork Kings (3.2%) LSFK	Upper South Fork Kings (2.5%) USFK	Mill Flat Creek (0.03%)	Dye Creek (0.03%)	Marble Fork Kaweah (14.3%) MbFKw	North Fork Kaweah (26%) NFKw	Middle Fork Kaweah (20%) MFKw	East Fork Kaweah (23%) EFKw	South Fork Kaweah (6.2%) SFKw	North Fork Tule (0.01%) NFT	GRAND TOTAL
Deciduous shrubland		4.9%	1.4%	2.3%	7.4%	10%	3.1%	7.1%	12%	19%	13%		10%
Evergreen shrubland	1.6%	3.2%	0.75%	2.5%			37%	21%	12%	16%	0.49%		17%
Mixed shrub/herbaceous			0.21%		11%		0.07%		0.16%	0.50%			0.17%
Deciduous forest	5.9%	2.1%	3.3%	9.7%			0.17%	0.85%	0.73%	0.69%	0.59%		1.2%
Deciduous woodland							12%	7.8%	6.6%	2.7%	3.3%		5.8%
Evergreen forest	45%	43%	37%	45%	33%	66%	36%	41%	46%	41%	48%		42%
Mixed evergreen deciduous forest	0.43%	3.1%	3.3%	7.3%	47%	24%	4.8%	13%	14%	10%	23%	100%	11%
Barren	37%	1.9%	24%	27%	1.6%		2.7%	1.9%	2.5%	2.1%	2.1%		4.0%
Mixed Coniferous Forest	9.2%	41%	30%	6.9%	0.96%		4.8%	8.4%	5.8%	8.8%	9.6%		9.1%

Data Sources and Types Used in Analysis

Vegetation datasets.

In our analysis, we used five different datasets from independent studies conducted in the park since 1969 (Table 2; Figure 1). Out of the five available datasets, the vegetation mapping plots for accuracy assessment (VMA) are by far the most numerous and widely distributed throughout the foothills (n= 389). These plots were specifically designed to support an ongoing mapping effort and were surveyed between 2002 and 2004, and their location is biased towards easily accessible areas. The second most abundant set, the Nature Resource Inventory (NRI) plots (n=77), were selected systematically through randomized sampling, which provided us with the most reliable description of the sampled areas. The low number of plots of this data set within the foothills limited the precision of our analyses because plots do not cover the full range of environments of the foothills (Figure 1). Despite this caveat, we use NRI plots over VMA plots to explore spatial patterns across the foothills due to their unbiased sampling scheme. For this reason, we can only explore spatial patterns in some foothill areas in the park; for instance, we do not have enough information to evaluate south, and southeast areas of Sequoia National Park.

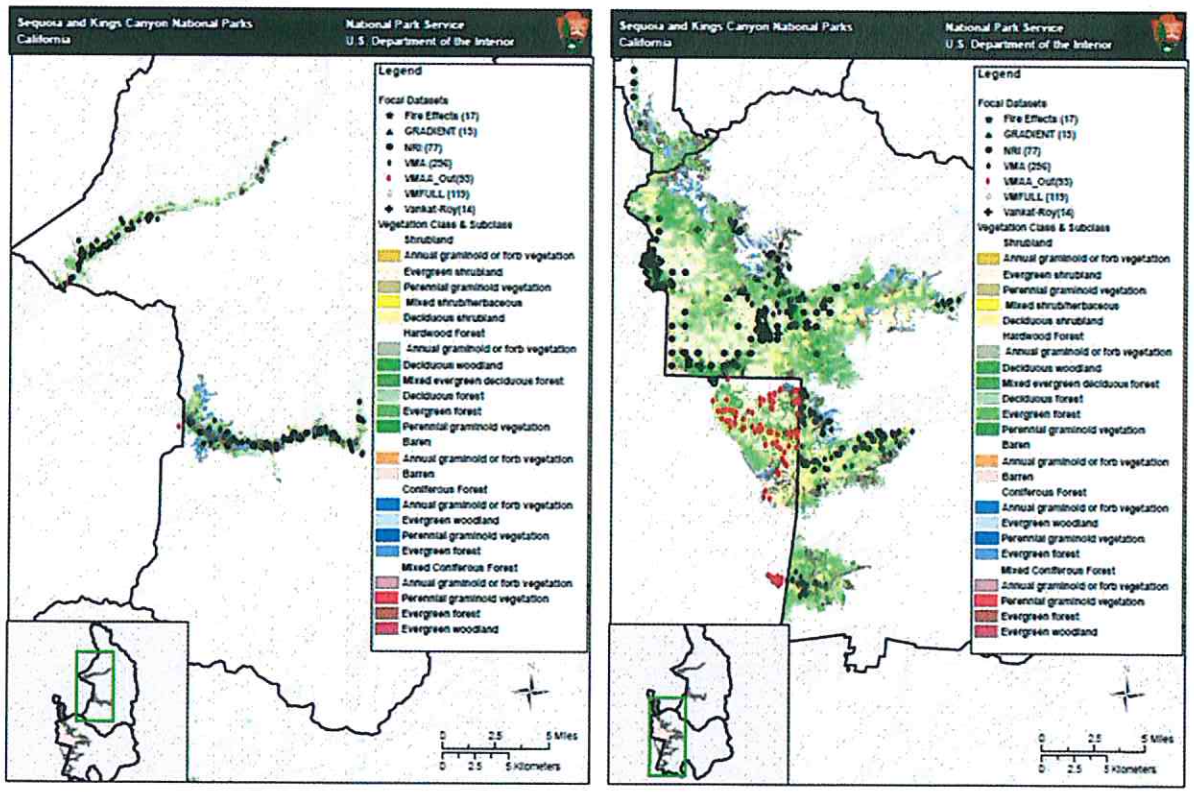

Figure 1. Location of plots used for the analysis of condition of plant communities at SEKI. Plots from different studies are indicated with different symbols. Left panel corresponds to Kings Canyon National Park and right panel to Sequoia National Park. We largely focus on spatial variation related to NRI plots (black circles). Note that some of the VMA plots occur outside of National Park boundaries (red diamonds); because they were outside of the park, they were not considered in analyses with stressors except for explicit consideration in grazing analyses. Abbreviations: NRI (Natural resource inventory plots), VMA (Vegetation Mapping plots for Accuracy assessment), VMAA_out (Vegetation Mapping plots

Table 2. Summary of available datasets for the analysis of current conditions in the foothill zone. In our analyses, we concentrate on NRI plots, as they were selected with a stratified randomized sampling scheme and encompassed a wide range of foothill plant communities. VMA plots, while more numerous than NRI plots, were more biased in location; we used these as a secondary data source for spatial analyses. The remaining three datasets were collected with specific purposes and have low sample sizes (n=13 to 17) in the foothills; we reserve the use of these datasets for focused analyses.

Data Set	Purpose	Year Sampled	Sampling Design	Sampled Area	Data recorded	Number of plots	Range Elevation (m a.s.l.)
Natural Resource Inventory Plots (NRI)	Describe the distribution and abundance of vascular plants	1985-1996	Stratified random sampling scheme using the 1-km UTM coordinate grid	0.1 ha circular plots	-DBH trees>1.3m -Herb Cover/Species -Shrub Cover/Species - Sapling/Species	77	475-1830
Vegetation Mapping Plots for accuracy assessment (VMA)	Support mapping efforts throughout the park	2000-2004	Stratified by vegetation map unit and location. Heavy sampling in accessible locations close to roads and creeks	0.1 ha circular plots	- Diameter Classes of Trees >1.4 m -Herb Cover/Species -Shrub Cover/Species	389 (+ 93 outside SEKI)	396-1830
Full Vegetation Mapping plots (VM Full)	Same as VMA	2000-2004	Same as VMA	Same as VMA	-Diameter Classes of Trees >1.4 m	119	464-1830
Gradient Plots (GP)	Describe the distribution of forest trees along environmental gradients	1983	Chosen to cover as wide a range as possible of environmental conditions	0.1 ha rectangular plots	-Diameter Classes of Trees >1.4 m -Herb Cover/Species -Shrub Cover/Species	13	1341-1826
Vankat-Roy Plots (VR)	Monitor long-term change in tree communities	1966 and 1996	On representative vegetation types along an elevation gradient	0.01 ha strips	-Diameter Classes of Trees and shrubs with DBH >1.3 m	14	354-670
Fire Effect Plots (FF)	Monitor pre- and post-fire fuel and vegetation conditions	1988-2009	Random selection within vegetation type	-In shrubland areas 30 m strips -In forest 0.1 ha plots	-DBH of all trees -Herb Cover/Species -Shrub Cover/Species	17	743-1793

To compare the spatial variation of community metrics we used the HUC-10 digit classification (established by the California Interagency Watershed Mapping Committee-IWMC), which roughly corresponds to watershed units used by SEKI (Table 1). It is important to note that HUC-10 units do not exactly match the delineation for Marble and Middle Fork Kaweah watersheds, and thus we will use the term HUC-10 unit (or unit with the specific name is given) instead of watershed. We did not have enough information from the NRI dataset to evaluate community patterns along Roaring River, South Fork Kaweah, North Fork Tule, Mill Flat Creek, and Dye Creek units.

In addition to these two datasets, we used three other datasets. We used plots called the fire effects plots (FE), to explore community response to fire events. These plots are exclusively located on the North, Middle and East Fork Kaweah River units. Two other datasets, the Gradient and Vankat-Roy plots, were infrequent and did not allow an extensive characterization of most foothill areas since they were used to describe more specific and spatially restrictive questions. Vankat-Roy plots were designed to characterize specific areas in the park in 1969 and were later resampled in 1996 with the purpose of assessing fire effects and general vegetation changes. Given that more extensive analyses have been previously published (Roy and Vankat 1999; Vankat 1970; Vankat and Major 1978), we only present summary metrics for these plots.

Climate and topographic variables.

We focused on a series of topographic and climatic variables thought to be important in structuring foothill vegetation communities (Table 3, with values summarized in Table D of the appendix). These include topographic characteristics (elevation, aspect, slope), temperature (divided into growing and non-growing season), precipitation (also divided into growing and non-growing season) and landscape characteristics (distance from roads and streams).

Potential stressors.

We concentrate our analyses on three potential stressors (invasive grasses, cattle grazing and fire) thought to be important in foothills vegetation. Grazing information was obtained directly from SEKI personnel and consisted of two variables. The first variable identified areas in the foothills that experienced unauthorized grazing up to 1986, when some of these areas were fenced, which significantly reduced grazing until 1997. In 1997 more fences were put in place to control trespassing (Harold Werner, pers. communication). In addition to this variable, we also identified areas in the foothills that are designated for authorized stock grazing (mainly mule and horses). Since we do not have detailed information on the intensity and frequency of use in both of these areas, our analysis is limited to comparisons between areas where grazing had been detected and comparable areas in elevation where no grazing had been recorded. According to this classification, areas that had experienced grazing are restricted to the west border of the park in the North Fork Kaweah River and the Marble Fork Kaweah River units (Figure 2). In particular, authorized grazing has exclusively occurred on the southernmost border of the Marble Fork Kaweah unit, which is around the area where the park headquarters are located.

Given the foothills have been actively protected from cattle grazing and logging, among other uses, we estimate the effect of this protection on biodiversity metrics. For this effect we calculated differences among VMA plots located right outside the park (red diamonds in Figure 1) boundaries along the East fork Kaweah and areas in the park at comparable elevations in the

same HUC-10 unit. We use the current (1940s) park boundaries for this analysis. It is important to note that large areas of SEKI were added to the original park in 1926 and most of King Canyon in 1940. Although after the expansions, existing grazing allotments continued to be grazed until the 1980s in both parks.

To describe fire regimes, we used the index of fire return interval departure (FRID) that categorizes areas where fire frequency has been as expected from historical records (high scores) and where fire frequency is severely far from the historical norm (low scores) (Table 5). These scores were designed to identify priority areas for fire management. Most areas in the foothills have high FRID scores (in 2009, 36% scored 2, 29% scored 1, 21% scored 3, and 8.9 scored 4, especially at medium and high elevations in Sequoia National Park. Although it is assumed that fire regimes probably changed at the end of the Little Ice Age and the end of Native American burning, very little is known about the historical fire regime at low elevations because fires are not clearly recorded in the annual growth rings of non-coniferous species. Given high level of uncertainty in historical fire regimes in the foothill that translates in high uncertainty in FRID values (Caprio and Lineback 2002), our analyses based on FRID should be considered a first approximation to relate community characteristics with departures from fire regimes.

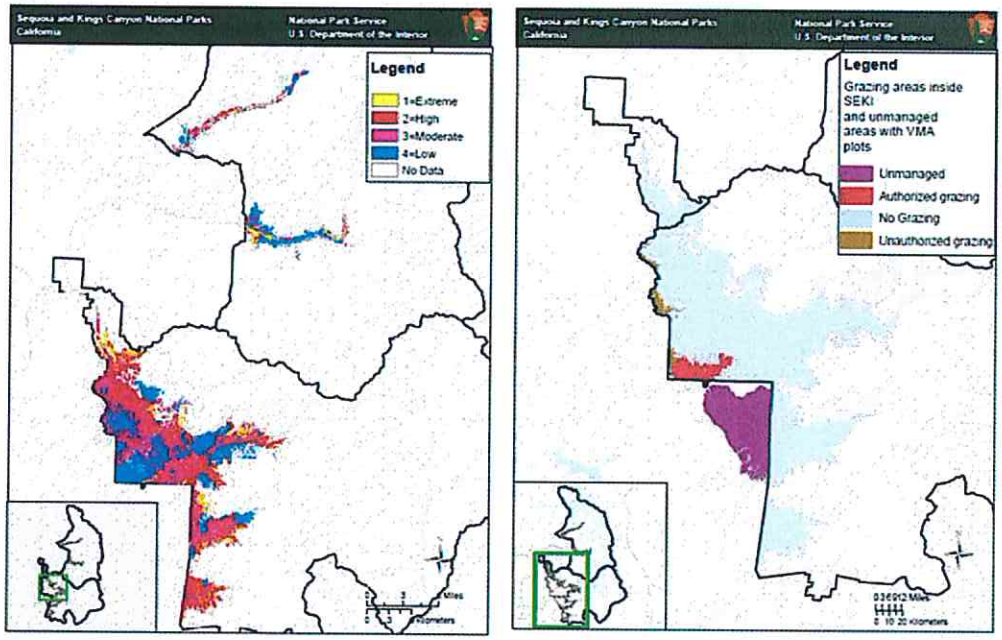

Figure 2. Values of two main stressors throughout the foothills. Right panel corresponds to FRID values and right panel to areas that have experienced or are still experiencing livestock grazing throughout the foothill zone of Sequoia National Park. Authorized grazed areas refer to areas of administrative use where stock pasture is authorized. Cattle grazed areas refer to areas that experienced unauthorized grazing until 1986, and that could have experienced light grazing up to 1997 when the park completed fences to prevent trespassing. Information for this variable was provided by SEKI. We used plots outside SEKI in the VMA data sets (unmanaged areas) to estimate the effect of park protection policies.

In addition, we explored the general disturbance history as described by a composite index showing the magnitude and duration of vegetation cover losses (regardless of cause) between 1985 and 2009 and obtained by Landsat image interpretation (R. Kennedy, Sierra Nevada Inventory and Monitoring Network, 2010) (Table 5). This index is based on reflectance values, and this not only identifies areas that have experienced fire, but also areas with significant tree or shrub mortality due to disturbance events or pathogens. In addition to duration and magnitude of disturbance, we also included a categorical variable that identified areas that have and have not experienced disturbance in the last 24 years (Figure 3). One of the limitations of this dataset is that it only provides information on the most prominent disturbances experienced in the last 24 years, and not on repeated disturbance events. It is also important to note that the NRI plots, on which we base our core analyses, were sampled between 1985 and 1996, and so this general disturbance descriptor should be interpreted as describing area having more or less probability of disturbance rather than the vegetation analyses describing response to particular disturbance events *per se*.

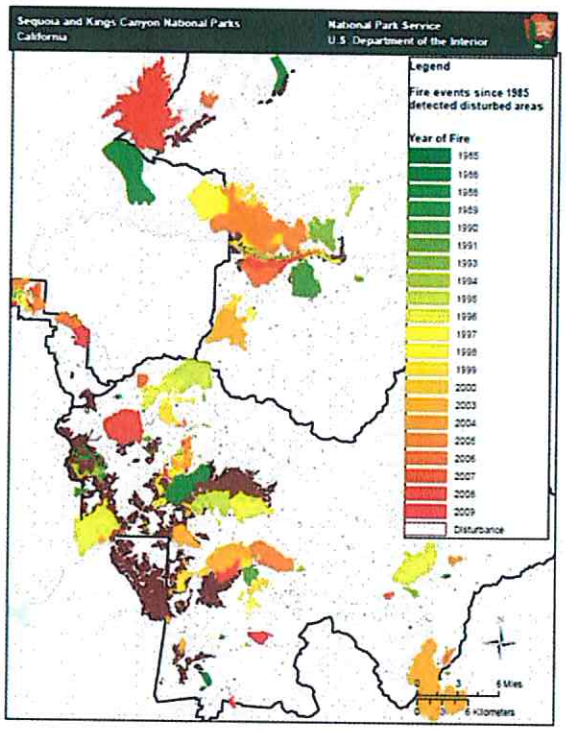

Figure 3. Areas that have experience fires since 1985 with respect to areas with detected vegetation cover loss. Areas with detected vegetation loss as reported by Kennedy (2010) are in dark red; all other polygons correspond to areas that have experienced fires in the last 26 years. Years of each fire are indicated in the legend with green colors representing early fires, and red colors more recent fires.

Based on this general disturbance index, changes in vegetation cover were detected throughout the foothills at SEKI. In general, disturbed areas were located at low elevations in all HUC-10 units, except on the South Fork Kaweah River unit, and on high elevations on the Middle, East, and South Fork Kaweah units. Several areas in the foothills experienced intense changes, declining in woody cover by almost 90%. These changes tended to last less than ten years. In most cases they do not last more than two years, and is stronger in hardwood forests (R^2=0.43, p-value<0.05) than in shrublands (R^2=0.22, p-value<0.05). Several of these vegetation changes correspond with major fires, especially in the Marble and Middle forks of the Kaweah River (Figure 3). Fires in the late 1980s and early 1990s affected the westernmost boundary of the North Fork Kaweah River, and high elevations at the Middle Fork. Fires in the late 1990s occurred close to the main park entrance, at lower elevations on the Marble Fork unit. Most recent fires have affected the Kings Canyon National Park, and the North and East Fork Kaweah River unit. Despite this coincidence, detected disturbance usually extended beyond the fire footprints, highlighting the potential importance of other causes vegetation loss (e.g. insect damage or fire independent tree mortality) in community dynamics.

Spatial and Temporal Analyses: Methods

General conditions and spatial patterns

Our general approach to explore spatial distribution in the foothill vegetation communities involved four steps (Figure 4). First, we estimated and summarized community level diversity metrics for each plot and explored general patterns at the HUC-10 unit level. For each plot we estimated the Shannon index of diversity ($H' = \sum_{i=1}^{S}(p_i \ln(p_i))$ where S is the total number of species considered and p_i relative abundance of species i, discriminating among native herbs, shrubs, and trees. During our analyses of the spatial variation of diversity, we also estimated spatial patterns of dominance using evenness; which derives from H' ($J' = \frac{H'}{\ln(S)}$). In addition, we calculated the percentage of native grasses, and abundance of the most common shrub and tree species in the database. We included the three most common shrub species in the foothills: chamise, birchleaf mountain mahogany (*Cercocarpus betuloides* Torr. & A. Gray), mountain misery (*Chamaebatia foliolosa* Benth.), and the three most common tree species: incense cedar (*Calocedrus decurrens* -Torr.- Florin), canyon live oak (*Quercus chrysolepis* Liebm.), and california black oak (*Quercus kelloggii* Newb). These metrics provide a general description of community composition by considering number of species, their relative abundance, and their overall dominance; in this sense they are preferable to just richness. We calculate these metrics for vegetation census plots in all five datasets; nevertheless, due to difference in species identification protocols between datasets, we focus on the variability within each dataset rather than comparisons across datasets.

Second, to describe spatial variation in these diversity metrics for NRI plots, we standardized diversity metrics using local Z- scores derived from hot-spot analysis in ArcGIS (Esri Inc., v.10). This score is calculated locally by summing the value of interest in a plot and its neighboring plots, and comparing it to the sum for all plots; significance of Z-scores is evaluated using standard normal distribution. Values higher than 1.96 or lower than -1.96 are considered significant deviations from the rest of the dataset with a 95% confidence level (i.e., these are areas with particularly high or low diversity for a given metric within each dataset).

Third, we explored the dependency of plot level metrics on topographic and climatic variables that characterize each plot, independent of the influence of potential stressors (Table 3). Our objective was to detect explanatory variables that are closely related with the intrinsic spatial variation of each metric. As many environmental variables are correlated with one another, we used a factor analyses (Johnson and Wichern 2007) to generate new composite variables as combinations of these topographic and climatic variables; we used five factors that explain almost 95% of the variability in the dataset (Table 4). Factor 1 explains more than half of the variability, and we interpreted it as describing the effects of elevation and climatic variables: when values in factor 1 increase, elevation and precipitation increase and temperature decreases. Factor 2 is solely associated with aspect, while factor 3 is associated with distance to streams, with high factor values representing areas away from streams. Contrary to factor 1, factor 4 values increase when elevation decreases and temperature increases. Finally factor 5 relates to slope and distance from roads; when areas are isolated and steep, values on this factor are high. We then used multiple regression models with spatial autocorrelated errors to explore the relationship of the Z-score for each diversity metric (explained above) and the composite factors derived from topographic and climatic variables.

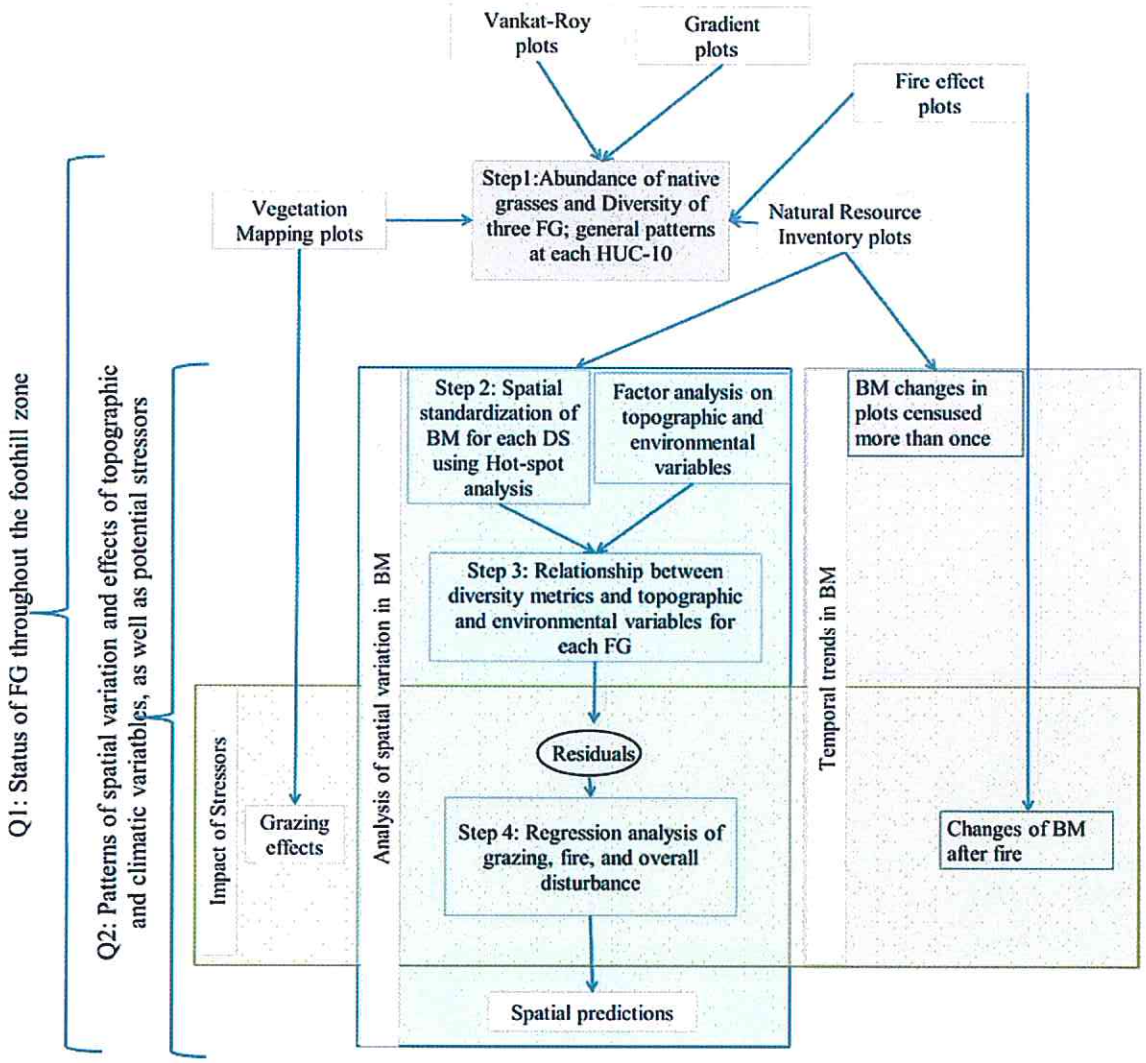

Figure 4. General framework for the analysis addressing the first two focal questions in this chapter. Four analytical steps and the datasets used are shown. Abbreviations: FG=Functional group, which are herbs, shrubs and trees; BM=Biodiversity metrics; DS=dataset, HUC-10=Hydric unit code, which is the same as the watershed.

Table 3. Topographic and climatic variables used to characterize each map unit. The source is indicated for each variable; we also indicate further manipulations for the datasets used for our analysis.

Type	Variable Name	Description	Source	Further manipulation
Topographic	Elevation (m.a.s.l)	Altitude in meters above the sea level	SEKI	None
	Aspect	Azimuth in degrees of slope surface	SEKI	Calculated from Elevation
	Slope	Percentage change of elevation over a specific area	SEKI	Calculated from Elevation
Environmental	Temperature during the growing season (°C)	Multiyear average of monthly temperature from 1971 to 2000	Bob Rice/PRISM Water quantity resource	Average, maximum and minimum between November and April
	Temperature during non-growing season months (°C)		Bob Rice/PRISM Water quantity resource	Average, maximum and minimum between May and October
	Precipitation during the growing season (mm)	Multiyear average of total monthly precipitation from 1971 to 2000	Bob Rice/PRISM Water quantity resource	Total, maximum and minimum between November and April
	Precipitation during non-growing season months (mm)		Bob Rice/PRISM Water quantity resource	Total, maximum and minimum between May and October

Table 4. Rotated loadings for each factor with respect to each of the original explanatory variables. Extreme loading values indicate a high correlation between a factor and the explanatory variable. The last two rows indicate the percentage variability explained by each factor, and the cumulative explained variability. Acronyms for variables used are as follow: MnGST = minimum growing season temperature, MxNGST = maximum non-growing season temperature, GSP = precipitation during growing season months, NGSP = precipitation during non-growing season months, Dist. Road = distance to main roads in meters, and Dist. Stream = distance to closest stream in meters.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Elev	0.897	-0.026	0.117	-0.267	0.081
Slope	-0.022	-0.018	0.08	-0.029	0.365
Aspect	-0.017	0.999	0.036	-0.018	-0.031
MnGST	-0.863	0.034	0.041	0.433	0.198
MxNGST	-0.895	0.009	-0.014	0.382	-0.072
GSP	0.958	0.014	-0.002	0.005	0.027
NGSP	0.956	0.005	0.01	0.071	0.03
Dist Roads	0.28	0.041	-0.031	-0.391	0.319
Dist Stream	0.047	0.039	0.982	0.018	0.18
Percent Explained	51.226	13.319	11.356	10.256	8.389
Cumulative Percent Explained	51.226	64.546	75.901	86.158	94.546

Finally, we investigated the influence of two potential stressors (cattle grazing and fire) as well as a composite index describing overall disturbance patterns detected by remote sensing (regardless of cause) (Table 5). To account for the spatial pattern in climate and topographical variables, we used residuals (the unexplained variance) from the multiple regression analysis.

Thus, this approach describes the influence of potential stressors on diversity after climate and topographic variation has been taken into account. In cases where environmental variables and potential stressors are tightly correlated, it is statistically impossible to distinguish which variable directly influences diversity: our approach here is conservative in terms of the influence of potential stressors as it only describes the influence of these potential stressors after the variability in environmental characteristics have been accounted for.

Table 5. Summary of variables depicting the effect of potential stressors of (fire, grazing history, and general disturbance characteristics) throughout the foothill zone in SEKI.

Category	General description	Variable	Description	Scale	Source
Fire effects	Fire return interval departures (FRID)	Fire Return Interval Departure	The severity of fire return interval departures considering the historical fire regime. Highly uncertain for low elevation foothill areas.	1=extreme departure 2=High,3=moderate, 4=low, 99=unburnable substrate	SEKI
Grazing	Cattle and Stock Grazing..	Trespassing	Evidence of trespassing cattle grazing in 1986	Categorical	Werner, 1986
		Authorized pastured areas	Areas authorized for stock grazing (mule and horses)	Categorical	SEKI
Disturbance	Overall park protection	Outside	Comparison of VMA plots inside and outside current park boundaries, comparable elevation range	Categorical	VMA dataset
	Landsat monitoring of vegetation cover changes	Disturbance Magnitude	Relative change in percent vegetation cover after disturbance for all vegetation cover types	1-100%, 100% indicates complete loss of cover	Kennedy (2010)
		Disturbance Duration	Measures the duration of the effect detected	Years	Kennedy (2010)
		Disturbance Year			Kennedy (2010)
		Disturbance Category	Categorized areas as disturbed or not in the year plot was surveyed	Categorical	Derived from Kennedy (2010)

Spatial Predictions

Using prediction models based on NRI plots, we estimated community metric values for the entire foothill zone. We began the prediction process by using the model built with the potential stressors (Table 5) to estimate the 95% prediction interval for each vegetation type. Using these limits, we adjusted the predicted standardized metric derived from applying the best model from our factor analysis (Table 4) to each of the vegetation map units i.e. each polygon in the vegetation map. We then used the multiple regression models of environmental factors to create prediction for entire foothill zone in terms of the original community metric variables. After upper and lower limits of the standardized values were obtained, we reverted the standardization using the mean and standard deviation estimated locally for each vegetation type. Thus, there are several sources of error for each prediction: one associated with prediction using the potential stressors, another with the prediction from the factor analysis, and a third comprising the remaining error from these procedures. The width of the final confidence intervals represents the level of uncertainty in our predictions.

Temporal trends

In addition to comparing changes in spatial patterns across datasets, we explore temporal trends in plant communities in the foothill zone by using NRI plots that were re-censused between 1985 and 1999. Given that there were few re-censused plots (n=9) and the time and frequency of re-censuses varied, we also explored temporal changes among NRI plots grouped by the decade they were censused. While this second approach compares trends over different plots, the methods of vegetation sampling remained the same.

In order to further characterize temporal trends in plant communities after a fire, we used the Fire Effect dataset to test for overall changes in community metrics before and after a fire (for more information see Table 2). Out of the 17 fire effect plots located in the foothill zone, only 7 were suitable for this analysis, mainly because they were monitored several years before or after a fire. The number of plots available and number of census with respect to a fire event is not suitable for conducting a time series analysis. Instead we tested for differences between overall means of pre- and post-fire conditions.

Reference Conditions

Reference conditions for community composition in these vegetation types are difficult to determine because of the recent influence of invasive species and long history of disturbance since the pre-settlement period (1700-1850). Pre-settlement composition of grasses and shrubs in grasslands and hardwood forest savannas is uncertain, in part due to active management practices by Native American communities. Nevertheless, it has been suggested that the Central Valley, the central and southern Coast Ranges, and valley in southern California were dominated by native perennials like *Nassella pulchra*, *Poa secunda*, *Leymus triticoides*, or *Muhlenbergia rigends* (Clements 1920; Holland and Keil 1995; Holstein 2001; Schiffman 2007). Alternative hypotheses suggesting pre-settlement dominance by woody vegetation (Hamilton 1997; Keeley 1993, Hopkinson and Huntsinger 2005) or native annuals (Solomeschch and Barbour 2006) have also received some support. In the 19th century, non-native grasses became a dominant component of these communities due to a combination of disturbance and droughts in the first and second halves of the century (Keeley 1990, Heady 1977). Although studies agree that presence of invasive grasses has been increasing, there is less agreement on the abundance of native grasses in foothill communities.

Because some foothill communities at Sequoia National Park have been protected since 1890, they may not have experienced the same dramatic pressures as other foothill areas in the region. Grazing has been greatly reduced in the park and has not been as intense as in nearby private lands. Southern Sierra Nevada foothills have had a complicated history of grazing (Menke et al. 1996), but areas in Sequoia National Park have been free from grazing for over a century except for packhorse grazing, and some areas that experienced unauthorized cattle grazing until 1986 when fences reduced this use; trespassing grazing was fully controlled in 1997. Thus, foothill communities at the park more likely represent reference conditions for other foothill areas with respect to potential stressor levels, with the exception of fire frequencies.

Foothills at SEKI may be diverging from their natural states due to the lack of regular fire disturbance. Between 1890 and 1960, fire suppression policies were implemented in the park, but this changed with the implementation of prescribed fires in 1968 (Vankat 1977). Under fire suppression policies, oak woodlands that evolved with frequent fires might have not experienced fires for more than 70 years, while other shrubland areas might be slightly over the upper limit of their optimum fire return intervals. Recruitment of shade intolerant species, herbs, and shrubs throughout the foothills might be minimal and risk of large and severe fires might be high in some areas (Vankat 1977; Stephens 1998). In blue oak woodlands, fire suppression is thought to be responsible for the increase of non-native grasses, which was estimated to be 99% of the herb community in the foothills in the park (Parsons and Stohlgren 1989). Although there is a high level of uncertainty in the historical fire regimes of lower elevation oak woodlands, infrequent fires have contributed to a shift in community composition.

In denser oak forests and shrublands, fire suppression might have reduced the advance of non-invasive grasses, but at the expense of an increased risk of severe fire. Chaparral is resilient to fire return intervals between 25 and 100 years (Keeley 1986; Zedler 1995); typical intervals are 50 to 70 years (Minnich 1995; Zedler 1995; Conard and Weise 1998). Community composition

under optimal circumstances shifts from communities dominated by obligate seeders to communities dominated by resprouting species with a competitive advantage under light-limited conditions (Keeley et al. 2005b). Overall diversity in interior chaparral communities peaks in the years immediate after a fire, from 2.34 (SE=0.08) in the first year post-fire to 1.92 (SE=0.06) in the fourth year post-fire (Keeley et al. 2005b). In general, these communities tend to be dominated by few species with many subdominant species. In particular, these communities have a much higher proportion of herbs than shrubs, but this decreased as post-fire recovery progresses (Keeley and Fotheringham 2003).

One of the products of this chapter is to estimate the relationship between diversity metrics at the plot level and variables describing the effect of fire, grazing, and overall disturbance across the SEKI foothills. In this sense, the results of our analyses can be used as reference condition for the spatial variability of foothill vegetation diversity in areas that have been protected for more than 70 years.

Spatial and temporal patterns

Diversity throughout the Foothills

There is a strong elevation gradient in the species composition of foothill communities. Low elevation areas (<800 m a.s.l.) are dominated by oak communities (71% of the total low elevation areas), including canyon live oak-California buckeye (*Aesculus californica*) association (27%), and blue oak associations (28%). Communities dominated by chamise-shrubland alliance represent 18% at this elevation. Shrubs are present with low coverage (<5 %) and herbaceous layer is dense (approx. 80% cover) and dominated with non-native grasses, in particular, species of *Avena* and *Bromus* (mainly *B. diandrus* and *B. hordeaceous,* Keeley et al, 2003). Mid-elevation areas (between 800 and 1500 m a.s.l.) are dominated by canyon live oak (44% of the mid-elevation foothill area) and chamise shrublands (11%), which are usually located along dry slopes. Communities dominated with canyon live oak present a closed canopy ecosystem with tall conifers and oaks representing 40-100% cover and a denser shrub community. Chamise, sticky white leaf manzanita (*Arctostaphylos viscida*) and buckbush (*Ceanothus cuneatus*) are the dominant shrubs, either with uninvaded closed canopies or intermixed with an understory dominated by alien annuals (Keeley et al. 2003). At this elevation, mixed coniferous forest is mostly represented by communities dominated by white fir (*Abies concolor*), incense cedar (*Calocedrus decurrens*), and canyon live oak (overall mixed coniferous coverage at mid-elevation is 6%). Mixed coniferous forests are better represented at higher elevations (1500-1830 m.a.s.l.) where 14% of the foothill area at this elevation is dominated by ponderosa pine (*Pinus ponderosa*), incense cedar, and black oak. Canyon live oak associations are most abundant at this elevation (38%), and shrublands (without a clear dominant association) are still important (13%).

When comparing across vegetation types, hardwood forests were characterized by relatively open canopies that favor growth of a dense understory layer dominated by herbaceous species. On the other hand, shrublands were usually dominated by few species that form dense, closed canopies that limit the presence of herbs herbaceous species. In particular, we found that diversity of native herbaceous species tended to be higher in hardwood forest plots than in shrubland communities (Figure 5, p-value for the comparison=0.036), which is explained in part by higher number of native species in forested areas. We also found a clear dominance of invasive grasses across all vegetation types. Finally, higher diversity of shrubs occurred in hardwood forests, while diversity of trees was lowest in these communities, reflecting the dominant role of canyon live oak and black oak.

Table 6. Summary statistics of community metrics for native herbaceous species, shrubs and trees for NRI plots across all community types. In each cell the first value indicates the mean and the two values in parentheses indicate the standard deviation and number of plots, respectively. Across the foothill zone, native herbaceous species comprised on average almost 80% of the total cover of herbaceous plants, although native grass abundance was much lower, even when considering native grass cover as a proportion of all grass cover (Figure 5). The most abundant shrub and tree were birchleaf mountain mahogany (17%) and canyon live oak (23%), respectively. Incense cedar and california black oak were also abundant tree species: they each made up an average of 7% in tree cover.

	Herbaceous plants	Shrubs	Trees
Richness (# species/0.1 ha	24 (13 ,77)	6.6 (3.9 ,69)	3.18 (1.658 ,61)
Shannon Index (H')	2.1 (0.78 ,77)	1.0 (0.60 ,69)	0.63 (0.46 ,61)
Native herbaceous richness (# species/0.1 ha)	20 (11 ,77)	-	-

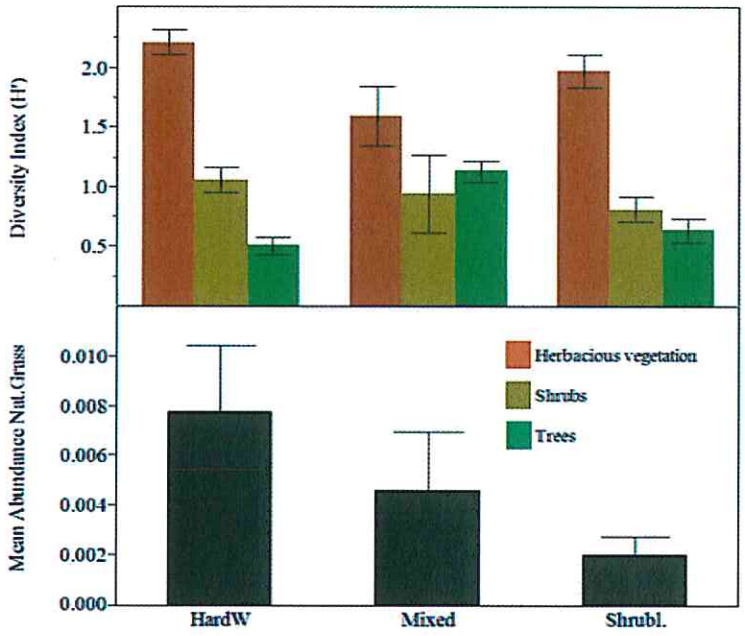

Figure 5. Average community metrics by community type using NRI plot data. Upper panel shows results for native herbaceous vegetation, shrubs, and trees, respectively; lower panel shows the mean abundance of native grasses estimated as proportion cover of native grass species/cover of all grass species. Error bars correspond to one standard error. Abbreviations: Shrbl=Shrubland, HardW=Hardwood forest, and Mixed=Mixed coniferous forest.

Spatial Patterns

Spatial variation of standardized metrics. Spatial patterns of standardized community metrics suggests that plant communities at Kings Canyon and along East Fork Kaweah are in better conditions than communities in the rest of the foothills at SEKI, although there is not a consistent pattern across metrics. Along the Middle Fork Kaweah and at higher elevations along the East Fork Kaweah watersheds, standardized values of native herbaceous Shannon diversity (H') derived from NRI plots tend to be lower than the overall average for the dataset (Figure 6).

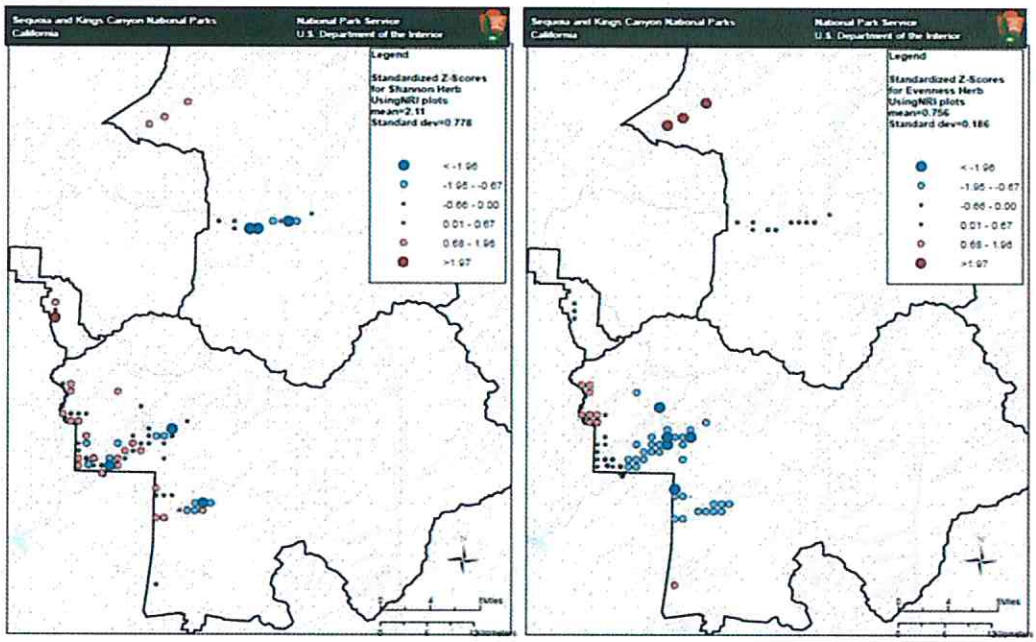

Figure 6. Standardized community metrics for native herbaceous species calculated using NRI plots. The panel on the left shows standardized Shannon diversity index (H') and the panel on the right shows Evenness (L'). Each marker represents a study plot in the corresponding dataset. Extreme colors and sizes represent increasingly significant values with respect to the overall mean for the whole dataset. Values more extreme than -1.96 or 1.96 are statistically significant at a confidence level of 95%.

Locations of highly diverse herbaceous communities do not necessarily correlate with locations of communities with high evenness, suggesting high variability in species richness. NRI plots with high dominance of a couple of herbaceous species (low evenness) were restricted to mid-elevations in the Middle Fork Kaweah, while plots that contain a more even distribution of species abundances were found at the Middle Fork Kings River unit in Kings Canyon National Park (Figure 6). Percentage of native grasses in NRI plots was low and homogenous throughout the landscape (Figure 7). Communities with high but average abundance of native grasses were found close to the administrative units of the park, along the Middle Fork Kaweah River. Lower abundances of native grasses consistently occurred along the East Fork Kaweah, although these values were not significantly different than the overall mean.

For shrubs, high diversity and evenness were located along the upper portion of both the Middle and Marble Fork Kaweah unit and at the East Fork Kaweah (Figure 8). Diversity of shrubs is low at the westernmost boundary of North Fork Kaweah watershed. High tree diversity was exclusively located along the South Fork Kings River, while plots with low diversity and high dominance were located at lower elevations along North Fork and Marble Fork Kaweah River units (Figure 9).

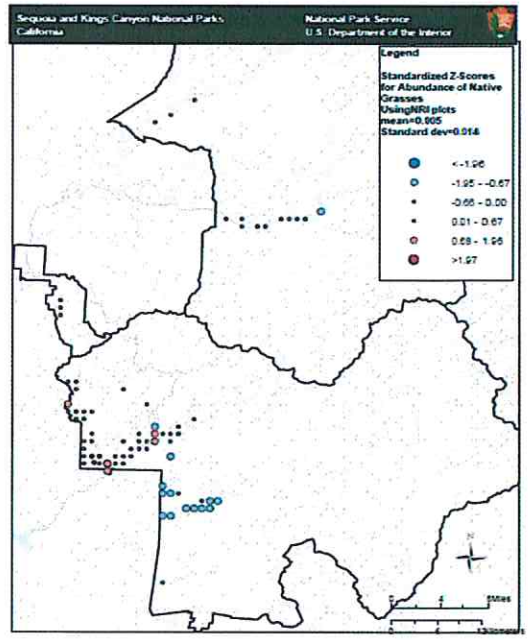

Figure 7. Standardized abundance of native grasses calculated using NRI plots. Each marker represents a study plot in the corresponding dataset. Extreme colors and sizes represent increasingly significant values with respect to the overall mean for the whole dataset.

Importance of Temperature and Climatic Variables. Most of the detected differences across HUC-10 units are due to the preponderant role of topographic and climatic variables. Factors derived from topographic and climatic variables explain between 9 and 64% of the variability in our standardized community metrics (R^2 values in Table 7). In general, diversity and evenness of trees were strongly correlated with environmental factors (more than 60% of the variability explained), while metrics for herbs and shrubs produced more variable results.

Factor 1, which is directly proportional to elevation and precipitation and inversely proportional to temperature, predominates in our models. This factor was negatively correlated with diversity metrics for shrubs, indicating that diversity is greatest in low elevation areas with low precipitation and hot temperatures. Conversely, diversity of trees and evenness of shrubs increased with elevation and precipitation.

Native herbaceous communities showed a more complex relationship with environmental factors. Diversity of native herbaceous species tended to decrease with precipitation and increase with isolation; the trend with elevation is less clear (Table 7). Native grasses increased in evenness and proportion cover with factor 1. Given the overall diversity of herbaceous species (native and non-natives) decreased with elevation (negative correlation with factor 1; R^2=0.18 $P<0.0001$), while native species abundance had a weaker relationship (R^2 =0.018 for a regression with factor 1, P=0.02), our results suggest that diversity here is driven by higher diversity of non-native species at lower elevations. In this sense our results agreed with previous studies in the same area that reported a negative relationship between overall understory diversity and elevation (Keeley et al. 2003).

Despite the strong explanatory power of factors associated with elevation and temperature (Factors 1 and 4), our models vary widely in terms of the percentage variability explained, which suggests that there are other important factors that are not incorporated in our analyses (Table 7). This is particularly true for native herbaceous diversity, given the low R^2 value in our best model.

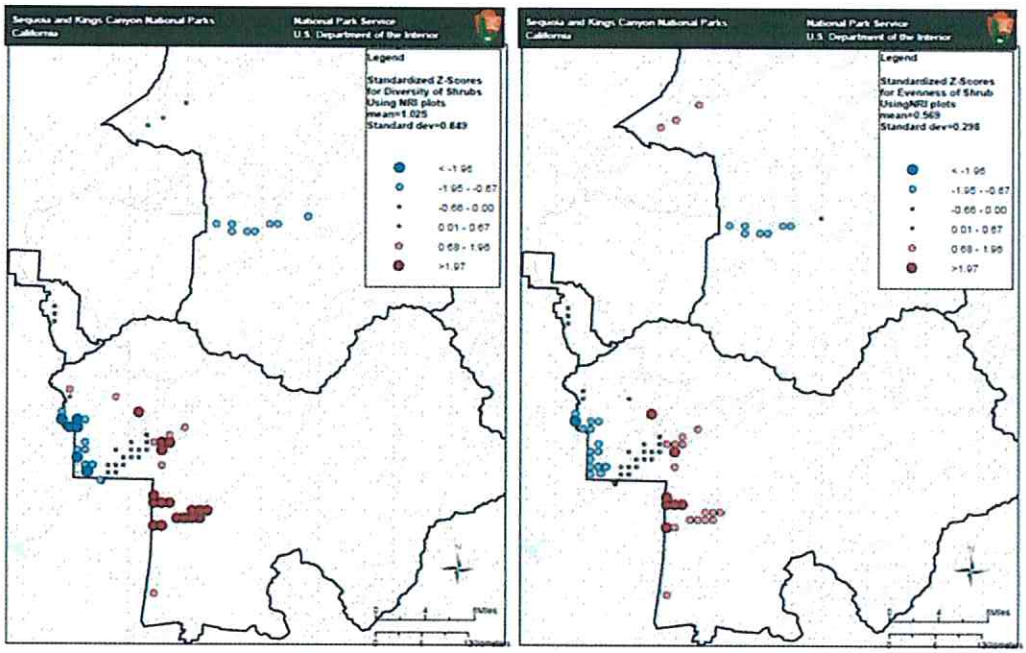

Figure 8. Standardized diversity metrics for shrubs calculated using NRI plots. The panel on the left shows standardized Shannon diversity index (H') and the panel on the right shows Evenness (L'). Each marker represents a study plot. Extreme colors and sizes represent increasingly significant values with respect to the overall mean for the whole dataset.

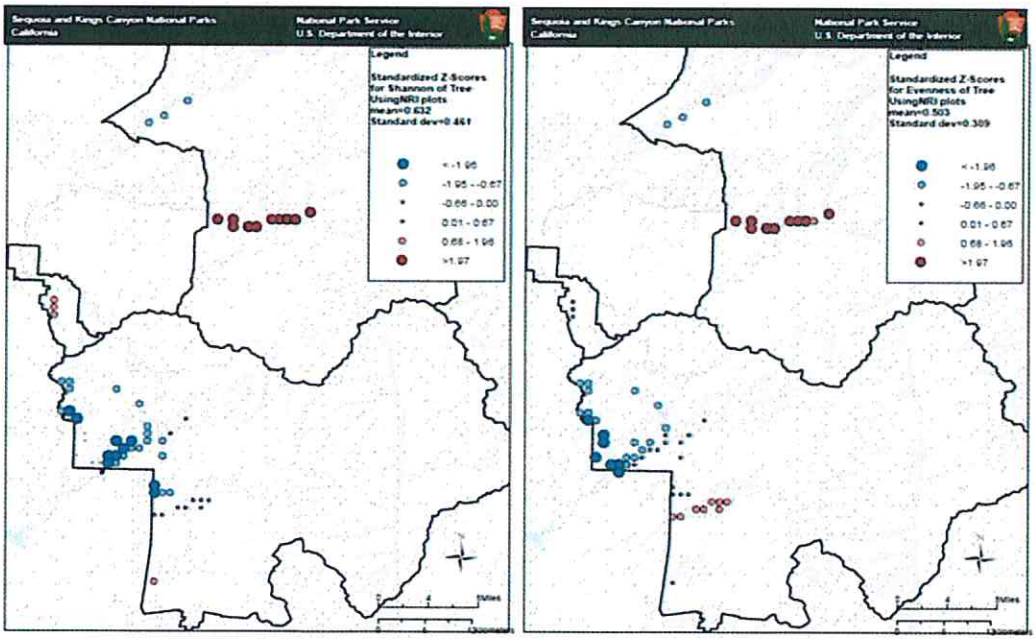

Figure 9. Standardized community metrics for trees calculated using NRI plots. The panel on the left shows standardized Shannon diversity index (H') and the panel on the right shows Evenness (L'). Each marker represents a study plot in the corresponding dataset. Extreme colors and sizes represent increasingly significant values with respect to the overall mean for the whole dataset (blue indicates areas of low diversity, red indicates areas of high diversity).

Table 7. Results from multiple regressions relating community metrics with topographic and climatic variables for NRI plots. The first half of the table summarizes results of fitting community metrics with the 5 factors derived using factor analysis on topographic and climatic variables. Model selection was performed using stepwise regression using minimum Bayesian Information Criterion (BIC). We only report the statistics associated with the best model, which include the R^2, and the overall fit test (F-statistics). The second half of the table provides the coefficient estimates and standard errors for factors included in the best model. Correlation of each factor with the original variables is indicated by + or – symbols below the factor's name. Abbreviations: elev=elevation, prec=precipitation variables, temp=temperature, dist=distance.

	Herbs			Shrubs		Trees	
	Shannon (H')	Evennes (L')	Native Grass Relative Abundance	Shannon (H')	Evennes (L')	Shannon (H')	Evennes (L')
R^2 Adjusted	0.166	0.200	0.468	0.347	0.154	0.632	0.618
Mean of Response	-0.063	-0.367	0.067	-0.006	0.082	-0.439	-0.170
Observations (#)	93	92	93	77	77	69	69
P-value	0.054	<.0001	<.0001	<.0001	0.046	<.0001	<.0001
				Estimates			
Factor1	-0.1407			-0.278	0.8345	0.5183	1.2624
(+elev,+prec,-temp)	(SE=0.0936)			(SE=0.0348)	(SE=0.1464)	(SE=0.1343)	(SE=0.1329)
Factor3				0.6571			
(+dist stream)				(SE=0.2283)			
Factor4	-0.3743	-0.7526	-0.2033				0.4727
(-elev,+temp,-dist road)	(SE=0.1614)	(SE=0.1546)	(SE=0.0603)				(SE=0.1463)
Factor5	0.4342						-0.916
(+slope,+dist road)	(SE=0.1239)						(SE=0.1901)

Effect of potential stressors. After we removed variation explained by topographic and climatic variables, we explored the effects of two main potential stressors: grazing and fire. In addition, we evaluated the relationship between community metrics and attributes associated with vegetation cover loss (which we term general disturbance). In all cases, we used multiple regressions with the residuals of the previous analyses and the continuous and categorical variables describing potential stressors (Tables 3 and 5). By comparing residuals after taking into account the effect of topography and climate, we can optimize comparison between factor categories. In addition to these analyses, we also explicitly compared differences across HUC-10 units within shrublands and hardwood forests. Given that we found a low correlation between categorical variables associated with fire, grazing, or overall vegetation cover changes with environmental factors (Table 8), we are confident that our analyses or effect of potential stressors is not confounded by environmental effects.

Table 8. Correlations between environmental factors and potential stressors. Value at each cell estimates the strength in the correlation between potential stressor variables and watershed units with environmental factors. For each cell R^2 is given assuming a linear model, except for magnitude of disturbance where the correlation coefficient. See table 4 for the relationship between environmental factors and environmental variables.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Watershed	0.39	0.07	0.09	0.58	0.34
Disturbance Category	0.02	0.01	0.05	0.03	0.02
Magnitude of Disturbance	0.14	-0.25	0.18	0.19	0.25
FRID	0.07	0.02	0.05	0.04	0.04
Grazing	0.35	0.05	0.00	0.00	0.03

Throughout our analysis, we found strong differences across watersheds (Table 9) regardless of potential stressor, which in several occasions explained most of the variability in the residuals after environmental characteristics were accounted for. In particular, Marble Fork showed

significantly higher abundance of native grasses given the environmental characteristics than the rest of the HUC-10 units and North Fork Kaweah showed lower than expected diversity of shrubs. Although East Fork Kaweah had lower than expected values of native grass abundance once environmental conditions were taken into account, it also had higher than expected shrub diversity for both shrublands and hardwood forests. Tree communities did not show differences across units. These results demonstrate that factors other than the ones we describe with our environmental characteristics influence spatial variation in diversity. For instance, floras may differ between HUC-10 units and our explanatory variables miss many (particularly longer-term) land use and disturbance history.

The second most important factor explaining the variability in diversity was recent disturbance as described by Landsat analysis (Kennedy 2010). We found that shrub communities where vegetation cover has been reduced by disturbance were less diverse than expected (based on environmental characteristics) compared to areas where a cover-changing disturbance was not detected (Table 9). In addition, as the magnitude of change in vegetation cover decreases (percentage of area that completely lost vegetation cover), the abundance of native grasses was reduced; this suggests the severity of disturbance detected in SEKI is high enough to favor higher abundance of invasive species. Thus, our results pointed out that overall disturbance events and not only fire have the potential to strongly influence community characteristics in SEKI.

Areas with a documented history of grazing are concentrated on the western portion the foothill zone, and are not represented in NRI sampling. To explore the potential impact of authorized and unauthorized grazing for plant communities in the park, we instead used Vegetation Mapping plots (VMA plots; Table 2) that were located in grazed areas, and compared them with VMA plots at comparable elevations that have not experienced cattle grazing. In addition, we contrast VMA plots inside and outside SEKI boundaries to explore general impact of protection policies in SEKI, which include prohibition of cattle grazing and logging. It is important to note the high uncertainty in both analyses, as a more biased dataset was used and some comparisons occurred outside NPS boundaries. In addition, we have no information on the intensity and duration of grazing history, or the intensity of wildlife grazing.

Given these limitations, one of the most interesting results related to grazing history was that native herbaceous diversity was higher than expected in previously grazed areas, while shrub communities showed lower diversity and evenness in areas with a history of grazing (Table 9). Grazed areas have experienced severe disturbance in the past years based on vegetation cover change, and moderate to low fire return interval departures (FRID is usually 3 or 4 in these areas, although these estimates are highly uncertain), circumstances that confound any potential effect of grazing. Despite this, it is clear from our results that native herbaceous communities in areas that have experienced cattle grazing until 1997 are no worse than in other areas throughout the foothills. Keeley found similar results for the SEKI foothills, which suggests that impact of grazing have signatures lasting several years (Keeley et al. 2003) or the level of grazing experienced was within levels that favored native species (Marty 2005; Hayes and Holl 2003; DiTomaso et al. 2008, Jackson and Allen-Diaz 2006; Huntsinger et al. 2007).

Diversity in plant communities in areas outside the park did not differ from comparable areas inside the park where grazing was restricted (Figure 10). In fact, we detected a significantly higher abundance of native grasses and Shannon diversity values for native herbaceous species outside the park than in comparable areas inside the park ($Abundance_{out}$=0.04 SE=0.018, $Abundance_{in}$=0.001 SE=0.02 with p-value <0.05 for the t-statistics; H'_{out}=0.54 SE=0.055, H'_{in}=0.25, SE=0.61). Trees and shrub diversity were similar in both locations. However, these differences could also be explained by differences in environmental conditions between areas (Figure 10). Furthermore, it is important to note that East Fork Kaweah plots ranked the last for abundance of native grasses in comparisons across watersheds (Table 9). More research specific to grazing impacts is needed to determine the influence of grazing history on the conditions of foothills areas in SEKI.

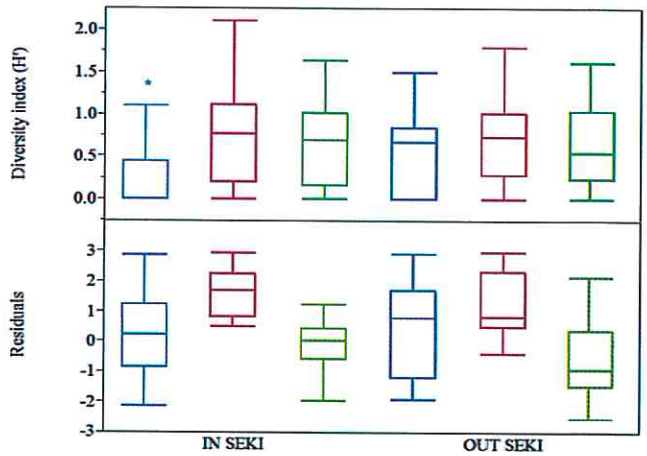

Figure 10. Comparison between areas in areas inside SEKI and areas outside the park. Upper panel shows the Shannon diversity index (H') for herbaceous vegetation (blue), shrubs (red), and trees (green). Lower panel shows the results after any correlations with environmental characteristics were taken into account. Within each vegetation group, we compared areas in and outside the park using t-tests; an asterisk indicates significant differences. For this comparison we used Vegetation mapping plots adjacent to the park on the East Fork Kaweah unit (Figure 1).

Due to limited understanding of historical fire regimes in the foothills, analyses relating FRID scores are uncertain, particularly in lowest elevation foothill areas. Despite the expectation that severe and extreme fire return interval departures will impact plant community diversity, particularly in shrublands, we found a weak signal of this factor in our analysis (Table 8). More research is needed to better understand historical fire regimes and the effects of departures from these regimes.

In chaparral, fires are typically high severity crown fires that could reset communities to bareground conditions. Under increased presence of invasive grasses, one of the major risks in these communities is strong departure from historical fire community fluctuations promoted by frequent fires (Keeley et al. 2008). While fire severity and frequency control which species persist in the community, pre-fire community composition will control the actual composition of communities after a fire (Keeley et al. 2003). In addition, community composition after fire changes as canopy closure limits regeneration of light intolerant species, and seed obligate species are replaced by resprouters (Keeley and Forthingham, 2003). Given that hardwood forests communities are dominated by fire tolerant species like blue oak, changes in plant diversity after disturbance are mostly driven by year to year changes in herbaceous species. The upper elevation hardwood forests dominated by canyon live oak and black oak are considered relatively stable (Bolsinger 1988).

Analysis of community response to fire using Fire Effect Plots (Table 2) did not show any signs of increased abundance of invasive species. Diversity of native herbaceous species was significantly higher after a fire ($Mean_{pre}$=0.79 SE=0,19, $Mean_{post}$=2.05 SE=0.29, p-$value_{tpair-test}$=0.002), most likely indicating the positive effect of canopy openings due to fire (Keeley et al. 2003). Diversity of shrubs significantly decreased after fire (for diversity $Mean_{pre}$=0.88 SE=0.19; $Mean_{post}$=0.18 SE=0.17), while tree diversity did not change (for diversity $Mean_{pre}$=0.63 SE=0.09; $Mean_{post}$=0.44 SE=0.11). In shrublands, the high proportion of herbs that are observed after fire yields to increased dominance of shrubs as recovery progresses (Keeley and Fotheringham 2003b). Although shrubland communities often recover within 2-3 years of a fire (Keeley et al. 2005a; Lozano et al. 2010), spatial variability can be high (Lozano et al. 2010) depending on pre-fire community composition (Keeley et al. 2005a). This limits pattern detection when only few sites are available, the case in our analysis.

Table 9. Results from multiple comparisons of residuals of diversity metrics (once environmental correlations have been accounted for) with potential stressors (these variables are explained in Table 5). We also explored differences among watershed units. We indicate the significant differences, and the percentage of residual variability explained is included in parentheses. For watersheds, multiple comparisons with Bonferroni corrections were conducted. Given that we did not find any significant effects of disturbance duration and fire (FRI Departure), we have not included them in this table. Because sample size was too low to conduct grazing history comparisons based on NRI plots, results for grazing (last column) are based on analyses with VMA plots. Acronyms for watershed units are the same as in Table 1

				Disturbance		Grazing*
Vegetation type	Layer	Variable	Watershed	Category	Magnitude	Category
Shrubland	Herbs	Shannon	n.s	n.s.	n.s.	n.s.
		Evenness	rest<NFKw (56%)	n.s.	n.s.	n.s.
		Abundance Native grasses	EFKw<rest<MbFKw (22%)	n.s.	Decrease with disturbance magnitude (26%)	n.s.
	Shrubs	Shannon	NFKw<rest<EFKw (45%)	NoDist>Dis t(1%)	Increase with disturbance Magnitude (1%)	n.s.
		Evenness	NFKw<rest<EFKw (43%)	NoDist>Dist (5.6%)	Increase with disturbance Magnitude (1%)	n.s.
Hardwood forest	Herbs	Shannon	n.s	n.s.	n.s.	NoGraz<Graz (4.1%)
		Evenness	rest<NFKw (72%)	n.s.	n.s.	NoGraz<Graz in NoDist (Graz=9.4%)
		Abundance Native grasses	n.s	n.s.	n.s.	NoGraz<Graz (5.1%)
	Shrubs	Shannon	MFKw<rest (70%)	n.s.	n.s.	Graz<NoGraz (1.1%)
		Evenness	NFKw<rest(74%)	n.s.	n.s.	n.s.
	Trees	Shannon	n.s	n.s.	n.s.	n.s.
		Evenness	n.s	n.s.	n.s.	n.s.

Spatial Predictions

At the extent of the foothill zone, our analyses predict that differences in diversity of native herbaceous plants are mostly associated with vegetation types. Thus, areas with more diverse native herbaceous communities are found where hardwood forests predominate (Figure 11); lowest diversity is predicted for Middle and East Kaweah units. Abundance of native grasses is highest in the Middle Fork Kings River and in the west and south borders of North and Marble Kaweah river units. Lowest abundance of invasive grasses is predicted at higher elevations (Figure 12).

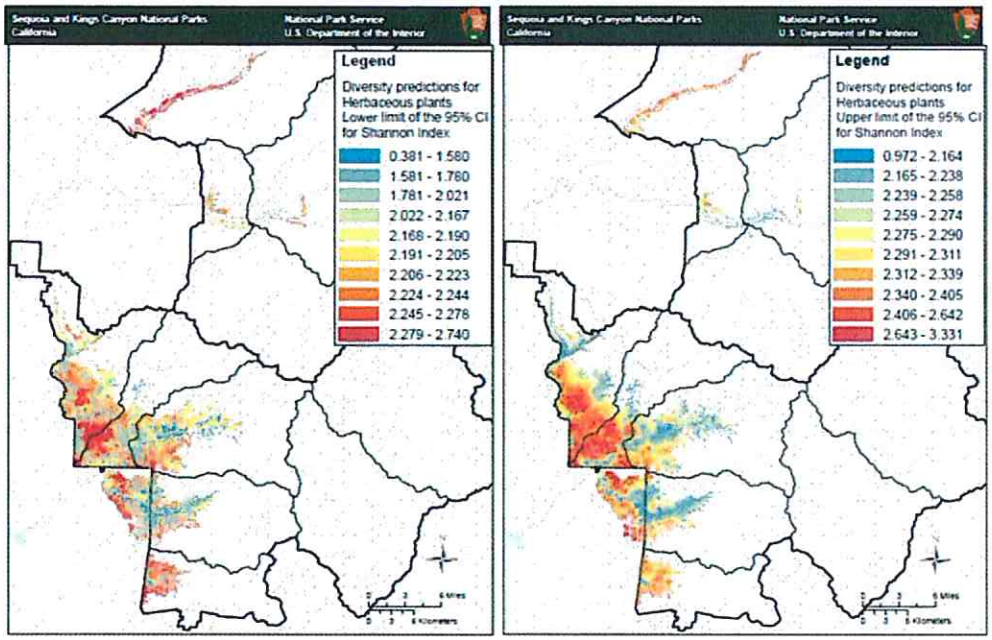

Figure 11. Predicted diversity (H') values for native herbs using NRI plots. Values were predicted for each vegetation cover separately using the best models after testing for effects of three stressors (disturbance, fire, and grazing) and topographic and climatic variables. Left and right panels show lower and upper limits for a 95% confidence interval for the mean.

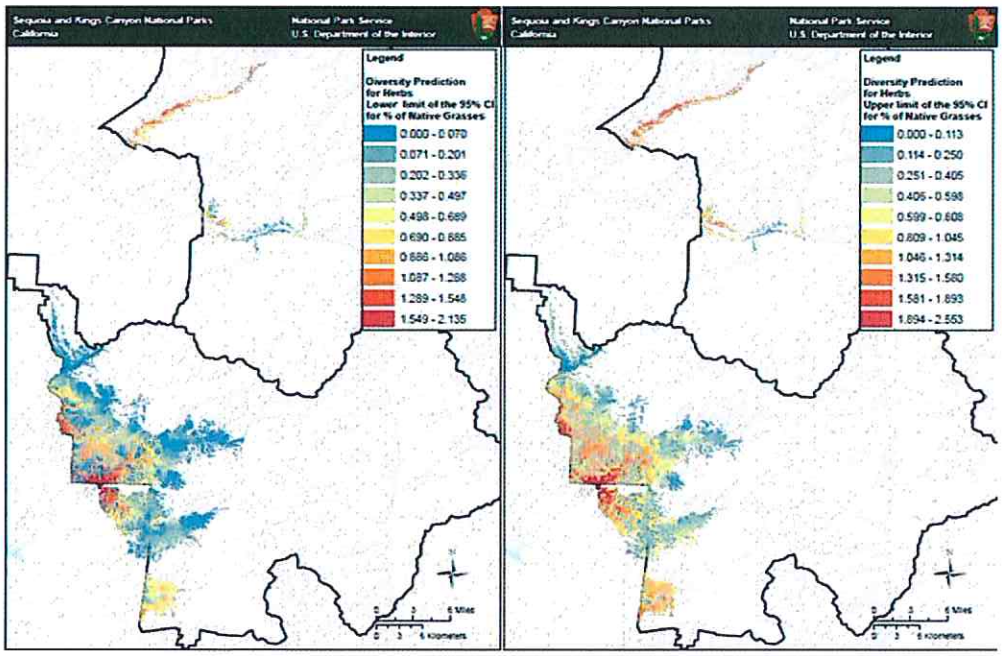

Figure 12. Predicted abundance of native grasses using NRI plots. Values were predicted for each vegetation type separately using the best models after testing for effects three stressors (disturbance, fire, and grazing) and topographic and climatic variables. Left and right panels show lower and upper limits for a 95% confidence interval for the mean.

Diverse communities of shrubs are located mainly at higher elevations along the Middle Fork Kings River and the East Fork Kaweah units; in addition, some areas throughout the Sequoia National park have high predictions of shrub diversity (Figure 13. On the other hand, tree communities are more diverse in Kings Canyon National Park and at higher elevations in the transitions between foothill communities and coniferous forests (Figure 14). Overall, we detected that areas with plant communities in the poorest condition relative to the rest of the SEKI foothills are located along Marble and Middle Fork Kaweah.

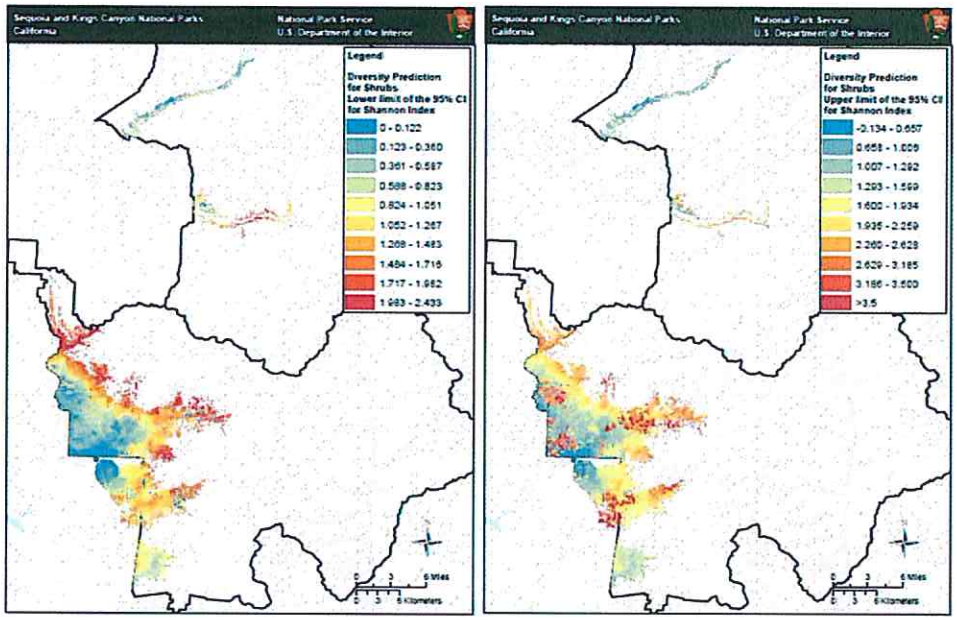

Figure 13. Predicted shrub diversity (H') using NRI plots. Values were predicted for each vegetation cover separately using the best models after testing for effects of three stressors (disturbance, fire, and grazing) and topographic and climatic variables. Left and right panels show lower and upper limits for a 95% confidence interval for the mean.

The value of these predictions for the entire foothill zone resides in the spatial patterns they suggest more than in the absolute value they represent. Similarly, given that standard error associated with our prediction increases as diversity values increase for most of our metrics, we have more confidence for low native herb diversity values than for high values; this is particularly the case for Kings Canyon National Park where our confidence is relatively low.

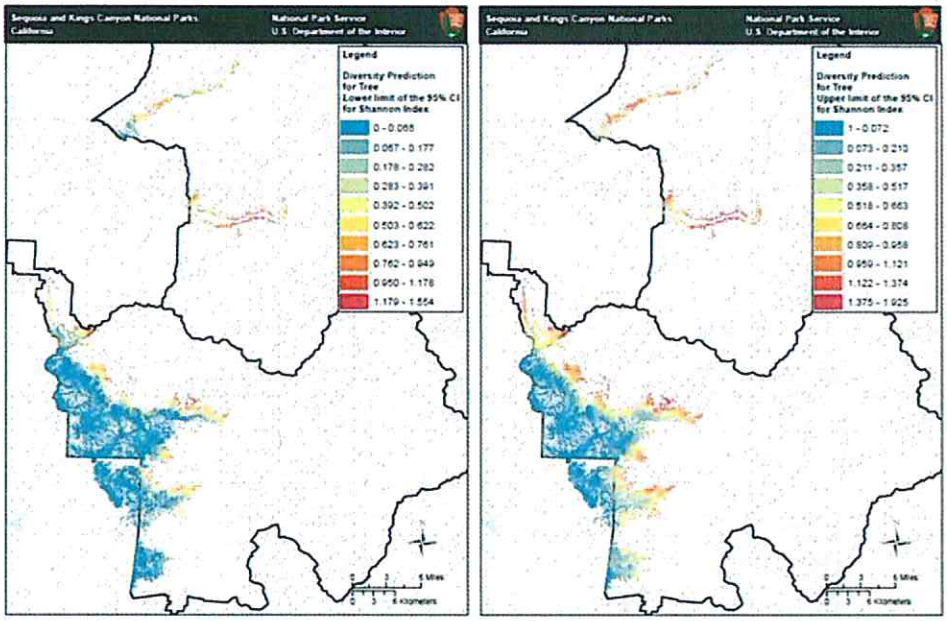

Figure 14. Predicted tree diversity (H') using NRI plots. Values were predicted for each vegetation cover separately using the best models after testing for effects of three stressors (disturbance, fire, and grazing) and topographic and climatic variables Left and right panels show lower and upper limits for a 95% confidence interval for the mean.

Temporal Trends

Analysis of NRI plots censused more than once between the 1980s and the 1990s indicates a general decline in plant community diversity, although this decline was only significant for herbaceous species diversity. For herbaceous species, diversity decreased at a rate of -0.02676 per year (SE=0.0084, R^2=0.9171), while communities became less even at a rate of -0.0130 per year (SE=0.003, R^2=0.6914). We did not detect any differences associated with HUC-10 units, although we could only test for differences within Sequoia National Park. In addition, these trends were similar across vegetation cover types (shrub and hardwood forest). Within plot variability was very high for both metrics; for diversity we found that plot variability constituted 88% of the total variability, and for evenness, plot variability constituted 50% of the total variability. Thus, although there was a significant relationship of declining native herb diversity with time, high intra-plot variability limits our ability to extrapolate.

When plot metrics were analyzed by decade, we did not find any evidence of temporal trends, except for a decline in diversity of shrubs, (Figure 15, $H'_{1980's}$=1.02 SE=0.08, $H'_{1990's}$=0.67 SE=0.14, t-test p-value=0.038).

Uncertainty Analysis

Several characteristics of the datasets used limit the power of our analysis to accurately describe plant community conditions throughout the foothills. Sample size is the major limitation of the NRI dataset. Given that we used it in all our spatial analyses and for developing our predictions, there is a high level of uncertainty in HUC-10 units where no NRI were located. In particular, areas along the Roaring river, South Fork Kaweah, North Fork Tule, Mill Flat Creek, and Dye Creek units did not contain NRI plots.

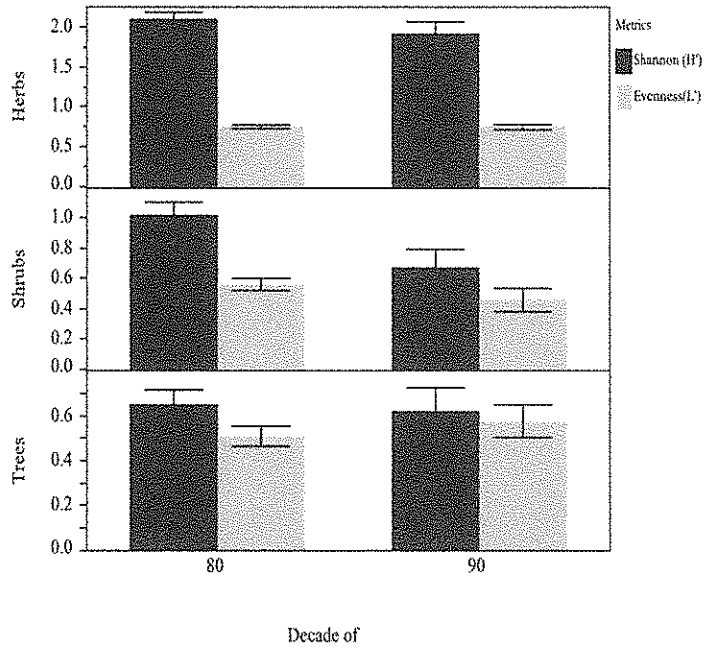

Figure 15. Changes in time of community metrics for NRI plots. Plots were grouped by the censused year in decadal intervals, and comparisons were performed on the residuals after our spatial analysis.

We limit our analyses to community level metrics as we have little confidence in considering species-specific response to potential stressors. We also are more uncertain about comparisons between areas that contain different communities compared to comparisons among areas with similar flora, e.g. King Canyon vs. Sequoia National park.

Native grasses have received relatively little monitoring attention and, while the datasets we use in our analysis do describe native grass abundance, sampling should be more intensive given the low abundance of this vegetation group. More specific mapping and distributional studies aimed at understanding native grass component of the foothills vegetation is needed.

The datasets available also had little resolution to determine the regeneration status of oak woodlands, as seedlings are not measured in most of the vegetation surveys. Thus, we have very limited ability to speculate about the status of oak woodlands in our analysis. Accordingly, in the next section of this chapter, we present a literature review focused on this community type.

In addition to this level of uncertainty, our analyses also have limited power to detect effects of grazing and fire return interval departures – the two major potential stressors of the foothills. We have most confidence in the general disturbance patterns associated with cover loss recorded via Landsat analyses (Kennedy 2010). Areas that had been grazed in the past showed high disturbance levels and moderate FRI departure (Figures 2 and 3). Thus, high spatial correlation between potential stressors limits our ability to separate their effect. In addition, we have very course-level information on grazing history available for analysis. Finally, we have limited understanding of historical fire regimes in the lower foothills and FRID values for these areas are

highly uncertain. More research is needed to understand the impacts of both of these potential stressors.

Regeneration of Blue Oak Woodlands

The objective of this section is to explore the current state of knowledge on factors impacting the integrity and vulnerability of the foothill vegetation within SEKI. The review concentrates on research that focuses on the past and present status of blue oak woodland and factors that affect regeneration of blue oaks, as this is one of the most dominant vegetation communities and important components of the foothill region.

It has been suggested that fire, grazing, and invasive species are particularly important human instigated factors affecting the regeneration of blue oaks. Historically, oaks have been removed for commercial fuel wood harvesting, to improve forage for grazing, to expand rangeland, to increase agriculture, and to create space for urban development (Bolsinger 1988; Alagona 2008). Although blue oaks survive well after fire (Haggerty 1994) and fires cause sprout development (Mensing 1992), fire history has been correlated with changes in population structure in oak savannas (McClaran 1986; Mensing 1992). In addition, grazing pressure has been negatively correlated with blue oak regeneration (Hall et al. 1992; Standiford et al. 1997; Swiecki et al. 1997a) and the invasion of exotic species (Gordon et al. 1989; Gordon and Rice 1993; McCreary and Tecklin 1997). Although there has been a massive amount of work in regeneration of blue oak and several recent reviews have evaluated the blue oak regeneration problem for California in general (see Swiecki and Bernhardt 1998, Allen-Diaz and Jackson 2005, Tyler et al. 2006), we specifically explored the potential threats to blue oak populations in SEKI. We have included in this review only work that have been conducted in areas comparable to SEKI, i.e. other foothill areas along the central and southern Sierras. Nevertheless, to complement our assessment of blue oak critical transitions and threats, we have summarized major findings in other areas in California where blue oak communities have been studied. For this reason although our literature review is comprehensive for areas comparable to SEKI, it does not reference directly studies conducted in other areas. Naturally occurring controls to blue oak regeneration will also be evaluated to give reasons for the current regeneration issue.

Regeneration processes

Regeneration of individuals or stands of trees refers to the renewal of adults lost to mortality via recruitment of new individuals, or the regrowth of individuals damaged by fire or other disturbance (Bartolome et al. 1987). In 1908, Sudworth noted that regeneration rates in several oak species appeared to be insufficient to replace natural mortality and removal of adult trees (Sudworth 1908). This initial observation generated demographic studies of blue oak populations over the past several decades, in an attempt to fully comprehend the regeneration problem.

During a comprehensive evaluation of blue oak cover changes throughout California, Davis et al. (1995) found that while some sites had noticeable decreases in tree cover, this loss was compensated by expanding tree cover in other regions. While large changes were recorded in individual regions sampled, the mean overall tree cover remained virtually unchanged from 1940 to 1998. They measured changes in extant blue oak foothill woodland cover and densities in 708 sites throughout the state using aerial photographs from the 1940s and the late 1980s.

Although their results indicate stable tree cover throughout the state for the years monitored, this does not necessarily suggest that oak woodland cover is under similar conditions today. In addition, there is a strong spatial variability in blue oak regeneration and different areas might be experiencing the effect of different potential stressors.

Locally, grazing, fire, and competition from invasive annual grasses have been suggested as determinants of blue oak seedling and sapling growth and survival, but there is little information about the relative importance of these factors (Phillips et al. 1996; Phillips et al. 2007), in particular in the long-term. As mentioned by McClaran (1985), the transition from seedling to sapling to tree appears to be more crucial in limiting regeneration than acorn germination and early seedling survival alone. Standiford et al.1997 found that although seedlings can be found in blue oak woodlands across the state, saplings between 1.5 to 3 m tall are generally absent. Therefore, we focused on disturbances that restrain seedling regeneration into the sapling stage of life. In the next section we review the state of knowledge of regeneration events in areas pertinent to SEKI

In SEKI, Vankat and Major (1978) reported a significant increase in blue oak cover since the late 1980s that was interpreted as the result of peak regeneration 1860 and 1880, corresponding to a period in time European settlements were expanding in the region (Vankat and Major 1978). Based on their results, they hypothesized that successful regeneration and subsequent increases in blue oak densities were the result of livestock grazing introduced by European settlers in the late 1800s. Intensive grazing removed herbaceous understory vegetation, which reduced fuel loads and thus fire frequency.

Two other studies in blue oak woodlands agree with the time at which regeneration has declined, although they found no positive effect of grazing. McClaran (1986) found a continuous representation of blue oak trees that had been established between 1860 and 1930 in Tulare and Yuba Counties. He divided his study between two sites, one which had been grazed, and another which had not. He found that regeneration in the ungrazed site peaked between 1870 and 1900, and noted a distinct lack of regeneration following the 1920s. On the other hand, in the grazed sites regeneration peaked between 1910 and 1930, with few new trees appearing after the 1940s.

Although McClaran found no clear relationship between grazing and regeneration, he did discover that fire had a positive relationship with increased oak densities. From 1850 to 1940, 70-85% of the blue oak trees that had established did so within one year of a fire. In the Tehachapi Mountains of Kern County, Mensing (1988) found a continuous establishment of trees from 1570 to 1856, a regeneration peak in 1856, and a noticeable lack of regeneration following the 1860s. Specifically, he found evidence of an increase in fire frequency from 1853 to 1856 and a distinct decrease in fires after 1863. He concluded that dry conditions in the mid-1850s stimulated an increase in fire frequency which resulted in a high percentage of multiple-stemmed and -centered trees, suggesting that the burst of regeneration in 1856 was primarily the result of sprouting encouraged by fire. Mensing pointed out that the lack of regeneration following the 1860s coincides with the introduction of livestock grazing on the site in 1864, and more likely reflect summer grazing on oak seedling. Thus although fire has been congruently identified as factor promoting demographic changes in oak populations, grazing effects are less clear.

Increased regeneration after fire is a direct result of blue oak capacity to resprout following disturbance such as fire, grazing, or cutting. Fire mechanically removes the tops of small blue oak trees and stimulates post fire sprouting (McClaran and Bartolome 1989, Mensing 1988, Arevalo et al. 2009). However, the success of sprout sapling establishment can vary widely between locations, and between different years at a location (Swiecki and Berndhart 2001). In addition there is a size limit for individuals to resprout, which reduces resilience of population to fire as individuals get older. Haggerty (1994) followed an intense, crown scorching arson fire in SEKI and made subsequent visits in 1988 and 1989 to record new mortality, sprouting, and formation of new scars on blue oak trees. Adult blue oaks were able to withstand this intense fire. The survival rate was 93% (without considering seedling and saplings). However, successful sprouting did not occur in blue oak individuals that were greater than 20 cm diameter at breast height (DBH). Johnson (1977) also found that degree of sprouting decreases with increasing stump diameter. McCreary et al (2006) found that blue oak sprouts generally grow more rapidly than seedling growing from acorns. He found that after two years of disturbance by fire, an average of 90 cm in growth of stump sprouts were well above the browse zone (1.5m). In this sense, fire is a factor controlling changes in oak population structure, although these changes do not imply renewal of oak population by acorn regeneration.

In a comprehensive study of blue oak populations at SEKI, Swiecki et al. (1993, 1997a and b) calculated an adult mortality rate of 25% over a 42 year period. They calculated net regeneration by comparing blue oak sapling regeneration with adult mortality rate, and found a small portion of plots might have a net gain (less than 8%), while most plots will not change (47%) or might have a net loss (45%). Swiecki et al. (1993, 1997a, 1997b) also established that saplings are more likely to occur in the open areas than under canopy (50% of these saplings were found in the open, 27% at the canopy edge, and 22% below the canopy). These results suggest that in Sequoia National Park, saplings are much more likely to occur in the open than under tree canopies, in contrast to small seedlings, which are most likely to be found beneath the canopy of the parent tree (Muick and Bartolome 1987). Swiecki et al. (1993) hypothesize that this shift in species occurrence within characteristic sites results when seedling regeneration beneath the canopy is released through canopy mortality or removal, creating environmental conditions favorable for saplings.

Additional studies in SEKI have suggested that grazing and climate changes more than fire could be responsible of lack of regeneration. In order to understand the effects of prescribed burning on woodland and forest composition and structure, 76 plots were established in the park in 1969 and re-censused in 1998 (Roy and Vankat, 1999). They compared population structure across areas with different fire history and found that in all areas tree densities had decreased in blue oak woodland by 19% (111 trees/ha) although it remained the dominant tree with 12% of all trees censused (78 trees/ha). Size distribution of blue oaks also revealed changes from 1969 to 1996 with a statistically significant decrease in the proportion of trees in the 10 to 19 cm DBH height size class, where mortality was 15%. At that time they did not detect regeneration of new individuals in any of the areas censused. They concluded that blue oak woodlands were experiencing a reversal from previous regeneration trends (peak between 1860 and 1890) and that fire was not a determinant factor in this reversal in the park; they further suggested that

grazing reduction and climate changes could have been responsible. Nevertheless, this conclusion does not consider a formal test of different grazing levels in the park.

In SEKI, saplings appear to be absent from areas of heavy grazing pressure of livestock browsing; in fact in these areas they identified chronic vegetation browsing as the main factor limiting sapling regeneration and they did not find a significant effect of recent fire events on sapling regeneration (Swiecki et al. 1993 and 1997b), although they tested several topographic and environmental variables. They studied the distribution of blue oak saplings at the stand level in 100 plots distributed along the Marble and Middle Forks of the Kaweah River. Of these plots, 83 were within the main pasture use for authorized grazing (grazed year round since 1977 at approximately 0.9 animal-month/acre/year), 15 were within the holding area (grazed between May and October at 5 animal-month/acre/year), and 2 were outside the pasture (light occasional grazing since 1962). This study reported that 22% of the plots had low sapling regeneration, 26% had moderate regeneration, and 4% had high regeneration (Swiecki et al. 1993 and 1997b). Thus, although sapling regeneration occurs in these areas, grazing indirectly increased the chance of sapling mortality, for smaller sapling classes are susceptible to being severely damaged or killed by wild predators, fires, or other agents that would not seriously affect larger saplings or trees.

In addition, time of grazing and the influence of wildlife grazing can be significant factors. Hall et al (1992) found a strong effect of time of grazing. Winter grazing at low and medium stock densities was the least damaging of their treatments, while spring or summer grazing at high stock densities was most damaging. In addition, other studies have suggested deer browsing as is an important factor in the lack of regeneration in oak populations as deer populations have increased with a consequent intensification of browsing pressures (White 1966, Griffin 1973, Swiecki et al. 1993, Kuhn and Johnson 2008). Damage to oak seedlings under oak trees may be greater when cattle or deer are present because they are often attracted to higher forage levels, forage quality and acorns present beneath the canopy.

Despite this uncertainty concerning natural levels of grazing variability, regeneration in areas not experiencing intense grazing or under active fire management might me more strongly controlled by variability in environmental conditions in space and time. Allen-Diaz and Bartolome (1992) examined the effects of prescribed fire and sheep grazing on naturally regenerating blue oak seedlings. They found that recent low-intensity prescribed burns applied during fall months following rain prevented grass and litter at the soil surface from being completely consumed by fire, and that sheep grazing did not affect regeneration, survival, or growth of blue oak seedlings over a four year period.

Spatial variability in oak regeneration, probably driven by local environmental conditions, seems to be the norm at regional and local scales. More recent studies in SEKI have not found the same sapling regeneration potential reported in Swiecki et al (1997b). Results from a CALFED report by Stahle et al. (2010) assessed seedling to adult ratios as an alternative to evaluating regeneration potential within the Kaweah River drainage of Sequoia National Park. They sampled a total of 103 blue oak trees per hectare and found no blue oak seedlings within their study site.

Our analysis of blue oak woodlands in the foothills also indicates strong spatial variability in population characteristics. We found that trees are relatively large in diameter and regeneration is occurring in some areas (Table 10). Our estimated average tree diameter is around 22.8 cm, and is consistent with reports across datasets. Nevertheless, this mean diameter is significantly lower than tree stature in old growth forests. Stahle et al. (2013) visited two old growth forests located close to SEKI and found that average tree diameter was about 39 cm. These differences reflect the presence of very large trees that recruited before 1600s in plots sampled by Stahl, rather than a difference in regeneration chronologies. In fact, peak regeneration for the park is between 1860 and 1890 (Vankat and Major, 1978) which coincides with regeneration episodes in plots outside the park (peak regeneration between 1860 and 1900, Stahle et al. 2013), and in general with peak regeneration across the state (McClaran 1986; Mensing, 1992; Stahle, 2010 and 2013).

The sapling to adult ratio can be used as a proxy for evaluating regeneration. Using this measure, we found that the ratio in some areas of SEKI was higher than one, indicating that successful regeneration of saplings could be occurring in some areas of the park. In particular, two locations along Middle Fork Kaweah (3-3.5 saplings/adult) and in one location at the west border of the park, close to Yucca Mountain (3 saplings/adult), show high ratios. These values contrast with values reported by Stahle in old growth forests (0-0.02 sapling/adult) and 0-0.02 sapling/adult in the other 15 NRI plots evaluated. Thus, although overall regeneration is low, there are areas inside the park with active sapling regeneration. Considering the strong signature of environmental variables in community composition; we would recommend to conduct a spatial evaluation of blue oak populations at SEKI.

Table 10. Summary of blue oak metrics at SEKI. Results are grouped by dataset where NRI = Nature Resource Inventory plots, VMA = Vegetation mapping areas, and VM Full plots = the second set of the Vegetation mapping plots. In each cell the first value indicates the mean and the two values in parentheses indicate the standard deviation and number of plots, respectively. DBH = diameter at breast height (in cm).

	Fire Effects	NRI	Stahle	Vankat-Roy (1966)	Vankat-Roy (1996)	VM Full Plots
Mean DBH	28	23	40	22	26	24
	(4.6 ,2)	(5.1 ,18)	(2.8 ,2)	(7.3,14)	(7.0, 14)	(4.9 ,12)
Min DBH	14	13	15	13	16	15
	(8.6 ,2)	(9.2 ,18)	(4.1 ,2)	(4.3,14)	(4.9,14)	(4.1 ,12)
Max DBH	38	39	78	34	39	41
	(4.7 ,2)	(13 ,18)	(2.0 ,2)	(17,14)	(16,14)	(15 ,12)
Sapling/ adult ratio	NA	0.54	NA	NA	NA	NA
		(1.7 ,18)				

Studies in areas close to SEKI have found reduced regeneration in blue oak population. Phillips et al. (1997) conducted a survey in Tulare and Kern Counties in California to evaluate blue oak regeneration factors including tree size class, acorn quality, and natural seedling survival. They found many individuals in the seedling and mature tree size classes, but consistently fewer in the sapling and pole size classes. Similarly, a technical report from the Pacific Northwest Research Station (Barrett and Waddell, 2006) explored the diameter distribution of blue oaks from three successive forest inventories in California (1981-1984, 1991-1994, 2001-2005). They concluded that diameter distributions have departed from the usual inverted J-shaped, which is characteristic of trees that are successfully regenerating. Their report concludes that sparse regeneration and low densities of small saplings for blue oak have been consistently observed for three decades of forest inventory.

Studies all agree in identifying a current lack of regeneration across the state, and in particular for populations at SEKI. Seedlings and saplings are rare in blue oak populations, but regeneration is spatially variable (Harvey 1989), as it is also observed in SEKI. Tree cover increased at SEKI since the 1920s, although density decreased up to 1996 (Vankat and Major 1978, Roy and Vankat 1999). Statewide, density has remained unchanged in most areas (Holzman 1993; Swiecki et al 1993), and changes in cover are variable (Davis et al. 1995). In general, fire seems to have been an important factor explaining pulse of regeneration and increased densities in many locations throughout the state. Grazing has been identified as a factor reducing seedling and sapling growth and survival, but only under intense levels.

Although these studies provide a good indication of changes in past regeneration and the present status of blue oak distribution, they do not differentiate between factors affecting transitions at each life stage of the blue oak. In order to understand how blue oak community composition may change in the future under different management practices and with a changing climate, it is necessary to consider factors that constrain oak regeneration. Specifically, we recommend further demographic modeling to investigate the factors that influence survival and mortality at each stage of the blue oak life cycle: acorn, seedling, sapling, sprout, and mature, seed bearing tree.

Other Factors affecting natural blue oak regeneration

Oak species produce seed crops that vary widely in quantity from one year to the next. Episodes of high acorn production occur through a process known as mast-fruiting, and are usually separated by several years of low acorn production. A study of acorn production patterns in five species of oak by Koening et al (1994) found that valley oak (*Quercus lobabta*) and blue oak had very similar acorn production patterns across years and that large acorn production one year was often followed by low acorn production the next. In fact, blue oaks exhibit a strong synchrony over large geographic scales of up to 135 km (Koenig et al 1999). Their results demonstrate that a local mass-fruiting event can influence acorn production over a large spatial scale, and can increase the probability of germination. Unfortunately, regular masting cycles and the processes that influence masting have not yet been identified for any species in the genus *Quercus*.

Several factors affect blue oak probability of germination and survival in the first years, most of these applicable to SEKI populations. Acorns tend to land beneath the canopy of their parent tree, but can be planted beyond the canopy through secondary dispersal by seed caching animals. blue oak acorns are viable for one year and within that time will germinate when moisture is available. A survey conducted in Kern County, assessed environmental factors that contribute to acorn quality and survival (Phillips 1992). The study exposed water drainage as an important environmental parameter that influences acorn weight. Elevation also appeared to greatly influence blue oak acorn germination. Acorns at lower elevations (620 meters) had the lowest germination rates of 19%. The highest germination rates of 82% occurred at mid-elevations, and this rate decreased to 46.2% with slight elevation gain up to 1,400 meters (Phillips 1992). Borchert et al. (1989) also found an altitudinal gradient related with moist conditions, with mesic sites at lower elevations having greater levels of seedling regeneration than cooler, higher elevation sites. Thus these results emphasize the importance of soil moisture in successful

germination. In fact, Borchert et al. (1989) found that regeneration rates for buried acorns were twice those for surface-sown acorns due to improved germination and reduced predation. Tecklin and McCreary (1991) found that acorn size significantly influenced survival, germination, and growth. Large acorns produced taller seedlings with heavier total root weight. These results suggest that increased growth and survival may be obtained by selecting large acorns for reproduction.

Predation by a variety of small and large mammals, birds, insects, and fungi also poses a natural threat to acorn survival. Foraging by livestock has proven to be a threat to acorn survival, since cattle often browse on fallen acorns. Within SEKI, the impact of livestock grazing on acorn survival is not an issue since grazing is no longer allowed in the park, and predation by wildlife is considered a greater threat to acorns. Past research on acorn predation has shown that many mammals, the most commonly mentioned being pocket gophers, mice, and deer, pose a threat to acorn survival. Despite this, there is no evidence that consumption of acorns is a primary cause for poor regeneration (Schmidt and Timm 1991).

Environmental conditions and microclimate are two other factors influencing natural regeneration in blue oak populations. Although acorns tend to accumulate below adult canopies, germination is not higher in these areas in general; it could be higher under drier conditions. Borchert et al. (1989) determined that oak canopy cover and herbaceous understory seemed to be significantly related to seedling regeneration, but these effects were minor and varied between sites. The oak understory provides cool, moist microhabitats compared to open grassland microsites (Parker and Muller 1982; Borchert et al. 1989). This suggests that understory sites may provide ideal microclimates for seedling regeneration only in xeric locations, while understory sites may be less beneficial in more mesic locations. Similarly, Standiford et al. (1991) found that although seedlings are usually found in blue oak populations, fewer seedlings and sapling have been found at low rainfall zones (230-380 mm/year) in oak woodland ranges within the foothills (lower than 1000 m.a.s.l.). Thus, moisture and geographic features appear to affect the emergence of blue oak seedlings. Although blue oaks are the most drought-tolerant of all the oaks, they still appear to be sensitive to periods of drought.

Mortality rates of blue oak seedlings and saplings are important in understanding future rates of regeneration. A 2007 survey by Phillips et al. evaluated the growth and survival of different age classes of blue oak seedlings in the foothills of Kern County, California. They found that older blue oak seedlings had higher rates of survival than younger seedlings. Their seedling studies demonstrated that up to 18% of blue oak seedlings within the site were more than 26 years old, and seedlings did not growth in height during a four year drought period that took place during the study. They also found that young saplings had higher rates of mortality, but if these young seedlings survive, they grow at a faster rate than older seedlings. Koenig and Knops (2007) found comparatively slow growth in a set of acorns planted in 1985, further supporting Phillips et al. (2007). This suggests that once a seedling survives and becomes established, there is greater chance that it will remain alive and recruit into a sapling, relative to a newly germinated seedling. In addition, these results point out the strong control of environmental conditions in growth variability and the sensitivity of regeneration to changing environmental conditions

It has been suggested that the introduction of annual grasses has been a major factor contributing to suppression of blue oak seedling growth and regeneration (e.g. Gordon and Rice 2000, Cheng and Bledsoe 2004). In a study that evaluated the effects of soil water between annual plants and blue oak seedlings, Gordon et al. (1989) and Gordon and Rice (2000) demonstrated that annual plant neighborhoods can influence the local availability of soil water for oak seedlings. They found that water content decreased most rapidly at high densities of *Bromus* sp and *Erodium* sp and this in turn impacted seedling root growth. In addition, they found that variation in early growth may affect the probability of seedling regeneration into sapling and larger size classes. Higher growth rates that persist longer into the summer drought would produce cumulatively larger seedlings with deeper roots, better able to exploit soil resources not available to the herbaceous understory (Gordon and Rice 2000).

Their results suggest that competition for soil water with introduced annual species contributes to the increased rate of blue oak seedling mortality observed in California. These studies suggest that the regeneration pattern of blue oak seedlings in California grasslands and woodlands may result from shifts in the seasonal soil water availability coincident with the replacement of native perennial herbaceous plants by Mediterranean annuals.

Conclusions and research needs.

In conclusion, these studies have identified that blue oak regeneration is occurring at SEKI, although it is occurring at a rate that does not compensate for adult mortality. Although fire has been identified as the major factor correlated with past regeneration peaks, concurrent changes in grazing intensity, fire, and arrival of invasive species limits our ability to rank the importance of these potential stressors in explaining current lack of regeneration. Beyond these three major suspects, other factors have been identified as major players in explaining temporal and spatial variability of regeneration. Acorn production is a time sensitive phenomenon that introduces large temporal variability in probability of successful regeneration. Similarly, sensitivity of seedling and saplings to environmental conditions not only influences when regeneration is most likely to occur, but also where. At smaller scales, sapling regeneration is higher under less dense canopy conditions, and at larger scales, elevation gradient and local climatic conditions limit sapling regeneration.

We recommend the following:

1. More research in less accessible areas, with particular emphasis to factors affecting blue oak growth that are applicable in SEKI.
2. Actively managing blue oak populations for grazing and impact of invasive species to ensure a seedling bank that guarantees future adult recruitment.
3. Given the spatial variability of factors influencing seedling and sapling growth, we recommend that any management practices incorporates an extensive representation of blue oak suitable habitats, rather than an intense protection of few representative areas.

Potential Stressors

Foothills at the Sequoia National Park are subject to several stressors due to proximity to progressively developed areas, its history of management, and the current regional and global trends in climatic conditions. We have shown in this chapter that characteristics of herbaceous, shrub, and tree communities at the foothills strongly vary with topographic and climatic conditions and specific characteristics at the watershed level. On top of strong differences between Sequoia and Kings Canyon units, native species tend to increase in diversity at higher elevations, where temperatures are lower and water availability during the growing season is greater. This relationship between diversity and elevation suggests that native plants might be strongly influenced by the global trend of increasing temperatures (Houghton et al. 2001), which is projected to be an increase of up to 3.8°C for the Sierra Nevada region (Snyder et al. 2002). This increase in temperatures will most likely imply an alteration of growing season conditions, in terms of length and water availability, as snowmelt runoff starts earlier in the season, reducing water availability in the summer (Cayan et al. 2001; Dettinger et al. 2004). Under these circumstances, native species might experience stronger competitive pressure from non-native annuals, especially with increased fire frequencies, and their ability to persist will depend on their ability to establish at higher elevations.

Because foothill communities at Sequoia National Park are protected, they have not experienced the same dramatic pressures as other foothill areas in the region. However, it is exceedingly difficult to establish robust reference conditions for this area, particularly with regard to fire regimes, and invasion of non-native annual grasses has occurred in the park, likely to a degree similar to outside the park. Given uncertainty in reference conditions, some evidence indicates that foothills may be diverging from their natural states due to changed disturbance regimes but more work is needed to set robust baseline conditions. In oak woodlands, for instance, fire suppression is thought to be responsible for the increase of non-native grasses, which was estimated to constitute as much as 99% of the herbaceous community in the foothills in the park (Parsons and Stohlgren 1989). In denser oak forests and shrublands, fire suppression may have reduced the advance of non-invasive grasses, but at the expense of an increased risk of severe fire. Despite this general expectation, we found that disturbance (based on vegetation cover change from Landsat analysis; Kennedy 2010) commonly occured throughout the foothill area in the last several decades. While these disturbances appear to negatively affect some aspects of shrub diversity and native grass abundance, the levels do not appear strongly detrimental to many characteristics of the plant communities.

Increases in disturbance frequency, mainly due to more frequent fire, will likely contribute to an increase in the presence of non-native grasses at higher elevations when temperatures increase. Although we did not detect a strong influence of time since fire or fire return interval departures with most of our community metrics, these measures are highly uncertain and we did detect a decrease in native grass abundance with magnitude of disturbance based on landsat imagery. This decline is likely related to the effect of disturbance severity on seedbank composition and the mortality of adult perennial grasses. Severe disturbances that cause removal of at least 90% of the vegetation cover are associated with intense fires, which greatly reduce abundance and diversity of seedbanks (Keeley et al. 2003). Although these results did not allow us to evaluate foothill community responses to different disturbance frequencies, they do suggest increased

disturbance frequencies may be detrimental to some components of the native vegetation. If predicted fire frequency increases above limits that allow community recovery, which has been estimated at two fires within ten years, the spread of invasive species will be favored (Keeley 2006) and foothill shrublands will most likely convert to grasslands dominated by invasive species.

Air quality in the foothills of the Sequoia National Park has deteriorated in the past years mainly because of the constant accumulation of air pollutants in the San Joaquin Valley, which are trapped by thermal inversions during the night and are delivered to the western slope of the Sierras during the day (Cahill et al. 1996). Probably one of the most important trends in pollutants affecting community characteristics in the foothills is the increase in atmospheric nitrogen deposition. Nitrogen deposition along the SEKI foothills is considered higher than the critical threshold for observing changes in lichen communities in oak woodlands and chaparral, and increased dominance of invasive grasses (5.5 kg N/ha, Fenn et al. 2010). Higher nitrogen deposition is a well-documented factor favoring proliferation of invasive species, with the subsequent reduction in herb species diversity and increase in dominance in forest (e.g. Gilliam 2007, Allen et al. 2007). Although ozone levels have been on the rise in the San Joaquin Valley, symptoms of ozone exposure have not been detected in herbs and shrubs at the foothills (Campbell et al. 2000) or have been shown moderate levels even for ozone sensitive species. Moderate ozone induced injuries have been detected in some species present in SEKI (*Cayophytum diffusum*, *Lepidium virginicum*, *Cordylanthus rigidus*), like aboveground biomass reduction in ozone sensitive species like the native bunchgrass (*Elymus glaucus*, Temple 1999, Yoshida et al. 2001). In the light of our results, probably the most threatening impact of increased air pollution on characteristics of the foothills is the potential loss of the spatial variability detected in this study; this may start with increased presence of invasive species at higher elevations and be followed by spatial homogenization across watersheds.

In recent years, plant pathogens have been shown to be an underestimated risk for plant communities, in particular for foothills communities. Sudden oak death is the current most evident pathogenic threat for oak woodlands and hardwood forests. This disease is caused by the pathogen *Phytophthora ramorum*, which lethally infects its hosts, or causes non-lethal foliar and twig infections (Rizzo and Garbelotto 2003). A recent state-wide evaluation of the risk of establishment and spread of sudden oak death in California classified SEKI as at low risk (Meetenmeyer et al. 2004, Barrett and Waddell 2006). This classification is based on spread predictions calculated using climatic and topographic information, as well as the abundance and distribution of potential hosts. Blue oak is not known to be host of the pathogen, and known hosts that are dominant in SEKI foothills scored the lowest in terms of their potential to spread *P. ramorum* (species evaluated included live and California black oaks, California buckeye, and whiteleaf manzanita -*Artostaphylos Manzanita*). However, monitoring should be employed to ensure early detection of sudden oak death or a similar pathogen in SEKI; in particular, Gold Spotted Oak Borer (*Agrilus auroguttatus,* GSOB). GSOB is potential threat SEKI foothill vegetation given that two of its host species are particularly abundant at SEKI (canyon live oak and black oak). Although the threat is not imminent, mortality in canyon live and black oak populations due to the attack of this beetle has been already detected in southern California (Coleman et al. 2011); for this reason we recommend a close monitoring of regional movements of this pest.

Assessment and Level of Confidence

In this chapter we have explored the relative conditions of plant communities in the foothill zone, with emphasis on community metrics across functional groups (herbaceous species, shrubs, and trees), and across vegetation types (shrublands and hardwood forests). Although our ability to detect the impact of specific potential stressors is weak, most of the variation we detected appears to be a consequence of differences across watersheds and strong trends in topographic and climatic factors, rather than a consequence of varying impacts of different potential stressors. Vegetation cover decline based on Landsat imagery was our most robust measure of disturbance; here we detected an impact on native grass abundance and little effect on most other diversity metrics. Although general response to levels of potential stressors does not indicate that foothill communities are at imminent risk, we have identified areas that are at a critical stage relative to other areas in the park. Table 11 summarizes our general assessment for each specific metric and identifies percentage of the foothill zone that is below our plot level estimates. Figures 16 and 17 identify critical areas at the scale of the watershed, indicating the level of confidence in our assessment. In general, our confidence levels are a direct consequence of the density and distribution of plots used during our analyses. Given that confidence in these predictions increases as diversity values increase for most or our metrics, we are more confident of low native herb diversity values than in high values; which is particularly true for Kings Canyon National Park where our confidence is relatively low.

Table 11. General conditions of foothill plant communities in relation to plot level estimates. For each of the metrics used, we estimated the percentage of the total foothill zone that is below the average calculated using NRI plots. This procedure highlights the overall spatial variation of conditions in the park.

Vegetation Type	Layer	Metric	Integrity Measure (average from plot measurements)	Condition (% of total foothill area below average)	Summary of Comments
Shrublands	Herbs	Shannon (H')	1.97 (SE=0.136 n=33)	Poor 96.2%	Lowest in Middle and East Fork Kaweah; Highest in North and Marble Fork Kaweah
		Abundance of Native Grasses	0.002 (SE=0.0007 n=33)	Poor 72.3%	Overall low abundance of native grasses, with highest values Marble Fork Kaweah and lowest at East Fork Kaweah
	Shrubs	Shannon (H')	0.82 (SE=0.10 n=32)	Poor 95.8%	Lowest in North and Marble Fork Kaweah.
Hardwood forest	Herbs	Shannon (H')	2.2 (SE=0.105 n=45)	Moderate 62.5%	Although the highest diversity of herbs was found in Hardwood forest, it is relatively high in Kings Canyon. Sequoia National Park showed the lowest diversity values
		Abundance of Native Grasses	0.008 (SE=0.003 n=45)	Poor 53%	Overall low abundance of native grasses, with highest values in Kings Canyon and Marble Fork unit
	Shrubs	Shannon (H')	1.07 (SE=0.10 n=35)	Poor 57.4%	Overall low with lowest in North and Marble Fork Kaweah.
	Trees	Shannon (H')	0.526 (SE=0.07 n=36)	Moderate 71.3%	Highest in Kings Canyon and East Fork Kaweah, strong increasing trend with elevation

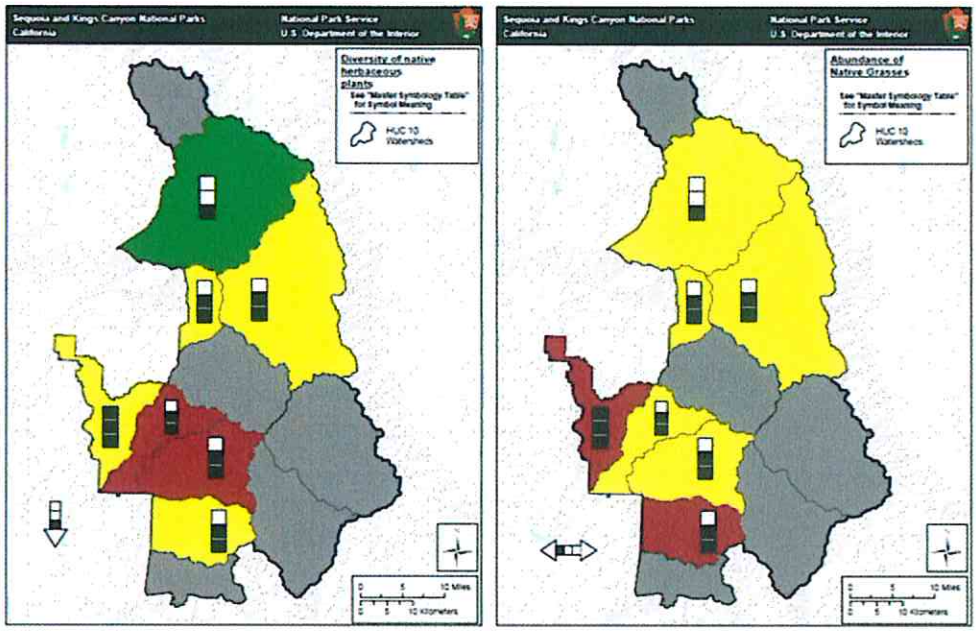

Figure 16. Assessment of current conditions and trends in native herbaceous communities throughout SEKI foothills. Estimation of current conditions is based on all our results and location of NRI plots; condition is reported for the entire watershed. Panel on the left indicates diversity of native herbs, panel on the right abundance of native grasses. The arrow (below right) summarizes the results of our trend analysis for the whole park, but in particular for the Sequoia National park where most of the plots were established

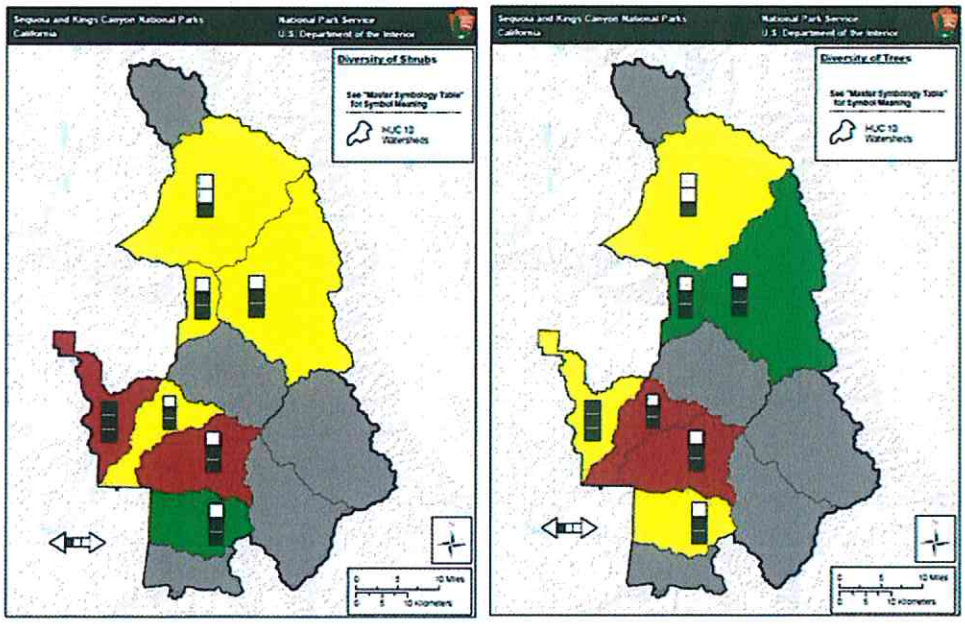

Figure 17. Assessment of current conditions and trends in shrub and tree communities throughout SEKI foothills. Estimation of current conditions is based on all our results and location of NRI plots; condition is reported for the entire watershed. Panel on the left indicates diversity of shrubs and panel on the right diversity of trees. The arrow summarized the results of our trend analysis for the whole park, but in particular for the Sequoia National park where most of the plots were established

Gaps in Understanding

Our emphasis in this chapter has been exploring the spatial variability of community diversity metrics throughout the foothills. We have tried to disentangled importance of factor that define environmental conditions, and factors that summarize history of disturbance (vegetation cover change as a general measure, as well as fire return interval departures, and grazing history). In general, we have a very weak understanding of the role of potential stressors in the foothills; more study on fire and grazing as well as other potential stressors such as nitrogen deposition are needed. In addition, without a clear understanding of the mechanisms that govern community assembly in the foothills, we are unable to predict the impact of future conditions at the community level. For example, current knowledge of the mechanisms that govern postfire community composition in shrublands (Keeley and Fotheringham 2003, Keeley et al. 2005b) allowed us to generate a hypothesis of the effect of increasing fire return intervals or disturbance, but this knowledge is not generalized for oak forests, in particular in areas where blue oak is not dominant. Communities dominated by canyon live oak have been less studied, and although they are considered more stable (Bolsinger 1988), there is a general lack of understanding of mechanisms governing response of these communities to disturbance, fire, or any of the other potential stressors acting in the park. In addition, there is very little knowledge of the status and distribution of native grasses in the foothill region; this vegetation type is in need of more research within the park.

The lack of mechanistic understanding was particularly limiting when we reviewed the state of knowledge regarding regeneration in oak populations. Demographic modeling is a key missing component concerning oak regeneration; efforts along these lines are needed to determine if oak populations are declining and, if so, what the most vulnerable life history stages are. In addition, although blue oak is the most prominent species in oak woodlands, canyon live oak assemblies are the dominant communities in SEKI foothills. There is a plethora of information about blue oak response to fire, grazing, and climatic changes, but information regarding other species is scarce. In order to fully assess the status of foothill vegetation at SEKI, future research should prioritize areas not dominated by blue oak, and explicitly explore questions regarding community assembly mechanisms in these areas.

Recommendations for Future Study/Research

During our analyses, we have identified several aspects that are poorly understood and that are a priority to accurately assess the current conditions of foothill plant communities:

- Our assessment is constrained by the distribution of sampled areas with respect to the full extent of the foothills. Several areas in the foothills are not represented by the NRI plots (we base our analysis on these plots, as they are the best available despite the limited sampling extent) and the more extensive dataset, VMA plots, have concerns about the biased location of the plots. It is crucial to determine how representative the NRI plots (or a combination of other monitoring plots) are with respect to spatial patterns across the entire foothill region of SEKI. This validation is particularly relevant native herbaceous

species, especially native grasses, given that our predictions estimate high diversity for this guild in areas that have not been sampled.

- We had limited information to assess temporal trends. We recommend recensusing plots on a regular basis. This is particularly relevant because our analyses are based on changes in spatial patterns rather than absolute changes in community metrics. For instance, it will be important to understand whether increased abundance of invasive grasses is associated with declines in native diversity.

- In addition to overall monitoring, we recommend focused monitoring and research program in two vegetation types of high conservation concern in the foothill area: blue oak woodlands and native perennial grasslands. It is difficult to use the limited monitoring data available to assess conditions or trends in these vegetation types, yet their status should be of high concern to SEKI. In particular, demographic studies of oak population and distribution mapping of native grasses are high priority research areas.

- While we can speculate on the role of potential stressors (e.g., fire, grazing, invasive plants), there is very limited understanding about fire or grazing history in the foothill areas of SEKI. For instance FRID values for low elevation areas are highly uncertain or unknown due to the difficulties in assessing historical fire regimes in these areas. This strongly limits our ability to assess current conditions relative to these potential stressors.

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Appendix

Table A 1. Detailed description of vegetation communities at the foothills of the SEKI.

Alliance common name grouped by vegetation subclasses	% Total Foothills Area	Average elevation (m a.s.l.)
Shrubland		
Deciduous shrubland		
Birchleaf Mountain Mahogany Shrubland Alliance	2.1%	1242.46
Birchleaf Mountain Mahogany-California Redbud-California Flannelbush Shrubland Association	1.3%	986.51
Birchleaf Mountain Mahogany-Whiteleaf Manzanita Shrubland Association	2.0%	1410.83
Bitter Cherry Shrubland Alliance	0.02%	1767.67
Bitter Cherry-Gooseberry spp. (Mountain Maple) Shrubland Mapping Unit	0.09%	1800.05
California Grape Association	0.01%	902.28
Deerbrush Shrubland Alliance	1.1%	1662.41
Oregon White Oak Shrubland Alliance	0.31%	1279.24
Oregon White Oak-Birchleaf Mountain Mahogany Shrubland Association	3.1%	1344.71
Willow spp. Riparian Shrubland Mapping Unit	0.19%	1644.75
Willow spp./Meadow Shrubland Mapping Unit	0.05%	1732.67
Deciduous shrubland Total	**10%**	**1364.27**
Evergreen shrubland		
Big Sagebrush Shrubland Alliance	0.04%	1812.11
Buckbrush Shrubland Alliance	0.14%	1282.22
Chamise Shrubland Alliance	7.7%	989.85
Chamise-Buckbrush Shrubland Association	0.59%	1130.20
Chamise-California Yerba Santa Shrubland Association	2.1%	1029.77
Chamise-Chaparral Yucca Shrubland Association	0.21%	908.96
Chamise-Whiteleaf Manzanita Shrubland Association	32%	1114.86
Chaparral Whitethorn Shrubland Alliance	0.25%	1147.02
Chaparral Yucca Shrubland Alliance	0.60%	1139.89
Greenleaf Manzanita Shrubland Alliance	0.22%	1699.63
Greenleaf Manzanita-Bush Chinquapin-Whitethorn Ceanothus Shrubland Superalliance	0.21%	1760.01
Indian Manzanita Shrubland Alliance	0.85%	1570.63
Mountain Misery Dwarf-shrubland Alliance	0.14%	1728.99
Whiteleaf Manzanita Shrubland Alliance	0.70%	1241.58
Evergreen shrubland Total	**16.9%**	**1163.91**
Mixed shrub/herbaceous		
Post Fire Shrub/Herbaceous Mapping Unit	0.17%	1634.41
Mixed shrub/herbaceous Total	**0.17%**	**1634.41**
Shrubland Total	**27%**	**1256.29**

Table A 2. Detailed description of vegetation communities at the foothills in SEKI.

Alliance common name grouped by vegetation subclasses	% Total Foothills Area	Average elevation (m a.s.l.)
Hardwood Forest		
Deciduous forest		
Bigleaf Maple Forest Alliance	0.17%	1580.21
Black Cottonwood Forest Association	0.06%	1688.28
Black Cottonwood Temporarily Flooded Forest Alliance	0.27%	1574.47
Montane Broadleaf Deciduous Trees Mapping Unit	0.01%	1726.21
Quaking Aspen Forest Alliance	0.00%	1819.57
White Alder Temporarily Flooded Forest Alliance	0.54%	1421.58
White Alder-Red willow-California Sycamore Forest Association	0.16%	752.99
Deciduous forest Total	**1.2%**	**1473.72**
Deciduous woodland		
blue oak Woodland Alliance	0.01%	957.24
blue oak/Brome spp.-American Wild Carrot Woodland Association	0.81%	767.26
blue oak-California Buckeye-(Interior Live Oak) Woodland Mapping Unit	1.3%	821.81
blue oak-Interior Live Oak/Brome spp.-American Wild Carrot Woodland Association	1.3%	695.99
California Buckeye Woodland Alliance	0.11%	911.72
California Buckeye-Canyon Live Oak Woodland Association	1.9%	1210.90
California Sycamore Temporarily Flooded Woodland Alliance	0.03%	611.88
California Sycamore-(Canyon Live Oak-Interior Live Oak) Forest Mapping Unit	0.41%	697.95
Deciduous woodland Total	**5.8%**	**904.51**
Evergreen forest		
Canyon Live Oak Forest Alliance	6.5%	1548.68
Canyon Live Oak-(Ponderosa Pine-Incense-cedar) Forest Superassociation	2.6%	1435.58
Canyon Live Oak/Birchleaf Mountain Mahogany Forest Mapping Unit	3.2%	1379.83
Canyon live oak/Greenleaf Manzanita Forest Association	0.97%	1748.15
Canyon Live Oak/Whiteleaf Manzanita Forest Association	3.1%	1536.41
Canyon Live Oak-California Laurel Forest Superassociation	16%	1359.60
Interior Live Oak Woodland Alliance	1.3%	854.51
Interior Live Oak-California Buckeye/Birchleaf Mountain Mahogany-California Redbud Forest Association	5.7%	875.06
Interior Live Oak-Canyon Live Oak Woodland Association	2.1%	997.56
Evergreen forest Total	**42%**	**1310.31**
Mixed evergreen deciduous forest	**11.2%**	**1592.96**
Hardwood Forest Total	**60%**	**1329.48**
Baren	**4.0%**	**1473.78**
Mixed Coniferous Forest	**9.1%**	**1571.03**
Grand Total	**100%**	**1334.54**

Table B. Distribution of study plots in SEKI. The number of plots at each watershed unit and the percentage of the dataset this represents are indicated above each watershed unit. Acronyms for each watershed unit are as follows: MFK=Middle Fork Kings River; USFK and LSFK are Upper and Lower South Fork Kings River, respectively; MbFKW, NFKW, MFKW, EFKW, SFKW correspond to Marble, North, Middle, East, and South Fork Kaweah River, respectively; NFT=North Fork Tule River.

		DATASET											
		Fire Effects		**Gradient**		**NRI**		**Vankat-Roy**		**VM Accuracy**		**VM Full Plots**	
Major Watershed	**Watershed Code**	**Number of plots**	**% Dataset**	**Number of plots**	**% Dataset**	**Number of plots**	**% Dataset**	**Number of plots**	**% Dataset**	**Number of plots**	**% Dataset**	**Number of plots**	**% Dataset**
Kings River	MFK	0		0		3	3.9%	0		50	13%	12	10%
	USFK	0		0		6	7.8%	0		25	6.5%	20	17.%
	LSFK	0		0		4	5.2%	0		18	4.7%	13	11%
Kaweah River	MbFKW	0		8	62%	16	21%	14	5	44	11%	34	29%
	NFKW	3	18%	1	7.7%	20	26%	2	7.1%	55	14%	15	13%
	MFKW	5	29%	3	23%	14	18%	12	43%	31	8%	10	8.6%
	EFKW	9	53%	1	7.7%	13	17%	0		130	34%	0	
	SFKW	0		0		1	1.3%	0		32	8.3%	12	10%
Tule River	NFT	0		0		0		0		2	0.52%	0	

Table C.. Dataset-specific manipulations during the estimation of community metrics. Fore each dataset we estimated relative abundance of each species grouped by vegetation stratum (herbs, shrubs, or trees).

		VMA	VM full plots	NRI	Gradient	Fire Effects	Vankat-Roy
Herb	Sampling	0.1Ha rectangular plot	NA	6 quadrants in groups of 2 along each of the four aspects of the plot (North, South, East, West)	25 small quadrants	0.1 Ha plots in forest and 30m strip in shrubland	NA
	Data	Cover per species	NA	% cover of each species at each quadrant	% cover class per species. Seven classes were used with the following midpoint (0.5%,3%,7.5%,17.5%,37.5%,62.5%,87.5%)	cover per species	NA
	Abundance Estimations	Sum cover per species divided total cover per plot per stratum	NA	To estimate species abundace per plot we add species abundance across plots	Sum midpoint cover per species divided by 2187.5	Sum cover per species divided total cover per plot per stratum	NA
Shrubs	Sampling	0.1Ha rectangular plot	NA	2 perpendicular transect disecting the plot in directions North and East. Total length of the transects varies	Line intercept method	0.1 Ha plots in forest and 30m strip in shrubland	NA
	Data	Cover per species	NA	Linear intercept of each species along	per species	cover per species	NA
	Abundance estimations	Sum cover per species divided total cover per plot per stratum	NA	Sum of point intercept divided by the total transect length	Sum of cover values per species divided by 2500	Sum cover per species divided total cover per plot per stratum	NA
Tree	Sampling	0.1Ha rectangular plot	0.1 rectangular plots	0.1ha circular plots	0.1ha rectangular plots	0.1 Ha plots in forest and 30m strip in shrubland	0.01Ha transect
	Data	Cover per species	Diameter at breast height (DBH) trees taller than 1.4 m	Diameter at breast height (DBH) trees taller than 1.3 m	Class of Diameter at breast height (DBH) trees taller than 1.4 m. Classes of 5 cm width were used.	DBH per species	DBH per species
	Manipulation	Sum cover per species divided total cover per plot per stratum	NA	Diameter sum per species/ Total diameter sum for plot	Sum of midpoint dimeter per species, divided by sum for all species	Sum of DBH per species divided by total sum in the plot	Sum of DBH per species divided by total sum in the plot
Saplings	Data	NA	NA	0.1 Ha circular plot	NA	NA	NA
	Manimulation	NA	NA	Sapling /adult ration for each specie	NA	NA	NA

Table D. Summary statistics for topographic and climatic variables used. Statistics are estimated for the extent of the foothill zone only.

	Mean	Std Dev	Min	Max	Quantile 25	Quantile 75
Elevation (ma.s.l)	1344.15	357.35	431.50	1862.00	1078.18	1647.39
Slope (%)	27.79	8.63	0.00	61.06	23.15	33.25
Aspect (degrees)	South (194.44)	71.52	-0.18	346.24	142.86	250.48
Distance to road (km)	2.592	3.674	0.00	20.287	0.598	2.838
Distance to Stream (m)	227.31	184.18	0.00	1228.15	90.88	315.96
Temperature during the growing season (°C)	6.64	2.29	0.17	11.08	4.76	8.51
Temperature during non-growing season months (°C)	18.01	2.66	10.68	23.39	15.90	20.16
Precipitation during the growing season (mm)	131.43	15.87	92.45	166.63	119.63	145.53
Precipitation during non-growing season months (mm)	21.64	2.40	14.67	27.38	19.83	23.43

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 102/121027, June 2013

National Park Service
U.S. Department of the Interior

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2. Forest Health Protection Survey (USDA Forest Service, April 2015).

Aerial Detection Survey – April 15th-17th, 2015

Background: California is in its third year of drought. In 2014, a large increase in tree mortality was observed, especially in the Central Coast and Southern Sierra Ranges. Ground observations noted a continued increase in mortality after the 2014 surveys were flown in July. Early season aerial surveys were conducted in the spring of 2015 in response to the continuing drought and the resulting tree mortality. Another early survey over portions of Southern California was flown the week of April 6th.

Objective: Detect and map extent and severity of tree mortality and damage which occurred after the 2014 aerial surveys in California Forests along the southern Sierras.

Surveyors: J. Moore, Z. Heath, B. Bulaon

Methodology: Recently dead or injured trees were mapped visually by a surveyor using a digital aerial sketch-mapping system flying in a light fixed-wing aircraft approximately 1,000 feet above ground level. The surveyor recorded the number and species of affected trees and type of damage (mortality, defoliation, etc.) at each mapped location.

Details:

- More than 4.1 million acres were surveyed; covering western portions of Stanislaus, Sierra and Sequoia National Forests and Yosemite and Sequoia-Kings Canyon National Parks. The Tehachapi Range and nearby private lands were also surveyed. See Figures1, 3.
- In general mortality was quite severe in many pine species especially in ponderosa and pinyon at lower elevations and more southern areas.. See Figure s 3.
- Along the foothills mortality was often widespread and severe especially in ponderosa but also gray pine and likely blue and live oak. See Figures 4, 6. It unknown if the oaks that were mapped were truly dead or had died back/defoliated due to the drought.
- On the Stanislaus, mortality was scattered in northern areas, but pockets of severe ponderosa and other pine mortality were seen in the southern low areas. Mortality roughly doubled since July 2014 in the areas of the Stanislaus that were resurveyed this spring. See Figure 5.
- At higher elevations conifer mortality was scattered. The survey was too early to detect full extent of mortality levels and anemic levels of snow were common. See Figure 7.
- On the Sierra and Sequoia NF pine mortality, mostly from western pine beetle, was common and severe almost everywhere at lower elevations. Estimated number of trees killed on these two Forests together exceeded 5 million. Only about 300,000 trees were estimated killed last year in the same area.
- Southeastern portions of the Sequoia NF and Wilderness areas further east were also flown and widespread, at times, intense pinyon mortality was observed. See Figure 8, 10.
- On the Tehachapi Range and on private lands along the foothills of the Sierras, extensive areas of pine mortality were common. Large areas of oak mortality was also suspect. See Figures 5-6, 11-12.

Summary:
Area surveyed: 4.1 million acres
Areas with mortality: 835,000 acres
Estimated number of trees killed: 10,450,000

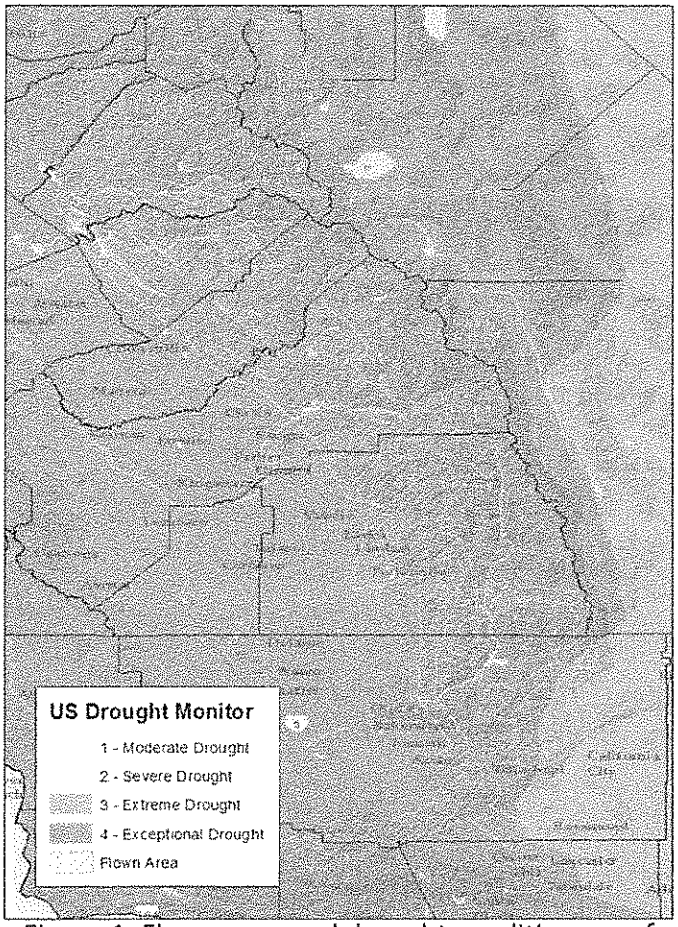

Figure 1. Flown area and drought conditions as of April 21,2015

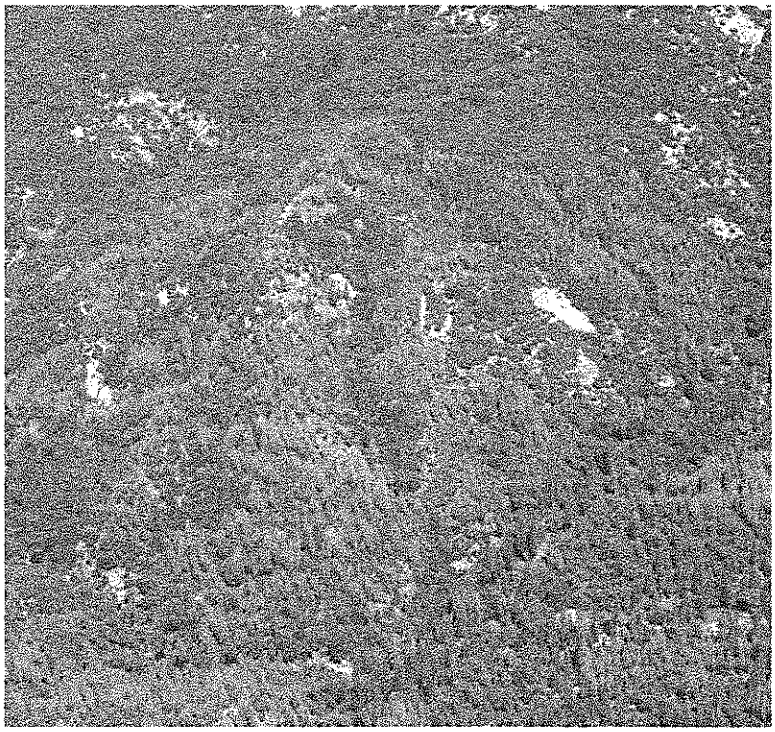

Figure 2. Intense pine mortality near Goodmill on the Hume Lake Ranger District of the Sequoia NF .

Direct questions pertaining to this report to Jeffrey Moore (email: jwmoore02@fs.fed.us phone: 530-759-1753). Report Date Apr 24, 2015.

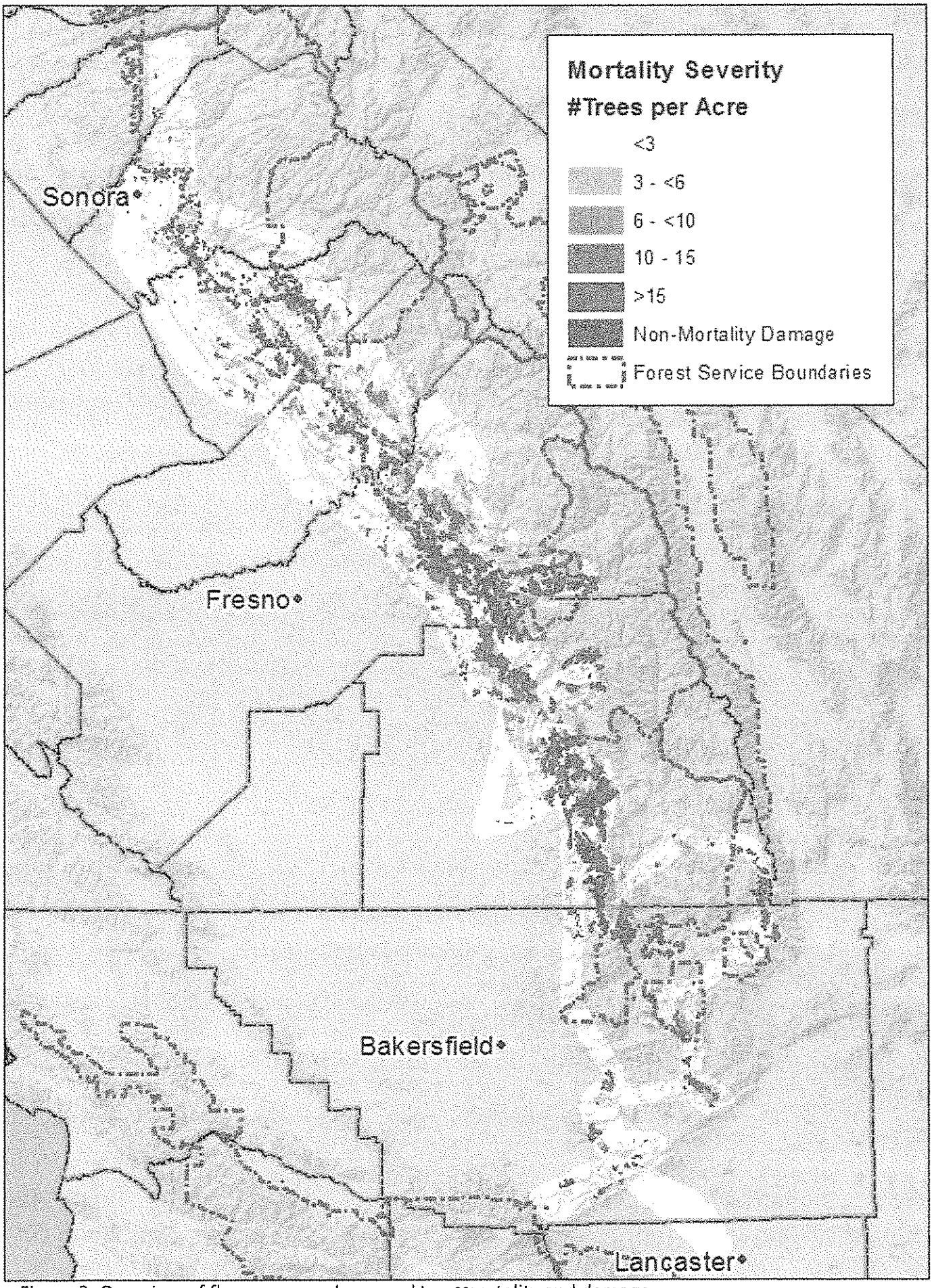

Figure 3. Overview of flown area and mapped tree mortality and damage .

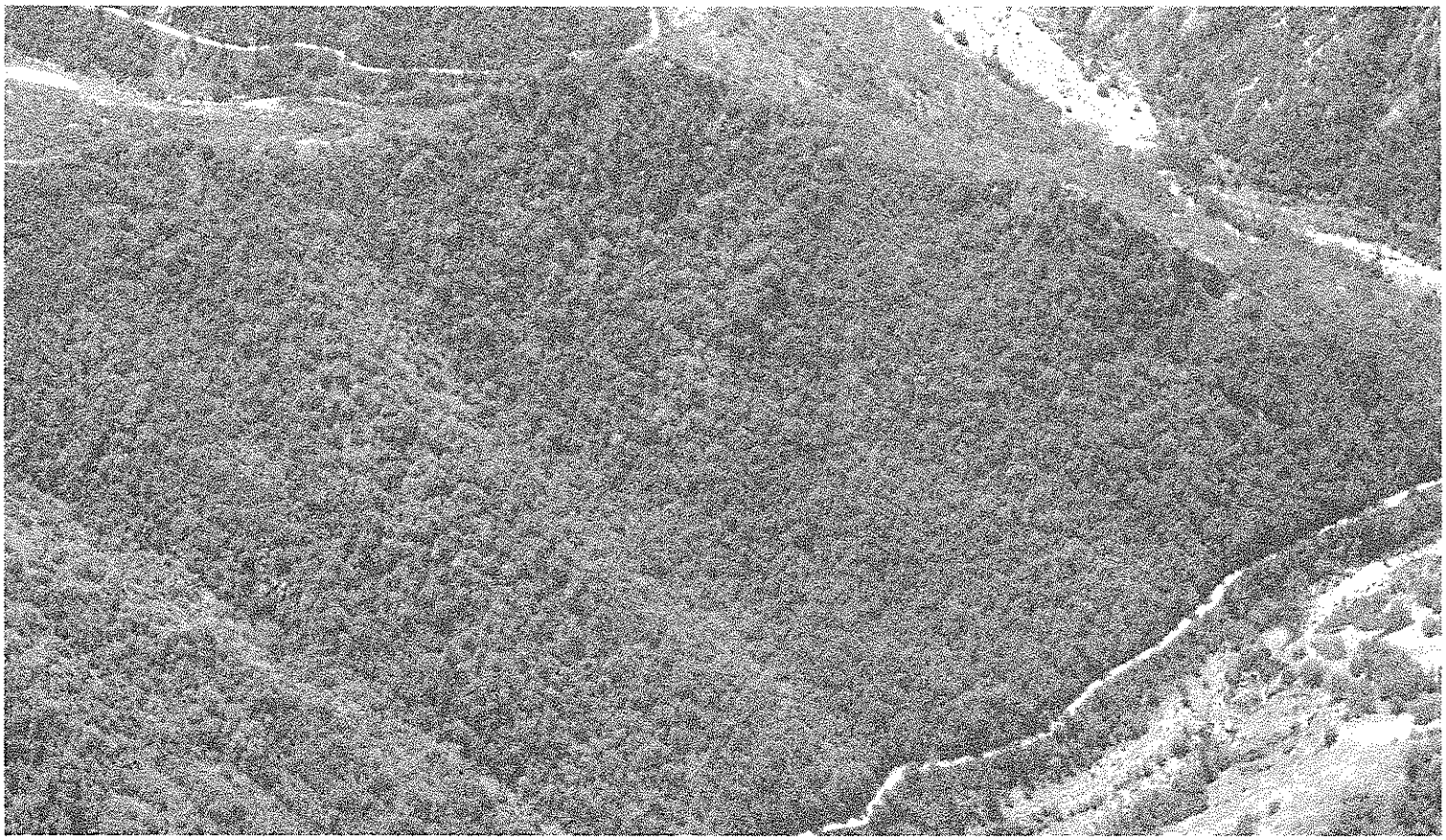

Figure 4. Gray pine and possible live and blue oak mortality east of Pine Flat Reservoir on the High Sierra Ranger District, Sierra NF.

Figure 5. Ponderosa and gray pine mortality south of Sonora near the Stanislaus NF.

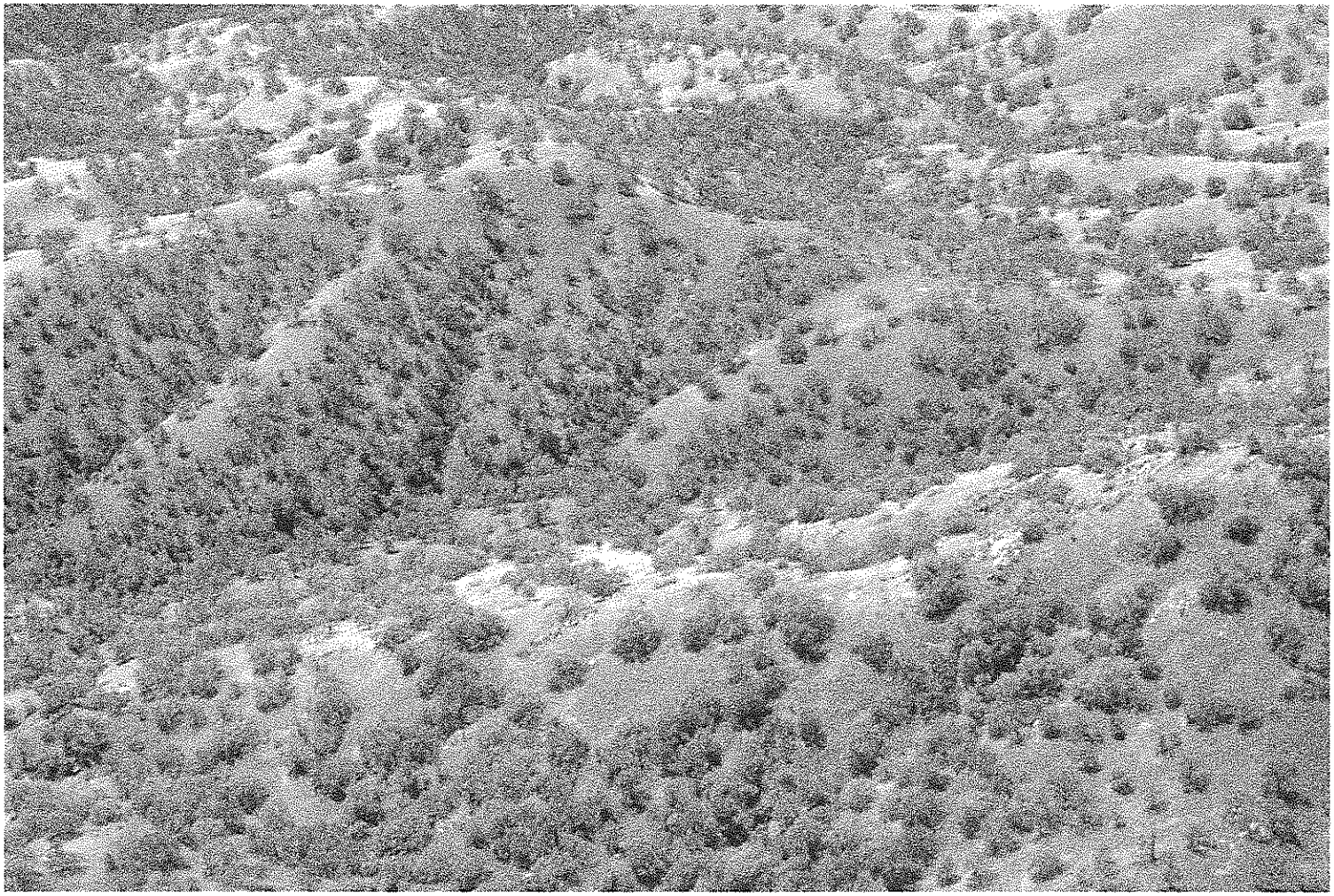

Figure 6. Possible live oak and blue oak mortality Near Dalton Mtn. south of Pine Flat Reservoir. Sites like this were common and extensive.

Figure 7. Widely scattered fir and pine mortality was already noticeable even in high elevation areas such as this one southeast of Sherman Peak in the Domeland Wilderness of the Sequoia National Forest.

Figure 8. Jeffrey and pinyon pine mortality south of Pinyon Peak in the Scodie Mountains, Sequoia NF.

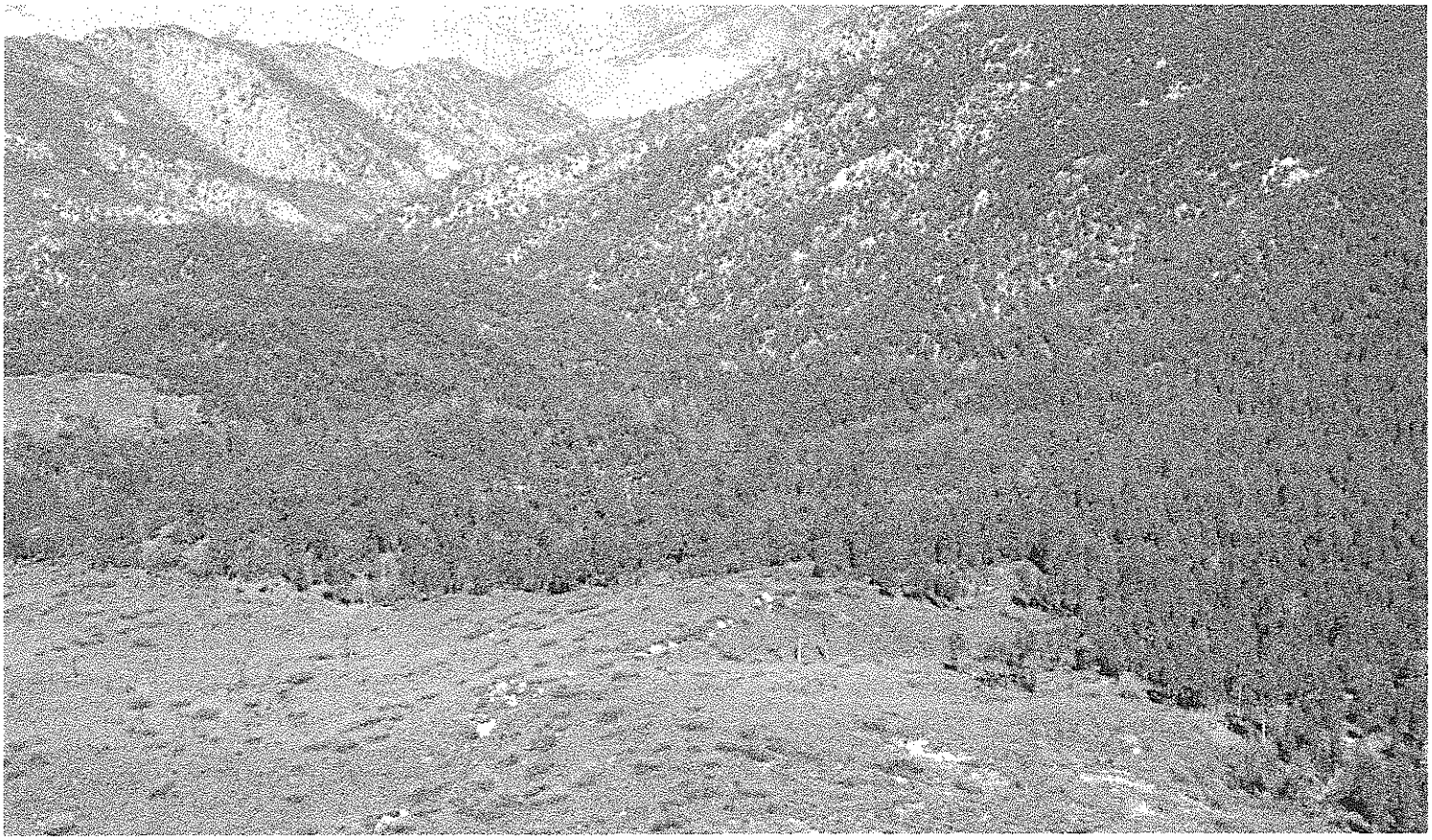

Figure 9. Scattered as well as intense pockets of Jeffrey pine mortality south of Inspiration Point in the Piute Mountains, Sequoia NF.

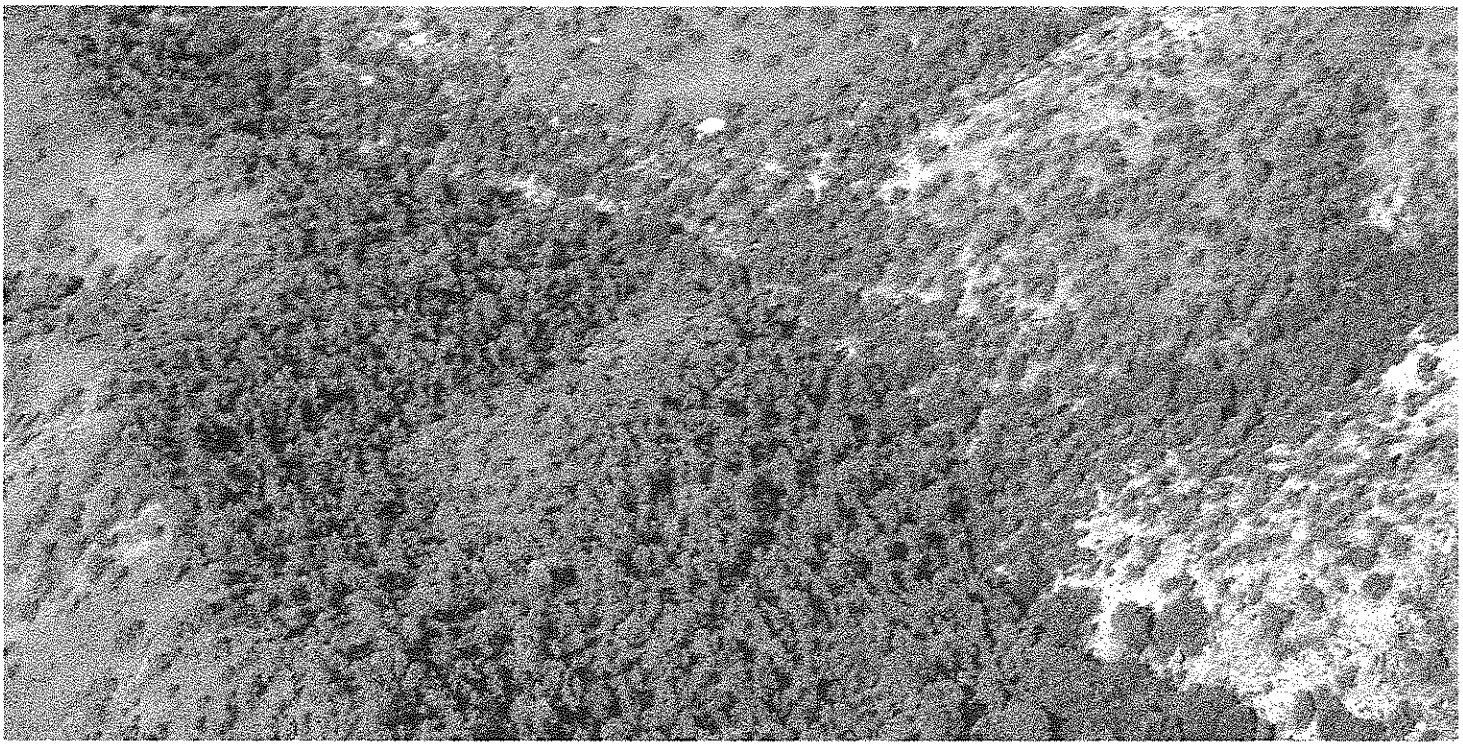

Figure 10. Pinyon mortality and discoloration near Lamont Peak in the Owen Peak Wilderness.

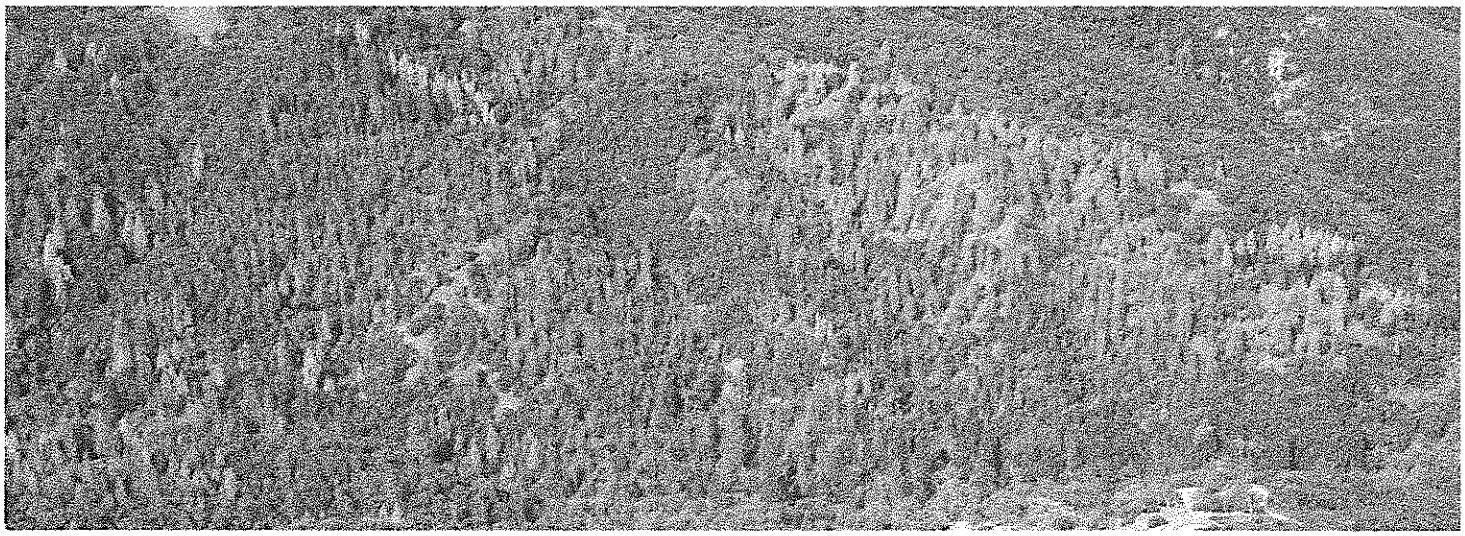

Figure 11. Increasingly intense pine mortality near Twin Lakes, Tehachapi Mountains.

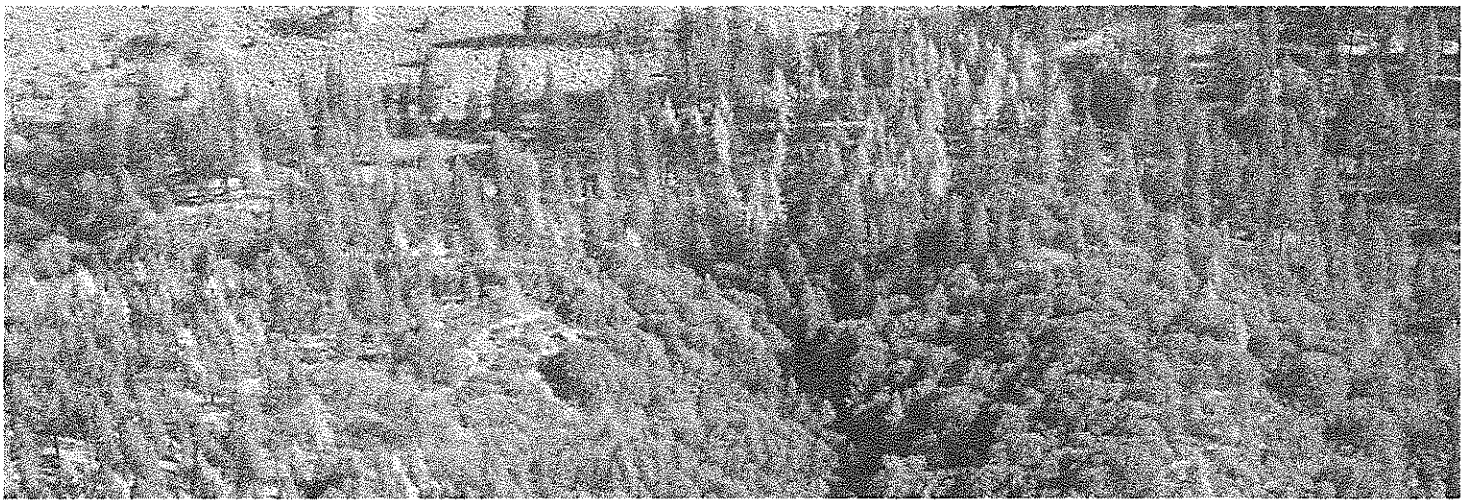

Figure 12. Pine mortality north of Five Points, Tehachapi Mountains.

3. Modeled Regional Climate Change and California endemic oak ranges (UC Santa Cruz, November 2005).

Modeled regional climate change and California endemic oak ranges

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Edited by Christopher B. Field, Carnegie Institution of Washington, Stanford, CA, and approved September 20, 2005 (received for review February 23, 2005)

In the coming century, anthropogenic climate change will threaten the persistence of restricted endemic species, complicating conservation planning. Although most efforts to quantify potential shifts in species' ranges use global climate model (GCM) output, regional climate model (RCM) output may be better suited to predicting shifts by restricted species, particularly in regions with complex topography or other regionally important climate-forcing factors. Using a RCM-based future climate scenario, we found that potential ranges of two California endemic oaks, *Quercus douglasii* and *Quercus lobata*, shrink considerably (to 59% and 54% of modern potential range sizes, respectively) and shift northward. This result is markedly different from that obtained by using a comparable GCM-based scenario, under which these species retain 81% and 73% of their modern potential range sizes, respectively. The difference between RCM- and GCM-based scenarios is due to greater warming and larger precipitation decreases during the growing season predicted by the RCM in these species' potential ranges. Based on the modeled regional climate change, <50% of protected land area currently containing these species is expected to contain them under a future midrange "business-as-usual" path of greenhouse gas emissions.

Quercus douglasii | species range displacement | *Quercus lobata* | regional climate model | conservation

Endemic species face relatively great risks from human activities because of their limited geographic distribution. For more than a century, ecologically and culturally valuable endemic oaks of California have experienced pressure from cutting for fuel, grazing, conversion of woodlands to vineyards and orchards, water resource development, competition with invasive grasses, and urban expansion (1). Here, we report how the regional manifestation of anthropogenic global climate change may present an even graver threat, complicating conservation planning for these and other restricted species (2, 3). Specifically, we highlight how predictions of future suitable habitat for endemic species can depend greatly on whether the scenario for climate change is derived from a relatively coarse-resolution global climate model (GCM) or a fine-resolution regional climate model (RCM).

California endemic oaks *Quercus douglasii* Hook. & Arn. and *Quercus lobata* Née (blue and valley oak, respectively) are sensitive to temperature and precipitation at many stages of their life history. Both experience the Mediterranean-like climate of much of California, with winter rain and summer drought. Blue oak occurs in the foothills of the Coast Ranges and western Sierra Nevada, forming both woodland and savannah habitat. It is winter-deciduous and drought-tolerant, remaining active well into the long, dry summers (4, 5). Tree-ring data show greater growth in years with greater mean annual precipitation, although there is geographic variation in the strength of this effect (6). Blue oak seedlings are sensitive to soil moisture availability, with higher mortality and lower growth where competition with annual plants leads more rapidly to growing season soil moisture deficits (7, 8). Valley oak occurs on deeper soils in the Great Central Valley and in riparian habitats of the foothills and has seen much of its former habitat degraded or eliminated (4). Valley oak is also winter-deciduous but is less drought-tolerant than blue oak. It is highly sensitive at both seedling and adult stages to water stress (9). Higher acorn production by both species is correlated to warmer April temperatures (10), probably a result of greater pollen advection and therefore greater fertilization under warmer, less humid spring conditions (11).

Modern geographic distributions of blue and valley oaks also suggest that their ranges are constrained by climate factors (Fig. 1). We hypothesized that (*i*) the potential range of each species would be related to climate variables, (*ii*) climate change could alter the geographic location of suitable habitat for each species, and (*iii*) predicted future distributions would be sensitive to the spatial and temporal details of predicted future climate change. With respect to (*iii*), we were particularly concerned that predicted range shifts based directly on GCM-derived climate change scenarios could differ qualitatively and quantitatively from RCM-derived scenarios. Predicted climate change impacts to agricultural crop yields and agroeconomic activity (12–14) and to water yield in specific river basins (15) are known to depend on the scale of climate scenario used (GCM vs. RCM), suggesting that predictions for species range shifts could be similarly sensitive.

Methods

Climate Envelope Modeling. We used quadratic discriminant analysis to identify the multivariate climate and soil envelopes, and thereby suitable habitat, for each species. Discriminant analysis is similar to other statistical climate envelope approaches and has been used previously for predicting potential future species ranges with climate change (16). Discriminant analysis identifies the multivariate distance between a given cell and the centroids of all cells in the "oak-present" and "oak-absent" groups, assigning the cell to the closest centroid. We assumed unequal variances between groups and transformed explanatory variables when possible to achieve normal frequency distributions. We first built the statistical model based on modern climate and soils data and then applied the model to GCM- and RCM-based scenarios of future climate.

We selected four explanatory climate variables based on field observations of these species (5–11) and on factors likely to limit the ranges of deciduous trees (17): mean temperatures of the coldest and warmest months, total annual precipitation, and April–August precipitation. We selected three soil variables that reflect the importance of soil properties in regulating moisture availability, including available water-holding capacity, soil depth, and surface layer clay content.§ We used

Conflict of interest statement: No conflicts declared.

This paper was submitted directly (Track II) to the PNAS office.

Abbreviations: GCM, global climate model; RCM, regional climate model; CSM, Climate System Model.

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§Natural Resource Conservation Service (1994) *State Soil Geographic (STATSGO) Data Base for California* (U.S. Department of Agriculture, Fort Worth, TX).

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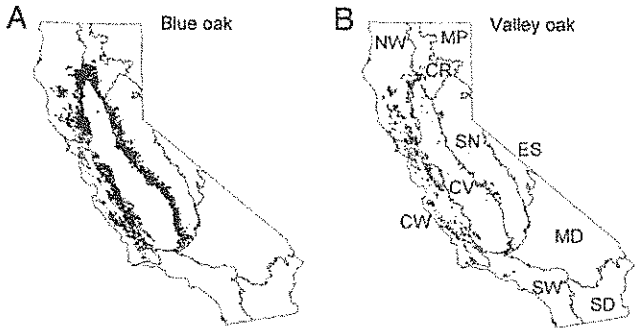

Fig. 1. Modern satellite-based distributions of blue oak (*A*) and valley oak (*B*).[¶] California ecoregions labeled in *B* are as follows: NW, northwest California; CR, Cascade Ranges; MP, Modoc Plateau; SN, Sierra Nevada; CV, Great Central Valley; ES, east of Sierra Nevada; CW, central west California; MD, Mojave Desert; SW, southwest California; and SD, Sonoran Desert.[¶]

satellite-based estimates of modern (≈1990) blue and valley oak distributions[¶] and modern climate values derived from 1971–2000 weather station data interpolated to 4-km resolution[‖] as the basis for the discriminant models. (Links to digital versions of the annotated data sources may be obtained from the authors upon request.) Discriminant model-derived modern distributions somewhat overpredict oak presence relative to the satellite data (Table 1) but capture the geographic pattern of both species. The discriminant model predictions have better matches to historic range maps (18) (Table 1), suggesting that the model may be more representative of potential oak distributions before extensive habitat conversion.

We varied the criterion by which cells were assigned to the oak-present group by comparing thresholds of 50% and 80%. Using the higher probability threshold reduced the extent of modern potentially suitable oak habitat, resulting in better matches to the original satellite data and to range maps (Table 1). Raising the probability threshold from 50% to 80% also resulted in 28–40% less future suitable habitat, depending on the species and climate model output used. Therefore, the reported 50% threshold discriminant models, which overpredict modern potential habitat, may also overpredict future suitable habitat for any given future climate scenario.

We used output from a climate change experiment using the RCM RegCM2.5 and the GCM CSM (Climate System Model) (see below) to calculate differences between annual averages of the years 2080–2099 and 1980–1999 for the selected climate variables and added the anomalies to the modern climate 1971–2000 values. We thereby created a projected future California climate based on RCM output and a projected future California climate based on GCM output. We then used the discriminant models derived for each species to predict potential ranges after climate change, holding soil properties constant. We did not explore the third alternative of calculating a future California climate based on statistically downscaled GCM output. However, the relatively smooth, GCM-like signal for summer temperature change in California in a study using statistically downscaled GCM output (19) suggests that this approach may yield predictions that are more similar to those using GCM output than RCM output (see below).

[¶]Davis, F. W., Stoms, D. M., Hollander, A. D., Thomas, K. A., Stine, P. A., Odion, D., Borchert, M. I., Thorne, J. H., Gray, M. V., Walker, R. E., *et al.* (1998) *The California Gap Analysis Project: Final Report* (Univ. of California, Santa Barbara).

[‖]Daly, C., Gibson, W. & Taylor, G. (2002) *103-Year High-Resolution Precipitation Climate Data Set for the Coterminous United States* (Spatial Climate Analysis Service, Corvallis, OR).

Table 1. Skill of discriminant models in predicting the modern distributions of blue and valley oak

	Satellite data		Range maps	
Model	Percent correct	κ	Percent correct	κ
Blue oak				
(50%)	82	0.41	84	0.50
(80%)	87	0.48	87	0.53
Valley oak				
(50%)	71	0.10	81	0.52
(80%)	79	0.12	83	0.51

Numbers in parentheses indicate the likelihood threshold for assigning individual cells to the oak-present group in the discriminant model. Increasing the threshold from 50% to 80% likely improves the models' match to the satellite data and range maps, reducing the modern area predicted as suitable for blue oak (−24%) and valley oak (−27%). Percent correct reflects the percentage of all cells correctly assigned to oak-present and oak-absent groups. κ values account for the cells that would be assigned correctly by chance, where $\kappa < 0.4$ is poor agreement, $0.4 < \kappa < 0.55$ is fair agreement, $0.55 < \kappa < 0.70$ is good agreement, and $\kappa > 0.7$ is very good to excellent agreement (24).

Regional Climate Modeling. Most estimates of potential shifts in species' ranges with future climate change are based on relatively coarse GCM output (20–23). However, RCM-based climate scenarios may be better in California than GCM-based scenarios for several reasons. First, GCMs have topographically smooth landscapes, with each grid cell representing average land surface properties and climate over hundreds of kilometers, whereas RCMs can describe the land surface and topography at much higher spatial resolution. As a specific example, the Sierra Nevada Mountains and the Great Central Valley, which define climatologically distinct ecoregions in California, are represented in the RCM but not the GCM (24). Second, within regional models, with resolutions on the order of tens of kilometers, local topography, distance from the coast, and latitude can result in a more highly resolved, subregionally varying estimate of climate change (Table 2). Lastly, we used the RCM RegCM2.5, which has been used and validated for the western U.S. (25, 26) and compares more favorably to observations than a GCM for a range of temperature and precipitation variables in this region (26). RegCM has also been shown to produce elevationally dependent climate change consistent with observations in other regions (27), a climatic feature not well captured by relatively coarse-resolution GCMs.

We ran the RCM RegCM2.5 from 1980–1999 and 2080–2099, with atmospheric conditions at the domain boundaries derived from the National Center for Atmospheric Research global CSM (28). RegCM2.5 was run with a horizontal resolution of ≈40 km, compared with the 2.8° (≈250 km) horizontal resolution of CSM. CSM is a fully coupled atmosphere, ocean, land, and sea-ice model that was run from 1870 to 2099 with observed increases in greenhouse gas concentrations until 1998 and increases thereafter from the ACACIA-BAU (A Consortium for the Application of Climate Impact Assessments Business-as-Usual) emissions scenario. ACACIA-BAU is a "business-as-usual" scenario of greenhouse gas emissions and climate policy similar to Intergovernmental Panel on Climate Change (IPCC) IS92a but with sulfate emissions more consistent with the Special Report on Emissions Scenarios (SRES) average (29). ACACIA-BAU CO_2 emissions rise from 7 to 19 gigatons of $C \cdot yr^{-1}$ between 1990 and 2100, an emissions trajectory slightly higher than the midrange IPCC SRES scenario A1B (30). CO_2 concentrations in CSM increased to ≈710 ppm by 2099 with this scenario, whereas the 2080–2099 RegCM2.5 CO_2 concentrations were kept constant at 660 ppm, the CSM midpoint for those years (28, 29). In CSM, mean global temperatures increased 1.9°C from 1990 to

Table 2. Change in average climate variables between 1980–1999 and 2080–2099 from GCM and RCM output

Region	Model	Mean temperature of the coldest month, °C	Mean temperature of the warmest month, °C	Annual precipitation, mm	April–August precipitation, mm
California	GCM	2.53	2.52	−12.49	−5.27
	RCM	2.45	2.82	−5.18	−19.87
Northwest California	GCM	2.16	2.16	−30.69	−11.81
	RCM	2.27	2.98	31.11	−16.03
Cascade Ranges	GCM	2.51	2.49	−6.95	−2.03
	RCM	2.60	3.33	39.15	−20.45
Modoc Plateau	GCM	2.54	2.52	−3.65	−0.44
	RCM	2.64	3.65	39.81	4.26
Sierra Nevada	GCM	2.57	2.55	−2.12	−0.65
	RCM	2.66	2.90	−17.20	−46.43
Great Central Valley	GCM	2.45	2.43	−6.28	−2.36
	RCM	2.37	2.41	−3.63	−24.56
East of Sierra Nevada	GCM	2.71	2.71	−0.85	−0.58
	RCM	2.86	3.53	−18.16	−25.39
Central west California	GCM	2.25	2.23	−18.08	−7.44
	RCM	2.21	2.15	−20.35	−18.78
Mojave Desert	GCM	2.83	2.84	−14.07	−6.81
	RCM	2.68	3.07	−13.77	−10.82
Southwest California	GCM	2.58	2.58	−15.26	−7.41
	RCM	2.28	2.41	−31.38	−16.12
Sonoran Desert	GCM	2.80	2.79	−14.37	−7.31
	RCM	2.04	2.53	−38.06	−5.79
Blue oak	GCM	2.38	2.37	−12.65	−4.94
	RCM	2.37	2.56	2.71	−24.45
Valley oak	GCM	2.32	2.34	−13.27	−5.26
	RCM	2.32	2.49	0.04	−23.26

The first two rows reflect mean changes for all of California; subsequent rows reflect changes within the ecoregions identified in Fig. 1*B*. Blue oak and valley oak rows reflect changes within the modern potential habitat for those species, as determined by the discriminant model described in the text.

2100, a projection at the low end of the IPCC multiscenario, multimodel envelope (31).

Overall, CSM has a cold bias (≈1–2°C annual average) and tends to be wet (up to 5 $mm \cdot d^{-1}$) in western North America compared with observations (28, 29). Compared with observations, RegCM2.5 is cool (by 2–4°C on a monthly basis), wet during the rainy season (by 2.0 $mm \cdot d^{-1}$), and dry in the late summer (by 0.6 $mm \cdot d^{-1}$) (28). In California, RegCM2.5 slightly underestimates both the warmest and coldest month temperatures, whereas CSM overestimates the coldest month temperatures and underestimates the warmest month temperatures, as compared with observations. RegCM2.5 overestimates both annual (by ≈800 $mm \cdot yr^{-1}$) and April–August (by ≈240 $mm \cdot yr^{-1}$) precipitation, particularly in northwest California and the Sierra Nevada; CSM underestimates annual precipitation in northwest California and the Sierra Nevada (by ≈400 $mm \cdot yr^{-1}$) and overestimates April–August precipitation in these subregions (by ≈200 $mm \cdot yr^{-1}$). Overall, RegCM2.5 better captures the spatial patterns of temperature and precipitation throughout the state when compared with high-resolution observational data (32) (see Fig. 3, which is published as supporting information on the PNAS web site).

Because we used the change in climate between two time periods for projecting changes in suitable oak habitat, model bias is less relevant than model sensitivity to transient climate forcing, such as by greenhouse gases. When driven by the global atmospheric model HadAMH, RegCM reproduced slight winter warming trends in some subregions of Europe, but not all, and a related winter drying trend in the Mediterranean region over the 20th century (33). For the European temperature trends, much of the model agreement with observations (or lack thereof) is attributed to global model forcing, whereas local feedbacks within the regional model appear to improve trend simulation for precipitation in some subregions (33). CSM, the global model we used as initial and boundary conditions, reproduces the pronounced global warming trend in the late 20th century, although it did not capture the rapid midcentury warming seen in observations (29). CSM also captures the slight positive trend in northern mid- to high-latitude precipitation over the 20th century but does not represent decadal variations in the El Niño southern oscillation very well, a point of concern for the tropics and our western U.S. region.

Conservation Area Calculations. To estimate the fraction of potential modern and future oak habitat overlapping with existing conservation areas, we combined digital maps of U.S. National Wilderness Areas** and of National Parks, California State Parks and Reserves, and private conservation areas†† into a single data layer. We then examined the change in the number of oak-present cells overlapping with all conservation areas

**U.S. Geological Survey (2004) *National Atlas of the United States of America* (U.S. Geological Survey, Reston, VA).

††California Resources Agency (2003) *California Legacy Project* (California Resources Agency, Sacramento, CA).

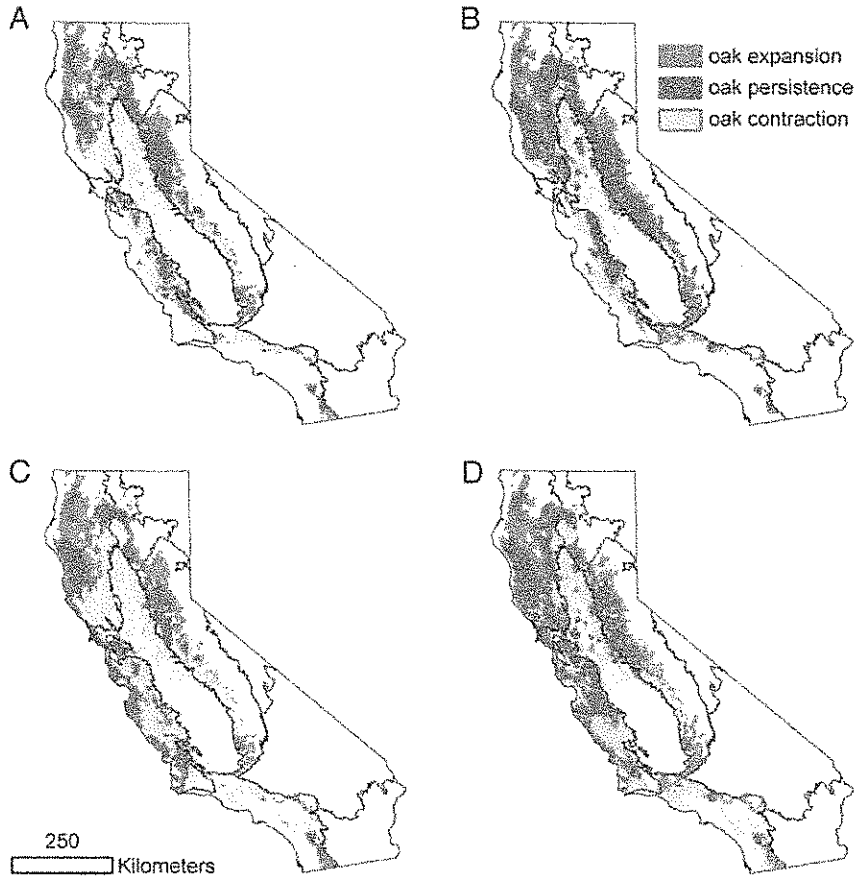

Fig. 2. Potential modern (light blue and brown) and future (brown and green) distributions of blue oak (*A* and *B*) and valley oak (*C* and *D*). *A* and *C* reflect distributional changes based on the RCM scenario; *B* and *D* reflect changes based on the GCM scenario.

between the modern and future scenarios. We used SYSTAT 8.0 for all statistical analyses and ARCGIS 8.3 for geospatial associations among climate, soil, species, and conservation area maps.

Results and Discussion

With RCM-based climate change, suitable habitat shrank to 59% and 54% of modern potential range sizes for blue and valley oak, respectively (Fig. 2 *A* and *C*). With GCM-based climate change, we saw more modest overall contractions to 81% and 73% of current range sizes (Fig. 2 *B* and *D*). For both species and model scenarios, we saw some expansion into northwestern California and the Sierra Nevada Mountains, with more persistence and expansion at the southern end of the species' range under the GCM cases. Under the RCM scenario, ≈39% of the predicted future habitat is new, whereas ≈30% is new under the GCM scenario.

The difference between RCM- and GCM-based predictions can be explained primarily by the larger predicted decreases in RCM April–August precipitation and by larger increases in temperature within the oaks' modern potential ranges, which include the Great Central Valley and Sierra Nevada regions (see Fig. 4, which is published as supporting information on the PNAS web site; see also Table 2). For example, in areas that lost blue oaks under the RCM case, annual precipitation changed <1%, April–August precipitation declined 43%, and both coldest month and warmest month mean temperatures increased by >2.3°C, resulting in a more heat- and drought-stressed environment during these winter-deciduous species' growing season. Mean temperature of the warmest month increases more in the RCM than in the GCM, especially in Northern California, in the Sierras, and east of the Sierras. This discrepancy could be due to the fact that the RCM has more detailed topography than the GCM, resulting in greater warming at higher elevations, an effect that has been observed in the Alps (27). Changes in precipitation may also be elevation-dependent (27), but the larger decrease in summertime precipitation in the RCM is likely due to better resolution of spring circulation patterns. As a result of the large GCM grid cell size, storm systems may be more extensive in the GCM than in the RCM, with the most pronounced differences in the month of May. Additional factors that could yield stronger signals in temperature and precipitation in subregions of the RCM include more heterogeneous land cover, and therefore albedo and energy partitioning, and better resolution of convective activity and cloud cover.

Our predictions are based on only one RCM realization of potential climate change in the western U.S. Consistent with our RCM scenario, Leung *et al.* (34) found a nonsignificant warm season drying trend in California between 1995 and 2060 using an RCM, MM5, and a GCM, PCM. However, using another RCM, MAS, and GCM, HadCM2, Kim *et al.* (35) found a small increase in summer precipitation between control and enhanced CO_2 runs. Differences among scenarios may be due in part to GCM input but also to how the RCMs resolve circulation patterns and parameterize convective precipitation. Model scenarios yielding growing season precipitation increases may result in an expansion of suitable oak habitat rather than a contraction, as we found.

Our results indicating decreases and northward shifts in potential blue and valley oak habitat are consistent with

modeled vegetation change in the California region predicted by dynamic vegetation models. Using the model MC1, Lenihan *et al.* (36) found that mixed evergreen woodland decreases in extent relative to the historic case under two different GCM scenarios for the 2070–2099 time period, losing out to mixed evergreen forest in one scenario (HadCM2) and to grassland in the other (PCM). Mixed evergreen woodland persists or expands slightly at the northern and upper elevation limits of its historical distribution. Also using MC1 but statistically downscaled output from four GCM scenarios, Hayhoe *et al.* (19) found overall decreases in the extent of mixed evergreen woodland with climate change by 2050 and 2100, primarily to expansion by grassland.

Our results showing impacts dependent on the scale of the climate model scenario are also consistent with studies of agricultural yield changes under RCM and GCM scenarios for climate change. In the midwestern U.S., yield differences between RCM and GCM scenarios were most pronounced where the climate models differed in precipitation, temperature, and humidity during key periods of the growing season, leading to differential water stress in some crops (13). Similarly, in the southeastern U.S., crop-specific sensitivity to RCM vs. GCM changes in growing season precipitation and temperature resulted in differences in predicted yield (12). The latter study also found that by adjusting planting dates for corn, the effects of decreased precipitation during the summer months in the RCM scenario were mitigated. For predicting impacts, this result underscores the importance of understanding the ability of agricultural and natural systems to adapt to climate changes, as well as the importance of using accurate climate change scenarios.

With our RCM-based results, we found that of the current conservation area encompassing current potential oak ranges, <50% (33% for blue oak and 40% for valley oak) also encompassed future suitable habitat, indicating that today's conservation areas may not provide protection for future oak habitat (data not shown). Future overlap between oak habitat and protected areas established to protect other species and ecosystems would depend on the ability of these two species to disperse northward and to compete with existing coniferous vegetation in the predicted future ranges. Climate-driven range shifts will be constrained by nonclimate factors that affect recruitment and establishment, including fire regimes, browsing by domestic and wild animals, acorn predation, and competition with annual grasses and conifers (37–39). For valley oak, small genetic "neighborhoods" also suggest limited genetic exchange across the modern landscape (40), indicating that the ability of this species to migrate significant distances in response to climate change may be limited. Given the above challenges to range shifts by these species, their persistence may be highly dependent on their ability to adapt to climate change *in situ*, perhaps by adjusting their growing season.

Our results show that conservation planning guided by GCM output or by the expectation of simple upward elevational shifts in distributions for these and other restricted species could be misdirected. In California, RCM-based patterns of warming and drying between April and August in the Sierra Nevada Mountains and Great Central Valley result in unexpected reductions and shifts in suitable habitat for two highly valued endemic species, a quantitatively different result than that obtained by using GCM output. This precipitation sensitivity is consistent with the observed importance of water stress to both species' growth and reproduction, leading us to believe that if the spatial variation in predicted climate change is more realistic in the RCM, these and other moisture-sensitive species may be particularly vulnerable to climate change in California. As conservation planners confront climate change, it will be critical that they employ a selection of RCM-based scenarios that resolve variation in climate response on scales relevant to restricted species and regional reserves. Similarly, planning for potential climate change impacts on biogenic trace gas emissions, water resource timing and availability, or agricultural yield and crop suitability should take into account regionally specific results from state-of-the-art RCMs.

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4. Climate Change Effects on Vegetation Distribution, Carbon and Fire in California (USDA Forest Service, September 2002).

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CLIMATE CHANGE EFFECTS ON VEGETATION DISTRIBUTION, CARBON, AND FIRE IN CALIFORNIA

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Abstract. The objective of this study was to dynamically simulate the response of vegetation distribution, carbon, and fire to the historical climate and to two contrasting scenarios of climate change in California. The results of the simulations for the historical climate compared favorably to independent estimates and observations, but validation of the results was complicated by the lack of land use effects in the model. The response to increasing temperatures under both scenarios was characterized by a shift in dominance from needle-leaved to broad-leaved life-forms and by increases in vegetation productivity, especially in the relatively cool and mesic regions of the state. The simulated response to changes in precipitation were complex, involving not only the effect of changes in soil moisture on vegetation productivity, but also changes in tree–grass competition mediated by fire. Summer months were warmer and persistently dry under both scenarios, so the trends in simulated fire area under both scenarios were primarily a response to changes in vegetation biomass. Total ecosystem carbon increased under both climate scenarios, but the proportions allocated to the wood and grass carbon pools differed. The results of the simulations underscore the potentially large impact of climate change on California ecosystems, and the need for further use and development of dynamic vegetation models using various ensembles of climate change scenarios.

Key words: California, USA; carbon; climate change; dynamic vegetation model; fire; vegetation distribution.

INTRODUCTION

California, USA, is one of the most climatically and biologically diverse areas in the world. There is more diversity in the state's land forms, climate, ecosystems, and species than in any comparably sized region in the United States (Holland and Keil 1995). The diversity of landscapes and climates supports a broad range of natural ecosystems ranging from the cool and wet redwood forests of the northwestern bioregion to the hot and dry Mojave and Sonoran Deserts (Fig. 1; Hickman 1993). This diversity of habitats sustains a greater level of species diversity and endemism than is found in any other region of the nation. The California flora includes ~25% of the flora of the continental United States, and ~25% of the plant species are endemic to the state (Davis et al. 1998).

Much of California's biological wealth is threatened by the state's burgeoning population and the consequent impacts on the landscape. Throughout the state, natural habitats have been and continue to be altered and fragmented, endangering the state's biological diversity (Barbour et al. 1993). Most of the state's forests have been logged, native oak woodlands are in serious decline, native grasslands have almost completely disappeared, and nearly 90% of the state's wetlands and riparian areas have been severely degraded or destroyed. Even relatively unmanaged natural systems have been significantly altered by introduction of nonnative species and fire suppression (Field et al. 1999).

In the future, global climate change will increasingly interact with and intensify the pressures of a growing population on the natural ecosystems of California. Recent studies show that even gradual and apparently small changes in climate can lead to catastrophic shifts in ecosystems when ecosystem resilience has been compromised by human exploitation (Scheffer et al. 2001). Regional climate studies indicate that on average California may experience substantially warmer and wetter winters, somewhat warmer summers, and an enhanced El Niño Southern Oscillation (ENSO) during the next century (Field et al. 1999, Gutowski et al. 2000). All natural ecosystems, whether managed or unmanaged, will be impacted by these changes in climate. It is not possible to accurately predict the response of the natural systems to global climate change through direct experimentation. The physical extent, complexity, and expense of even a single factor experiment for an entire ecosystem is usually prohibitive (Aber et al. 2001). However, analyses of the sensitivity of natural ecosystems to climate change can be made using ecosystem models that integrate information from direct experimentation.

In this study we used MAPSS-CENTURY 1 (MC1; Daly et al. 2000, Bachelet et al. 2001*a*), a state-of-the-

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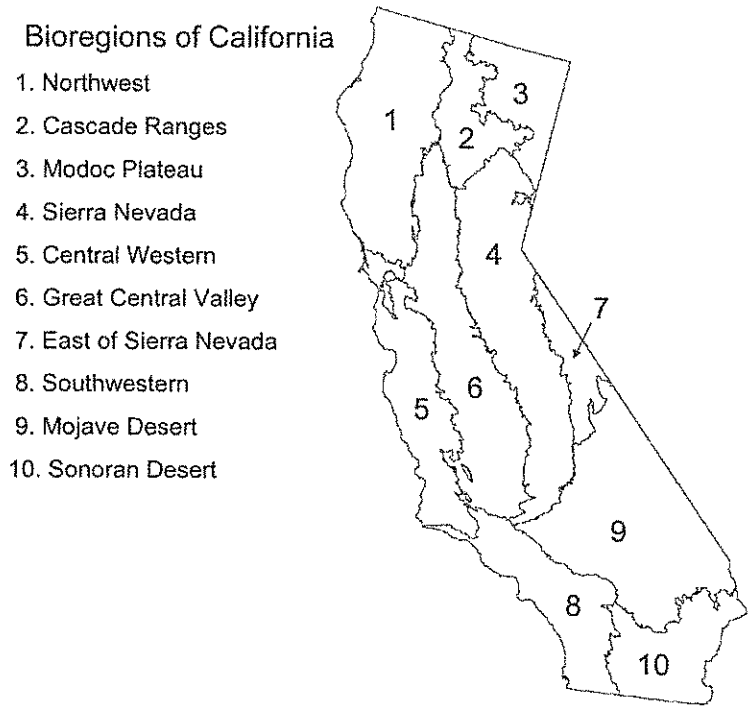

FIG. 1. Bioregions of California, USA (Hickman 1993).

art dynamic vegetation model, to investigate the sensitivity of natural ecosystems in California under two different future climate scenarios. MC1 simulates vegetation succession at large spatial extents through time while estimating variability in the carbon budget and responses to episodic events such as drought and fire. While MC1 does not as yet simulate interactions with land use effects or constraints on ecosystem change imposed by dispersal of propagules, the model has been used to examine the sensitivity of natural ecosystems to global climate change for several national-scale studies, most recently for the United States Global Change Research Program's National Assessment of Climate Change Impacts on the United States (Aber et al. 2001, National Assessment Synthesis Team 2001).

METHODS

The model

MC1 is a dynamic vegetation model (DVM) that simulates life-form mixtures and vegetation types; ecosystem fluxes of carbon, nitrogen, and water; and fire disturbance. MC1 is routinely implemented (Bachelet et al. 2000, 2001*b*, Daly et al. 2000, Aber et al. 2001) on spatial data grids of varying resolution (i.e., grid cell sizes ranging from 900 m^2 to ~2500 km^2) where the model is run separately for each grid cell (i.e., there is no exchange of information across cells). The model reads climate data at a monthly time step and calls interacting modules that simulate biogeography, biogeochemistry, and fire disturbance.

Biogeography module.—The biogeography module simulates the potential life-form mixture of evergreen needleleaf, evergreen broadleaf, and deciduous broadleaf trees, and C_3 and C_4 grasses. The tree life-form mixture is determined at each annual time step by locating the grid cell on a two-dimensional gradient of annual minimum temperature and growing season precipitation. Life-form dominance is arrayed along the minimum temperature gradient from more evergreen needleleaf dominance at relatively low temperatures to more deciduous broadleaf dominance at intermediate temperatures to more broadleaf evergreen dominance at relatively high temperatures. The precipitation dimension is used to modulate the relative dominance of deciduous broadleaved trees, which is gradually reduced to zero towards low values of growing season precipitation. Mixtures of C_3 vs. C_4 grasses are determined by reference to their relative potential productivity during the three warmest consecutive months. Potential grass production by life-form is simulated as a function of soil temperature using equations from the CENTURY model (Parton et al. 1994). The tree and grass life-form mixtures together with wood and grass biomass simulated by the biogeochemistry module are used in a rule base to determine which of 22 possible potential vegetation types occurs at the grid cell each year.

Biogeochemistry module.—The biogeochemistry module is a modified version of the CENTURY model (Parton et al. 1994), which simulates plant productivity,

organic matter decomposition, and water and nutrient cycling. Plant productivity is constrained by temperature, effective moisture (i.e., a function of soil moisture and potential evapotranspiration), and nutrient availability. In this study, simulated vegetation productivity was assumed to be unconstrained by nutrient availability. The simulated effect of increasing atmospheric CO_2 is to increase maximum potential production and to decrease transpiration (thus reducing the constraint of effective moisture on productivity). Trees compete with grasses for soil moisture, light, and nutrients. Competition for water is structured by rooting depth. Trees and grasses compete for soil moisture in the upper soil layers where both life-forms are rooted, while the deeper-rooted trees have sole access to moisture in deeper layers. Grass productivity is constrained by light availability in the understory, which is reduced as a function of tree leaf carbon. Parameterization of the tree and grass growth processes in the model is based on the current life-form mixture, which is updated annually by the biogeography module. For example, an increase in annual minimum temperature that shifted the dominance of evergreen needle-leaved trees to codominance with evergreen broadleaved trees would trigger an adjustment of tree growth parameters (e.g., the optimum growth temperature) that would, in turn, produce a modified tree growth rate.

Fire disturbance module.—The MC1 fire module (Lenihan et al. 1998) simulates the occurrence, behavior, and effects of fire. The module consists of several mechanistic fire behavior and effect functions (Rothermel 1972, Peterson and Ryan 1986, van Wagner 1993, Keane et al. 1997) embedded in a structure that provides two-way interactions with the biogeography and biogeochemistry modules. Live crown structure and fuel loading in several size classes of both dead and live fuels are estimated using life-form-specific allometric functions of the different carbon pools. The moisture content of each dead fuel size class is estimated as a function of antecedent weather conditions averaged over a period of days dependent on size class. The moisture content of each live fuel class is a function of the soil moisture content to a specific depth in the profile. Fuel moisture and distribution of the total fuel load among different size classes determine potential fire behavior estimated using the Rothermel (1972) fire spread equations.

The rate of fire spread and fire line intensity are the model estimates of fire behavior used to simulate fire occurrence and effects. The occurrence of a fire event is triggered by thresholds of fire spread, fine fuel flammability, and coarse woody fuel moisture (given a constraint of just one fire event per year). The thresholds were calibrated to limit the occurrence of simulated fires to only the most extreme events. Large and severe fires account for a very large fraction of the annual area burned historically (Strauss et al. 1989). These events are also likely to be least constrained by heterogeneities in topography and fuel moisture and loading that are poorly represented by relatively coarse-scale input data grids (Turner and Romme 1994).

The direct effect of fire in the model is the consumption and mortality of dead and live vegetation carbon that is removed from (or transferred to) the appropriate carbon pools in the biogeochemistry module. This direct effect is a function of the simulated fraction of the cell burned, fire line intensity, and tree canopy structure. The fraction of the cell burned depends on the simulated rate of fire spread and the time since the last fire event relative to the current fire return interval simulated for the cell. Higher rates of spread and longer intervals between fires generally produce more extensive fire events in the model. Live carbon mortality and consumption within the area burnt are functions of fire line intensity and the tree canopy structure (i.e., crown height, crown length, and bark thickness). Dead biomass consumption is simulated using functions of fire intensity and fuel moisture that are fuel-class specific.

Fire effects extend beyond the direct impact on carbon and nutrient pools to more indirect and complex effects on tree vs. grass competition. Fire tends to tip the competitive balance towards grasses in the model because much, or all, of the grass biomass consumed regrows in the year following a fire event. Woody biomass consumed or killed is more gradually replaced. A greater competitive advantage over trees promotes greater grass biomass which, in turn, produces higher fine-fuel loadings and changes in the fuel bed structure that promote greater rates of spread and thus more extensive fire.

Climatic data

The climate data used as input to the model in this study consisted of monthly time series for all the necessary variables (i.e., precipitation, minimum and maximum temperature, and vapor pressure) distributed on a 100-km^2 resolution data grid for the state of California. Spatially distributed monthly time series data for historical (1895–1993) precipitation, temperature, and vapor pressure already existed at a 100-km^2 resolution. This data set was developed from a subset of climate data generated by VEMAP (Kittel et al. 1997) and from observed California station data interpolated to the data grid by the PRISM model (Daly et al. 1994).

Spatially distributed climatic time series data for the two potential future climatic periods (1994–2100) were constructed using coarse-scale monthly output generated by two general circulation models (GCMs): the Hadley Climate Center HADCM2 model (HAD) and the National Center for Atmospheric Research (NCAR) Parallel Climate Model (PCM). Both are state-of-the-art GCMs that include the influence of dynamic oceans and aerosol forcing on the atmosphere. Most GCM experiments predict a warmer and wetter future for California. That prediction is represented in this study by

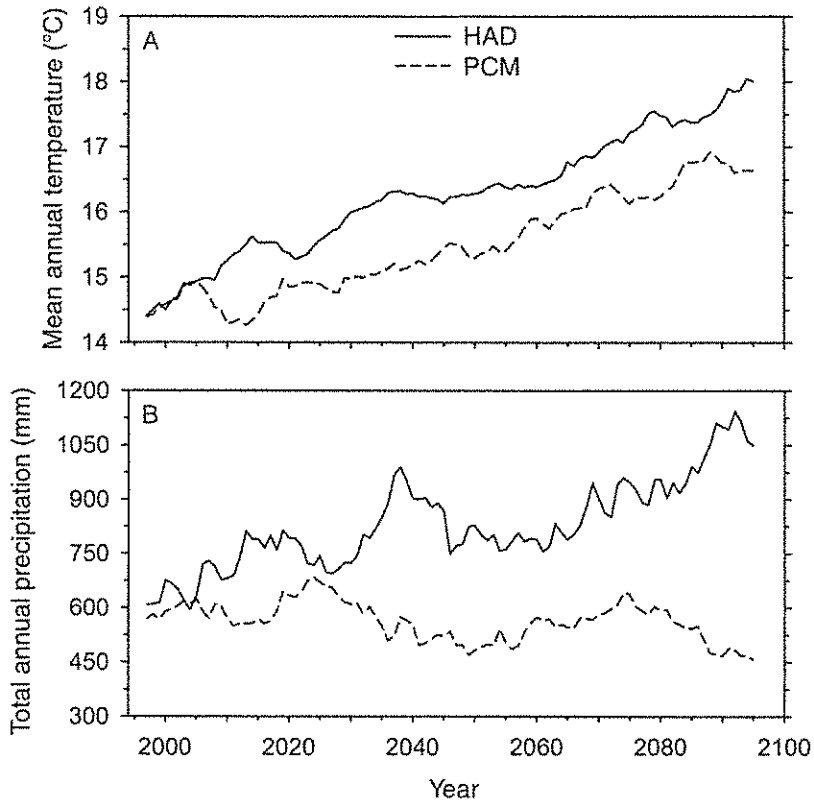

FIG. 2. Future trends in (A) mean annual temperature and (B) total annual precipitation under the the Hadley Climate Center HADCM2 model (HAD) and the National Center for Atmospheric Research's Parallel Climate Model (PCM) future climate scenarios. Annual values are means across all grid cells. Trends were smoothed for display using a 10-yr running average.

the HAD scenario developed from results of the HADCM2SUL integration (Mitchell and Johns 1997). The second climate scenario generated from results of the PCM B06.06 simulation (Dai et al. 2001) predicts a generally warmer and drier California. The PCM scenario thus provided a useful contrast to the HAD scenario for testing the model's sensitivity to climatic change. Both GCMs were run from the 1800s to 1995 using observed increases in greenhouse gas concentrations and into the future using Intergovernmental Panel on Climate Change (IPCC) projections of a 1% increase per year (Kattenberg et al. 1996).

There are distinctly different trends of mean annual temperature and total annual precipitation under the two future climate scenarios. Both scenarios show an increase in annual temperature relative to the mean for the historical base period (Fig. 2A), but the increase is significantly greater for the HAD scenario. The two scenarios are even more distinct in terms of projected trends in precipitation (Fig 2B). The HAD scenario is wetter and the PCM scenario is drier than the historical mean for most years, but the contrast between the two is especially pronounced in the last few decades of the future period.

A change in the seasonal trend of temperature and precipitation may have as much impact on ecosystem properties as changes in annual trends. Mean monthly values for temperature and precipitation over the 30-yr historical base period (Fig. 3) show the characteristic trends for a Mediterranean climate with cool wet winters and hot dry summers. For both scenarios, monthly temperature and precipitation averaged over the future 30-yr period retain these seasonal trends. Changes in monthly temperature and precipitation under the two scenarios interact to produce shifts in the amount of precipitation that falls while vegetation growth is dormant or active. Given an approximate threshold of 13°C to define the beginning and end of the growing season, dormant season precipitation increases by ~46% relative to historical levels under the HAD scenario and declines by ~19% under the PCM scenario. This is an important feature of the scenarios in determining the response of the model because dormant season precipitation is most effective at recharging the deep soil moisture exclusively available to the woody life-forms. Thus an increase in dormant season precipitation, such as that under the HAD scenario, will be more advantageous to the growth and competitiveness of the

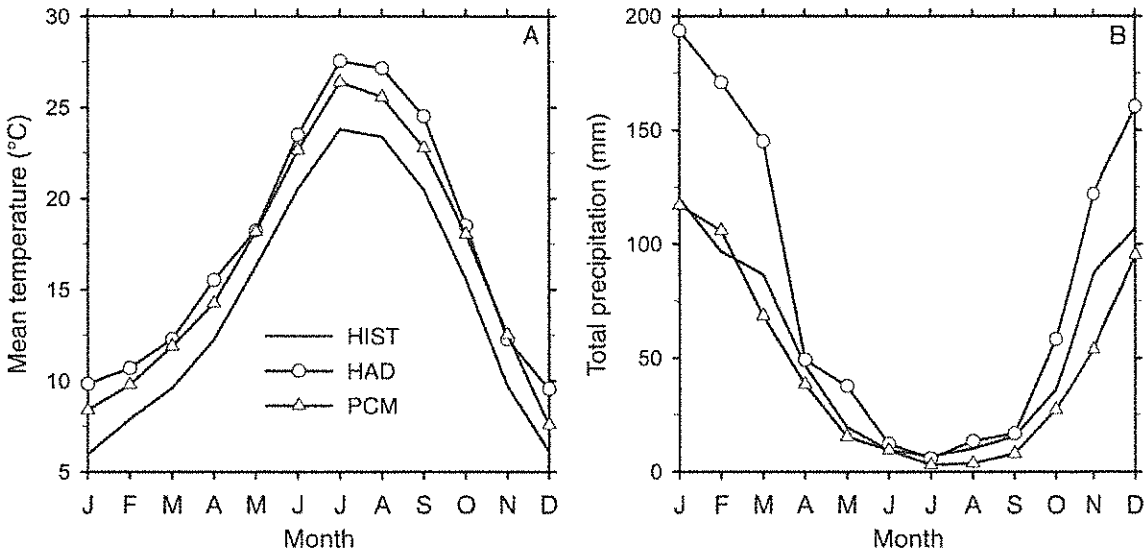

FIG. 3. Seasonal trends in (A) mean monthly temperature and (B) total monthly precipitation trends for the historical period (1961–1990) and the future period (2070–2099) of the Hadley Climate Center HADCM2 model (HAD) and the National Center for Atmospheric Research's Parallel Climate Model (PCM) future climate scenarios. Monthly values are means for the time period and across all grid cells.

woody life-forms in the model. A decline in precipitation during the dormant season, such as that under the PCM scenario, will produce a decline in the growth and competitiveness of the woody life-forms to the benefit of the grass life-forms in the model.

RESULTS AND DISCUSSION

Vegetation distribution

Response to the historical climate.—Of the 22 possible vegetation types predicted by the biogeography module, 12 occurred in the simulations for California. These types were aggregated into seven vegetation classes to simplify the visualization of results. The aggregation scheme and lists of typical regional examples in each vegetation class (Table 1) indicate the range of each class in terms of physiognomy and species dominance.

The results of the vegetation class simulation for the historical period are shown (Fig. 4A) as the distribution of the most frequent vegetation type simulated for the 1961–1990 climate period. The simulated vegetation class distribution is difficult to validate against different maps of vegetation available for California. The MC1 biogeography module simulates the life-form mixture and vegetation type that could potentially occur given climatic conditions and the simulated fire regime. Many of the available vegetation maps show the distribution of vegetation types highly modified by urbanization, agriculture, and forestry practices including fire suppression. Others show the distribution

TABLE 1. MC1 vegetation type aggregation scheme and regional examples of the vegetation classes.

MC1 vegetation class	MC1 vegetation type	Regional examples
Alpine/subalpine forest	tundra, boreal forest	alpine meadows, lodgepole pine forest, white-bark pine forest
Evergreen conifer forest	maritime temperate conifer forest, continental temperate coniferous forest	coastal redwood forest, coastal closed-cone pine forest, mixed conifer forest, ponderosa pine forest
Mixed evergreen forest	warm temperate/subtropical mixed forest	Douglas-fir–tan oak forest, tan oak–madrone–oak forest, ponderosa pine–black oak forest
Mixed evergreen woodland	temperate mixed Xeromorphic woodland, temperate conifer xeromorphic woodland	blue oak woodland, canyon live oak woodland, northern juniper woodland
Grassland	C_3 grassland C_4 grassland	valley grassland, southern coastal grassland, desert grassland
Shrubland	mediterranean shrubland, temperate arid shrubland	chamise chaparral, southern coastal scrub, sagebrush steppe
Desert	subtropical arid shrubland	creosote brush scrub, saltbrush scrub, Joshua tree woodland

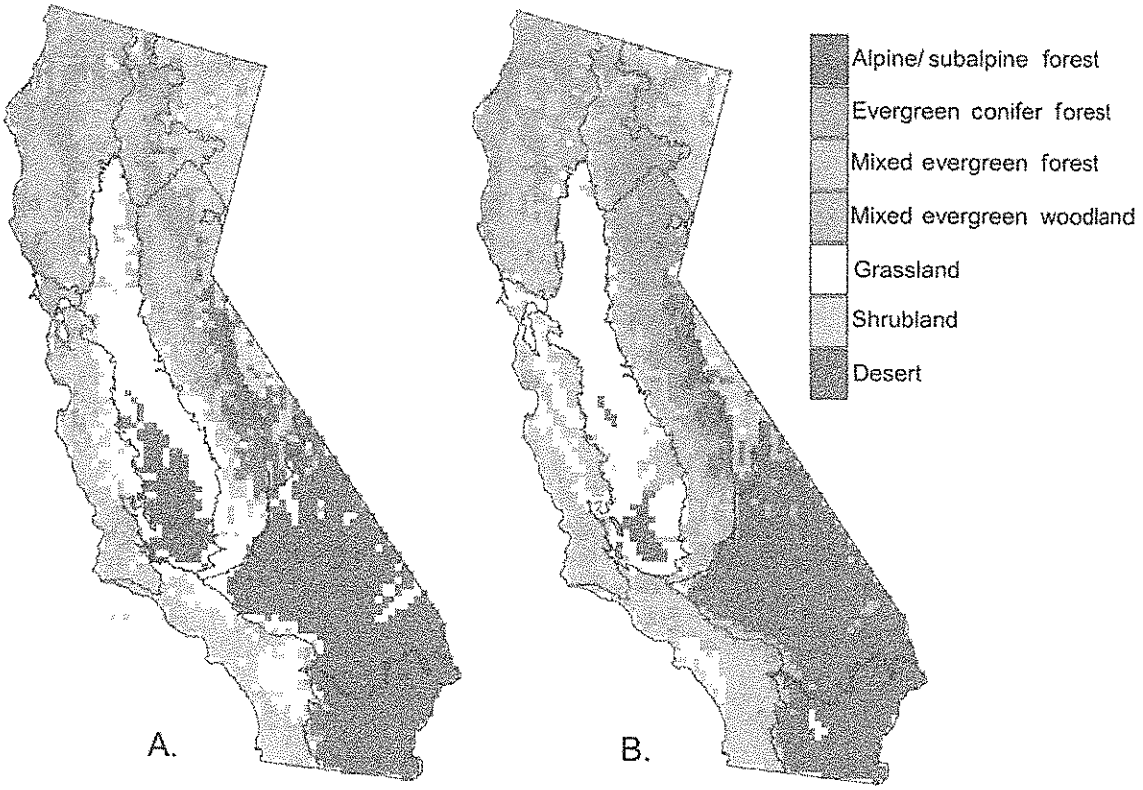

FIG. 4. (A) Map of the distribution of the simulated vegetation classes for the historical period (1961–1990) and (B) baseline vegetation map. The vegetation class mapped at each grid cell in (A) is the most frequent class simulated during the historical period.

of potential vegetation types, but comparisons to these involve difficulties associated with different criteria for classification and potential errors associated with cross-walking different classification schemes. The Küchler (1975) potential vegetation map of the United States was selected as a baseline for comparison against the vegetation class simulation for the historical period. A baseline vegetation map (Fig. 4B) was created for California by aggregating the 28 vegetation types mapped by Küchler in California into the seven vegetation classes simulated by MC1.

The overall distribution of the vegetation classes simulated for the historical period was very similar to the distribution on the baseline vegetation map. The percentage of coverage of the vegetation classes for the MC1 simulation also compared favorably to the baseline map (Fig. 5). However, there were a few notable differences in terms of both distribution and coverage in the different regions of the state. For example, MC1 predicted greater coverage of mixed evergreen forest, especially along the western slope of the Sierra Nevada where the baseline map shows evergreen conifer forest. In the Central Western Region, MC1 predicts a mixture of evergreen conifer forest and mixed evergreen forest where the baseline map shows evergreen woodland and

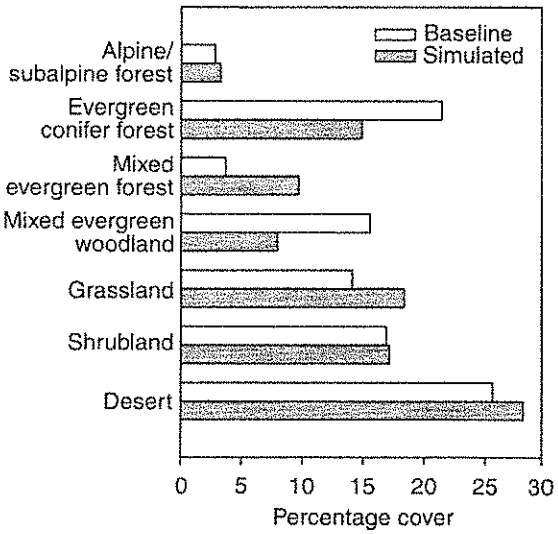

FIG. 5. Percentage of land cover of vegetation classes for the historical period (1961–1990) simulation compared to the baseline vegetation map.

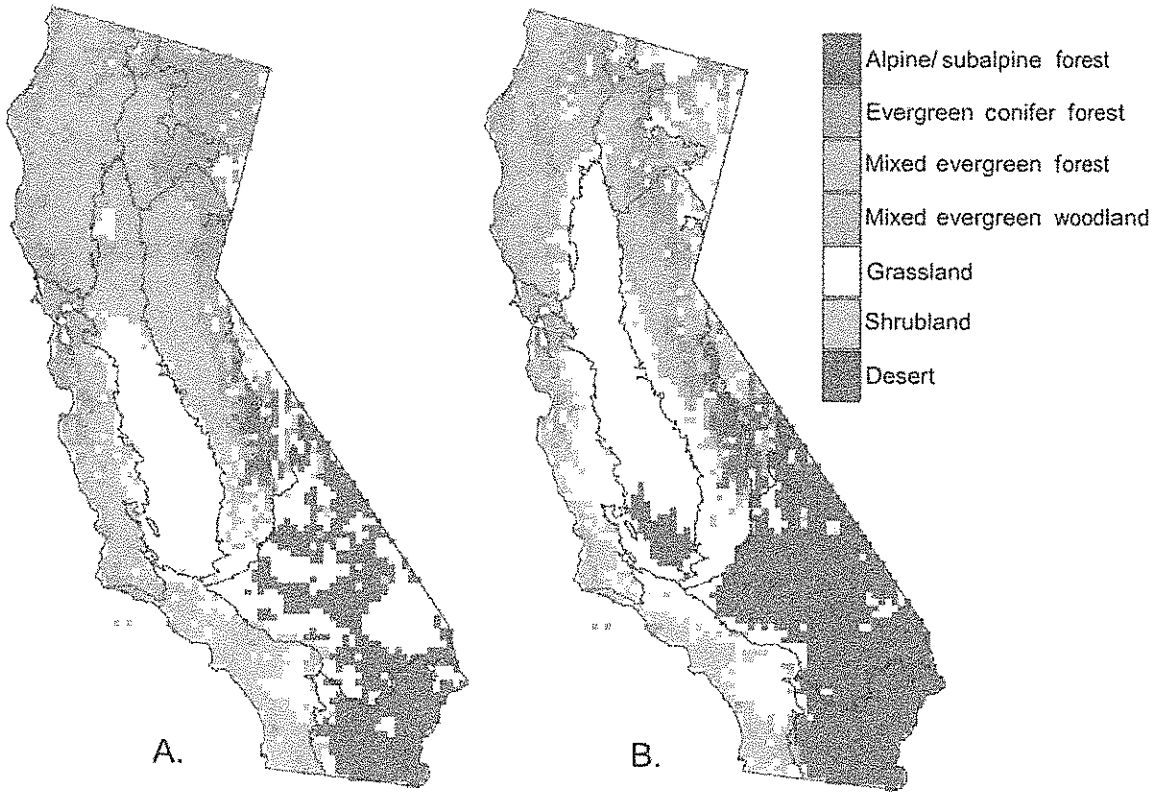

FIG. 6. Distribution of the vegetation classes simulated for the future period 2070–2099 by (A) the Hadley Climate Center HADCM2 model (HAD) and (B) the National Center for Atmospheric Research's Parallel Climate Model (PCM) climate scenarios. The vegetation class mapped at each grid cell is the most frequent class simulated during the time period.

shrubland. Other discrepancies occur in the Southwestern Region and at the southern end of the Sierra Nevada where the MC1 simulation shows more grassland than the baseline map and in the eastern half of the Cascade Range region where MC1 predicted more shrubland.

Not all the instances in which the simulated vegetation class distribution differs with the baseline distribution are necessarily errors in the simulation. For example, on the baseline map there is no mixed evergreen forest in the region between mixed evergreen woodland and evergreen conifer forest along the western slope of the Sierra Nevada. However, a Sierran mixed hardwood forest with a strong resemblance to the mixed evergreen forests of the coastal mountains has been described for this region (Holland and Keil 1995). The simulated occurrence and distribution of evergreen conifer and mixed evergreen forest along the coastal sector of the Central Western Region is also supported by descriptions of closed-cone coniferous forest and mixed hardwood forest (Holland and Keil 1995, Sawyer et al. 1995, Vogel et al. 1995) for this region of California.

Response to the future climate scenarios.—The response of vegetation class distribution under the two future climate scenarios was determined by comparing the distribution of the most frequent vegetation type simulated for the 30-year historical period (Fig. 4A) against the same for the last 30 years (2071–2100) of the future scenarios (Fig. 6A, B). The simulated response of the vegetation classes in terms of changes in percentage of coverage (Fig. 7) was surprisingly similar under the two future climates. There was agreement on the direction of change (i.e., decrease or increase in coverage) for all but the evergreen conifer forest class, and the amounts of change were comparable for a few of the vegetation classes. However, these similarities in the response of class coverage were often the net result of very different responses to each scenario in terms of the spatial distribution of vegetation classes as discussed below.

A prominent feature of the response of the vegetation class distribution under the HAD scenario (Fig. 6A) was the advancement of forest classes into the Modoc Plateau, into the northern end of the Great Central Valley, towards higher elevations in the Sierra Nevada, and inland along the coast. Increases in both temperature and dormant season precipitation under this scenario favored expansion of forest, and they were especially favorable for mixed evergreen forest. The rel-

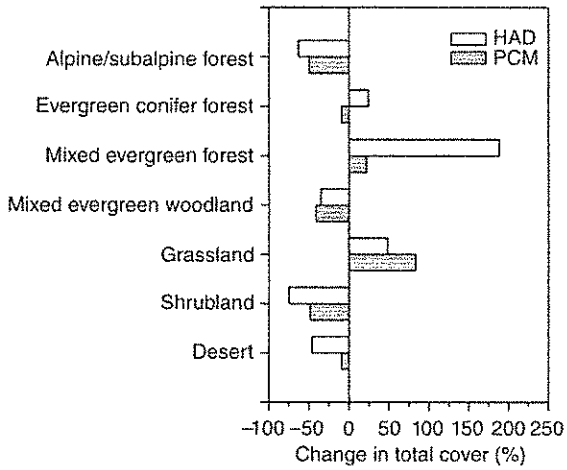

FIG. 7. Percentage changes in the total cover of the vegetation classes under the Hadley Climate Center HADCM2 model (HAD) and the National Center for Atmospheric Research's Parallel Climate Model (PCM) scenarios.

atively high degree of warming under the HAD scenario promoted a widespread change in the simulated life-form composition from needleleaf dominance to mixed needleleaf–broadleaf in the northern half of the state. Consequently, mixed evergreen forest replaced evergreen conifer forest throughout much of the latter's simulated historical range. Two examples of this transition in terms of species dominance within the different bioregions might include the replacement of Douglas-fir–white fir forest by Douglas-fir–tan oak forest in the Northwest Region, and the replacement of white fir–ponderosa pine forest by ponderosa pine–black oak forest in the Sierra Nevada. Greater moisture availability under the HAD scenario also promoted the advancement of mixed evergreen forest into mixed evergreen woodland, shrubland, and grassland. Movement into the northern end of the Great Central Valley could represent the replacement of blue oak woodlands, chaparral, and perennial grassland by tan oak–madrone–canyon live oak forest with scattered Douglas-fir and ponderosa pine. In the Central Western and Southwestern bioregions, mixed evergreen forests of coast live oak–madrone or canyon live oak–Coulter pine might replace chaparral and live oak woodlands.

Evergreen conifer forest showed a net increase in percentage of coverage under the HAD scenario despite the loss of much of its simulated historical range to mixed evergreen forest. The main region of evergreen conifer advancement was in the cold desert region of the Modoc Plateau and east of the Sierra Nevada Range. Here higher moisture availability promoted the advancement of evergreen conifer forest into mixed evergreen woodland and shrubland. On the Modoc Plateau, this transition would likely be characterized by replacement of northern juniper woodland and Great Basin sagebrush scrub by ponderosa pine–Jeffrey pine forest. Another region of evergreen conifer forest expansion under the warmer and wetter HAD scenario was along the coast, especially in the Central Western Region. Here the simulated advancement of this class into mixed evergreen forest and shrubland would likely represent the expansion of redwood and closed-cone pines from remnant, fragmented groves into surrounding canyon live oak–madrone forests and chaparral. Evergreen conifer forest also advanced into the high-elevation subalpine/alpine forest in the Cascade Range and Sierra Nevada regions under the HAD scenario. Here the model responded to an increase in the length of the growing season past a threshold in the biogeographic rule base. Advancement of red fir or lodgepole pine forest into subalpine parks and meadow would be a likely example of this transition.

In addition to widespread advancement of forest, another prominent feature of the response of vegetation distribution under the HAD scenario was the advancement of grassland, particularly in the southern end of the Great Central Valley and in the uplands of the Mojave Desert where grassland replaces desert. Here the response to increased precipitation was an increase in both tree and grass biomass. The increase in grass biomass translated to more fine flammable fuels in the fire disturbance module, promoting more fire that in turn reduced the competitiveness of the woody life-forms. In the Mojave Desert, this transition could represent an increase in the extent of desert grassland interspersed with Joshua tree desert woodland and creosote bush scrub.

The most prominent feature of the vegetation class response to the drier PCM scenario (Fig. 6B) was the advancement of grassland into the simulated historical range of mixed evergreen woodland and shrubland. This transition was prompted by a decline in the competitiveness of woody life-forms as a response to the decline in dormant season precipitation, and an increase in fire, which further constrained the woody life-forms. The advancement of grassland occurred primarily on the Modoc Plateau, in the foothills surrounding the Great Central Valley, and in the interior of the Central Western Region. On the Modoc Plateau, a likely example of this transition would be an increase in the extent of the grassland interspersed within the northern juniper woodland and sagebrush scrub communities. A similar transition is already occurring under present-day conditions in the sagebrush scrub communities of the intermountain west. Here drought, increasing cheatgrass abundance, and fire are interacting to significantly reduce the woody scrub component (D'Antonio and Vitousek 1992). In the foothills of the Great Central Valley and Central Western Region, the model simulation could indicate the loss of various oak woodland and chaparral communities to nonnative grassland communities.

Mixed evergreen woodland and shrubland show too little advancement to compensate for the loss to grass-

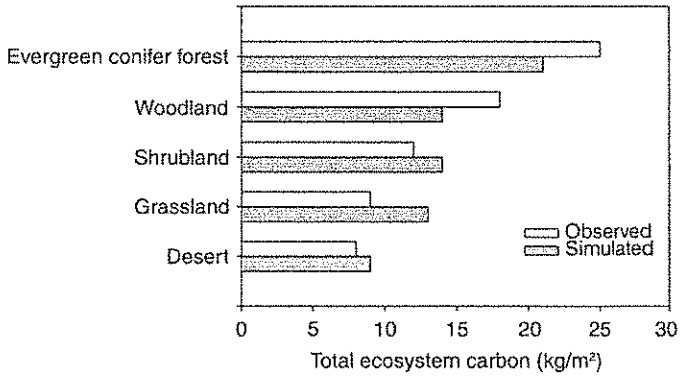

FIG. 8. Observed vs. simulated values for total ecosystem carbon density by vegetation class. Simulated values are mean annual values for the historical period (1961–1990) averaged across the state. Observed values are estimates for the United States reported by Houghton and Hackler (2000) and Atay et al. (1979).

land under the PCM scenario. Consequently, there is a net decline in the coverage of mixed evergreen woodland and shrubland and a narrowing of the simulated ecotones between forest and grassland. One local exception to this trend is in the eastern half of the Northwest Region, where there was some mixed evergreen woodland advancement into forest. In this bioregion, northern oak woodland advancing into Douglas-fir–tan oak and Douglas-fir–white fir forests would be a likely example of this transition. An exception to the general decline in shrubland was in the Sierra Nevada region, where shrubland advanced into alpine/subalpine forest. Here a regional example of the model's response to a lengthened growing season could be an increase in whitebark pine krummholtz within alpine meadow communities.

In contrast to the simulation for the HAD scenario, the distribution of mixed evergreen forest and evergreen conifer forest remained relatively static under the PCM scenario. Mixed evergreen forest showed a relatively small gain in coverage with limited advancement into evergreen conifer forest in the Northwest and Sierra Nevada regions. This transition was prompted by a temperature-driven shift in life-form composition like that under the HAD scenario, but the response was more constrained under the cooler PCM scenario. There was a net loss in the statewide coverage of evergreen conifer forest, but the class showed some advancement at high elevations in the Sierra Nevada and on the Modoc Plateau, and along the coast in the Central Western Region. In these relatively cool regions of the state, tree productivity increased as a response to increases in temperature and relatively small declines in precipitation.

Carbon

Response to the historical climate.—The successful simulation of the vegetation class distribution for the historical climate was, in part, a result of accurately simulating the relative distribution of wood and grass carbon across the state. The model also accurately predicted the absolute density of carbon within the different vegetation classes. Carbon density values within each of the simulated classes were averaged over the last 30 yr of the historical simulation and compared to observed values for equivalent vegetation classes (Fig. 8). The observed values (Atjay et al. 1979, Houghton and Hackler 2000) are for the United States across the entire range of each vegetation type, so there was likely some error associated with their use in representing observed values for California alone. Nevertheless, the results of the comparison showed a strong similarity between simulated and observed values.

Response to the future climate scenarios.—The trend in simulated annual net primary production (NPP) for the entire state of California (Fig. 9A) was a response to the continuous increase in temperature and fluctuations in precipitation under each scenario. The increase in temperature under both scenarios (Fig. 2A) increased the maximum productivity of life-forms in the model. Under the HAD scenario, the temperature-driven increase in NPP was relatively unconstrained by precipitation, which also increased throughout the future period (Fig. 2B). Nevertheless, fluctuations in the trend of NPP under the HAD scenario were clearly related to fluctuations in the trend of precipitation. In contrast to the HAD scenario, the temperature-driven increase in NPP was more constrained under the drier PCM scenario. Periods of decline in NPP corresponded to declines in precipitation below mean historical precipitation. Not until the end of the future period, where mean annual temperature was highest, did NPP under the PCM scenario remain above the historical mean despite declining precipitation.

When heterotrophic respiration was subtracted from NPP to derive net ecosystem productivity (NEP), there was a narrowing of the gap between trends in productivity under the two scenarios (Fig. 9B). This was also a response to the contrasting trends in temperature and precipitation. There was a greater annual percentage loss of soil carbon to heterotrophic respiration under the warmer and wetter HAD scenario compared to the cooler and drier PCM scenario.

When simulated losses of carbon to biomass consumption by fire are subtracted from NEP to derive net ecosystem exchange (NEE, Fig. 9C), the trends in pro-

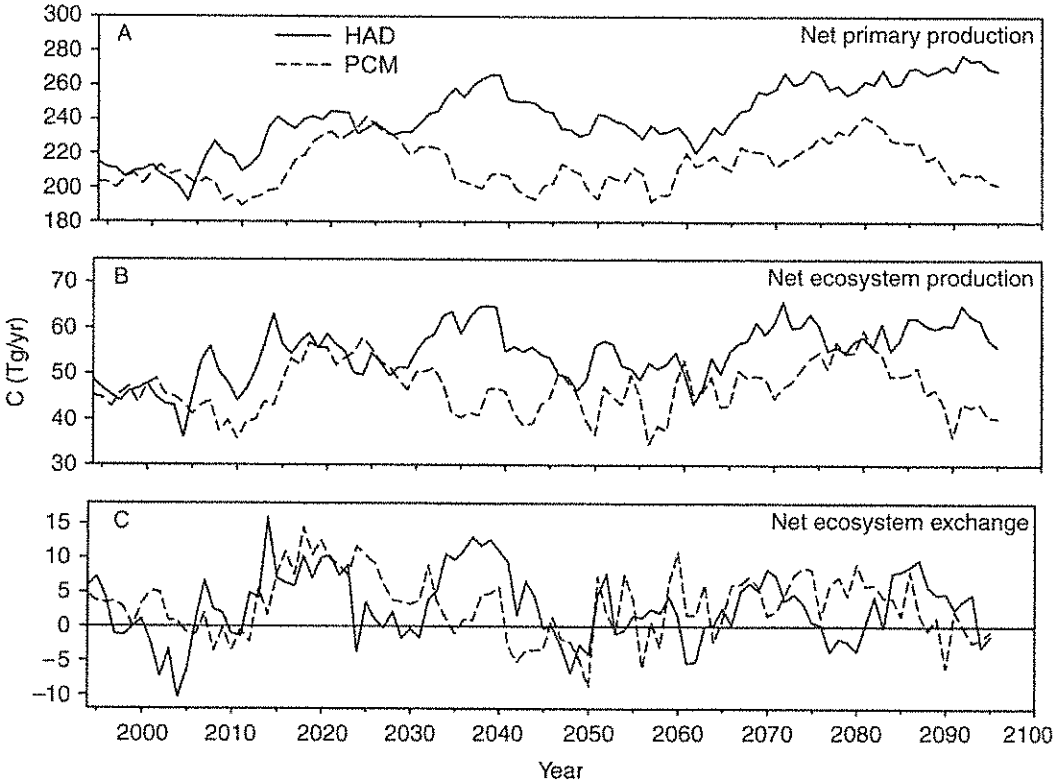

FIG. 9. Simulated trends in (A) total net primary production, (B) total net ecosystem production, and (C) total net ecosystem exchange for the entire state of California under the Hadley Climate Center HADCM2 model (HAD) and the National Center for Atmospheric Research's Parallel Climate Model (PCM) scenarios.

ductivity under the two scenarios became even less disparate. NEE under the PCM scenario actually exceeded that under the HAD scenario for certain periods. This somewhat counterintuitive result stemmed from the response of the model to changes in dormant season precipitation. Under the HAD scenario, where there was a significant increase in dormant season precipitation relative to the historical level, the model allocated relatively more annual production to woody biomass. Under the PCM scenario, where dormant season precipitation declined, more production was allocated to grass biomass. Consumption by fire had less effect over time on grass biomass because a greater proportion of grass biomass is stored underground where it is protected from fire. Moreover, any grass biomass consumed by fire was quickly reestablished the following year, in contrast to woody biomass, which was more gradually replaced. After periods of fire, NEE was relatively lower for longer periods of time under the HAD scenario because a greater proportion of the predominately woody biomass was consumed and was slower to reestablish.

TABLE 2. Size of the historical carbon pools simulated for the state of California, USA, and future changes in size simulated under the Hadley Climate Center HADCM2 model (HAD) and the National Center for Atmospheric Research's Parallel Climate Model (PCM) climate scenarios.

Carbon pool	Historical Mass (Tg)	HAD		PCM	
		Mass (Tg)	Change (%)	Mass (Tg)	Change (%)
Total ecosystem	5765	6077	5.4	6090	5.6
Soil and litter	5305	5508	3.8	5551	4.6
Live vegetation	461	568	23.2	539	16.9
Live wood	300	399	33.0	338	12.7
Live grass	161	170	5.6	202	25.5

Notes: Historical values in teragrams are the mean masses for the 30-yr (1961–1990) base period. HAD and PCM change values in teragrams are the mean masses for the 30-yr (2070–2099) future period subtracted from the mean masses for the historical period.

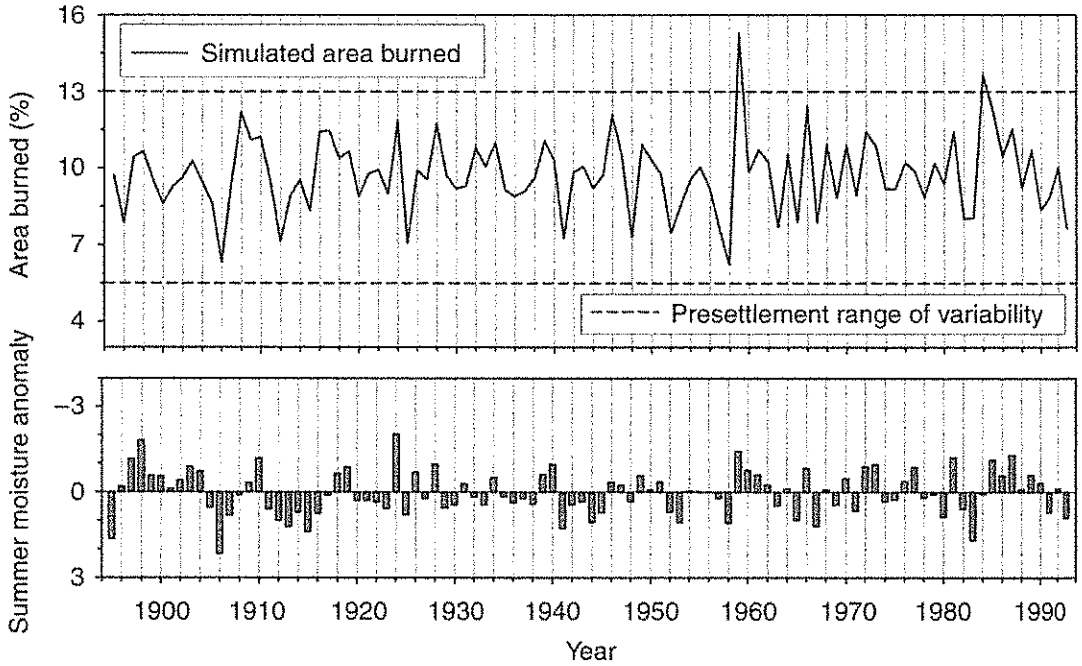

FIG. 10. Trend in the simulated annual percentage of area of California burned for the historical period (1895–1993) compared to the mean annual summer moisture anomaly. Statewide values of the summer moisture anomaly were calculated by averaging observed values (National Climatic Data Center 1994) for three summer months (June–August) for all five climatic divisions in California.

Mean simulated NEE over the last 30 yr of the future period was 2.5 and 3.1 Tg/yr under the HAD and PCM scenarios, respectively. Mean total ecosystem carbon storage over the same period was also similiar under the two scenarios (Table 2). The increase in total carbon storage was just less than 6% over the historical mean under both scenarios. This was the net result of a greater increase in soil carbon under the PCM scenario and a greater increase in live vegetation carbon under the HAD scenario. A greater percentage of the total increase in live vegetation carbon was allocated to the live grass biomass pool under the PCM scenario as a result of the decline in dormant season precipitation, which was especially steep during the last three decades of the future period (Fig. 2B). The decline in precipitation and the proportional increase in grass carbon relative to woody carbon were both factors in the increase in soil and litter carbon under the PCM scenario. Soil decomposition was slower under the drier conditions, and grass carbon is an especially effective contributor to soil carbon in the model because of the fast turnover rate and the large proportion of biomass belowground.

Fire

Response to the historical climate.—The MC1 fire module simulates fire severity under conditions of potential natural vegetation and no fire suppression, so validating the historical simulation of fire involves some of the same difficulties listed for the vegetation class simulation. Martin and Sapsis (1995) estimated that fire burned 5.5–13% of California annually under presettlement conditions. The range of percentage of total area burned simulated by MC1 during the 100 yr of the historical simulation (6.3–15.5%, Fig. 10) was remarkably similar to this independent estimate. The simulated trend of percentage of area burned showed a significant and fairly strong relationship (Spearman rank correlation = −0.70, $P < 0.001$) with the historical trend of a drought index (Fig. 10) calculated from the monthly moisture anomaly (i.e., a product of the moisture departure of the most recent 4 wk and a climate weighting factor; Palmer 1965). A state-wide annual value of the index was calculated by averaging published values of the moisture anomaly (National Climatic Data Center 1994) over three summer months (June–August) and over all five climatic divisions in California. Several severe fire years simulated by the model were coincident with some of the driest years (e.g., 1910, 1924, 1928, 1959, 1966), and several of the least severe fire years were coincident with some of the wettest years (e.g., 1906, 1912, 1941, 1958, 1983). Three of the most severe fire years (e.g., 1908, 1959, 1984) were preceded by one or more relatively wet years in which a build-up of fuels was simulated by the model. A similar pattern of large fire years promoted by sequences of wet seasons followed by average or drier than average seasons has been identified

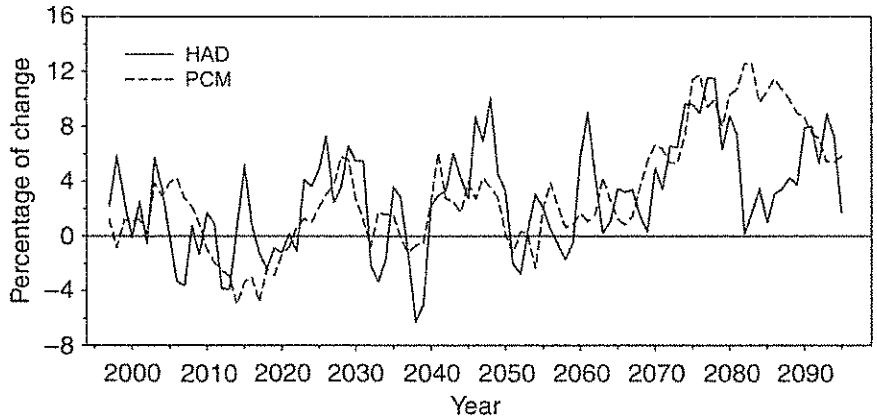

FIG. 11. Simulated trend in percentage change of total annual area burned relative to the historical (1895–1993) mean under the Hadley Climate Center HADCM2 model (HAD) and the National Center for Atmospheric Research's Parallel Climate Model (PCM) climate scenarios.

in the southwestern United States (Swetnam and Betancourt 1998).

Response to the future climate scenarios.—The simulated trends in percentage of area burned under both scenarios (Fig. 11) show periods of both increase and decline relative to the mean for the historical period. Only in the last few decades of the future period did area burned stay consistently above the historical mean. However, linear regression analysis showed that only in the case of the PCM scenario was the slope of the overall trend for area burned significantly different than zero.

The simulated fluctuations in area burned under both scenarios was a complex response to temperature and precipitation as they affected fuel moisture and to the buildup of fuel biomass prior to dry years that triggered fire events The influence of biomass buildup was particularly evident under the HAD scenario where the coefficient of variation for the overall trend in area burned (21%) was higher than for either the PCM scenario or the historical period (10% and 15%, respectively). The increase in precipitation under the HAD scenario served to increase the variability of the fire regime by reducing area burned to lower levels and contributing to greater biomass buildup during relatively wet years, thus setting the stage for higher levels of area burned promoted by higher fuel loads during relatively dry years. This interaction between fuels and the interannual variability in precipitation produced the somewhat counterintuitive result of more severe fire years simulated under the wetter HAD scenario than under the drier PCM scenario. Three years under the HAD scenario were also more severe in terms of total area burned than any year in the simulation for the historical period. Under the PCM scenario, less interannual variation in precipitation together with a higher proportion of fine fuels with a relatively rapid drying rate (i.e., grass biomass) produced a less variable simulated fire regime.

CONCLUSIONS

The MC1 simulation for the historical climate of California appeared to have achieved a reliable level of prediction, although validation of a broad-scale model of potential vegetation presents numerous difficulties. The simulation of the coverage and distribution of vegetation classes was largely in agreement with the baseline vegetation map, and some of the discrepancies between the two were likely attributable to lack of detail in the baseline map. The success of the vegetation class simulation was, in part, a result of successfully simulating the relative distribution of tree and grass carbon. And the absolute values of simulated total vegetation carbon per vegetation class were largely in agreement with published values for equivalent classes. Simulated values of total area burned over the length of the historical simulation were within a range of values expected for California under the assumptions of the model (i.e., a natural fire regime unconstrained by fire suppression). Also, the simulated peak fire years during the historical period were coincident with observed drier-than-normal years, in conformance to the well-established relationship between drought and severe fire episodes.

More rigorous validation of the simulation results for the historical climate was difficult given the nature of the simulations. The model simulates dynamic ecosystem properties only as a function of climate and soils and does not include the effects of land use practices that modify life-form mixtures, carbon stocks, and fire regimes. Also, the model does not include lags in vegetation change due to migration and dispersal over a landscape fragmented by land use practices. Ongoing efforts to incorporate land use effects in MC1 and to increase the spatial resolution of the model simulations should increase the realism of the model results and facilitate their validation against observed data from the extant landscape.

Compounding the uncertainty arising from the limitations of the model are the existence of a large number of GCM-generated global climate change scenarios that could be used to construct regional-scale scenarios for California. In a recent analysis, the California portions of over 20 GCM simulations were examined to ascertain any consistent projections of climate change (T. Wrigley, *personal communication*). All the models estimated warmer temperatures for the state, but there was much less consistency regarding precipitation. The models ranged from estimating a 56% increase to a 10% decrease in winter precipitation, with about two-thirds of the models estimating an increase in winter precipitation. The mean change in summer precipitation was near zero. The conclusion was that California is likely to be warmer and probably wetter during the winter months. This scenario is well-represented by the HAD scenario. However, none of the available scenarios should be interpreted as predictions of climate change in California. Their proper use is in the investigation of the sensitivities of natural and managed systems to potential changes in climate.

The results of the MC1 simulations for California demonstrate certain ecosystem sensitivities and interactions that are likely to be features of the response of both natural and seminatural (e.g., managed forests and rangelands) systems to the relatively certain rise in temperature and the less certain changes in precipitation. An increase in temperature could increase vegetation productivity given adequate moisture availability, especially in cooler regions of the state (e.g., along the north-central coast or at high elevations). For example, currently the highest monthly mean temperatures along the north-central coast (14.6°–16.8°C; Major 1995) are below the mean summer temperature for optimal coast redwood forest productivity (17.8°C; Kuser 1976) and for optimal redwood seedling growth (18.9°C; Hellmers and Sundahl 1959). An increase in temperature could also alter forest composition by increasing the competitiveness of evergreen hardwood species that are less tolerant of low winter temperatures than conifers (Woodward 1987).

The relative dominance of woody life-forms could be sensitive to the changes in dormant season precipitation forecast for California, especially given the predicted persistence of a Mediterranean climate where woody plants must compete with more drought-tolerant grasses during the dry growing season. With the increase in winter precipitation forecast by the majority of GCMs for California, the model results suggest a widespread expansion of forest, overtaking both woodland and shrubland, and constrained only where climate is still arid enough to support sufficient grass biomass to fuel frequent fire.

The model results indicate fire will play a critical role in the adjustment of vegetation to any of the altered precipitation regimes forecast for California, be it slowing the encroachment of woody vegetation in grasslands under wetter conditions or hastening the transition from woody communities to grassland under drier conditions. With a persistence of the summer dry climate, changes in the fire regime are likely to be less a product of altered fire weather than changes in the amount and character of fuels. The model results suggest that an increase in dormant season precipitation, especially when accompanied by greater interannual variability in rainfall, could lead to greater accumulation of relatively coarse woody fuels during sequences of wet seasons, fuels that retain relatively high moisture content during all but relatively infrequent years of fire-promoting drought. The result could be an altered fire regime characterized by more year-to-year variability in area burned and more extreme events.

The model results also suggest that changes in fire and shifts in the relative dominance of woody and grass life-forms could buffer the effect of different climatic perturbations on total ecosystem carbon storage. Under a wetter climate, an increase in carbon storage with the increase in vegetation productivity could be limited by greater losses to combustion during more extreme fire events. Under a drier climate, a decrease in carbon storage with the decrease in vegetation productivity could be limited by a shift towards greater dominance of grass life-forms that are better adapted to more frequent fire and more effective contributors to soil carbon stocks.

While neither of the model simulations for the two climate scenarios should be taken as predictions of the future, it is evident from the results that all the natural ecosystems of California, whether managed or unmanaged, are likely to be affected by changes in climate. Changes in temperature and precipitation will alter the structure, composition, and productivity of vegetation communities, and wildfire may become more frequent and intense. The incidence of pest outbreaks in forests stressed by a changing climate could act as a positive feedback on the frequency and intensity of fire. Nonnative species preadapted to disturbance could colonize altered sites in advance of native species, preventing the already problematical redistribution of natives across a landscape highly fragmented by land use practices. Both plants and animals already stressed by human development will be further stressed by climate change. Some may not be able to adapt, and there could be a significant rise in the number of threatened and endangered species. Tree species better adapted to a changed climate could be planted in forests managed for wood production, but better-adapted species may not have the same market value (e.g., conifer species vs. hardwood species). The expansion of grasslands under a drier climate might profit grazing livestock, but any gains might be offset by decreased water availability.

Considerable uncertainty exists with respect to regional-scale impacts of global warming. Much of this uncertainty resides in the differences among the dif-

ferent GCM climate scenarios as illustrated in this study. In addition, models that translate climatic scenarios into projections of ecosystem impacts can always be improved through reexamination and improvement of model processes. Nevertheless, the results of this study underscore the potentially large impact of climate change on California ecosystems and the need for further use and development of dynamic vegetation models using various ensembles of climate change scenarios.

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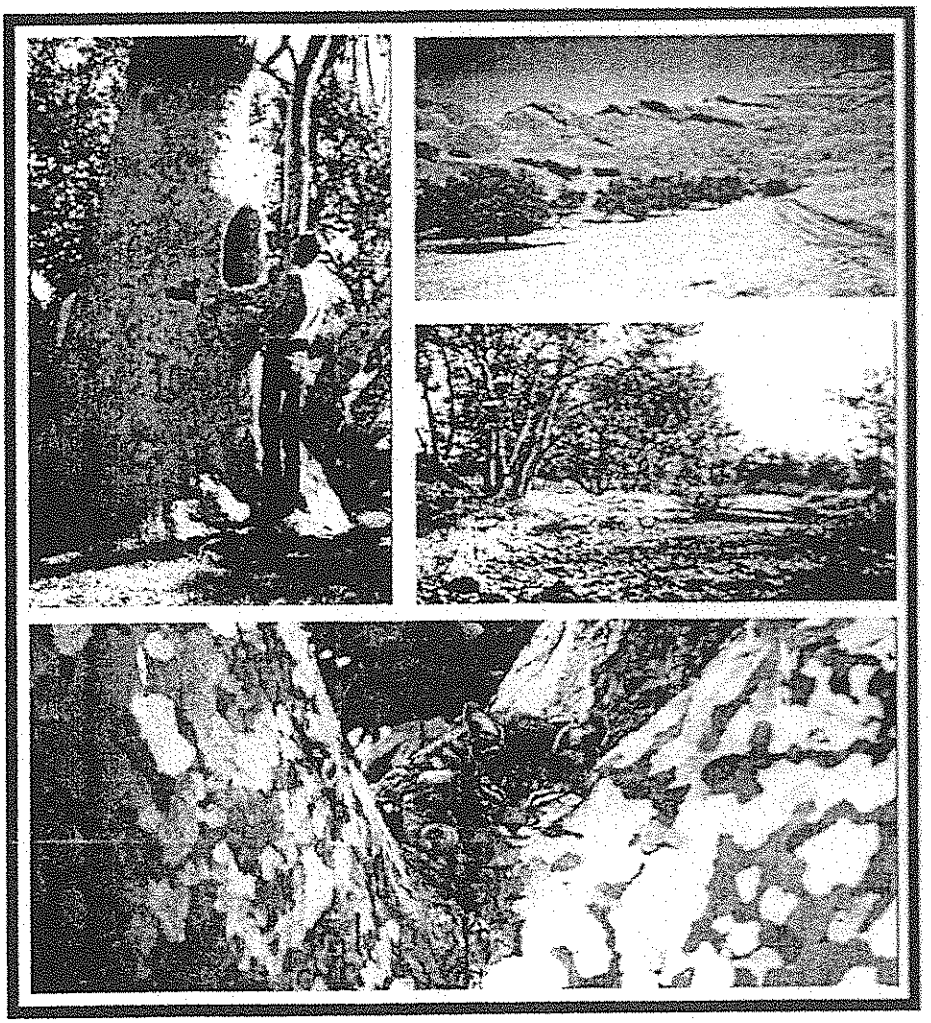
The Definition and Location of Central California Sycamore Alluvial Woodland



Prepared for:
Division of Planning
California Department of Water Resources

Prepared by:
Natural Heritage Division
Bay-Delta and Special Water Projects Division
California Department of Fish and Game

May 1997

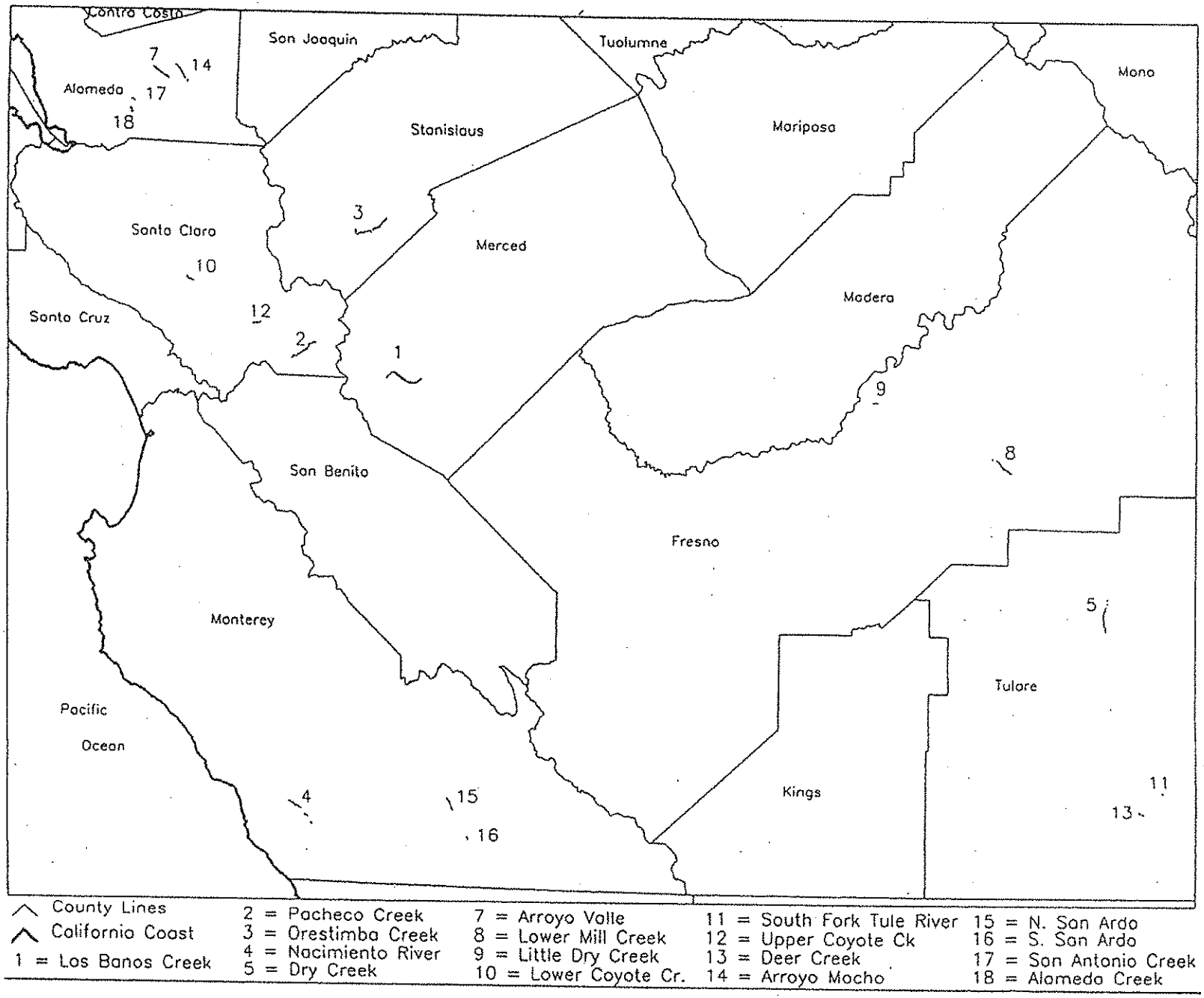


Figure 15. The Distribution of Central California Sycamore Alluvial Woodland

STAND DESCRIPTIONS

The following descriptions cover all 17 stands located and defined in this study. Each is accompanied with a map displaying the extent of the stand as it has been digitized into the NHD GIS system. Acreage totals are listed in Table 6. The stand numbers beside each heading in this section are the same numbers as they are assigned in the NDDB inventory (see also Figure 15). Note there is no occurrence 6. Several sample sites discussed in previous chapters (see table 2) are not included here. This is because they did not meet the quantitative criteria for inclusion as Central California Sycamore Alluvial Woodland or their size was below the minimum mapping unit of 10 acres. A summary of the quantitative sycamore density and age data discussed in the stand descriptions may be found in Table 7.

Table 6. Acreages for Occurrences of Central California Sycamore Alluvial Woodland

Occurrence	Drainage	Acres	N\1.	Access Status\2
1	Los Banos Creek	425.9	13	+
2	Pacheco Creek	135.4	4	0
3	Orestimba Creek	249.0	12	0
4	Nacimiento River	101.3	3	+
5	Dry Creek	211.1	7	0
7	Arroyo Valle	211.2	4	+
8	Lower Mill Creek	229.0	4	+
9	Little Dry Creek	28.6	1	+
10	Coyote Creek	40.1	2	+
11	South Fork Tule River	15.9	1	+
12	Upper Coyote Creek	49.2	2	+
13	Deer Creek	45.2	2	+
14	Arroyo Mocho	87.4	2	+
15	North San Ardo	62.2	0	--
16	South San Ardo	11.4	0	--
17	San Antonio Creek	23.8	2	+
18	Alameda Creek	105.2	3	+
	Total	*2,031.9*		

\1. N represents the number of samples taken within each occurrence
\2. Access status key: '+' = no problems (access with landowner permission to all points selected), '0' = some problems (certain access points unavailable), '--' = access denied (no samples taken)

burned, initiating many resprouts at the bases of surviving stems. The fire was caused by military maneuvers within Fort Hunter Leggett.

Stand 5; Dry Creek, Tulare County

1. Stand Size, Distribution, and Surrounding Environment: The Dry Creek stand covers approximately 211.1 acres (85.5 ha) along over 5 miles of Dry Creek. It extends from the vicinity of Hog Spring Canyon, south and downstream to an area 0.4 mile upstream from the confluence of Dry Creek with the Kaweah River (Figure 24). Approximately 1.4 miles downstream from its sparse and narrow upstream end, the stand becomes continuous, reaching a maximum width of 0.25 mile.

2. Adjacent Vegetation, Topography: Vegetation adjacent to the Dry Creek stand consists largely of annual grassland and blue oak woodland. At the downstream end of the stand, nearby land is also used for growing hay and alfalfa. The sycamores in this stand grow on terraces along single and multi-channeled reaches of Dry Creek. Terraces vary in width from less than 200 ft to almost 1000 ft and rise from 1 to 10 ft above adjacent channels. Most of the stand has a substrate derived from mixed metasedimentary and metavolcanic rocks. Surface composition varies slightly with each transect. Sand comprises the majority of the surface material over most of the lower part of the stand, with rocks comprising more of the surface towards the upper end.

3. Estimated Density and Numbers of Sycamore Stems, Age of Stems, Reproduction: Based upon 7 samples, we estimate that 48,840 sycamore stems over 1 cm in diameter exist in this stand with an average of approximately 5 stems per clump. The average stem diameter for trees exceeding 1 cm in diameter is 38.3 cm and the range of stem diameters is 1.2 to 122.1. The estimated growth rate of average sized trees in the stand is 3.9 rings/cm, and the estimated growth rate of the largest trees in the stand is 3.5 rings/cm. We estimate the number of sucker sprouts to be 33,744 with 3.5 sprouts/clump, on the average. No seedlings or saplings were observed in this stand.

4. Variation in Cover and Association type: All samples within The Dry creek stand were classified by TWINSPAN as part of the interior group with close affiliation to many of the Los Banos, Orestimba, Little Dry, and Mill creeks stands (Figure 25). As with the Mill Creek stand, valley oak was a relatively constant member of the tree layer. Oregon ash, *Fraxinus latifolia*, and red willow also occurred occasionally as small trees. The sycamore-dominated vegetation transcends upstream to the foothill group and downstream, quite abruptly, to Fremont cottonwood-dominated stands associated with permanent surface water near long-established gravel mining operations.

5. Current Impacts to and Condition of Stand: The sycamore trees in this stand are affected to varying degrees by anthracnose and only lightly by lacebugs. Evidence of grazing was apparent at five of the seven transects, and the effects of irrigation overflow were observed at

Figure 24: Dry Creek
Sycamore Alluvial Woodland Stand 5

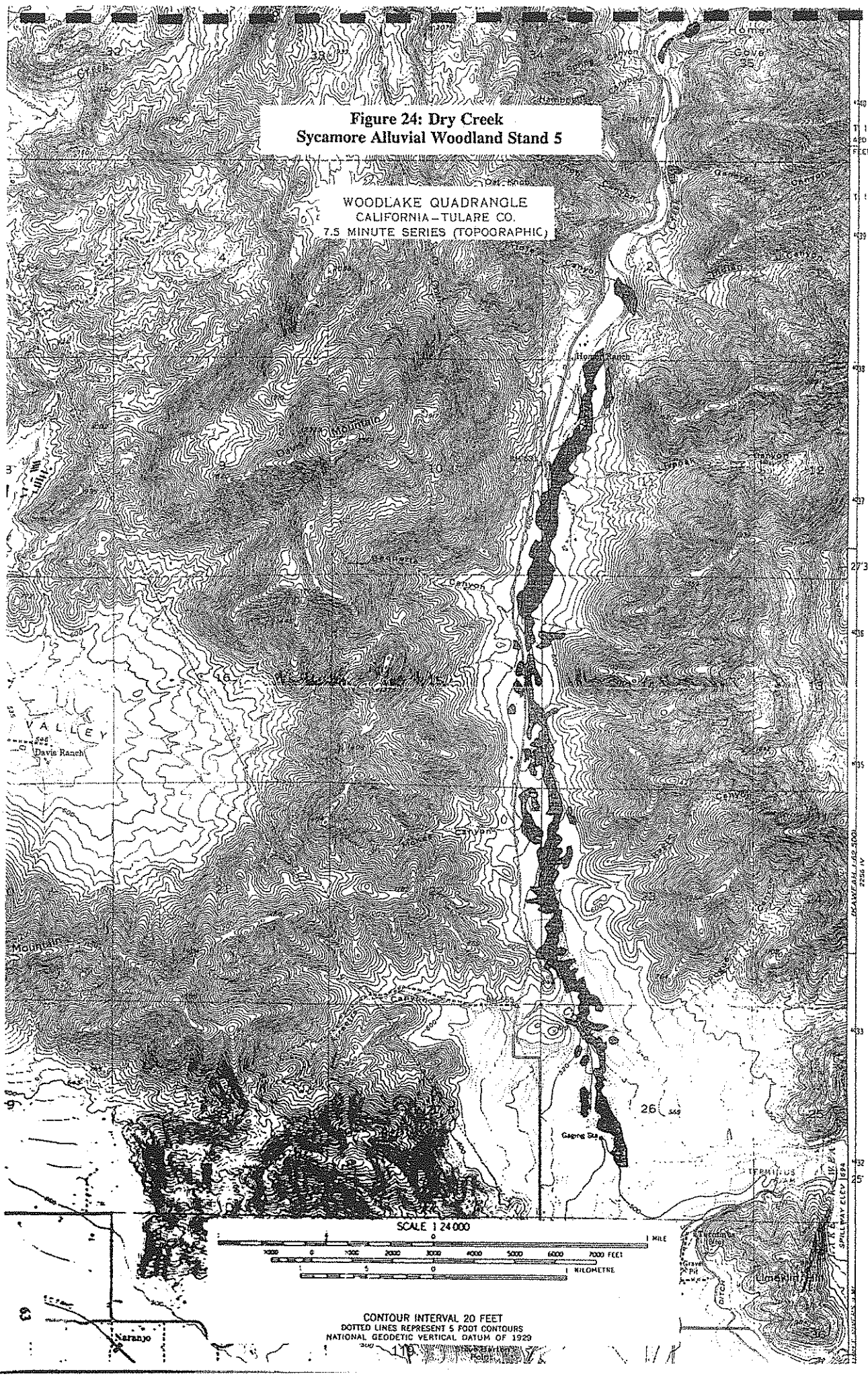


Figure 25. Dry Creek Stand at Transect #L1; Note Figure in Right Distance for Scale.

the downstream end of the stand. Gravel mining was observed to occur within the southern third of the stand. In the past several years gravel mining has increased substantially in the lower portion of the stand. The recent activity has included bulldozing and uprooting many sycamores from an area of approximately 70 acres (Figure 26). Future plans for this area including digging several deep pits up to 90 ft. (G. Presley, pers. comm. 1994, Carol Court pers comm. 1995). These activities likely will affect the upstream portion of the stand through alteration of the water table. Jacobs (1993) discusses how extensive degradation from gravel mining may affect riparian vegetation and water supply wells by inducing a decline in the alluvial water table as the stream banks are effectively drained to a lowered level.

Stand 7; Arroyo Valle, Alameda County

1. Stand Size, Distribution, and Surrounding Environment: The Arroyo Valle stand covers approximately 211.2 acres (85.5 ha) along 3 miles of Arroyo Valle (Figure 27). It extends from Arroyo Road near the Veteran's Administration Hospital downstream to the intersection of Alden Lane and Isabel Avenue. The stand is nearly continuous, with some small open breaks toward the downstream end. Much of the stand is wide, truncating abruptly at both its upstream and downstream ends. The stand ranges from 200 to 1400 ft. in width.

2. Adjacent Vegetation, Topography: Vegetation adjacent to the Arroyo Valle stand consists largely of annual grassland with scattered valley and coast live oak woodland in some areas, and vineyards. The sycamores in this stand grow on terraces along the braided multi-channel of Arroyo Valle. Terraces reach widths of up to 800 ft and rise from 3 to 10 ft above adjacent stream channels. The substrate is derived from non-marine sedimentary alluvium, playa, lake, and terrace deposits. Silt and sand comprise a majority of the surface material, with silt usually contributing a higher percentage. Gravel and rock comprise the remainder.

3. Estimated Density and Numbers of Sycamore Stems, Age of Stems, Reproduction: Based upon four samples, we estimate that 53,010 sycamore stems over 1 cm in diameter exist in this stand with an average of approximately 7 stems per clump. The average stem diameter for trees exceeding 1 cm in diameter is 31.2 cm dbh, and the range of stem diameters is 1.3 to 109.2 cm. The estimated growth rate of average sized trees in the stand is 4.5 rings/cm and the estimated growth rate of the largest trees in the stand is also 4.5 rings/cm. We estimate the number of sucker sprouts in this stand to be 162,450, with 21.1 sprouts per clump on the average. No seedlings or saplings were observed in this stand.

4. Variation in Cover and Association Type: The four samples in the Arroyo Valle stand are classified by TWINSPAN as part of the mid-coastal group (Figure 28). The scattered occurrence of coast live oak in the canopy of particularly the upper portion of the stand, and the scattered occurrence of shrubs such as creek snowberry and poison oak also substantiate the coastal influence in this stand.

of agriculture, primarily orchards and fallow fields. Upstream from the site sycamores become less important, with coast live oak, valley oak, red willow, and California bay increasing in cover (Figure 35). The sycamores in this stand grow on terraces along a single channel at the upstream end of the stand, and on terraces along a braided multichannel at the downstream end of the stand. Terraces supporting this stand are less than 200 ft in width and rise from 1 to 6 ft above adjacent channels. The substrate is derived from sedimentary rock.

Towards the upper end of the stand, the surface is silty, with a few large and medium rocks. Towards the downstream end, sand and gravel comprise a majority of the surface material.

3. Estimated Density and Numbers of Sycamore Stems, Age of Stems, Reproduction: Based upon two samples, we estimate that 7,452 sycamore stems over 1 cm in diameter exist in this stand, with an average of approximately 3 stems per clump. The average stem diameter for trees exceeding 1 cm in diameter is 41.0 cm; the range of stem diameters is 2.1 to 86.8 cm. The estimated growth rate of average sized trees in the stand is 4.4 rings/cm and the estimated growth rate of the largest trees in the stand is 3.2 rings/cm. We estimate the number of sucker sprouts in this stand to be 11,664, with 2.6 sprouts per clump, on the average. No seedlings or saplings were observed in this stand.

4. Variation in Cover and Association Type: Both samples taken in the Lower Coyote Creek stand are classified by TWINSPAN as part of the mid-coastal group, with close affiliation to Arroyo Valle, Pacheco, Alameda, and San Antonio creeks stands. The presence of California bay and coast live oak scattered in the canopy are indicative of this mid-coastal affiliation. Additional occasional trees include red willow, bigleaf maple, *Acer macrophyllum*, valley oak, California black walnut, and gray pine. The understory is variable, but is characterized by a higher shrub cover than many stands. Shrubs include *Symphoricarpos rivularis, Rosa californica, Baccharis pilularis* var. *consanguinea,* and poison oak. Giant reed, *Arundo donax,* is a problem invader in parts of the stand.

5. Current Impacts to, and Condition of Stand: The sycamore trees in this stand are affected severely by anthracnose and some trees in the stand exhibit stem cavities. It appears from the looseness of the soil, the smoothness of grade, and the amount of trash, that the lower portion of this area was previously used as a landfill or gravel pit, and that the area has been refilled and graded. Anderson Reservoir (about 1 mile upstream from the stand) regulates the flow of water to this area of Coyote Creek. In the summer of 1992, the lower portion of this stand was burned. By fall, sprouts of sycamores were already over 18 inches high. A double freeway overcrossing (Hwy 101) traverses the lower portion of the stand and a paved bicycle path borders its entire length.

Stand 11; South Fork Tule River, Tulare County

1. Stand Size, Distribution, and Surrounding Environment: The South Fork Tule River stand

Figure 35. Overview of Lower Coyote Creek Stand from the Top of Anderson Reservoir Dam Looking Northwest up the Santa Clara Valley. Foreground is Dominated by Coast Live Oak, Background Right is Sycamore Stand. Note Numerous Surrounding Land Uses

covers approximately 15.9 acres (6.4 ha), making it the second smallest stand inventoried in this study. It occurs along less than 0.5 mile of the South Fork of the Tule River about 2 miles west of the Tule River Indian Reservation boundary (Figure 36). The stand is continuous and is about 0.12 mile wide at its widest point.

2. Adjacent Vegetation, Topography: Vegetation adjacent to the South Fork Tule River stand consists of annual grassland and valley oak woodland. Riparian vegetation immediately upstream and downstream is dominated by either white alder or Fremont cottonwood (Figure 37). The sycamores in this stand grow on terraces along a braided multi-channeled stretch of the river. Flow along this stretch is intermittent with some late summer pools persisting (these are bordered by young willows and white alders, and in one case by *Typha*). Terraces are 400-ft wide or less and rise from 1 to 6 ft, above adjacent stream channels. The substrate is mostly granitic alluvium derived from the Sierra Nevada Batholith. A large majority of the surface material is sand, with the remainder comprised of rock.

3. Estimated Density and Numbers of Sycamore Stems, Age of Stems, Reproduction: Based upon one sample, we estimate that 3328 sycamore stems over 1 cm in diameter exist in this stand, with an average of approximately 4 stems per clump. The average stem diameter for trees exceeding 1 cm is 32.6 cm and the range of stem diameters is 2.6 to 81.1 cm. The estimated growth rate of average sized trees in the stand is 3.8 rings/cm and the estimated growth rate of the largest trees in the stand is 5.3 ring/cm. We estimate the number of sucker sprouts in this stand to be 11,264, with 14.7 sprouts per clump, on the average. No seedlings or saplings were observed in the stand.

4. Variation in Cover and Association Type: This stand occurs adjacent to intermittently flowing stretches of the South Fork Tule River . *Bromus diandrus* and *Cynodon dactylon* are the most important herbaceous understory species. Buttonwillow is an important shrub in the understory. Sycamores are the only tree present in the sample; however, valley oak is present adjacent to the sample.

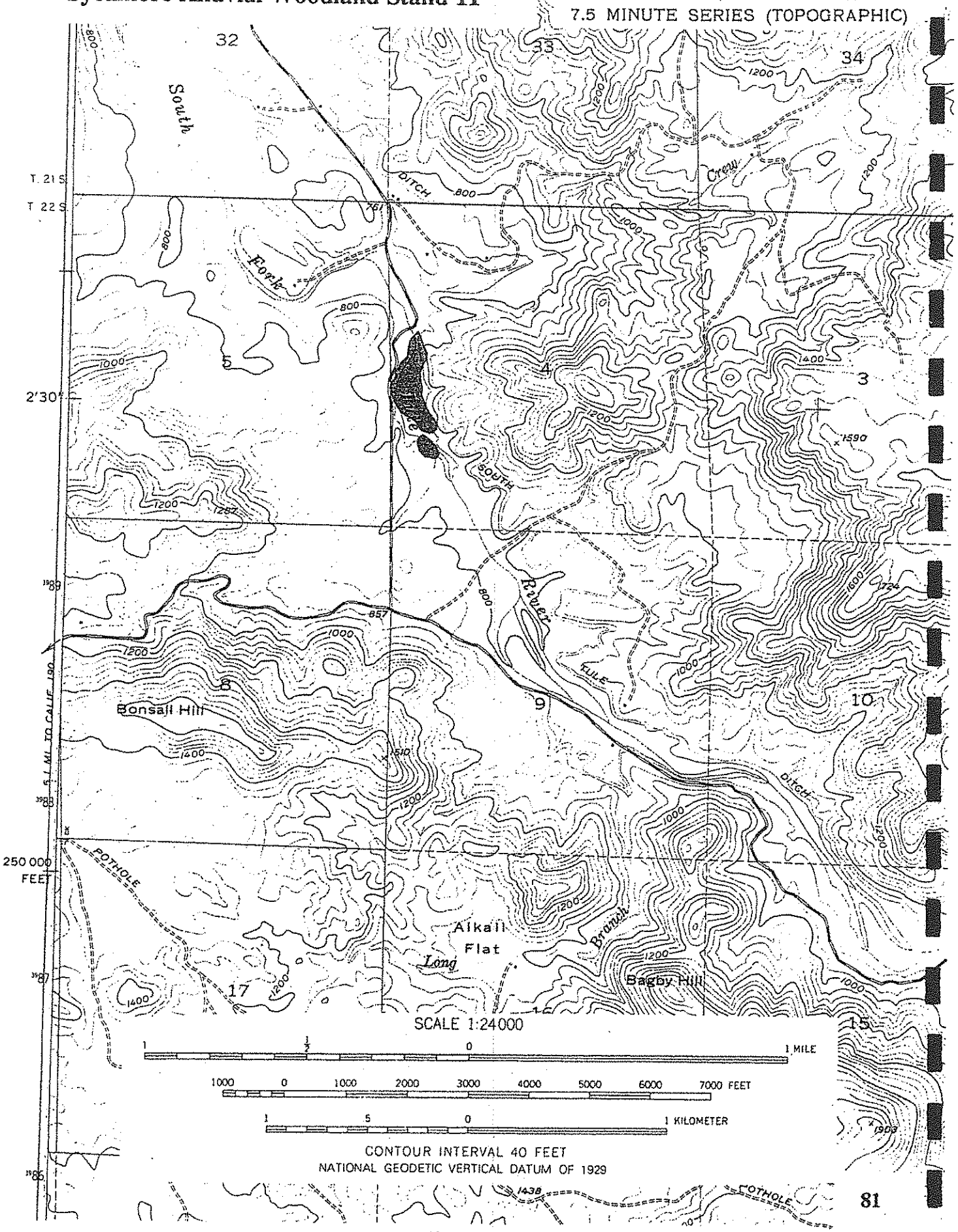
This stand is part of the interior alluvial group. TWINSPAN classifies this stand as a distinct subunit of the sycamore alluvial woodland along with the one of the North Fork Los Banos Creek stands and two of the Dry Creek (Tulare County) stands.

5. Current Impacts to, and Condition of Stand: The sycamore trees in this stand are heavily affected by anthracnose. Although it appears no grazing occurred in 1992, past evidence of grazing is apparent. About 0.25 mile downstream of this stand, the valley is subdivided into ranchettes.

Stand 12; Upper Coyote Creek, Santa Clara County

1. Stand Size, Distribution, and Surrounding Environment: The Upper Coyote Creek stand covers approximately 49.2 acres (19.9 ha) extending for about 1.5 miles upstream from the confluence of Coyote Creek with Bear Creek (Figure 38). Hills rise steeply on the north side

Figure 36: South Fork Tule River Sycamore Alluvial Woodland Stand 11



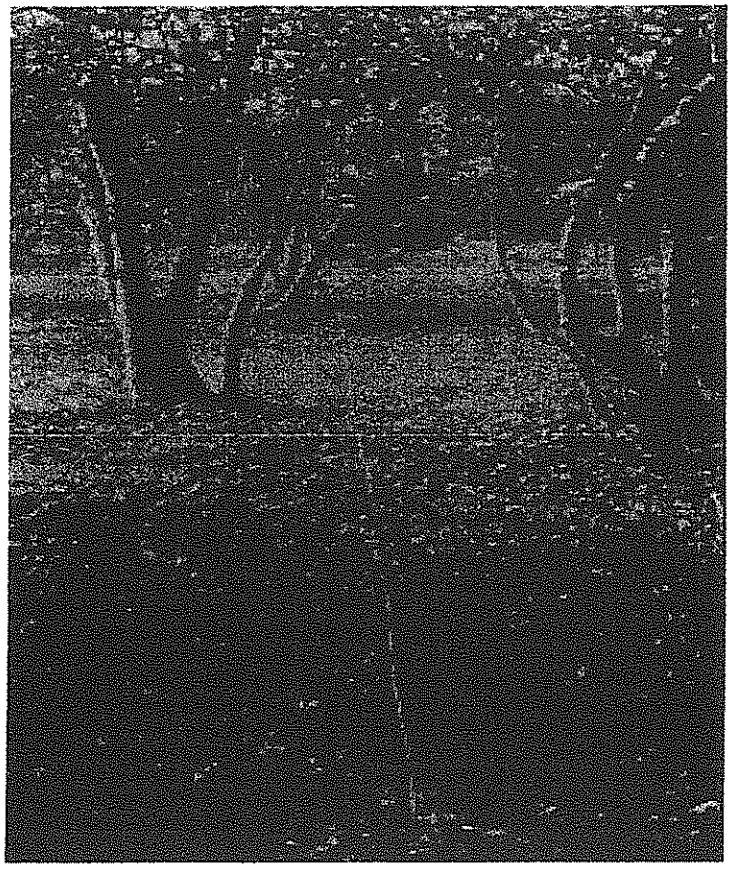


Figure 37. South Fork Tule River Stand.

of the valley bottom stand and are covered with a mixture of coast live oak , blue oak, and gray pine woodland, with patches of Diablan sage scrub (Figure 39). While the downstream end of this stand is fairly continuous, the upstream end is patchy, with some 0.12 mile breaks between patches of sycamore dominance.

2. Adjacent Vegetation, Topography: Vegetation adjacent to the upper Coyote Creek stand consists of coast live oak woodland with small patches of non-native grassland. The sycamores in this stand grow on terraces along this multi-channeled stretch of Upper Coyote Creek. Terraces vary in size, reaching maximum widths of 600 ft and rise from 3 to 10 ft above existing channels. The substrate is derived from Franciscan Formation sedimentary and metasedimentary rocks, including sandstone and shales. Surface composition varies slightly for each transect, with sand comprising the large majority of the surface and silt comprising the remainder.

3. Estimated Density and Numbers of Sycamore Stems, Age of Stems, Reproduction: Based upon two samples, we estimate that 8,358 sycamore stems over 1 cm in diameter exist in the stand, with an average of approximately 5 stems per clump. The average stem diameter for trees exceeding 1 cm is 35.1 cm; the range of stem diameters is 2.0 to 84.6 cm. The estimated growth rate of average sized trees in the stand is 4.2 rings/cm and the estimated growth rate of the largest trees in the stand is 4.5 rings/cm. We estimate the number of sucker sprouts in this stand to be 62,884, with 39.5 sprouts per clump, on the average. No seedlings or saplings were observed in this stand.

4. Variation in Cover and Association Type: Both samples had at least small amounts of coast live oak and one had California bay, in addition. Understory cover was predominantly annual grasses, including *Bromus diandrus* and *B. mollis*, however, each had some woody understory species (Figure 40). One sample had *Symphoricarpos rivularis, Aesculus californica, Ceanothus cuneatus,* and a sapling of Digger pine while another had *Ribes* sp. and *Brickelia californica*.

TWINSPAN classified each sample somewhat differently within the mid-coastal group. The sample with the highest coast live oak cover sorts with Alameda Creek and Lower Coyote Creek stands while the other shows greater affinity for certain Los Banos Creek, Orestimba Creek, Pacheco Creek and Kaweah River stands.

5. Current Impacts to, and Condition of Stand: The sycamore trees in this stand are severely affected by anthracnose and impacts due to grazing range from moderate to heavy. Recent high stream flows resulted in scouring of stream channels and exposure of sycamore root systems.

Stand 13; Deer Creek, Tulare County

1. Stand Size, Distribution, and Surrounding Environment: The Deer Creek stand covers

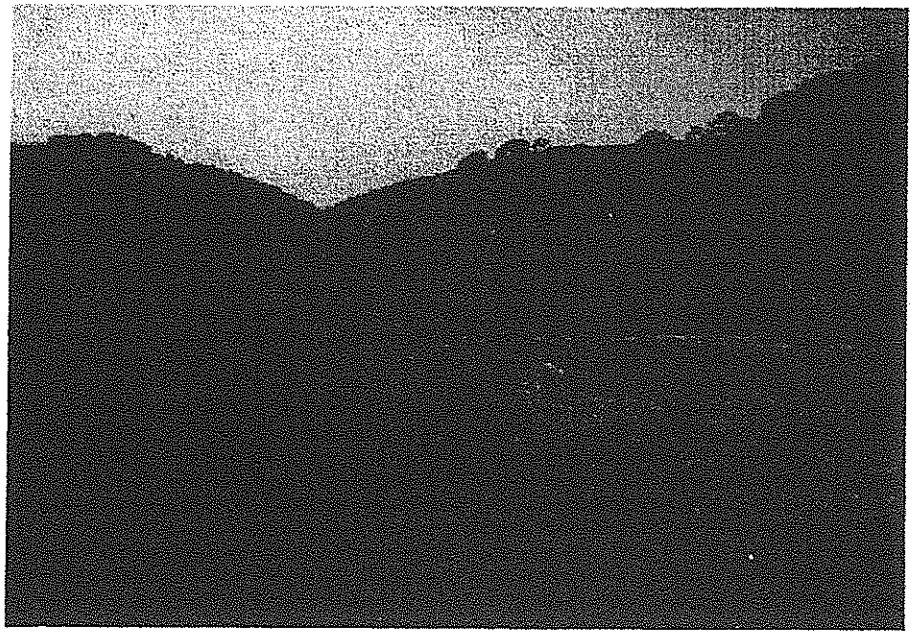


Figure 39. View Looking Northwest of Western Portion of Upper Coyote Creek Stand Showing Surrounding Hills with Coast Live Oak and Blue Oak Woodland.

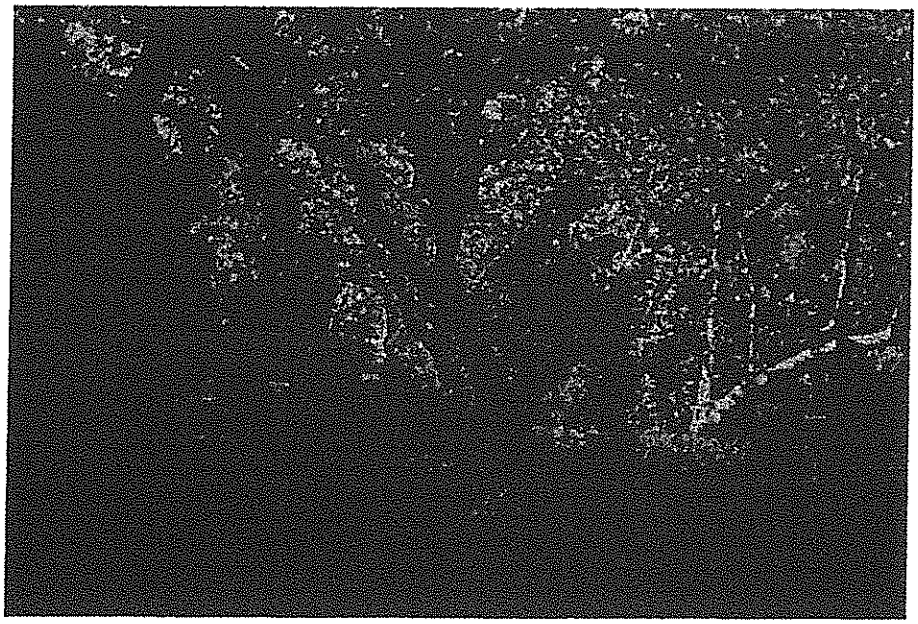


Figure 40. Interior View of Upper Coyote Creek Stand with Typically Dense Canopy of Sycamores and Coast Live Oak with Patches of the Shrub *Symphoricarpos rivularis* in the Understory.

approximately 45.2 acres (18.3 ha) scattered along about 1 mile of Deer Creek east of Road 298 in Tulare County (Figure 41). This stand consists of two patches on high terraces on opposite sides of the stream channel, separated by about 0.33 mile of annual grassland and sparse willow and cottonwood riparian along the active channel. The stand occupies a portion of a broad valley just below where Deer Creek debauches from a narrower valley in the southern Sierra foothills.

2. Adjacent Vegetation, Topography: Vegetation adjacent to the Deer Creek stand consists of blue oak woodland and annual grassland. Low foothills covered with non-native grassland and open blue oak woodland occur several hundred yards away from the stand. The sycamore trees in this stand grow on terraces along single and multi-channeled Deer Creek. Terraces are from 400 to over 1000 ft wide and rise from 3 to 20 ft above adjacent stream channels. The substrate is largely granitic alluvium derived from the Sierra Nevada Batholith. The surface material consists mostly of sand, with the remainder comprised of silt, gravel, and rock.

3. Estimated Density and Numbers of Sycamore Stems, Age of Stems, Reproduction: Based upon two samples, we estimate that 33,294 sycamore stems over 1 cm in diameter exist in this stand with an average of approximately 5 stems per clump. The average stem diameter for trees exceeding 1 cm is 37.3 cm and the range of diameters is 1.3 to 98.2. The estimated growth rate of average sized trees in the stand is 2.3 rings/cm and the estimated growth rate of the largest trees in the stand is 2.6 rings/cm. We estimate the number of sucker sprouts to be 1,830, with 2.5 sprouts per clump. No seedlings or saplings were observed in this stand.

4. Variation in Cover and Association Type: TWINSPAN classifies both samples as closely related to one another in the same division as Little Dry Creek, and the majority of the Pacheco Creek sites and half of the Arroyo Valle sites. Species diversity at both sites is low with only 5 and 13 understory species tallied (Figure 42). One site had a relatively high percentage of red willow in the tree layer. Dominant understory species were annual grasses.

5. Current Impacts to, and Condition of Stand: Anthracnose affects the sycamore trees in this stand only slightly and in some cases not at all. The sycamores are affected lightly to moderately by lacebugs. Grazing impact varies from light to heavy, with plant species in the area indicating a history of heavy, grazing. Access roads to corrals and ranch outbuildings were present adjacent to the stands.

The height of the terraces, particularly on the north side of the creek, suggests that downcutting of Deer Creek has been substantial over the past several decades. Although no dam exists upstream, probability of natural flooding regimes initiating sycamore regeneration cycles in the Deer Creek stand is slight.

Stand 14; Arroyo Mocho, Alameda County

1. Stand Size, Distribution, and Surrounding Environment: The Arroyo Mocho stand covers

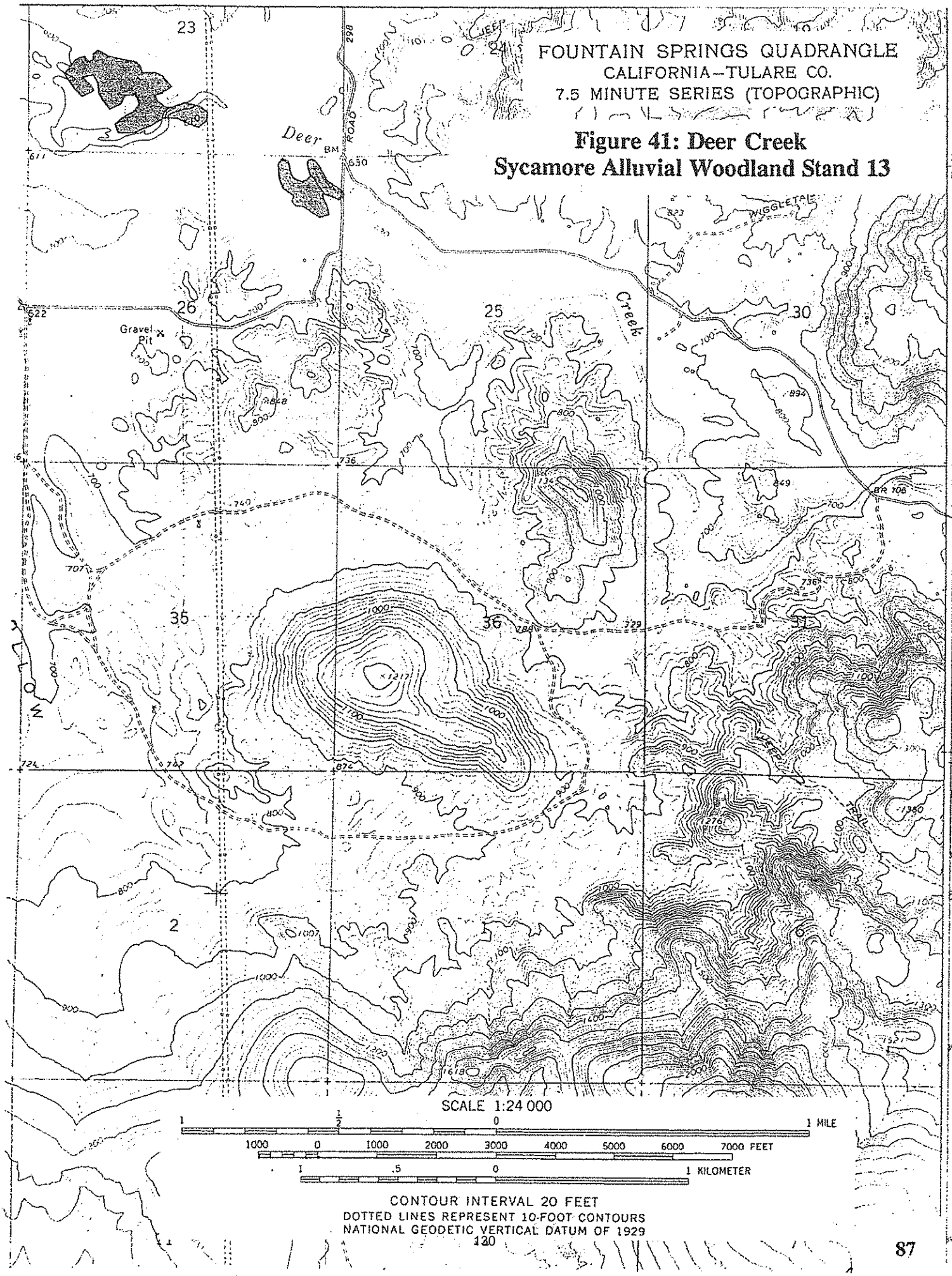


Figure 41: Deer Creek Sycamore Alluvial Woodland Stand 13

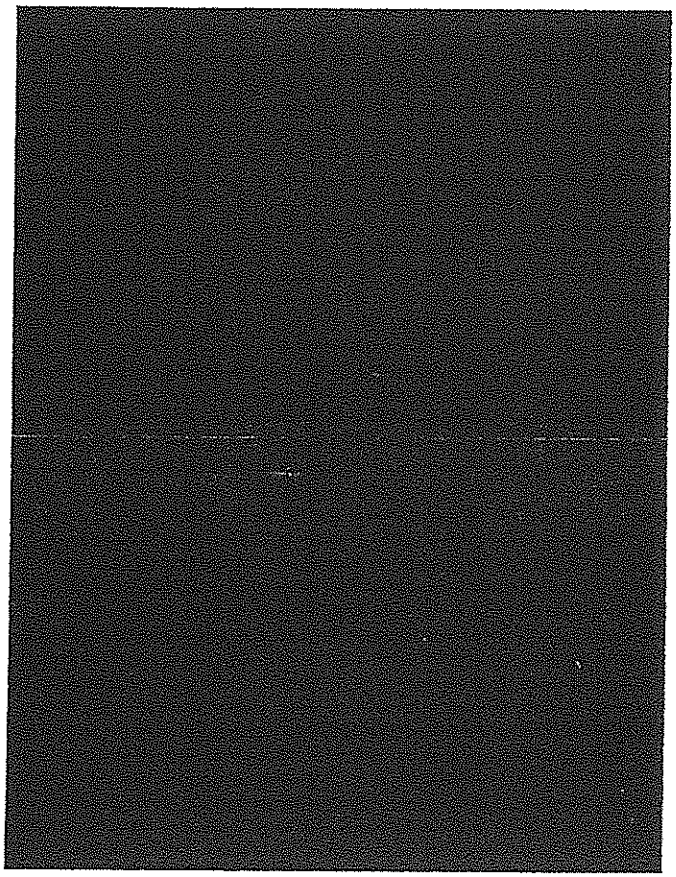


Figure 42. Vegetation Sampling in the Understory in the Open Woodland of the Eastern Portion of the Deer Creek Stand.

6. Different fire–climate relationships on forested and non-forested landscapes in the Sierra Nevada ecoregion (International Journal of Wildland Fire 2015).

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Different fire–climate relationships on forested and non-forested landscapes in the Sierra Nevada ecoregion

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Abstract. In the California Sierra Nevada region, increased fire activity over the last 50 years has only occurred in the higher-elevation forests on US Forest Service (USFS) lands, and is not characteristic of the lower-elevation grasslands, woodlands and shrublands on state responsibility lands (Cal Fire). Increased fire activity on USFS lands was correlated with warmer and drier springs. Although this is consistent with recent global warming, we found an equally strong relationship between fire activity and climate in the first half of the 20th century. At lower elevations, warmer and drier conditions were not strongly tied to fire activity over the last 90 years, although prior-year precipitation was significant. It is hypothesised that the fire–climate relationship in forests is determined by climatic effects on spring and summer fuel moisture, with hotter and drier springs leading to a longer fire season and more extensive burning. In contrast, future fire activity in the foothills may be more dependent on rainfall patterns and their effect on the herbaceous fuel load. We predict spring and summer warming will have a significant impact on future fire regimes, primarily in higher-elevation forests. Lower elevation ecosystems are likely to be affected as much by global changes that directly involve land-use patterns as by climate change.

Additional keywords: area burned, chaparral, climate change, non-forested ecosystems, spring temperature, snow pack.

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Introduction

Wildfire activity and fire severity have increased in many western USA forests over the past several decades, and these changes are widely attributed to a combination of climate change and past fire suppression (McKenzie *et al.* 2004; Westerling *et al.* 2006; Littell *et al.* 2009; Miller *et al.* 2009). However, despite the generalisations that fire activity is increasing across the western US, these patterns are not universal and some non-forested landscapes have not experienced recent increases in fire activity (Baker 2013). As the bulk of the western USA landscape comprises non-forested ecosystems, and the relationship between climate and fire activity has not been as thoroughly studied for these ecosystems, we investigated temporal patterns of fire activity on forested and non-forested landscapes and the role of annual variation in seasonal temperatures and precipitation.

Historical relationships between fire and climate are one of the few tools we have for understanding future climate change impacts on fire regimes (McKenzie *et al.* 2004; Safford *et al.* 2012). Western landscapes are highly heterogeneous with varying histories of human impacts (Parisien *et al.* 2012) and with very different fire–climate relationships from one region to the next (McKenzie *et al.* 2004; Gedalof *et al.* 2005; Collins *et al.* 2006; Littell *et al.* 2009); thus, one way to parse out climate from other influences is by narrowing the focus to a single region. The Sierra Nevada ecoregion is a good focal point because of its immense importance to California water supply, recreation, forestry and ecosystem conservation (SNEP 1996). This region represents many of the issues in understanding future fire regimes as it includes both high-elevation coniferous forests and low-elevation mixed vegetation on landscapes more heavily influenced by human interference. More importantly, a greater proportion of California burns annually than other parts of North America (Stephens 2005; Keeley *et al.* 2009), and the state has a very long, well-documented fire history for both forested and non-forested landscapes (see Methods).

Here, we examine a 101-year fire record on US Forest Service (USFS) lands and a 92-year record on California Department of Forestry and Fire Protection (Cal Fire) lands in the Sierra Nevada mountains, foothills and adjacent valleys (Fig. 1) for long-term trends in area burned and the relationship between annual fire activity and seasonal climate.

Methods

To stay within a climatically homogeneous area, we restricted our analysis to National Oceanographic and Atmospheric

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Fig. 1. California's Sierra Nevada National Oceanographic and Atmospheric Administration (NOAA) climate Division 5 with Cal Fire lands (brown) and US Forest Service (FS) lands (green) indicated. A portion of Cal Fire lands is distributed on the western sides of counties that fall outside of the Sierra Nevada ecoregion. The historical fire database does not allow these lands to be separated out; however, they represent a minor portion of Cal Fire fire activity and are climatically very similar to the eastern portion of these counties (see Abatzoglou *et al.* 2009).

Administration's (NOAA's) National Climatic Data Center (NCDC) California Climate Division 5 (http://www.ncdc.noaa.gov/temp-and-precip/time-series/index.php?parameter=pdsi&month=1&year=2008&filter=p12&state=4&div=5, verified 6 November 2014). This did not include the far northern portion of what is often included in the Sierra Nevada Mountains. California Climate Division 5 has been discussed more fully by Abatzoglou *et al.* (2009), who noted very strong correlations between low- and moderate-elevation sites; however, winter temperatures in the valleys were markedly affected by persistent winter inversion layers. As described in more detail below, we have accounted for these differences by using separate PRISM data for the montane USFS lands and the valley and foothill Cal Fire landscapes. The USFS and Cal Fire lands used in this study are illustrated in Fig. 1. This landscape comprises more than 3 million ha of largely coniferous forested USFS lands (average elevation 2200 m) and approximately equivalent-size lower-elevation (average 500 m) Cal Fire lands of grasslands, shrublands and woodlands (Fig. 2*a* and *b*).

Fire history data were obtained from two sources: (1) USFS fire data covered five national forests (north to south: Eldorado, Stanislaus, Sierra, Inyo–Mono and Sequoia) and included largely mid-elevation forested landscapes for the years 1910–2010. Annual data on numbers of fires by cause and area burned are published and available in research libraries and are spatially explicit at the level of the forest. Over the period of record, national forest area ranged from 2.4 to 3.0 million ha. (2) Cal Fire data covered direct protection areas (DPA), which are mostly state responsibility lands with small amounts of federal lands, and included eight counties with complete coverage from 1919 to 2010 (from north to south: El Dorado, Amador, Calaveras, Tuolumne, Mariposa, Madera, Fresno and Tulare). Counties that began record-keeping after 1919, and not used for the time-course analysis (discussed below) but included in the fire–climate analysis, were San Joaquin, Stanislaus, Merced, Kings, Inyo, Kern and Mono counties. Over the period of record, DPA ranged from 1.7 to 4.4 million ha. Data from 1931 to 2010 are available in the annually published *Redbook* series (available at http://www.fire.ca.gov/fire_protection/fire_protection_fire_info_redbooks.php, verified 6 November 2014), but data from 1919 to 1930 are unpublished and only available at the California State Archives in Sacramento. For each year, area burned and fire frequency were normalised to the land area protected by USFS and by Cal Fire.

Despite informal discussions that early fire records are unreliable, serious study of fire histories in California does not support that idea (Clar 1959; Cermak 2005, but cf. Stephens 2005), and personal studies of fire records in the State Library and State Archives suggest a level of thoroughness not unlike contemporary fire record-keeping. We believe there is a strong case that statistics on area burned are highly reliable throughout the period of record. As presented below, the peak in area burned on both USFS and Cal Fire lands was in the 1920s decade, which would not be consistent with the hypothesis of early records failing to record fire events adequately. Data on numbers of ignitions, particularly of lightning ignitions in remote locations, are potentially underestimated in the early part of the record owing to difficulties of detection. We estimate this potential error was ~1% on Cal Fire lands and 12% on USFS lands, based on the percentage of fires due to lightning in the first two decades compared with the last two decades of record.

To characterise the differences between USFS and Cal Fire lands, elevation, vegetation type and housing density were estimated by overlaying 500 random sample points on USFS and Cal Fire lands, then extracting and summarising spatial data for those points. Source of geographic information system (GIS) data included: National Elevation Dataset of the USGS (30 m, http://ned.usgs.gov/, verified 8 June 2014), CALVEG existing vegetation maps (http://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5365219, verified 8 June 2014), and housing density from the year 2000 within census partial block groups (Hammer *et al.* 2004).

To evaluate climate impact on fire activity, we utilised PRISM climate for the USFS lands and the Cal Fire lands (Fig. 1). For every year in the analysis, we extracted 2.5-arc-minute PRISM data (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, 2014) for areas within the boundaries of the Cal Fire and USFS regions. For each region and year, we computed area-weighted averages of monthly mean precipitation and temperature.

Snow-pack data extending back in time to cover a substantial part of our fire record were not widely available within the elevation zone prone to fires. The longest record close to the

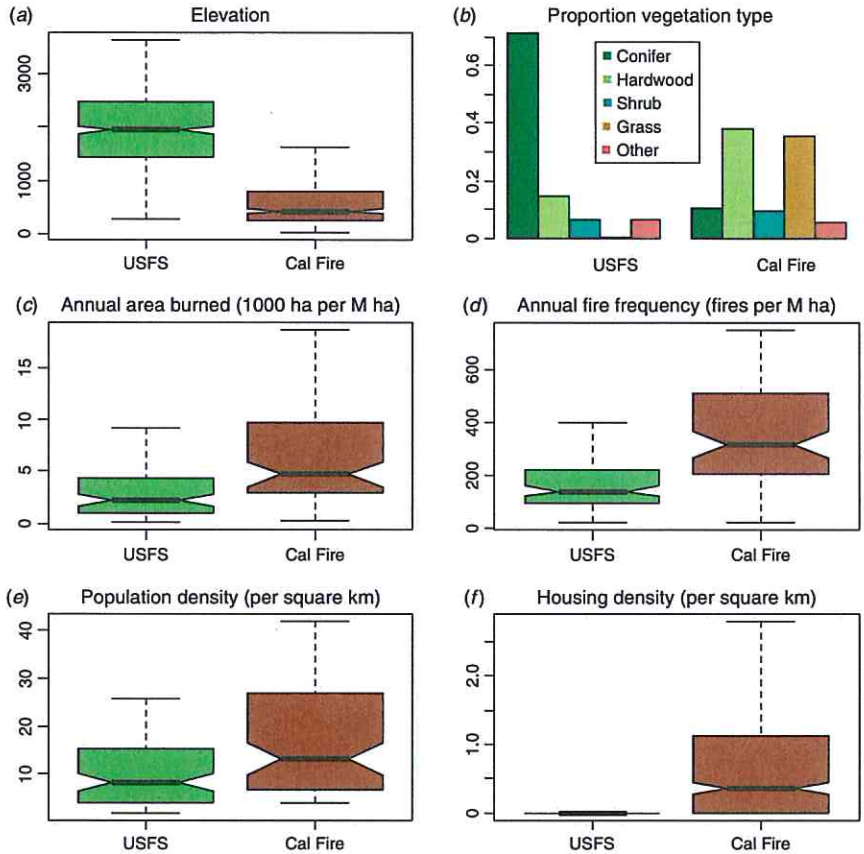

Fig. 2. Characteristics of US Forest Service (FS) and Cal Fire lands and fire statistics: (*a*) mean elevation; (*b*) major vegetation types; (*c*) average annual area burned over the period of record, per million ha protected; (*d*) average fire frequency per million ha protected; (*e*) population density; and (*f*) housing density. Box plots show the median, the first and third quartiles, and the 95% confidence interval of the median.

mean elevation of US Forest Service lands included here was from Giant Forest at 1950 m in Sequoia National Park (http://www.wrcc.dri.edu/for), latitudinally approximately mid-way in the study region (http://www.wrcc.dri.edu/).

Bivariate regressions were conducted with *Systat 11.0* software (http://www.systat.com/). We developed multiple regression models explaining area burned for USFS and Cal Fire based on seasonal temperature, precipitation and prior-season precipitation variables. We considered all possible combinations of the predictor variables and used Akaike information criterion (AICc) to rank and select the best-supported models for each region using package *MuMIn* in R (Burnham and Anderson 2002; R Development Core Team 2012). To ensure multicollinearity would not be an issue, we calculated correlation coefficients among all potential explanatory variables. No variables were correlated ($R < 0.5$), so all were considered in the analysis. Because Cal Fire lands comprised a mosaic of grasslands, shrublands, and woodlands and forests (Fig. 2*b*), and the database presented data by vegetation type, we determined models separately for these three vegetation types.

Results

Over the period of record, there were substantially more fires and more area burned on Cal Fire lands than on USFS lands (Fig. 2*c*, *d*). Direct human impacts were potentially greater on Cal Fire landscapes as population density and housing density were greater (Fig. 2*e*, *f*). This impact is also reflected in the proportion of fires ignited by humans: on Cal Fire lands, humans accounted for 97% of all fires early (1920s decade) and late in the record (2000 decade), whereas on USFS lands, humans accounted for 62% and 50% respectively. Most USFS lands were coniferous forests (Fig. 2*a*) whereas the Cal Fire landscape comprised a mosaic (Fig. 2*b*). Throughout the period of record, grasslands and shrublands were the vegetation types in which the bulk of area was burned (Fig. 3).

Historical trends

On USFS lands, total area burned peaked in the 1920s and declined over subsequent decades until the latter part of the 20th century when fire activity began to increase (Fig. 4*a*). Cal Fire lands likewise showed a peak in area burned in the 1920s but this

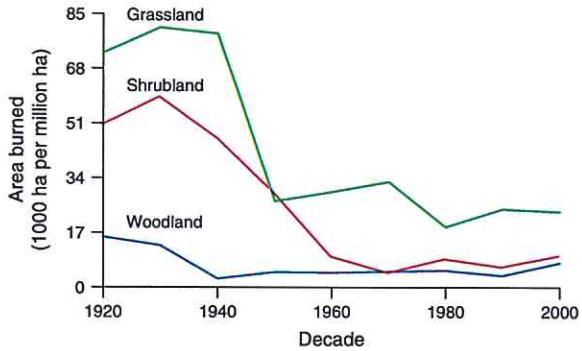

Fig. 3. Decadal burning by vegetation type on Cal Fire lands over the 90 years of record.

declined to a generally constant level of burning over the past half-century, and no subsequent increase in recent decades has been detected (Fig. 4*b*).

Very little of the variation in annual area burned is correlated with patterns of ignitions. Both landscapes had the fewest ignitions in the 1920s (Fig. 5) when the highest area burned on both USFS and Cal Fire lands. There was a highly significant increase in ignitions up through the 1980s and then a highly significant decline in the last couple of decades. Over the period of record, humans were the dominant ignition source (95%) on Cal Fire lands, whereas lightning ignitions were slightly higher (54%) on USFS lands. The decline in ignitions on USFS lands in the last two decades is due to a drop in both human-ignited and lightning-ignited fires; comparing the last two decades with the 1970s and 1980s, there was a 38% drop in human-ignited and 47% drop in lightning-ignited fires.

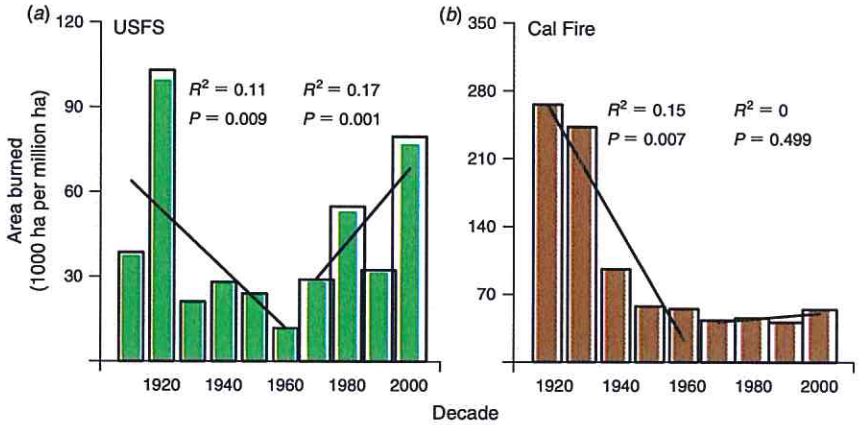

Fig. 4. (*a*) One hundred years of burning in the six US Forest Service (FS) forests of the Sierra Nevada (green bars) based on hectares protected. Because trends changed over time, regression lines are for decades 1910–50 and 1960–2000; and (*b*) 90 years of burning on lands protected by Cal Fire (brown bars) in Sierra Nevada counties with complete data for the years 1920–2009; regression lines are for decades 1920–50 and 1960–2000.

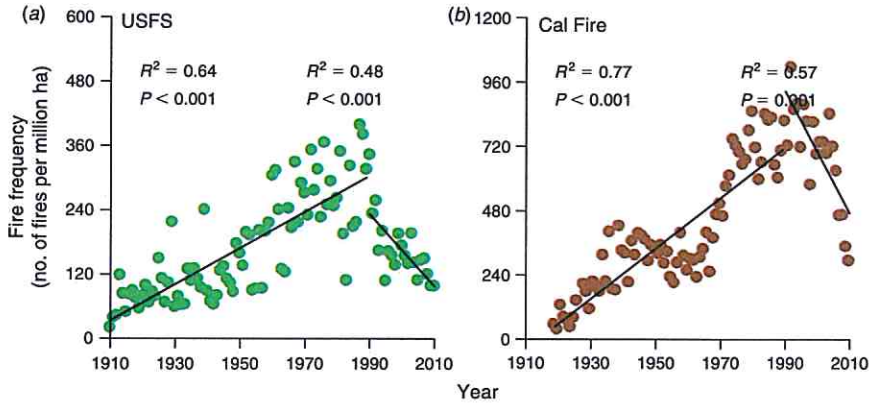

Fig. 5. Annual fire frequency for (*a*) US Forest Service (FS) data from 1910 to 2010; and (*b*) Cal Fire in counties with complete data for the years 1919–2010. Regression lines are for years 1910 or 1919 to 1989 and 1990 to 2010.

Annual fire–climate relationships

For all of these analyses, we compared annual fire activity with both seasonal climate parameters as well as monthly parameters. The monthly analysis provided results comparable with seasonal data, although R^2 values were in most cases higher than those for individual months. Thus, the presentation here will focus on fire response to seasonal patterns of temperature and precipitation.

On USFS lands, spring and summer temperatures over the past 101 years of record exhibited a highly significant positive relationship with annual area burned (Fig. 6). Neither winter nor autumn temperatures were correlated with area burned. On Cal Fire lands, area burned was only weakly related to spring temperature and exhibited no significant relationship with winter, summer or autumn temperature (Fig. 7).

Patterns of seasonal precipitation pretty much mirrored temperature effects on fire activity. On USFS lands (Fig. 8), annual area burned was most strongly tied to spring precipitation, and winter precipitation, which comprises the bulk of the annual rainfall, was only weakly related to area burned. In contrast, area burned on Cal Fire lands showed no relationship with seasonal precipitation (Fig. 9).

As spring temperature and precipitation were most strongly tied to fire activity in the higher USFS landscapes, it was hypothesised that area burned would be correlated with spring snowpack. This proved to be the case (Fig. 10*a*), and not surprisingly, fire activity in the lower-elevation Cal Fire lands was not related to spring snow pack in the higher elevations (Fig. 10*b*). The spring snow pack level was best predicted by the model: April snow depth = 1.08 (winter precipitation (ppt)) − 174 (mean winter temp) − 194 (mean spring temp); adjusted $R^2 = 0.46$, $P < 0.001$ (these independent variables were not significantly correlated at $P > 0.05$ with each other).

We investigated the consistency of the fire–climate relationship throughout the 100-year history with multiple regression models for the first half of the fire record and compared those with the second half of the record. On USFS lands during the first half of the 20th century, winter, spring and summer precipitation were the important determinants of area burned (Table 1). However, in the second half up to the present, summer temperature became a significant predictor, along with spring precipitation, of fire activity and during this most recent era, the model explained over half the variation in annual area burned. Consistent with these temporal switches in fire–climate relationships, on a monthly basis the highest R^2 was for March precipitation during the first 50 years and mean June temperature in the last 51 years.

Because Cal Fire lands comprise a mosaic of grasslands, shrublands and woodlands (including a small amount of conifer forest), we calculated models collectively for all Cal Fire

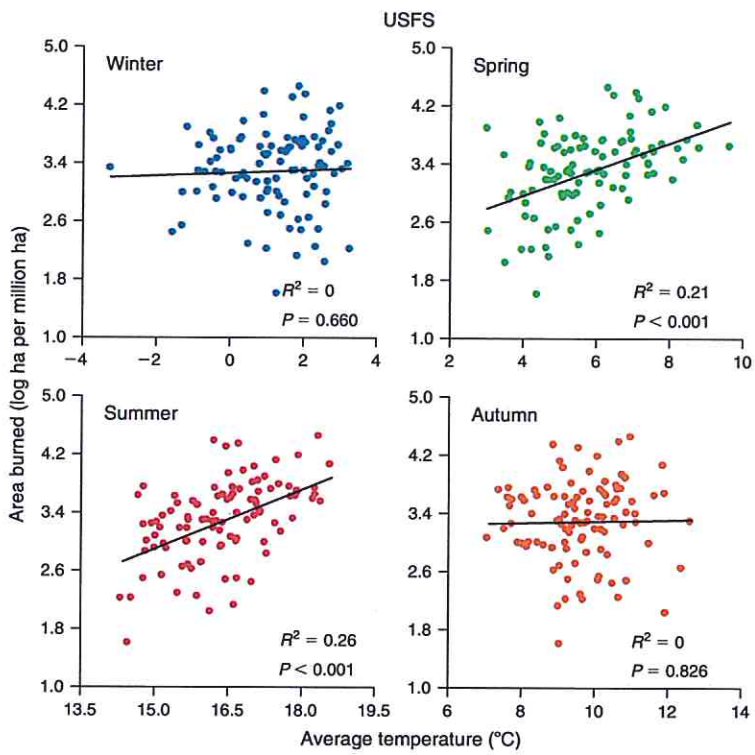

Fig. 6. Relationship of mean seasonal temperature and area burned for US Forest Service (FS) (1910–2010) lands; winter = Dec–Feb; spring = Mar–May; summer = Jun–Aug; autumn = Sep–Nov.

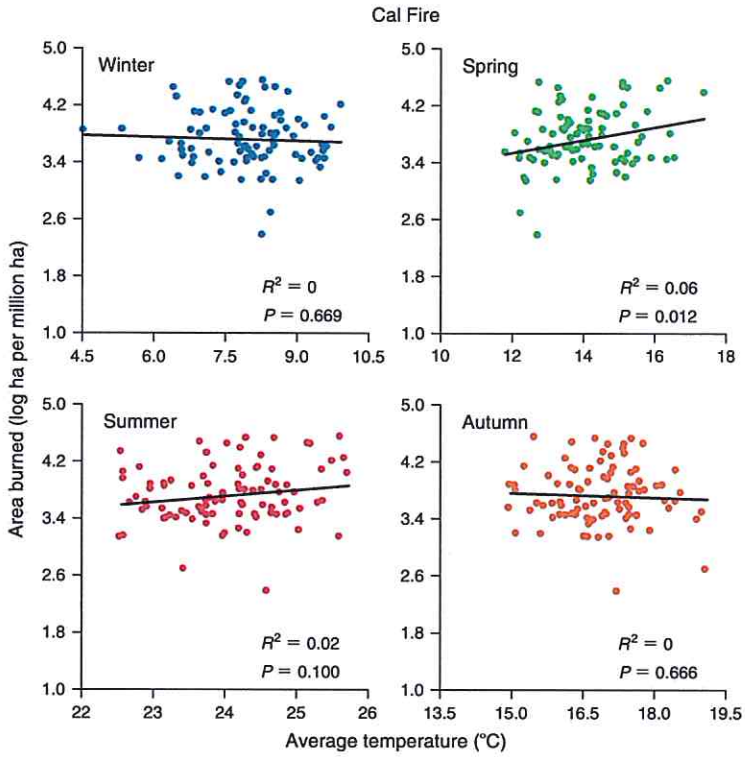

Fig. 7. Relationship of mean seasonal temperature and area burned for Cal Fire (1919–2010) lands.

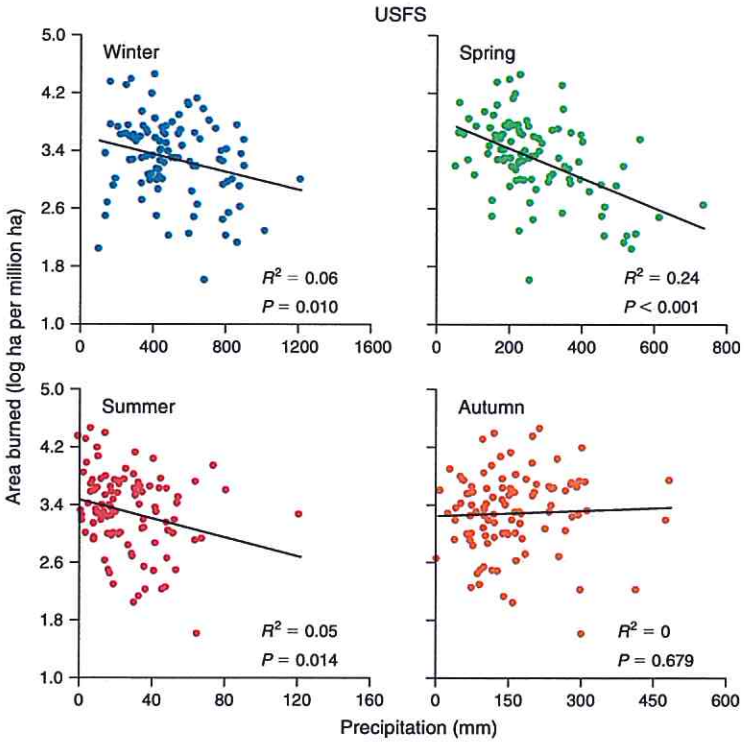

Fig. 8. Relationship of total seasonal precipitation and area burned for US Forest Service (FS) (1910–2010) lands.

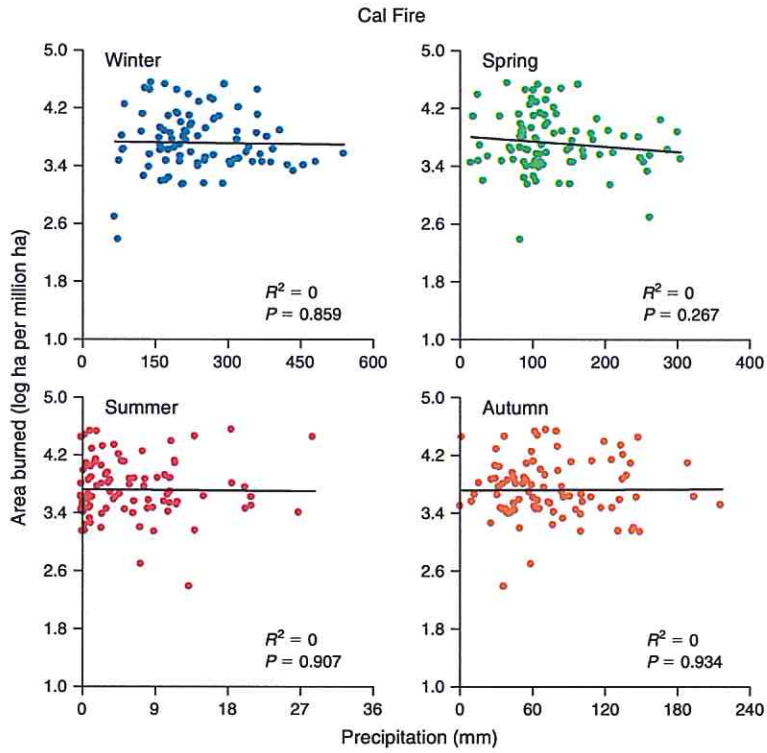

Fig. 9. Relationship of total seasonal precipitation and area burned for Cal Fire (1919–2010) lands.

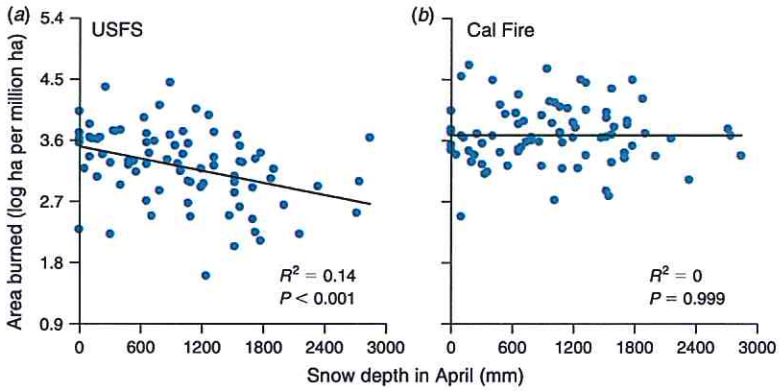

Fig. 10. Snow pack depth (mm) at Giant Forest (Sequoia National Park) for years 1930–2010 *v.* area burned on (*a*) US Forest Service (FS); and (*b*) Cal Fire lands.

landscapes, and separately by vegetation type (Table 1). The most obvious difference with USFS lands is that climate during the fire year has not been as important in determining fire activity as the level of precipitation in the year before fire activity. For total area burned, the prior year spring precipitation was an important determinant of fire activity in both the first half and second half of the records. It is of some interest that far less of the annual variation is explained by climate parameters in the last 50 years than in the first part of the record.

Discussion

20th-Century trends in fires

In this region over the past century, the peak fire activity in both the montane forests (USFS) and the lower foothills and valleys (Cal Fire) was during the 1920s decade (Fig. 4) and this 1920s peak is mirrored on USFS lands throughout the western US (Littell *et al.* 2009). Although limited fire suppression effectiveness in the early 20th century may be a factor, it is not the

Table 1. Akaike information criterion regression models of climate variables on area burned (temperatures are the seasonal mean and precipitation (ppt) the seasonal total)

	Adjusted R^2	P
US Forest Service 1910–59		
Log(ha burned) = −0.002(spring ppt) − 0.0008(winter ppt)	0.41	<0.001
US Forest Service 1960–2010		
Log(ha burned) = 0.317(summer temp) − 0.001(spring ppt)	0.53	<0.001
Cal Fire 1919–59		
Log(ha burned) = 0.002(prior year spring ppt) + 0.07(spring temp) + 0.023(summer ppt) + 0.003(autumn ppt)	0.34	<0.001
Log(grassland ha burned) = 0.002(prior year spring ppt) + 0.028(summer ppt) + 0.003(autumn ppt)	0.24	0.005
Log(shrubland ha burned) = 0.002(prior year spring ppt) + 0.023(summer ppt) + 0.003(autumn ppt) + 0.07(spring temp)	0.34	<0.001
Log(woodland ha burned) = −0.002(prior year winter ppt) − 0.003(spring ppt) + 0.021(summer ppt)	0.23	0.008
Cal Fire 1960–2010		
Log(ha burned) = 0.001(prior year spring ppt) + 0.001(prior year winter ppt) + 0.002(summer temp)	0.27	0.005

whole answer as much less area burned during the first decade of record from 1910 to 1919 in California (Fig. 4*a*), and throughout the western USA (Littell *et al.* 2009), when presumably fire suppression capabilities were as limited if not more so than in the 1920s. In Sierra Nevada USFS forests, our models for the first half of the 20th century (Table 1) support the idea that this 1920s peak may have been attributable in large part to climate; however, climate was not a strong factor in the lower-elevation Cal Fire landscapes. Human factors also may have contributed to the peak of fire activity in the 1920s as this was an era of rapid road building that brought an order of magnitude increase in automobile use and human wildfire ignitions in rural and mountainous landscapes (Keeley and Fotheringham 2003).

In the decades after the 1920s, area burned on forested and non-forested lands in the region declined markedly and a major factor was better equipped and organised fire suppression (Cermak 2005). However, in recent decades, the trajectories of area burned on these two landscapes have been divergent (Fig. 4). On USFS lands beginning in the latter quarter of the 20th century, area burned has increased steadily (Fig. 4*a*) whereas on the lower-elevation Cal Fire landscapes, there has not been a late-20th-century–early-21st-century increase in fire activity (Fig. 4*b*). This observation is important because it illustrates that the often-observed increase in area burned in recent decades in the western USA landscape (Westerling *et al.* 2006; Miller *et al.* 2009; Littell *et al.* 2009) is apparently a reflection of the fact that most studies have focussed on higher-elevation forested ecosystems and not on lower-elevation non-forested landscapes. In short, area burned has not increased in recent decades on all landscapes throughout the west (e.g. Baker 2013).

The historical pattern of ignitions (Fig. 5) does not seem to be an obvious explanation for these burning patterns. The 20th-century rise in ignitions on both landscapes (Fig. 5) is hypothesised to be largely the result of human population growth, although there was a substantial increase in lightning-ignited fires during the 1970s and 1980s. The decline in ignitions over the past couple of decades is not clearly understood, but is the result of proportionally similar drops in both lightning-ignited and human-ignited fires.

Global warming has been suggested as part of the explanation for increased area burned in western forests in recent decades (Westerling *et al.* 2006; Littell *et al.* 2009). As discussed below, this could explain our observed increase in area burned on USFS lands over the past 50 years, and consistent with this hypothesis is the weak relationship between climate and area burned on Cal Fire lands and the lack of any observed increase in fire activity on those landscapes.

Despite the evidence that climate variables affect fire activity in Sierra Nevada USFS forests (see below), it is apparent that they account for only approximately half of the annual variation in area burned (Table 1). As suggested by other authors, past fire management practices may account for some of the unexplained variation. Fuel accumulation from fire suppression has been repeatedly invoked (McKenzie *et al.* 2004; Westerling *et al.* 2006). An issue not well studied but having a potential role (Miller *et al.* 2009) is a change in fire management. The late-20th-century increase in fire activity observed across the western USA (e.g. Fig. 4*a*) began at a time of change in USFS policy (Cermak 2005). In the 1960s, in response to numerous issues, including recognition of the natural role of fire in western forests and the resource benefit from fire, the so-called '10 am policy' was replaced with a policy of 'constrain and contain'. The former policy mandated aggressive action towards immediate suppression of all fires with the goal of having the fire extinguished by 10 am the following morning, but was replaced by a change in fire response during the 1960s and 1970s that did not mandate immediate suppression. The goal of this new policy was to constrain and contain fires within a watershed or other boundaries and consequently allowed fires to increase in size beyond what might have happened under the earlier policy. This change could account for some of the unexplained increase in area burned on USFS lands over the past several decades, and similar changes in management have been invoked to explain changes in fire activity in other regions of the world (e.g. Brotons *et al.* 2013). Consistent with this model is the fact that Cal Fire has retained the aggressive '10 am policy' to the present and this region has not experienced a late-20th-century increase in area burned (Fig. 4*b*). This hypothesis deserves further examination as a factor in the late-20th-century increase in area burned on USFS lands.

Fire–climate patterns

The fire–climate relationships documented here support models published elsewhere that climate affects fires through its impact

on fuels and this can occur in two ways: by changing fuel moisture and by changing fuel volume (Keeley *et al.* 2009; Littell *et al.* 2009; Batllori *et al.* 2013). Climate influences fire activity in forests through effects on fuel moisture that lead to longer and drier fire seasons (Dennison *et al.* 2008). However, in non-forested ecosystems of the foothills and valleys, it appears that year-to-year variation in area burned is influenced much less by drying conditions on fuels than by the effect of higher rainfall contributing to increased herbaceous fuel volume, which contributes to greater area burned the following year.

The role of climate in driving forest fire regimes hypothesised here is consistent with results from other studies in the western US derived through somewhat different methods. Westerling *et al.* (2006) reported that the number of fires over 4.05 km^2 was explained by the timing of peak spring stream flow; they hypothesised that this was the result of higher spring temperatures, which reduced the spring snow pack, leading to a longer and drier fire season. Our study supports the conclusion that spring and summer temperatures are important (Fig. 6), but questions whether they act primarily through effects on snow pack. This is suggested by our model of factors controlling winter snow pack, which were largely winter precipitation and winter temperature, and yet those variables were not strongly tied to area burned. The climatic water balance approach of Littell and Gwozdz (2011) would seem to hold promise for more clearly understanding the link between fire activity and climate. One of the least-emphasised limitations of the study of Westerling *et al.* (2006) was that it did not consider non-forested ecosystems, and these ecosystems dominate much of the western US landscape, yet there is much less evidence that these fire regimes are likely to be affected by global warming.

Interpretations of the Westerling paper in the media make it clear that it is widely believed that these patterns are driven by global warming, which has manifested itself during the last several decades. This conclusion is supported by the fact that temperature became an important driver of area burned in the last 50 years of record, whereas precipitation patterns during the first 50 years produced almost as a strong a relationship with area burned (Table 1). The lower-elevation Cal Fire lands have not experienced an increase in area burned over the past several decades (Fig. 4*b*), and annual variation in area burned is not strongly controlled by year-to-year variation in temperature. This may derive from the hotter, drier conditions in the lower elevations being conducive to fires most years, and factors other than climate such as ignitions, fuel condition, continuity or composition being more critical to determining the amount of area burned.

Fire–climate relationships throughout the western US differ not just between forested and non-forested ecosystems. There is extraordinary variation from region to region in the relative roles of temperature, seasonal patterns of temperature and precipitation (e.g. Gedalof *et al.* 2005; Collins *et al.* 2006; Littell *et al.* 2009; Abatzoglou and Kolden 2013; Morton *et al.* 2013). Our models suggest that over the past century, temperature and precipitation have varied in their importance to area burned and this pattern is reflected in other studies (Miller *et al.* 2009). This variation over space and in time may have resulted from a variety of factors that not only include changing interactions among climate and fuel properties, but could also stem from interactions with topography and human land use.

Implications for climate change

The variable role of climate and other factors driving fire activity underlines the importance of context when considering the impacts of climate change on future fire regimes. Nevertheless, a warmer future looks to be inevitable, as climate model projections consistently agree there will be significant temperature increases, although forecasts of precipitation change are more variable and spatially heterogeneous (Knutti and Sedláček 2013; Kumar *et al.* 2013). To this end, our historical analyses suggest that global warming will indeed increase the likelihood for further increases in fire activity in high-elevation forested landscapes, at least in the short term. Longer time periods bring greater uncertainty, however, because climate change may significantly shift fuel properties through changing species' distributions and forest structure (Chen *et al.* 2011; Keane *et al.* 2013). Increased fire activity in the short term may also decrease subsequent fire intensity through the reduction in fuels (Batllori *et al.* 2013). Predicting the effects of climate change in lower-elevation non-forested landscapes is more complicated because, climatologically, fire activity in these areas has not been keyed to temperature, but is driven instead by interactions among precipitation and fine-fuel load. Not only are future projections of average precipitation more variable, but the frequency and intensity of extreme precipitation events are also likely to change. If vegetation composition shifts to become increasingly herbaceous, changing precipitation patterns may play an even larger role in future fire activity. Beyond consideration of the role of climate, however, it will be important to account for other global change factors when predicting future fire activity, particularly the role of population growth and land-use change, which have been so influential in the past and present (Syphard *et al.* 2007).

Conclusions

After reviewing the early history of fire in California forests, Cermak (2005) concluded 'The *sine qua non* of a severe fire season in California is dry spring weather'. His conclusion has since been borne out by other studies (Westerling *et al.* 2006; Littell *et al.* 2009; present study). This has implications for understanding how future climate change will impact fire regimes and is consistent with the issues raised by Hessl (2011) in her review of climate change impacts on fire regimes. Our study shows that three issues need to be considered in making forecasts of future fire regimes. (1) Models predicting changes in annual temperature will be of limited value in understanding future fire regimes unless they pay close attention to seasonal temperature changes. The present study suggests that global warming during the winter will have less impact on future fire regimes than spring and summer warming. (2) The relationship between fire activity and climate is not static. In the present study, fires in Sierra Nevada forests were far more heavily influenced by precipitation patterns in winter, spring and summer during the first half of the 20th century than in the second half (Table 1). (3) Non-forested ecosystems appear to have a weak link between climate and fire activity, likely reflecting the over-riding influence of more direct human impacts.

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(b) Sample Tree Inventory and Sampling.

1. The Tree Inventory (University of Connecticut).

THE TREE INVENTORY

What is a tree inventory?

A tree inventory is the gathering of accurate information on the health and diversity of the community forest. How many street trees are there? What kind? In what condition are they? You cannot manage the community forest effec- tively unless you know its condition. Tree inventories are an essential tool of good management.

Why should my community do a tree inventory?

There are many good reasons for doing a tree inventory in your community. The inventory may be used:

- To determine the need for a community forestry program. For example, if the inventory reveals many dead and diseased trees or areas that are bare of trees, this suggests that a program incorporating tree planting is badly needed.
- To prioritize maintenance schedules in order to reduce the potential liability that results from hazardous trees. It also streamlines the efficiency of street crews and facilitates long-term budgeting.
- To educate residents about the benefits of a healthy, well-managed community forest, and to inform them about species best suited to the community.
- To facilitate the planning that is essential to the community's quality of life.
- To provide the basis for the development of a comprehensive community forestry management plan.

What information should be collected during an inventory?

Only data that will be put to use should be collected. Your community must determine what objectives it wishes to achieve prior to conducting an inventory. Bear in mind that information translates into expense: the more data gathered on each tree, the greater the cost of the inventory. Generally however, information on the following is collected:

- Species: To avoid costly mistakes, record the scientific names of trees. Don't use common names or codes.
- Size: DBH (diameter at breast height- 4.5 feet above ground), height and crown spread.
- Condition: Indicate what maintenance procedure is needed. Does the tree need corrective pruning? Does it require removal? It is important to note that if the tree is deemed to be a hazard to the public and removal is mandatory, rather than record "hazardous", it is prudent to record "removal."
- Damage: Record insect infestations, injuries and diseases by indicating the precise procedure necessary. For example, rather than describe lightning damage, indicate the need for pruning or removal. It is prudent to have a skilled tree crew correct the problem as soon as possible.
- Management/maintenance: Record need to fertilize, apply fungicide/insecticide, prune, repair curb and/or sidewalk damage inflicted by roots, remove stump/tree, or plant in an empty planting site. Do so in order to schedule maintenance work, allocate equipment and prepare budgets.
- Site characteristics: How much space is available for the root system? What is the condition and health of the soil in the planting space? The proximity of overhead/underground utilities and tall

buildings? The potential for road salt/traffic damage? Is it zoned commercial?
- Planting spaces: Research suggests that a community should give highest priority to planting trees on streets where yard trees are few. Identify planting spaces to encourage the planting of bare areas.
- Historic/Distinctive Trees and Groves: Special trees require more intensive management. (Note that trees of this nature may also serve to justify the inventory itself if the community is hesitant to undertake a management program.)

What type of inventory should my community do?

There are many different types of inventories and you should select an inventory type only when you know precisely what you want to accomplish. Data gathered on your communitiy's trees must have practical value. To guarantee that your tree management program will be effective today and useful tomorrow, you must match an appropriate inventory to your objectives. The most common types include:

- Specific Problem inventory: Gathers data about a specific problem or condition for work contracts or work schedules. For example, a survey of hazard trees or the extent of Dutch elm disease are specific problem inventories. Note that every community should conduct a yearly survey of hazardous trees. (Marking hazardous trees is not recommended since doing so may increase liability.)
- Partial Inventory: Gathers data from a sample (or samples) and information is extrapolated to apply to the whole forest. Survey is easily completed by an observer walking or driving and is generally used to work out maintenance contracts.
- Complete Inventory: Surveys the entire tree population but it is time consuming and expensive.
- Cover-type Survey: Information is gathered by at least partial use of aerial photographs and sometimes with geographical information system. This type of survey is used increasingly in urban areas to examine the entire tree population in order to plan long-term land use. It is especially useful in intensively managed areas such as parks and campuses, but it can be expensive and produces detail that few community tree management programs can use effectively.

How should the inventory be done?

The tree inventory may be done by professionals or volunteers, but, in either case, all crews, regardless of experience, require training before and during the inventory. (Please note that it is advisable that the municipal tree warden assist or lead the tree inventory process. It is also advisable that a person trained in hazard tree assessment review all trees surveyed and assess them for hazardous condition.)

Individuals working alone tend to be more productive, but crews attract attention, and this fact may be exploited to good advantage: professionals who carry brochures about the tree management program and the inventory can educate community residents. Crews should wear uniforms if possible and carry identification cards. Where crime is a problem, two or more people must work together for safety.

When should the inventory be done?

During the summer favorable weather makes inventory work more pleasant and students are often available to help, On the other hand, winter conditions allow crews to observe trees for hazardous limbs and dead wood. Professional foresters often choose to conduct inventories in the winter.

How should the inventory be updated?

Tree populations undergo constant change, and, as an inventory ages, it becomes less accurate and useful. No inventory will provide information that is useful beyond five or ten years. Consider the damage a single storm can do. Hurricane winds can render an inventory obsolete overnight. The ideal way to keep the inventory current is to make use of specially designed computer programs that provide easy and logical locations for data entry specific to tree inventories. Good programs also allow you to easily query data and produce reports, graphs, tables and perform some statistical analysis.

Hazardous trees

Stress conditions exist in the community firest severely affecting health of individual trees. Those trees that pose a hazard to public safety need to be detected and treated by removal or pruning as soon as possible. It is prudent that the municipal tree warden assess trees for hazardous conditions frequently.

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2. California Native Plant Society/California Department of Fish and Wildlife Protocol for Combined Vegetation Rapid Assessment and Releve Sampling Field Form (April, 2014).

CALIFORNIA NATIVE PLANT SOCIETY / DEPARTMENT OF FISH AND GAME
PROTOCOL FOR COMBINED VEGETATION RAPID ASSESSMENT
AND RELEVÉ SAMPLING FIELD FORM
(April 10, 2014)

Introduction

This protocol describes the methodology for both the relevé and rapid assessment vegetation sampling techniques as recorded in the combined relevé and rapid assessment field survey form of the same date as this protocol. The same environmental data are collected for both techniques. However, the relevé sample is plot-based, with each species in the plot and its cover being recorded. The rapid assessment sample is based not on a plot but on the entire stand, with 12-20 of the dominant or characteristic species and their cover values recorded. For more background on the relevé and rapid assessment sampling methods, see the relevé and rapid assessment protocols at www.cnps.org.

Selecting stands to sample:

To start either the relevé or rapid assessment method, a stand of vegetation needs to be defined.
A stand is the basic physical unit of vegetation in a landscape. It has no set size. Some vegetation stands are very small, such as alpine meadow or tundra types, and some may be several square kilometers in size, such as desert or forest types. A stand is defined by two main unifying characteristics:

1) It has compositional integrity. Throughout the site, the combination of species is similar. The stand is differentiated from adjacent stands by a discernable boundary that may be abrupt or indistinct.
2) It has structural integrity. It has a similar history or environmental setting that affords relatively similar horizontal and vertical spacing of plant species. For example, a hillside forest originally dominated by the same species that burned on the upper part of the slopes, but not the lower, would be divided into two stands. Likewise, sparse woodland occupying a slope with very shallow rocky soils would be considered a different stand from an adjacent slope with deeper, moister soil and a denser woodland or forest of the same species.

The structural and compositional features of a stand are often combined into a term called homogeneity. For an area of vegetated ground to meet the requirements of a stand, it must be homogeneous (uniform in structure and composition throughout).

Stands to be sampled may be selected by evaluation prior to a site visit (*e.g.,* delineated from aerial photos or satellite images), or they may be selected on site during reconnaissance (to determine extent and boundaries, location of other similar stands, etc.).

Depending on the project goals, you may want to select just one or a few representative stands of each homogeneous vegetation type for sampling (*e.g.,* for developing a classification for a vegetation mapping project), or you may want to sample all of them (*e.g.,* to define a rare vegetation type and/or compare site quality between the few remaining stands).

For the rapid assessment method, you will collect data based on the entire stand.

Selecting a plot to sample within in a stand (for relevés only):
Because many stands are large, it may be difficult to summarize the species composition, cover, and structure of an entire stand. We are also usually trying to capture the most information as efficiently as possible. Thus, we are typically forced to select a representative portion to sample.

When sampling a vegetation stand, the main point to remember is to select a sample that, in as many ways possible, is representative of that stand. This means that you are not randomly selecting a plot; on the contrary, you are actively using your own best judgment to find a representative example of the stand.

Selecting a plot requires that you see enough of the stand you are sampling to feel comfortable in choosing a representative plot location. Take a brief walk through the stand and look for variations in species composition and in stand structure. In many cases in hilly or mountainous terrain look for a vantage point from which you can get a representative view of the whole stand. Variations in vegetation that are repeated throughout the stand should be included in your plot. Once you assess the variation within the stand, attempt to find an area that captures the stand's common species composition and structural condition to sample.

Plot Size
All relevés of the same type of vegetation to be analyzed in a study need to be the same size. Plot shape and size are somewhat dependent on the type of vegetation under study. Therefore, general guidelines for plot sizes of tree-, shrub-, and herbaceous communities have been established. Sufficient work has been done in temperate vegetation to be confident the following conventions will capture species richness:

Herbaceous communities: 100 sq. m plot
Special herbaceous communities, such as vernal pools, fens: 10 sq m plot
Shrublands and Riparian forest/woodlands: 400 sq. m plot
Open desert and other shrublands with widely dispersed but regularly occurring woody species: 1000 sq. m plot
Upland Forest and woodland communities: 1000 sq. m plot

Plot Shape
A relevé has no fixed shape, though plot shape should reflect the character of the stand. If the stand is about the same size as a relevé, the plot boundaries may be similar to that of the entire stand. If we are sampling streamside riparian or other linear communities, our plot dimensions should not go beyond the community's natural ecological boundaries. Thus, a relatively long, narrow plot capturing the vegetation within the stand, but not outside it would be appropriate. Species present along the edges of the plot that are clearly part of the adjacent stand should be excluded.

If we are sampling broad homogeneous stands, we would most likely choose a shape such as a circle (which has the advantage of the edges being equidistant to the center point) or a square (which can be quickly laid out using perpendicular tapes).

Definitions of fields in the protocol

I. LOCATIONAL/ENVIRONMENTAL DESCRIPTION

Polygon/Stand #: Number assigned either in the field or in the office prior to sampling. It is usually denoted with a four-letter abbreviation of the sampling location and then a four-number sequential number of that locale (*e.g.* CARR0001 for Carrizo sample #1). The maximum number of letters/numbers is eight.

Date: Date of the sampling.

Name of recorder: The full name of the recorder should be provided for the first field form for the day. On successive forms, initials can be recorded.

Other Surveyors: The full names of each person assisting should be provided for the first field form for the day. On successive forms, initials of each person assisting can be recorded.

GPS name: The name/number assigned to each GPS unit. This can be the serial number if another number is not assigned.

Datum: (NAD 83) The standard GPS datum used is NAD 83. If you are using a different datum, note it here.

Bearing°, left axis at SW point of Long or Short side: Fill this in for relevés only. For square or rectangular plots: from the SW corner (= the GPS point location), looking towards the plot, record the bearing of the axis to your left. If the plot is a rectangle, indicate whether the left side of the plot is the long or short side of the rectangle by circling "long" or "short" side (no need to circle anything for circular or square plots). If there are no stand constraints, you would choose a circular or square plot and straight-sided plots should be set up with boundaries running in the cardinal directions. If you choose a rectangular plot that is not constrained by the stand dimensions, the short side should run from east to west, while the long side should run from north to south.

UTM coordinates: Easting (UTME) and northing (UTMN) location coordinates using the Universal Transverse Mercator (UTM) grid. Record in writing the information from a GPS unit. These coordinates are always the base point of the survey. Soil samples and photos are taken from this point, and exposure, steepness, topography, etc. are measured here. If the GPS is not within the stand (ie: the point is projected), these are the UTMs of the base point.

For relevé plots, take the waypoint in the southwest corner of the plot whenever possible or in the center of a circular plot.

UTM zone: Universal Transverse Mercator zone. Zone 10 is for California west of the 120th longitude, zone 11 is for California east of 120th longitude, which is the same as the straight portion of California's eastern boundary.

Error: ± The accuracy of the GPS location, when taking the UTM field reading. Please record the error units by circling feet (ft), meters (m), or positional dilution of precision (pdop). If your GPS does not determine error, insert N/A in this field.

Is GPS within stand? Yes / No Circle"Yes" to denote that the GPS waypoint was taken directly within or at the edge of the stand being assessed for a rapid assessment, or circle "No" if the waypoint was taken at a distance from the stand (such as with a binocular view of the stand). If the point is taken at the edge of the stand, note the direction to the stand.

If No, cite from GPS to stand: distance (in meters), bearing (in degrees), inclination (in degrees): From the base GPS point, measure the distance to the projected point using a range finder. Record the compass bearing from the base point to the projected point; record the inclination if the base and projected points are not at the same elevation. **and record projected UTMs:** These are the coordinates of the projected point, or the point being surveyed. They are generated in the field if the GPS units have the ability to calculate projected points. If the GPS unit does not have this capability, make a note to that effect and leave these fields blank.

Elevation: Recorded from the GPS unit or USGS topographic map. Please circle feet (ft) or meters (m).

Photograph #s: Write the name of the camera or the initials of the camera owner, JPG/frame number, and direction of photos. *Take four photos in the main cardinal directions (N, E, S, W) clockwise from the north, from the GPS location.* If additional photos are taken in other directions, please note this information on the form. If this is a distance survey to a projected point, take the four cardinal photos at the base point and at least one photo of the stand.

Stand Size: Estimate the size of the entire stand in which the sample is taken. As a measure, one acre is about 4000 square meters (approximately 64 x 64 m), or 208 feet by 208 feet. One acre is similar in size to a football field.

Plot Size: If this is a relevé, circle the size of the plot.

Plot Shape: Record the length and width of the plot and circle measurement units (i.e., ft or m). If it is a circular plot, enter radius (or just put a check mark in the space).

Exposure: (Enter actual ° and circle general category): With your back to the general uphill direction of the slope (i.e., by facing downhill of the slope), read degrees of the compass for the aspect or the direction you are standing, using degrees from north, adjusted for declination. Average the reading over the entire stand, even if you are sampling a relevé plot, since your plot is representative of the stand. If estimating the exposure, write "N/A" for the actual degrees, and circle the general category chosen. "Variable" may be selected if the same, homogenous stand of vegetation occurs across a varied range of slope exposures. Select "all" if stand is on top of a knoll that slopes in all directions or if the same, homogenous stand of vegetation occurs across all ranges of slope.

Steepness: (Enter actual ° and circle general category): Read degree slope from a compass or clinometer. If estimating, write "N/A" for the actual degrees, and circle the general category chosen. Make sure to average the reading across the entire stand even if you are sampling in a relevé plot.

Topography: First assess the broad (**Macro**) topographic feature or general position of the stand in the surrounding watershed, that is, the stand is at the top, upper (1/3 of slope), middle (1/3 of slope), lower (1/3 of slope), or bottom. **Circle *all* of the positions that apply for macrotopography.**
Then assess the local (**Micro**) topographic features or the lay of the area (*e.g.,* surface is flat or concave). **Circle only *one* of the microtopographic descriptors**.

Geology: Geological parent material of site. If exact type is unknown, use a more general category (*e.g.,* igneous, metamorphic, sedimentary). *See code list for types.*

Soil Texture: Record soil texture that is characteristic of the site (*e.g.,* coarse loamy sand, sandy clay loam). *See soil texture key and code list for types.*

Upland or Wetland/Riparian (circle one): Indicate if the stand is in an upland or a wetland. There are only two options. Wetland and riparian are one category. Note that a site need not be officially delineated as a wetland to qualify as such in this context (*e.g.,* seasonally wet meadow).

% Surface cover (abiotic substrates). It is helpful to imagine "mowing off" all of the live vegetation at the base of the plants and removing it – you will be estimating what is left covering the surface. **The total should sum to 100%.** Note that non-vascular cover (lichens, mosses, cryptobiotic crusts) is not estimated in this section.

- **% Water**: Estimate the percent surface cover of running or standing water, ignoring the substrate below the water.
- **% BA Stems**: Percent surface cover of the plant basal area, *i.e.*, the basal area of stems at the ground surface. Note that for most vegetation types BA is 1-3% cover.
- **% Litter**: Percent surface cover of litter, duff, or wood on the ground.
- **% Bedrock**: Percent surface cover of bedrock.
- **% Boulders:** Percent surface cover of rocks > 60 cm in diameter.
- **% Stone:** Percent surface cover of rocks 25-60 cm in diameter.
- **% Cobble:** Percent surface cover of rocks 7.5 to 25 cm in diameter.
- **% Gravel:** Percent surface cover of rocks 2 mm to 7.5 cm in diameter.
- **% Fines:** Percent surface cover of bare ground and fine sediment (e.g. dirt) < 2 mm in diameter.

% Current year bioturbation: Estimate the percent of the sample or stand exhibiting soil disturbance by fossorial organisms (any organism that lives underground). Do not include disturbance by ungulates. Note that this is a separate estimation from surface cover.

Past bioturbation present? Circle Yes if there is evidence of bioturbation from previous years.

% Hoof punch: Note the percent of the sample or stand surface that has been punched down by hooves (cattle or native grazers) in wet soil.

Fire Evidence: Circle Yes if there is visible evidence of fire, and note the type of evidence in the "Site history, stand age and comments section," for example, "charred dead stems of *Quercus berberidifolia* extending 2 feet above resprouting shrubs." If you are certain of the year of the fire, put this in the Site history section.

Site history, stand age, and comments: Briefly describe the stand age/seral stage, disturbance history, nature and extent of land use, and other site environmental and vegetation factors. Examples of disturbance history: fire, landslides, avalanching, drought, flood, animal burrowing, or pest outbreak. Also, try to estimate year or frequency of disturbance. Examples of land use: grazing, timber harvest, or mining. Examples of other site factors: exposed rocks, soil with fine-textured sediments, high litter/duff build-up, multi-storied vegetation structure, or other stand dynamics.

Disturbance code / Intensity (L,M,H): List codes for potential or existing impacts on the stability of the plant community. Characterize each impact as **L** (=Light), **M** (=Moderate), or **H** (=Heavy). For invasive exotics, divide the total exotic cover (e.g. 25% Bromus diandrus + 8% Bromus madritensis + 5% Centaurea melitensis = 38% total exotics) by the total % cover of all the layers when added up (e.g. 15% tree + 25% shrub + 40% herbs = 80% total) and multiply by 100 to get the % relative cover of exotics (e.g. 38% total exotics/80% total cover = 48% relative exotic cover). L = 0-33% *relative* cover of exotics; M =34-66% relative cover, and H = > 66% relative cover. *See code list for impacts.*

II. HABITAT AND VEGETATION DESCRIPTION

California Wildlife-Habitat Relationships (CWHR)

For CWHR, identify the size/height class of the stand using the following tree, shrub, and/or herbaceous categories. These categories are based on functional life forms.

Tree DBH: Circle one of the tree size classes provided when the tree canopy closure exceeds 10 percent of the total cover, or if young tree density indicates imminent tree dominance. Size class is based on the average diameter at breast height (dbh) of each trunk (standard breast height is 4.5ft or 137cm). When marking the main size class, make sure to estimate the mean diameter of all trees over the entire stand, and weight the mean if there are some larger tree dbh's. The "**T6 multi-layered**" dbh size class contains a multi-layered tree canopy (with a size class T3 and/or T4 layer growing under a T5 layer and a distinct height separation between the classes) exceeding 60% total cover. Stands in the T6 class need also to contain at least 10% cover of size class 5 (>24" dbh) trees growing over a distinct layer with at least 10% combined cover of trees in size classes 3 or 4 (>11-24" dbh).

Shrub: Circle one of the shrub size classes provided when shrub canopy closure exceeds 10 percent (except in desert types, where MCV rules allow lower shrub cover) by recording which class is predominant in the survey. Shrub size class is based on the average amount of crown decadence (dead standing vegetation on live shrubs when looking across the crowns of the shrubs).

Herb: Circle one of the herb height classes when herbaceous cover exceeds 2 percent by recording the predominant class in the survey. Note: *This height class is based on the average plant height at maturity, not necessarily at the time of observation.*

Desert Palm/Joshua Tree: Circle one of the palm or Joshua tree size classes by averaging all the stem-base diameters (*i.e.* mean diameter of all stem-base sizes). Diameter is measured at the plant's base above the bulge near the ground.

Desert Riparian Tree/Shrub: Circle one of the size classes by measuring mean stem height (whether tree and/or shrub stand).

Overall Cover of Vegetation

Provide an estimate of cover for the following categories below (based on functional life forms). Record a specific number for the total aerial cover or "bird's-eye view" looking from above for each category, estimating cover for the living plants only. Litter/duff should not be included in these estimates. The porosity of the vegetation should be taken into consideration when estimating percent cover (how much of the sky can you see when you are standing under the canopy of a tree, or how much light passes through the canopy of the shrub layer?).

To come up with a specific number estimate for percent cover, first use generalized cover classes as reference aids such as the CWHR cover classes (<2%, 2-9%, 10-24%, 25-39%, 40-59%, 60-100%) or the modified Braun-Blanquet cover-abundance scale (<1%, 1-5%, >5-15%, >15-25%, >25-50%, >50-75%, >75%). While keeping these intervals in mind, you can then refine your estimate to a specific percentage for each category below.

% NonVasc cover: The total cover of all lichens, bryophytes (mosses, liverworts, hornworts), and cryptogamic crust on substrate surfaces including downed logs, rocks and soil, but not on standing or inclined trees or vertical rock surfaces.

% Vasc Veg cover: The total cover of all vascular vegetation taking into consideration the porosity, or the holes, in the vegetation, and disregarding overlap[1] of the various tree, shrub, and/or herbaceous layers and species.

% Cover by Layer

% Conifer Tree /Hardwood Tree: The total foliar cover (considering porosity) of all live tree species, disregarding overlap[1] of individual trees. Estimate conifer and hardwood covers separately.
Please note: These cover values should not include the coverage of regenerating tree species (i.e., tree seedlings and saplings).

% Regenerating Tree: The total foliar cover of seedlings and saplings, disregarding overlap[1] of individual recruits. See seedling and sapling definitions below.

%Shrub: The total foliar cover (considering porosity) of all live shrub species disregarding overlap[1] of individual shrubs.

%Herbaceous: The total cover (considering porosity) of all herbaceous species, disregarding overlap[1] of individual herbs.

---

[1] Porosity reduces the total cover of the canopy. Overlapping strata should not be included in the total cover percent; for instance, if a shrub is growing under a tree, only the cover of the tree will be added into the total; the cover of the shrub will be disregarded, except for the amount by which it fills in the porosity of the tree canopy.

Height Class by Layer

Modal height for conifer tree /hardwood tree, shrub, and herbaceous categories: Record an average height value per each category by estimating the mean height for each group. Please use the following height intervals to record a height class: 01 = <1/2 m, 02 = 1/2-1 m, 03 = 1-2 m, 04 = 2-5 m, 05 = 5-10 m, 06 = 10-15 m, 07 = 15-20 m, 08 = 20-35 m, 09 = 35-50 m, 10 => 50 m. Note: *For the herbaceous layer height, this height class is based on the average plant height at the time of observation, as opposed to how this is recorded in the CWHR section (at maturity).*

Species List and Coverage

For rapid assessments, list the 10-20 species that are dominant or that are characteristically consistent throughout the stand. These species may or may not be abundant, but they should be constant representatives in the survey. When different layers of vegetation occur in the stand, make sure to list species from each stratum. As a general guide, make sure to list at least 1-2 of the most abundant species per stratum.

For relevés, list all species present in the plot, using the second species list page if necessary.

For both sample types, provide the stratum:
T = Tree. A woody perennial plant that has a single trunk.
S = Shrub. A perennial, woody plant, that is multi-branched and doesn't die back to the ground every year.
H = Herb. An annual or perennial that dies down to ground level every year.
E = SEedling. A tree species clearly of a very young age that is < 1" dbh or has not reached breast height. Applies only to trees propagating from seed; resprouts are not recorded here even if they meet the size requirements.
A = SApling. 1" - <6" dbh and young in age, OR small trees that are <1" dbh, are clearly of appreciable age, and are kept short by repeated browsing, burning, or other disturbance. Includes trees that are re-sprouting from roots or stumps following fire, logging or other disturbance. These re-sprouts may exhibit a shrubby form, with multiple small trunks, but are species that are generally considered trees. If a majority of the trunks are >6" dbh, then the re-sprouts would be recorded under the "Tree" stratum.
N = Non-vascular. Includes moss, lichen, liverworts, hornworts, cryptogammic crust, and algae.

Be consistent and don't break up a single species into two separate strata. The only time it would be appropriate to do so is when one or more tree species are regenerating, in which case the Seedling and/or Sapling strata should be recorded for that species. These may be noted on the same line, e.g.:

Strata	Species	%Cover	C
T/E/A	Quercus douglasii	40/<1/<1	

If a species collection is made, it should be indicated in the collection column with a "C" (for collected). If the species is later keyed out, cross out the species name or description and write the keyed species name in pen on the data sheet. Do not erase what was written in the field, because this information can be used if specimens get mixed up later. If the specimen is then thrown out, the "C" in the collection column should crossed out. If the specimen is kept but is still not confidently identified, add a "U" to the "C" in the collection

column (CU = collected and unconfirmed). In this case the unconfirmed species epithet should be put in parentheses [e.g *Hordeum (murinum)*]. If the specimen is kept and is confidently identified, add a "C" to the existing "C" in the collection column (CC = Collected and confirmed).

Use Jepson Manual nomenclature. Write out the genus and species of the plant. Do not abbreviate. When uncertain of an identification (which you intend to confirm later) use parentheses to indicate what part of the determination needs to be confirmed. For example, you could write out *Brassica* (*nigra*) if you are sure it is a *Brassica* but you need further clarification on the specific epithet.

Provide the % absolute aerial cover for each species listed. When estimating, it is often helpful to think of coverage in terms of the following cover intervals at first:

<1%, 1-5%, >5-15%, >15-25%, >25-50%, >50-75%, >75%.

Keeping these classes in mind, then refine your estimate to a specific percentage. All species percent covers may total over 100% because of overlap.

Include the percent cover of snags (standing dead) of trees and shrubs. Note their species, if known, in the "Stand history, stand age and comments" section.

For rapid assessments, make sure that the major non-native species occurring in the stand also are listed in the space provided in the species list with their strata and % cover. For relevés, all non-native species should be included in the species list.

Also for relevés, you can record the <1% cover in two categories: r = trace (i.e., rare in plot, or solitary individuals) and + = <1% (few individuals at < 1% cover, but common in the plot).

Unusual species: List species that are locally or regionally rare, endangered, or atypical (*e.g.,* range extension or range limit) within the stand. This field will be useful to the Program for obtaining data on regionally or locally significant populations of plants.

INTERPRETATION OF STAND

Field-assessed vegetation alliance name: Name of alliance or habitat following the most recent CNPS classification system or the Manual of California Vegetation (Sawyer J.O., Keeler-Wolf T., and Evens, J. 2009). Please use scientific nomenclature, *e.g., Quercus agrifolia* forest. An alliance is based on the dominant or diagnostic species of the stand, and is usually of the uppermost and/or dominant height stratum. A dominant species covers the greatest area. A diagnostic species is consistently found in some vegetation types but not others.

Please note: The field-assessed alliance name may not exist in the present classification, in which case you can provide a new alliance name in this field. If this is the case, also make sure to state that it is not in the MCV under the explanation for "Confidence in alliance identification."

Field-assessed association name (optional): Name of the species in the alliance and additional dominant/diagnostic species from any strata, as according to CNPS classification. In following naming conventions, species in differing strata are separated with a slash, and species in the uppermost stratum are listed first (*e.g., Quercus douglasii/Toxicodendron diversilobum*). Species in the same stratum are separated with a dash (*e.g., Quercus lobata-Quercus douglasii)*.

Please note: The field-assessed association name may not exist in the present classification, in which you can provide a new association name in this field.

Adjacent Alliances/direction: Identify other vegetation types that are directly adjacent to the stand being assessed by noting the dominant species (or known type). Also note the distance away in meters from the GPS waypoint and the direction in degrees aspect that the adjacent alliance is found
(e.g., *Amsinckia tessellata* / 50m, 360° N *Eriogonum fasciculatum* /100m, 110°).

Confidence in Identification: (L, M, H) With respect to the "field-assessed alliance name", note whether you have L (=Low), M (=Moderate), or H (=High) confidence in the interpretation of this alliance name.

Explain: Please elaborate if your "Confidence in Identification" is low or moderate. Low confidence can occur from such things as a poor view of the stand, an unusual mix of species that does not meet the criteria of any described alliance, or a low confidence in your ability to identify species that are significant members of the stand.

Phenology: Indicate early (E), peak (P) or late (L) phenology for each of the strata.

Other identification problems or mapping issues: Discuss any further problems with the identification of the assessment or issues that may be of interest to mappers. Note if this sample represents a type that is likely too small to map. If it does, how much of the likely mapping unit would be comprised of this type. For example: "this sample represents the top of kangaroo rat precincts in this general area, which are surrounded by vegetation represented by CARR000x; this type makes up 10% of the mapping unit."

Note: Field forms are generally filled out in pencil, so that changes may be made easily while working in the plot or stand. Once out of the stand, however, entries on the field form should not be erased, but should be crossed out and corrected in a different-colored ink.

GEOLOGY CODE

IGTU	**Igneous (type unknown)**
MIIG	Mixed igneous
ULTU	Ultramafic (type unknown)
VOLC	General volcanic extrusives
ANDE	Andesite
ASHT	Ash (of any origin)
BASA	Basalt
DIAB	Diabase
OBSI	Obsidian
PUMI	Pumice
PYFL	Pyroclastic flow
RHYO	Rhyolite
VOFL	Volcanic flow
VOMU	Volcanic mud
INTR	General igneous intrusives
DIOR	Diorite
GABB	Gabbro
GRAN	Granitic (generic)
MONZ	Monzonite
PERI	Peridotite
QUDI	Quartz diorite
METU	**Metamorphic (type unknown)**
MIME	Mixed metamorphic
GREE	Greenstone
BLUE	Blue schist
FRME	Franciscan melange
GNBG	Gneiss/biotite gneiss
HORN	Hornfels
MARB	Marble
PHYL	Phyllite
SCHI	Schist
SESC	Semi-schist
SLAT	Slate
ULTU	Ultramafic (type unknown)
SERP	Serpentine
SETU	**Sedimentary (type unknown)**
BREC	Breccia (non-volcanic)
CACO	Calcareous conglomerate
CALU	Calcareous (origin unknown)
CASA	Calcareous sandstone
CASH	Calcareous shale
CASI	Calcareous siltstone
CHER	Chert
CONG	Conglomerate
DOLO	Dolomite
FANG	Fanglomerate
LIME	Limestone
MISE	Mixed sedimentary
SAND	Sandstone
SHAL	Shale
SILT	Siltstone
CLAL	Clayey alluvium
DUNE	Sand dunes
GLTI	Glacial till, mixed origin, moraine
GRAL	Gravelly alluvium
LALA	Large landslide (unconsolidated)
LOSS	Loess
MIAL	Mixed alluvium
SAAL	Sandy alluvium
SIAL	Silty alluvium
MIRT	Mix of two or more rock types
OTHE	Other than on list

ROCK SIZE

Boulder	> 60 cm diameter
Stone	25 cm to 60 cm
Cobble	7.5 cm to 25 cm
Gravel	2 mm to 7.5 cm
Fines	< 2 mm

DISTURBANCE CODES

01 Development
02 ORV activity
03 Agriculture
04 Grazing
05 Competition from exotics
06 Logging
07 Insufficient population/stand size
08 Altered flood/tidal regime
09 Mining
10 Hybridization
11 Groundwater pumping
12 Dam/inundation
13 Other
14 Surface water diversion
15 Road/trail construction/maint.
16 Biocides
17 Pollution
18 Unknown
19 Vandalism/dumping/litter
20 Foot traffic/trampling
21 Improper burning regime
22 Over collecting/poaching
23 Erosion/runoff
24 Altered thermal regime
25 Landfill
26 Degrading water quality
27 Wood cutting
28 Military operations
29 Recreational use (non ORV)
30 Nest parasitism
31 Non-native predators
32 Rip-rap, bank protection
33 Channelization (human caused)
34 Feral pigs
35 Burros
36 Rills
37 Phytogenic mounding
38 Sudden Oak Death

Simplified Key to Soil Texture
(Adapted from Brewer and McCann 1982)

Place about three teaspoons of soil in the palm of your hand. Take out any particles ≥ 3 mm in size.

A. Does soil remain in ball when squeezed in your hand palm?

Yes, soil does remain in a ball when squeezed..... **B**

No, soil does not remain in a ball when squeezed..... **sand**

SAND Sand (class unknown)
Very coarse texture.....COSA Coarse sand
Moderately coarse texture..... MESN Medium sand
Moderately fine texture..... FISN Fine sand

B. Add a small amount of water until the soil feels like putty. Squeeze the ball between your thumb and forefinger, attempting to make a ribbon that you push up over your finger. Does soil make a ribbon?

Yes, soil makes a ribbon; though it may be very short.....**C**

No, soil does not make a ribbon.....**loamy sand**

Very gritty with coarse particles.....COLS Coarse, loamy sand
Moderately to slightly gritty with medium to fine particles.....MELS Medium to very fine, loamy sand

C. Does ribbon extend more than one inch?

Yes, soil extends > 1 inch.....**D**

No, soil does not extend > 1 inch.....Add excess water

Soil feels gritty or not smooth..... **sandy loam or loam**

LOAM Loam (class unknown)
Very gritty with coarse particles.....MCSL Moderately coarse, sandy loam
Moderately gritty with medium to fine particles.....MESA Medium to very fine, sandy loam
Slightly gritty .....MELO Medium loam

Soil feels very smooth.....**silt loam**

MESIL medium silt loam

D. Does ribbon extend more than 2 inches?

Yes, ribbon extends more than 2 inches, and does not crack if bent into a ring.....**E**

No, soil breaks when 1–2 inches long; cracks if bent into a ring.....Add excess water

Soil feels gritty or not smooth.....**sandy clay loam or clay loam**

Moderately to very gritty..... MFSA Moderately fine sandy clay loam
Slightly gritty or not smooth..... MFCL Moderately fine clay loam

Soil feels very smooth.....**silty clay loam or silt**

Moderately fine texture.....MFSL Moderately fine silty clay loam
Very fine texture..... MESI Medium silt

E. Soil makes a ribbon 2+ inches long; does not crack when bent into a ring.....Add excess water

Soil feels gritty or not smooth.....**sandy clay or clay**

Moderately to very gritty..... FISA Fine sandy clay
Slightly gritty or not smooth..... FICL Fine clay
CLAY Clay (class unknown)

Soil feels very smooth.....**silty clay**

FISC Fine silty clay

UNKN = UNKNOWN PEAT = PEAT MUCK = MUCK

3. Minimum Data Collection Attributes for CAL FIRE Grant-Funded Urban Tree Inventories (CAL FIRE 2014).

APPENDIX G

Minimum Data Collection Attributes for CAL FIRE Grant-Funded Urban Tree Inventories

IMPORTANT NOTE:

Failure to gather data to the below attributes will result in the denial of reimbursement of grant funds unless specific written authorization to deviate from the attributes has been provided by a CAL FIRE Regional Urban Forester or the Program Manager prior to invoice submittal.

- **Mapping coordinate.** X and Y coordinate locations (latitude and longitude). Each tree and planting site will be located using GIS and/or GPS equipment.
- **Block side.** The location of each street tree and planting site so that they can easily be identified for future work. Street trees and planting sites will be located using a street name, side of lot, tree number, and block side information (on street, from street, and to street).
- **Location.** The tree's physical location in relation to public Right of Way and/or public space will be recorded.
- **Species.** Trees will be identified by *genus* and *species,* and by common name.
- **Diameter.** Tree trunk diameter will be recorded. This should be to the nearest 1-inch.
- **Stems.** The number of stems a tree has will be recorded.
- **Condition.** In general, the condition of each tree will be recorded in one of the following categories adapted from the rating system established by the International Society of Arboriculture:

Excellent	100%
Very Good	90%
Good	80%
Fair	60%
Poor	40%
Critical	20%
Dead	0%

- **Maintenance need.** The following maintenance categories (*or similar approved by CAL FIRE prior to collection*) will be collected:

1. Priority 1 Removal. Trees designated for removal have defects that cannot be cost-effectively or practically treated. The majority of the trees in this category will have a large percentage of dead crown and pose an elevated level of risk for failure. Any hazards that could be seen as potential dangers to persons or property and seen as potential liabilities would be in this category. Large dead and dying trees that are high liability risks are included in this category. These trees are the first ones that should be removed.
2. Priority 2 Removal. Trees that should be removed but do not pose a liability as great as the first priority will be identified here. This category would need attention as soon as "Priority One" trees are removed.
3. Priority 3 Removal. Trees that should be removed, but that pose minimal liability to persons or property, will be identified in this category.
4. Priority 1 Prune. Trees that require priority one pruning are recommended for trimming to remove hazardous deadwood, hangers, or broken branches. These trees have broken or hanging limbs, hazardous deadwood, and dead, dying, or diseased limbs or leaders greater than four inches in diameter.
5. Priority 2 Prune. These trees have dead, dying, diseased, or weakened branches between two and four inches in diameter and are potential safety hazards.
6. Large Tree Routine Prune. These trees require routine horticultural pruning to correct structural problems or growth patterns, which would eventually obstruct traffic or interfere with utility wires or buildings. Trees in this category are large enough to require bucket truck access or manual climbing.
7. Small Tree Routine Prune. These trees require routine horticultural pruning to correct structural problems or growth patterns, which would eventually obstruct traffic or interfere with utility wires or buildings. These trees are small growing, mature trees that can be evaluated and pruned from the ground.
8. Training Prune. Young, large-growing trees that are still small must be pruned to correct or eliminate weak, interfering, or objectionable branches in order to minimize future maintenance requirements. These trees, up to 20 feet in height, can be worked with a pole-pruner by a person standing on the ground.
9. Stump Removal. This category indicates a stump that should be removed.
10. Plant Tree. During the inventory, vacant planting sites will be identified by street and address. The size of the site is designated as small, medium, or large (indicating the ultimate size that the tree will attain), depending on the growing space available and the presence of overhead wires.

- **Clearance Required.** Trees, which are causing or may cause visibility or clearance difficulties for pedestrians or vehicles, will be identified, as well as those trees blocking clear visibility of signs or traffic signals.

- **Hardscape Damage.** Damage to sidewalks and curbs by tree roots are noted. Notes on potential fixes for the problem are encouraged (redesign options etc...)

- **Overhead Utilities.** The inventory indicates whether overhead conductors or other utilities are present at the tree site that could result in conflicts with the tree.

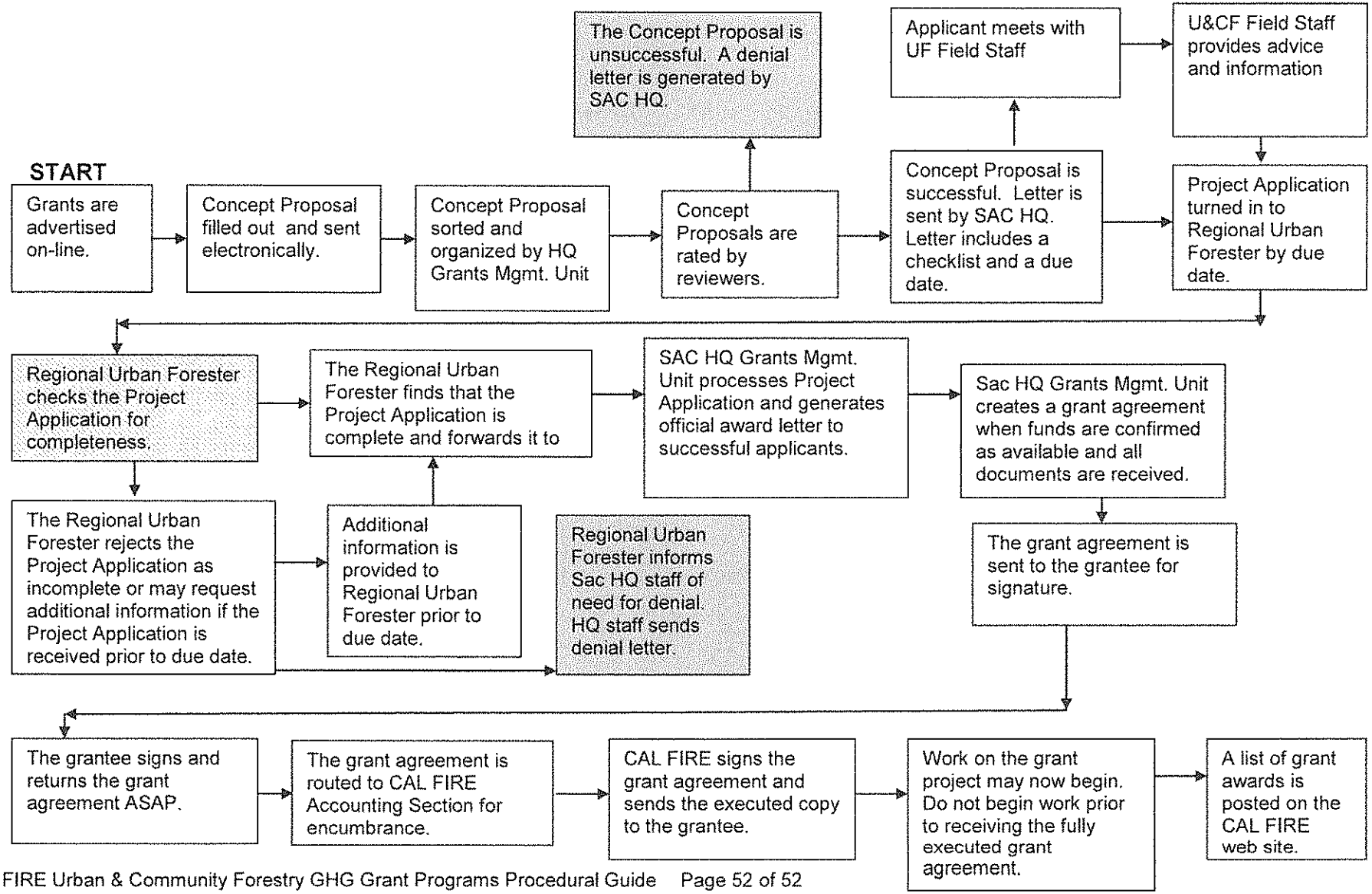
- **Grow space.** The area within the growing space is categorized as:

T	Tree Lawn
W	Well/Pit
M	Median
P	Raised Planter
O	Open/Unrestricted
I	Island
U	Unmaintained Area

- **Space Size.** The narrowest dimension of the Grow Space, in feet. (I.e., 3'x3' cut-out, 4' parkway strip, open parkland, etc.....)

- **Notes.** Additional information regarding disease, insect, mechanical damage, etc. can be included in this field.

APPENDIX H: CAL FIRE Urban & Community Forestry Program Grant Process Flow Chart



(c) Urban Forest Practice Ordinance Guidelines.

1. Guidelines for Developing Urban Forest Practice Ordinances (Oregon Department of Forestry, November 1999).

Guidelines For Developing Urban Forest Practice Ordinances

"STEWARDSHIP IN FORESTRY"

Oregon Department of Forestry
Forest Practices Program
Urban and Community Forestry Program

Oregon Department of Land Conservation and Development

November 1999

Acknowledgments

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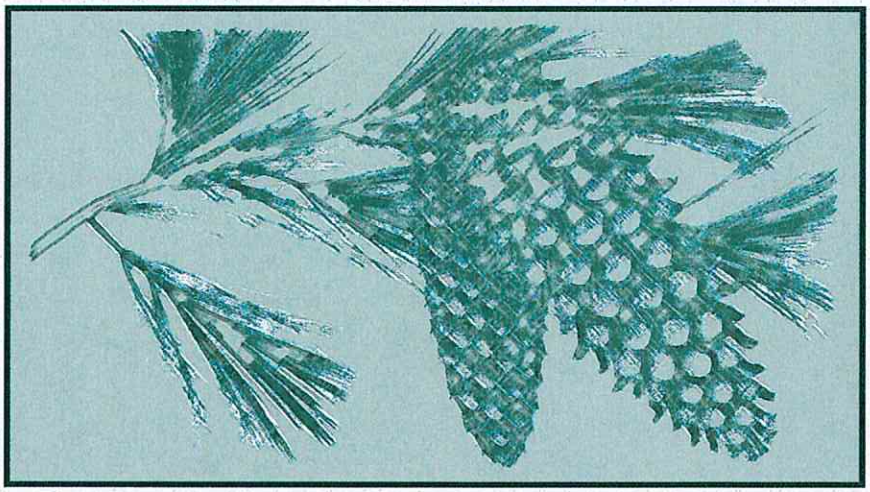

Western White Pine
Pinus monticola

Paul C. Bell, Forest Practice Policy Analyst, ODF
Scott Plamondon, Urban and Community Forestry Program Manager, ODF
Michael Rupp, Rural Planning Coordinator, DLCD

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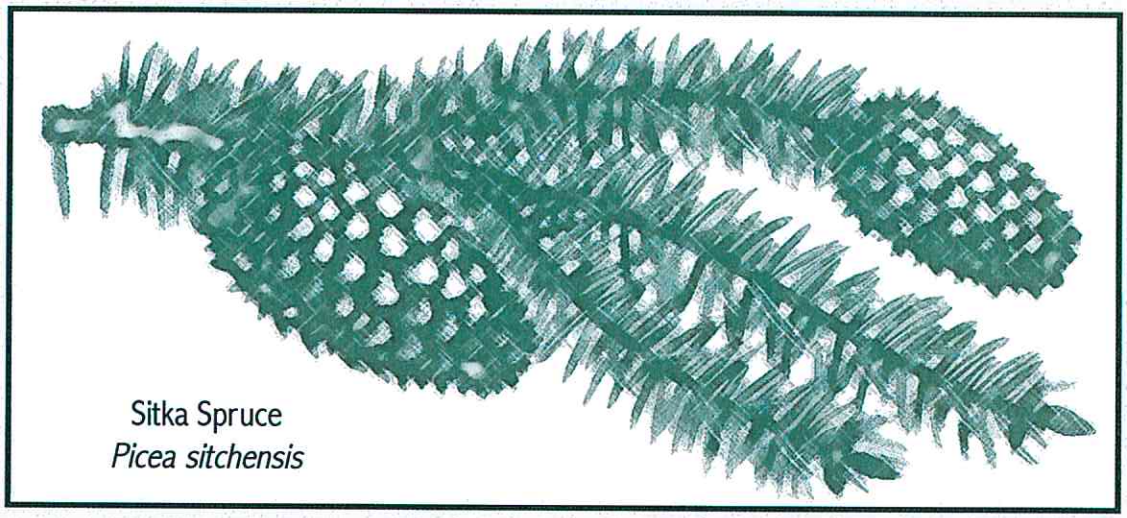

Sitka Spruce
Picea sitchensis

1.0 INTRODUCTION

Trees are an important part of Oregon's economy, its environment and its identity. Trees provide a myriad of benefits such as lumber, helping to protect our air and water, and shade for our homes in the summer. Trees are even found on our car license plates. The importance of trees and the need to effectively manage our forests was recognized by the Oregon Legislature, which passed the nation's first Forest Practices Act (FPA) in 1971. This law provided unprecedented levels of environmental protection and, for the first time, required reforestation after harvest. The FPA has been amended over the years to include protection for sensitive nesting sites for wildlife, stream and riparian area protection, and protection for a variety of other resource needs.

Since the FPA's adoption 28 years ago, issues regarding the application of the FPA within urban areas have increased. As parcels closer to and within urban areas have been harvested, citizens have voiced a desire for greater levels and different types of forest protection than provided by administration of the FPA.

The FPA was designed to promote the proper management of Oregon's forests. Its mandates for reforestation and resource protection have ensured that forestland remains healthy and productive. The FPA was not designed to regulate forest practices to meet individual community goals within urban settings. This publication has been developed to help cities and counties decide whether the level and type of protection offered by the FPA within urban growth boundaries (UGBs) and city limits as administered by the Oregon Department of Forestry (ODF) is appropriate for their needs. Where the FPA does not meet the goals and objectives of local government within UGBs and city limits, this publication can also help in the preparation of locally administered forest regulations.

The Oregon Legislature has given cities and counties the authority to regulate forest practices within UGBs in place of having ODF administer the FPA. This "local option" has been used by many cities in Oregon. The law is designed to have either ODF or the local government regulating forest operations in the designated area, but not both. If local governments regulate, the FPA no longer applies. Some cities have unknowingly invoked this provision by passing ordinances that regulate the harvesting of trees while creating unintended consequences such as the failure to address other resource protection issues covered by the FPA.

1.1 This Publication

The Oregon Department of Forestry, in cooperation with the Oregon Department of Land Conservation and Development, offers this publication as a guide for cities and counties to use in the development of urban forest practice regulations. This publication is designed to assist local governments in balancing community objectives with economic and environmental concerns as they relate to forest regulations. It outlines a process by which cities or counties can develop regulations that meet their particular goals while meeting state and federal legislative mandates to protect soil, air, water, and fish and wildlife resources.

These guidelines provide several model ordinance clauses that may address local objectives in an urban forest practices program. However, it is not advisable for any city to merely adopt these model clauses and expect the regulations to be useful. The most successful local regulations are those that meet community goals and objectives while addressing applicable statewide land use planning goals that protect specific natural resources and provide for orderly development.

2.0 THE OREGON FOREST PRACTICES ACT (how it works)

While most local governments are aware the state has a Forest Practices Act, they do not know how it works or to what extent it may apply to timber harvesting and other forest practices within their jurisdiction. This section provides a brief overview of the FPA and examples of how various resources are protected. As a city or county considers developing local forest practice regulations, it is important to evaluate current forest practice regulations against what may be proposed.

Specific resources that receive protection under the FPA include environmentally sensitive sites, riparian areas and stream corridors, air, soil, and water quality, and fish and wildlife habitat. The FPA, adopted by the Oregon Legislative Assembly and administered by the Oregon State Board of Forestry through the Oregon Department of Forestry (ODF), applies to all commercial forest operations on non-federal forestlands in Oregon.

The FPA establishes standards for forest practices, including timber harvesting, road building and maintenance, slash disposal, reforestation and use of pesticides and fertilizer. Monitoring by ODF staff shows a high degree of compliance by landowners and operators with the law, assuring that trees are being planted for tomorrow's forests and that other forest resources are being protected.

The FPA has evolved over the years. Protection measures have been strengthened as more scientific data has become available and as social values and federal requirements have changed. The Oregon Forest Practice Rules, which interpret and establish specific standards under the FPA, are administered and enforced in the field by ODF Forest Practices Foresters (FPFs). FPFs operate out of local field offices, with each FPF responsible for a specific geographic area.

Oregon law (ORS 527.670) requires that the operator, timber owner or landowner notify ODF before commencing any forest operation activity. The FPF then reviews operation notifications filed in their area. Notifications are prioritized for field inspections according to type of operation and the resources involved. Depending on the nature of the activity and resources involved, a written plan may be required which describes how the operator will conduct an operation while protecting certain resources as required by the FPA. For example, harvesting timber within 100 feet of a fish-bearing stream requires special attention to protect the stream's temperature, water quality and the riparian area's habitat values.

2.1 Examples of FPA Resource Protection

Some resource protection standards, required by the FPA, are provided below as examples to convey how and what resources are protected by the FPA. As local governments consider developing their own forest practices regulations which would replace the FPA, the following examples show types of regulations that could be developed and adopted to protect soil, air and water quality, and fish and wildlife.

2.1.1 Water Protection Rules

The FPA's water protection rules set standards for vegetation retention within riparian management areas (RMAs). RMAs are areas along each side of specified waters of the state within which vegetation retention and special management practices are required to protect water quality, hydrologic functions, and fish and wildlife habitat. The rules require that trees and understory vegetation be retained within RMAs, and that written plans describe how resource protection will be accomplished during the operation. Standards for tree retention vary by stream size (large, medium, or small) and beneficial uses of water (fish or domestic uses). For example, a large stream used by fish requires the following standards:

- Riparian management area 100 feet wide on each side of the stream.
- All understory vegetation within 10 feet of the high water level.
- All trees within 20 feet of the high water level.
- All trees leaning over the channel.
- Additional trees as needed to meet rule required targets (minimum of 50 to maximum 250 per 1000 ft).
- Retention of all downed wood and snags that are not safety or fire hazards within the RMA.

2.1.2 Significant Wetland Protection

Significant wetlands include wetlands larger than eight acres, estuaries, bogs and important springs in eastern Oregon. Operators are required to submit written plans describing how they will prevent adverse effects to wetland vegetation required to be retained, and on water quality, hydrologic functions or soil productivity. Significant wetland protection standards include:

- Retention of approximately 50 percent of the live trees, by species and diameter class.
- Minimizing disturbances to soil and hydrologic functions.
- Retention of understory vegetation.
- Retention of all snags and downed trees within the wetlands and the applicable riparian management areas.

2.1.3 Chemical Application

Statewide, the application of chemicals on all land uses is regulated by the Oregon Department of Agriculture. However, to ensure protection of forest resources, the FPA contains additional rules regulating the application of forest chemicals. Some of these include:

- Aerial applications of chemicals may not be directly applied within 60 feet of:
  - Significant wetlands,
  - The aquatic areas of fish and domestic use streams,
  - the aquatic areas of large lakes, or any lakes with fish use.
- Ground applications of chemicals may not be directly applied within 10 feet of the above resources.
- Daily records of chemical applications must be maintained.

2.1.4 Road Construction and Maintenance

The FPA provides standards for the construction and maintenance of roads that provide the maximum practical protection to maintain forest productivity, water quality, and fish and wildlife habitat.

These standards require prior approval for road construction:

- Where a risk exists for road materials to enter waters of the state;
- Where use of machine activity is planned in fish-bearing and domestic use streams, lakes and significant wetlands;
- In riparian management areas;
- On high risk sites prone to landslides; and
- Before constructing stream-crossing fills over 15 feet deep.

2.1.5 Harvesting

The FPA rules set standards for harvesting that maintain the productivity of the land, minimize soil and debris entering waters of the state, and protect fish and wildlife habitat. These standards apply to:

- Log skidding and yarding practices;
- Landing construction;
- Drainage systems for landings, skid trails and fire trails;
- Treatment of waste materials;
- Harvesting on high risk sites;
- Slash treatment; and
- Reforestation.

2.2 Where The FPA Applies and Where it Does Not

Under the FPA, "forest practices" refers to the way in which "commercial" forest "operations" are conducted on "forestland." These operations can involve a number of different activities including but not limited to:

- Harvesting of forest tree species;
- Reforestation;
- Road construction and maintenance;
- Application of chemicals; and
- Disposal of slash.

The key words within this definition are "operation", "commercial" and "forestland":

- "Operation" means any commercial activity relating to the growing or harvesting of forest tree species.
- "Commercial" means engaged in work designed for the market: the exchange or buying and selling of commodities or services.
- "Forestland" means land used for the growing and harvesting of forest tree species, ***regardless of how the land is zoned, taxed or how any state statutes or local ordinances, rules or regulations are applied.***

The FPA rules apply to all non-federal forestland, including private, state-owned and local government-owned forestlands. However, the Oregon Forest

Practices Act does not prevent the conversion of forestland to another use. Where a landowner is actively converting forestland to a land use not compatible with forestry, the land is considered forestland until the trees are cleared and one of two things happen:

1. Forest practices related to stabilizing the site, such as water barring skid trails and revegetating soils, are completed; or

2. Non-forest related development activities begin.

Also, in the event of a land use change in conjunction with a harvest operation, the department may modify its procedures for protecting significant resources. For example, the FPA requires the retention of trees, understory vegetation and other attributes within riparian management areas (RMA) adjacent to fish-bearing streams. The width of the RMA, the number of trees retained and the harvest activities that could occur within the RMA is dependent on the size classification of the stream (small, medium or large). Landowners invoking a land use change (i.e., proving the new use to be incompatible with these FPA protection requirements) could be exempt from applying some forest practice regulations. Such exemptions require prior approval by ODF.

However, in such cases the landowner is still responsible for meeting other state regulations normally met by applying the FPA. Such regulations would likely include the Division of State Lands removal and fill regulations, the Department of Environmental Quality water quality standards, and local comprehensive and zoning code requirements.

2.3 Local Government Option

In 1987, the Legislature enacted a law (ORS 527.722) affecting local government's ability to regulate forest operations. Prior to 1987, local governments were thought to be prohibited from regulating forest operations except within a city's boundaries (city limits). However, with the change in statute local governments (generally cities) could choose to regulate all forest operations in any way or choose not to regulate them within UGBs and city limits.

In 1991, the Legislature amended ORS 527.722 to clarify ODF's role in applying the forest practice rules to forest operations conducted within UGBs. This amendment established that the Oregon Forest Practices Act applied to forestland within UGBs unless local governments adopted their own regulations governing forest practices. Existence or adoption of acknowledged local government forest practice regulations within UGBs relieves the State Forester of the responsibility to administer the Forest Practices Act within the affected areas. As a result of the 1991 legislative changes, ODF is responsible for administering the Oregon Forest Practices Act on forestland within UGBs except where acknowledged local forest practice regulations have been applied.

ODF worked closely with the Legislature in the development of these 1991 amendments to ORS 527.722. ***The clear intent of the bill was to ensure that all forest operations within the state are regulated to protect soil, air, water, and fish and wildlife resources***. However, if a local government desires different regulation than provided by the FPA, then the local government may regulate forest practices within all or a portion of an acknowledged UGB. ***Also, legislative intent was very clear that forest practices were to be regulated by either the FPA or local government regulation, not both.***

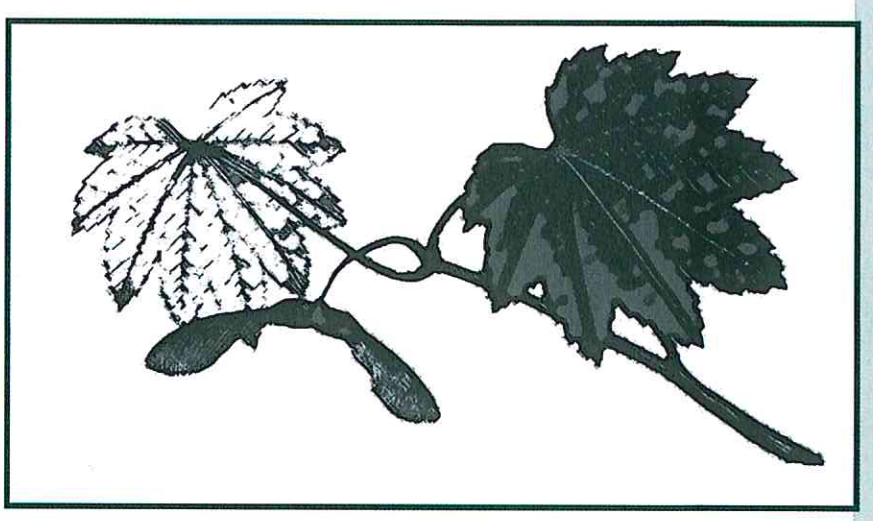
2.4 When Will ODF Not Administer the FPA?

It is ODF's interpretation that **any** acknowledged local ordinance that regulates harvesting, such as how or which trees may be harvested within a UGB,[1] constitutes local forest practices regulations under ORS 527.722. Where such regulations apply, ODF is relieved from administering the FPA.

For example, a local jurisdiction may choose to adopt an ordinance indicating that only selective harvesting (i.e., only so many trees per acre maybe harvested) may occur on forestland within their UGB. In this case, ODF would not administer the FPA within this jurisdiction's UGB.

Another example is a jurisdiction addressing the requirements of Statewide Planning Goal 5 by adopting the "safe harbor"

provisions[2] or other ordinances for protecting riparian vegetation along stream corridors and applying those ordinances or provisions to forest practices. In this case, the jurisdiction would administer its regulations within its riparian corridors, and the ODF would administer the FPA for those forestlands within the UGB not included within the riparian buffer.



Vine Maple
Acer circinatum Pursh

1 Except those regulations governing the removal of trees associated with certain other land use actions. For example, an ordinance regulating the removal of trees associated with the construction of a dwelling is not considered a forest practice regulation. Also, regulations that control the cutting of local "street trees" are not considered as forest practice regulations.

2 Currently, the Goal 5 rule safe harbor for streams with average stream flows greater than 1,000 cubic feet per second (cfs) is a 75 foot corridor on both sides of the stream; streams with an average flow of 1,000 cfs or less protect a 50 foot corridor on both sides.

3.0 URBAN FOREST PRACTICES OBJECTIVES

As stated, Oregon law provides cities and counties the opportunity to regulate forest practices within UGBs[1]. However, local governments that choose to regulate forest practices need to ensure that forest operations are conducted in a manner that protect soil, air, water, and fish and wildlife habitat. Local forest practice regulations that do not provide adequate protection for those resources could be regarded as deficient in meeting other state laws (e.g., the Department of Environmental Quality's water quality standards).

The scope of a forest practices program (determining exactly what trees and sites a local program should cover) is an important consideration since the type of standards and the extent of their application will depend upon this decision. Regulations designed to protect a limited number of specific trees (e.g., mature trees, heritage trees, or landscape trees) are completely different than regulations designed to regulate the removal of trees from managed forestland or trees growing on lands designated for development.

As with all regulations, programs designed to regulate forest operations within UGBs and/or city limits need to address specific objectives, as they do place limitations on private property. Programs that regulate individual private properties need broad community support and a demonstrated need in order to survive both politically and legally.

Protecting trees can be a useful complement to regulations already existing within a city's development code. In Oregon, cities already govern development through planning and zoning laws designed to provide for orderly development. Adding forest practices to the list of development standards may help a city maintain or improve its livability and the area's environment as well as ensure that aesthetically pleasing development occurs. To ensure that trees are not removed before a parcel is ready to be developed, cities should apply forest practice regulations to lands designated for future development.

For local forest regulations to be successful, trees need to be viewed from both the

community and individual property owners' perspectives. From the community perspective, trees need to be viewed not only as part of the overall landscape, but also as an important contributor to the overall environmental health of the community. For example, established trees within riparian corridors are critical for the conservation of fish and wildlife and maintaining water quality. Trees help in reducing both stream turbidity and higher water temperatures during the summer, and they provide a source of future large woody debris for fish habitat.

When developing a forest practices program specifically designed to transition from commercial timber land to a residential neighborhood, it is important to ensure that the development fits the site rather than clearing and grading the site to fit a preconceived development plan. Successful urban forest regulations do not attempt to save every tree. Instead, they protect the most valuable trees; those with the most potential to become assets to the site. Conversely, planners and landowners must be cognizant of stand age, topography and wind firmness when deciding which trees to retain.

Although this document does not address the issue of wildfire in the urban interface, communities within wildfire prone areas which are developing forest practice regulations should be cognizant of the need to maintain defensible space and nonflammable vegetation around structures. Included in Appendix 8.3 are reference materials which can be helpful in addressing these issues.

In preparing plan policies and implementing land use regulations to retain forestlands primarily to benefit other resource or community values, a local government may need to follow the procedures established by the Land Conservation and Development Commission (LCDC) in their Oregon Administrative Rules (OARs). Specifically, OAR 660, Division 23, which implements Goal 5, specifies a process for protecting riparian areas, wetlands, and fish and wildlife habitats. In addition, ordinance provisions developed to regulate forest practices may also need to include requirements addressing other statewide planning goals[1], as well as those of the Division of State Lands and the Department of Environmental Quality.

3.1 City and County Intergovernmental Agreement

Generally, city land use policies are found in the comprehensive land use plan and apply within the city limits and possibly to lands within the urban growth area (the area outside the city limits and inside the UGB). A county's tree-cutting land use regulations would only apply within the urban growth area unless the city and the county adopt the same regulations for lands inside the UGB. If a city wants its or the county's forest practices regulations to apply inside the UGB, it may be necessary for the city and county to amend their intergovernmental agreement (sometimes referred to as an Urban Growth Agreement or Urban Growth Management Agreement).

3.2 Preparing an Urban Forest Practices Program

The first step in developing a local urban forest practice program is to answer the following questions: Why does our community need an urban forest practices program? What problems are we trying to address? What can we gain in addition to what the Oregon Forest Practices Act already provides? Or what do we not want that the Forest Practices Act requires? Examples of issues addressed by urban forest practice programs may include:

- Maintaining forest canopy.
- Reducing tree loss during development.
- Retaining trees as a buffer between residential and industrial uses.
- Retaining trees within riparian corridors.
- Reducing damage to existing trees during construction.
- Strategically retaining trees while allowing harvests for solar access.
- Shade retention.
- Street/bikeway/pedestrian path beautification.
- Scenic view preservation.
- Strategically retaining trees or allowing harvests for view enhancement.

4 Goals 5 (Open Spaces, Scenic and Historic Areas, and Natural Resources), 15 (Willamette Greenway) and 17 (Coastal Shorelands).

Once reasons for developing forest practice regulations has been determined, specific goal or objective statements should be developed. For example, one goal maybe to have newer residential neighborhoods blend with older established neighborhoods. To meet this goal, not only would street patterns need to be coordinated, but also older trees would have to be retained on new lots, in street rights-of-way, and in future park and school locations. Such a goal may read as follows: *Ensure that new development near older neighborhoods is designed to blend with and compliment the attributes found in our older neighborhoods.* This goal could then lead to the development of **specific plan policies** specifying the need to leave trees on undeveloped forestlands located near existing residential neighborhoods.

For example, the following policy provides specific directions for retaining trees to achieve the previously stated goal:

It is the policy of the city to retain trees between 20 and 70 years old so that new developments can safely provide the following benefits: (1) Shade for future homes, schools, parks and streams; (2) An aesthetic buffer between automobiles and pedestrians and homes; and (3) Habitat for wildlife.

After a community determines precisely why they want to regulate forest practices, an **inventory or assessment** of the forestland resource should occur next. This inventory should identify the quantity, quality and location of the type or types of forestland the community wants to protect. This may be accomplished a number of ways, including "windshield" surveys, tree inventories, aerial photography, or the use of geographic information systems (GIS). Based on this inventory, the community has a number of decisions to make regarding what type of regulations to adopt, if any, and where to apply them.

After the community completes the inventory, it may be useful to examine alternatives to achieving the community's identified goals. For example, teaching landowners about the need to protect a certain type or number of trees in a given area may achieve the community's goal without having to prepare and apply regulations. In some cases, acquisition, covenants, deed restrictions, open space tax incentives or land trades can be used to achieve the same results. Involving the news media in the community's effort to achieve its goals and objectives may be useful in drawing attention to the need to protect certain trees or specific forestlands, thus rendering the need for an urban forest practice ordinance unnecessary.

A jurisdiction may choose to rely on the FPA to achieve its goals and objectives for certain types of inventoried forestlands while developing local regulations for other types of forestlands within the UGB. Under this scenario, **detailed mapping** of the properties subject to the FPA is necessary so that ODF knows which forestlands are still under its administration.

When a decision has been made that forest practices regulations may be appropriate and necessary, the next step should be to involve the public. In as much as the goals of a program reflect community values and opinions, an open and public process is an important element. Successful regulations have broad community and political support. If the citizens of a community do not agree with the need to develop and apply urban forest regulations, independent of the FPA, they will be even less willing to approve the funding necessary to see that the regulations are enforced.

As a forest practices program is developed, a process for evaluating the success of the regulations should also be developed. This step serves two purposes. First, most new programs need more than one revision before they successfully implement the stated polices. Second, by stating "up-front" that the community will reevaluate specific provisions of the program at a specific time (e.g., 2 years), it reinforces the attitude that the regulations are not "cast in stone." Thus, regulations that do not work, can be changed.

Once a need for local forest practice regulation is identified, determine if meeting the need will involve any Statewide Planning Goals, such as Goal 5. Some cities have adopted "tree protection regulations" without going through the post-acknowledgment plan amendment process (ORS 197.610). They have simply adopted a stand-alone ordinance to regulate tree cutting that requires, for example, a tree-cutting permit be obtained prior to cutting trees. It is strongly recommended that the city attorney or county counsel be consulted as to the need to go through post-acknowledgment plan amendment process or to adopt a stand-alone ordinance.

4.0 DEVELOPING AN URBAN FOREST PRACTICES ORDINANCE

Urban forest practice regulations should be tailored specifically to the needs of the community. A model ordinance does not exist that would meet the goals and expectations of every community. However, there are examples of regulatory language that can be tailored to address certain issues.

The following examples of regulatory language with accompanying descriptions are provided to help jurisdictions construct regulations that might meet local needs. These suggestions will need to be edited to fit the needs of the particular situation. Each clause is listed by title, includes a brief description, and is followed by sample language that addresses the specific issues.

4.1 Title

The title should be a brief description of the program:

This program shall be known as the [jurisdiction's name]Forest Practices Ordinance.

4.2 Purpose or Preamble

The purpose or preamble should clearly state the reasons or need for the program and should relate directly to the community's stated goals.

The city desires to provide for the orderly transition from open space and forestland to residential neighborhoods. The city recognizes the need to preserve some open space and maintain certain forest lands for their environmental and aesthetic values, which include wildlife habitat and clean water. This ordinance is intended to implement the goals and policies found in the "Urban Forest Program" section of the comprehensive plan. Upon application of this ordinance to the lands identified in the plan's "Urban Forest" section, the city assumes the responsibility of regulating forest practices on those lands under the authority granted the city by ORS 527.722.

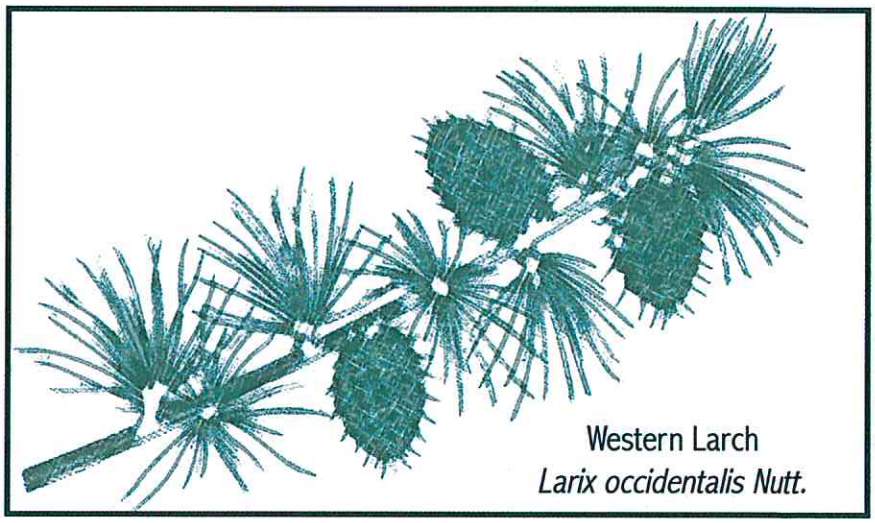
The purpose or preamble of an urban forest practices ordinance is the place where the city or county "makes its case" for applying the ordinance (also known as the "nexus" between the ordinance and the goals and policies to be implemented). Statements regarding the economic, social and environmental benefits of the forestlands in question can be included. Clearly stating the purpose of an ordinance is an important step in avoiding future legal misunderstandings.

4.3 Definitions

Definitions are important to clarify the meaning of certain words, phases or terms used in the ordinance. Some of the more common terms needing definitions may include: forest practice, developable land, certified arborist, forest operation, etc.

For the purposes of this program, the following words and phrases shall have the following meanings: . . . ."Certified Arborist" means an individual *who has passed certification exams and holds current status as a Certified Arborist through the International Society of Arboriculture. "Tree" means. . .*

The definitions section should clearly define words or terms that embody concepts that can be misinterpreted. Terms like "cut" or "damage" may have different meanings depending upon the circumstances. In some cases, an urban forest practices program may need to use the same term to implement different regulations. If that case arises, the jurisdiction may need to define the same term differently in specific sections of the ordinance. Such precision may be important in providing flexibility.



Western Larch
Larix occidentalis Nutt.

4.4 Scope and Application

Based on the policies in the comprehensive plan, the ordinance should clearly identify the types of forest practices to be regulated and the forestlands on which the particular program provisions will apply. For example, regulations contained within an urban forest practices ordinance could apply to one or more of the following situations:

- Forestland designated for development - any forested parcel or lot that can be subdivided and developed.
- Private trees - trees over a certain diameter size or of a particular species growing on private property.
- Historic Trees - trees with some historical significance.
- Tax-deferred lands and dedicated forestland - land currently under tax deferral through state and county programs to defer property taxes and encourage forest productivity.
- Riparian corridors - lands adjacent to wetlands, creeks, streams and rivers.
- Trees separating residential from industrial lands.
- Forestlands associated with identified scenic values.
- Trees valued for their proximity to certain streets, bike and pedestrian paths.

In some cases, communities may not want the same regulations to apply everywhere. For example, a community may want to regulate forestlands that are being harvested for the purpose of converting the land for development while not wanting the same regulations to apply to other forestland that continues to be used for growing and harvesting commercial timber. This may be done using a statement like the one that follows:

This forest practices ordinance applies to all forested parcels within the urban growth boundary that are designated in the comprehensive plan for residential, commercial or industrial development except for those forested parcels currently managed as forestland which are receiving a forest tax deferral.

It should be noted that regulations must be consistent with other state and local laws, and city policies or procedures. For example, some forested parcels within urban growth boundaries may be in a forest tax deferral status. In this situation, the county is allowing a landowner to pay a reduced level of taxes with the expectation that at the time of harvest, the county will recoup those revenues. Forestland receiving a tax deferral should be made part of the initial inventory so that an assessment can be made to determine whether or not an urban forest ordinance should be applied to those lands.

Another factor to consider is whether or not there is a need to apply an urban forest practices ordinance to all lands within the UGB or city limits to ensure adequate tree retention on forested lands designated for development. If a program is designed to regulate only forestlands involved in the development process, a landowner may clear the land of trees valued by the community before an application to develop is submitted, thus, circumventing the urban forest ordinance.

4.5 Operating Procedures

Below are examples of provisions a jurisdiction may want to include within an urban forest ordinance. These example address the application process, the application review procedure, notifications, permit requirements, fees, and the appeal procedure. Some cities may want to add provisions or develop more than one permit procedure (e.g., one for individual lots and another for reviewing subdivision proposals), depending on local circumstances.

Before any trees over___ inches in diameter are removed, a permit shall be obtained from ——(e.g., the Planning Department). Before a permit can be issued, the following must be obtained by the owner and submitted as part of the permit application: A survey of all trees over___ inches in diameter, a report by a Certified Arborist identifying those trees that can ***safely*** *be retained as: (1) shade trees for home or water bodies that provide fish and wildlife habitat; and (2) a buffer between cars and proposed pedestrian walkways.*

Ordinance Standards- The standards by which applications must be judged are crucial to the success of an urban forest practice program. Such standards could address:

- Tree retention - the number and types of trees that must be left on the site.
- Tree replacement - the number and types of trees that must be replanted.
- Air, water, soil, fish and wildlife habitat protection.

Examples of possible standards are as follows:

- Subdivisions and planned unit development applications shall include findings which show how the proposed development will be consistent with urban forest policies of the comprehensive plan.

- Trees smaller than ___ inches in diameter may be removed.

- Where necessary, certain trees of ___ inches in diameter, consistent with the Arborist's report, may also be removed to facilitate the construction of home sites and roads, provided no feasible alternative exists.

- Trees identified as diseased or structurally unsafe may also be removed.

- Proposed developments are required to maintain ___ percent of the existing tree canopy. Where a development is not able to maintain this standard, a mitigation requirement of three trees of ___ inches in diameter will be planted for every tree removed below the ___ percent standard.

- Trees within ___ feet of a stream or water body must be left (see also LCDC Goal 5 rules - OAR Chapter 660, Division 23).

- ANSI A300 Standards for Tree Maintenance and ANSI Z60.1 Standards for Nursery Stock will be required for all trees covered by this section.

11

To protect soil, air, water, and fish and wildlife resources, the ODF highly recommends communities adopt standards consistent with those in the FPA and the Forest Practices Rules. For example, a local jurisdiction developing tree retention standards along streams could adopt tree retention and understory vegetation requirements similar to those required by the FPA. FPA vegetation retention requirements are based on beneficial use of the water (fish or domestic) and stream size (large, medium or small). ODF has stream classification maps developed for the FPA that could be made available to local jurisdictions for the development of their ordinance. The benefits of having consistent statewide standards are: (1) at least an acceptable level of protection for these resources is provided; and (2) landowner/operator confusion is reduced when operations occur across jurisdictional boundaries.

Standards for tree retention and replacement will vary based on the community's objectives, the type of trees that grow within the region, the types of resources receiving some form of protection, and the types of land uses to be proposed. While ORS 527.722 dictates that cities must provide protection for air, water, soil, and fish and wildlife resources, it does not stipulate what level of protection is required. Cities must ensure that these resources are protected and that they satisfy other regulations such as the Clean Water Act (normally met by administering the FPA). Development of a local program will need to consider and ultimately decide on the levels of protection.

Enforcement - The local agency responsible for enforcement, the penalties for violating the program regulations, and the method of enforcement should be included in the urban forest practices program. The following is an example addressing these points:

The planning department is charged with the responsibility of enforcing the regulations of the forest practices program. Parties proposing developments will not be issued permits until proof is provided that the proposal complies with the urban forest practices program.

Where development permits have been issued and a violation has occurred, fines of $250 a day for every day not in compliance with these regulations will be assessed.

Penalties for unauthorized tree removal shall be assessed per offense.

Fines collected under this program shall be deposited into a special account to be used for enforcing this program. Any money collected beyond that shall be deposited into a special account to be used for tree planting within the city.

Fees - The city will need to adopt a fee schedule that reflects the cost of administering the program. Funding an enforcement mechanism is often accomplished by application fees. The use of consultants may be neces sary where a community's size does not allow for the hiring of a code enforcement officer. Incentives and education should also be a part of the implementation strategy. Mitigation measures and penalties for violating program regulations should be clear and should be strong enough to dissuade violators.

Appeals Process - The standard appeals process found in the existing development code or zoning ordinance should be referenced in the local jurisdiction's urban forest practices program.

As a result of the passage of Ballot Measure 56 by the Oregon voters in 1998, adoption of any new local regulations will likely require notification of those property owners affected. According to the law, such notices must be sent at least 20 (but not more than 40 days) days before the date of the first hearing.

The law requires that the notice **describe in detail** how the proposed ordinance would affect the use of the property. The law also requires that the notice "contain substantially" the following language in boldfaced type extending from the left-hand margin to the right-hand margin across the face page of the notice:

THIS IS TO NOTIFY YOU THAT THE (jurisdiction name goes here) HAS PROPOSED A LAND USE REGULATION THAT WILL AFFECT THE PERMISSIBLE USES OF YOUR LAND

The body of the notice must also contain substantially the following language:

On (date of public hearing), (jurisdiction name) will hold a public hearing regarding the adoption of Ordinance Number ___. The (jurisdiction name) has determined that adoption of this ordinance will affect the permissible uses of your property and may reduce the value of your property.

Ordinance Number ____ is available for inspection at (identify place) located at (list address here). A copy of Ordinance Number ___ also is available for purchase at a cost of (price here).

For additional information concerning Ordinance Number ____, you may call the (identify staff person or office to call) at (__) ___-____.

If you need further assistance regarding notice obligations under the law, please seek assistance from your legal counsel.

6.0 ADMINISTERING THE URBAN FOREST PRACTICES PROGRAM

Perhaps the greatest challenge facing local government is how to administer an urban forest practices program. While the Oregon Department of Forestry can provide technical guidance to help with the development of forest practices programs, the Department cannot be involved in the enforcement of local forest regulations. Most counties and cities do not have technical forestry expertise, so such expertise must either be acquired or contracted.

Local governments lacking forestry expertise may want to consider contracting with a consulting forester or arborist to handle inspections of projects. Consultants could also be used to monitor technical compliance and to enforce program standards as well as to review technical specifications. In order to avoid "reinventing the wheel," cities should consider reviewing and, where feasible, borrowing existing technical standards and adapting them to address local issues and need.

With any regulations, there are bound to be inconsistencies or unintended consequences that must be addressed. Anticipating the loopholes is a challenge all cities face while developing an urban forest practice ordinance.

7.0 SUMMARY

The Oregon Department of Forestry encourages cities and counties, where possible, to regulate forest practices inside Urban Growth Boundaries. As local governments evaluate the need for local forest practices regulations, ODF's Forest Practices and Urban Community Forestry Programs can provide technical assistance and review in the development and draft of ordinances.

Local governments that want to replace state administration of the forest practices act are encouraged to contact their local ODF field office. In order to provide smooth transition, ODF will provide information about active or planned operations within areas that will fall under local regulation.

The appendices contain a list of publications and documents which may be helpful in developing local forest regulations.

8.0 APPENDICES

8.1 List of Acronyms

FPA Forest Practices Act
ODF Oregon Department of Forestry
UGB Urban Growth Boundary
FPF Forest Practice Forester
ORS Oregon Revised Statute
RMA Riparian Management Area
HB House Bill
SB Senate Bill
OAR Oregon Administrative Rule
LCDC Land Conservation and Development Commission
GIS Geographic Information System
ANSI American National Standards Institute

8.2 Sources of Assistance

For more information about the Oregon Forest Practices Act or the Forest Practice Rules, please contact your local Oregon Department of Forestry district office listed below or the headquarters office at 2600 State Street, Salem, Oregon 97310, 503-945-7470. For information related to urban forestry and community assistance contact, the above address, phone number 503-945-7391.

Eastern Oregon
3501 E 3rd, Prineville 97754 541-447-5658
3701 W 13th, The Dalles 97058 541-296-4626
400 NW 9th, John Day 97845 541-575-1139
3200 DeLap Road, Klamath Falls 97601 541-883-5681
2290 4th Street, Lakeview 97630 541-947-3311
611 20th Street, La Grande 98750 541-963-3168
1055 Airport Road, Pendleton 97801 541-276-3491
802 West Hwy 82, Wallowa 97885 541-886-2881
Northwest Oregon
801 Gales Creek Road, Forest Grove 97116 503-357-2191
Route 1, Box 950, Astoria 97103 503-325-5451
405 E Street, Columbia City 97108 503-397-2636
4907 East 3rd Street, Tillamook 97141 503-842-2545
14995 South Hwy 211, Molalla 97038 503-829-2216
22965 North Fork Road SE, Lyons 97358 541-859-2151
24533 Alsea Highway, Philomath 97370 541-929-3266
825 Oak Villa, Dallas 97338 503-623-8146
763 Forestry Road, Toledo 97391 541-336-2273
Southern Oregon
1758 NE Airport Road, Roseburg 97470 541-440-3412
300 5th Street, Bay Park, Coos Bay 97420 541-267-4136
4690 Highway 20, Sweet Home 97386 541-367-6108
3150 Main Street, Springfield 97478 541-726-3588
87950 Territorial Highway, Veneta 97487 541-935-2283
5286 Table Rock, Central Point 97502 541-664-3328
5375 Monument Drive, Grants Pass 97526 541-474-3152

For current Oregon forest practice rule information, connect to the Oregon Department of Forestry's Forest Practices Program world wide web page at:
http://www.odf.state.or.us/forprac.htm
For Urban Forestry and Community assistance:
http://www.odf.state.or.us/urban.htm

8.3 References

"Oregon Forest Practices Act". ORS 527.610 to 527.992. Oregon Department of Forestry, Forest Practices Program, 2600 State Street, Salem, Oregon 97310.

"Oregon Forest Practice Administrative Rules". Division 600 to Division 665. Oregon Department of Forestry, Forest Practices Program, 2600 State Street, Salem, Oregon 97310.

"Stream Classification Maps". Oregon Department of Forestry, Forest Practices Program, 2600 State Street, Salem, Oregon 97310.

"Criteria For Determination of Wildfire Zones". OAR 629-044-0200 to 629-044-0260. These rules must be applied to activate the provisions of ORS 93.270(4) and portions of the Oregon One and Two Family Dwelling Specialty Code. Oregon Department of Forestry, 2600 State Street, Salem, Oregon 97310.

Division 23, Procedures and Requirements For Complying With Goal 5, OAR 660-023-000 to 660-023-0250. Oregon Department of Land Conservation and Development. Salem, Oregon.

Bernhardt, E. A.; Swiecki, T.J. 1991. Guidelines for Developing and Evaluating Tree Ordinances. California Department of Forestry and Fire Protection Urban Forestry Program. 76p.

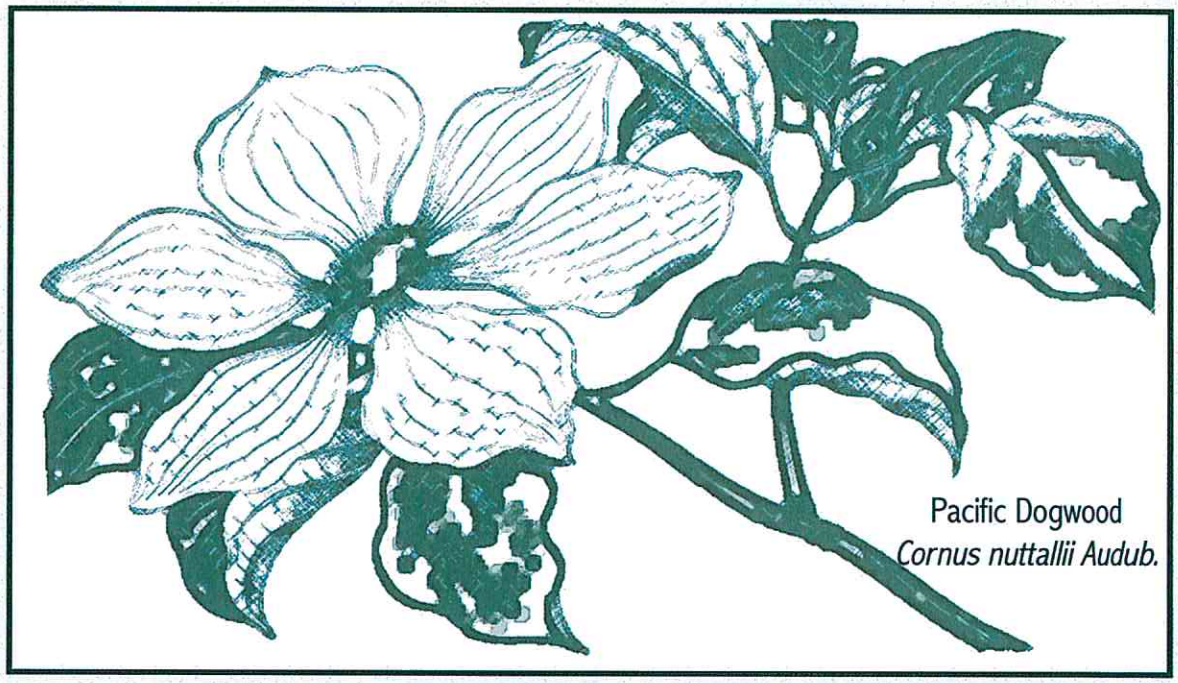
Duerksen, C. J.; Richman, S. 1993. Tree Conservation Ordinances. PAS Report Number 446. American Planning Association and Scenic America. Washington, DC. 107p.

Fazio, J. R., ed 1993. "Tree Protection Ordinances". Tree City USA Bulletin No. 30. The National Arbor Day Foundation. Nebraska City, Nebraska. 8p.

Minnesota Department of Natural Resources. 1995. "A Guide to Developing a Community Tree Preservation Ordinance" Department of Natural Resources Division of Forestry. St. Paul, Minnesota. 13p.

15 Oregon Department of Forestry. 1991. "Recommended Fire Siting Standards for Dwellings and Structures and Fire Safety Design Standards for Roads." Land Use Planning Notes. Salem, Oregon. 8p.

Washington State Department of Natural Resources. 1990." Home Protection Guide." Olympia, Washington. 32p.


Pacific Dogwood
Cornus nuttallii Audub.

(d) CAL FIRE Urban and Community Forestry Program Grants.

1. Urban Forest Management For GHG Reduction Grant Program Information.

Urban and Community Forestry Program Greenhouse Gas Reduction Fund (GGRF) Grants

Procedural Guide*(for all five grant project types - read this first.)*

Urban and Community Forestry GGRF Questions and Answers (Q&A)

Project Type	Description	Grant Amount	Match* State/Others	Forms
"Green Trees For The Golden State"	Urban tree planting projects and tree establishment care during the grant period. Preference will be given to the planting of trees to optimize the multiple benefits of urban forests in environmental justice communities with special attention given to GHG sequestration and avoided GHG emissions.	$150,000 - $750,000	75/25	RFP
Urban Forest Management For GHG Reduction	For cities, counties, and districts only. Establishing a new jurisdiction-wide tree inventory, and/or urban forest mapping and analysis, and/or long term management plan or updating existing versions of these critical management components. May include policy integration and ordinance development. Applicants must show how GHG will be reduced by the project. See RFP for requirements.	$150,000 - $750,000	75/25	RFP
Urban Wood and Biomass Utilization	Projects that will use urban woody biomass for its highest and best use, thereby diverting it from the urban waste stream and avoiding GHG emissions while sequestering GHG for a longer time period.	$150,000 - $500,000	75/25	RFP
"Woods in the Neighborhood" (Reclamation of blighted urban lands).	These projects are to assist local entities to purchase and improve unused, vacant urban neighborhood properties in environmental justice communities or to	$200,000 - $1,500,000	75/25	RFP

Urban Forestry Grants Section Links

- GGRF Grants Workshops/Webinar Slideshow
- Tools for Estimating Greenhouse Gas Benefits of Trees Webinar Recording
- Urban & Community Forestry Program

Resource Management Links

- Forest Practice
- Forestry/Landowner Assistance
- Environmental Protection and Regulations Program
- State Forests
- Climate Change

Urban Forestry Grants Project Application Forms & Information

- Procedural Guide
- Project Proposal
- CEQA Checklist
- Governing Resoultion
- Budget Template
- Payee Data Record (Std. 204)
- Nondiscrimination Compliance Statement (Std. 19)
- Drug-Free Workplace Certification (Std. 21)

Disadvantaged Communities Resource Links

- CalEPA Guidance On Disadvantaged Communities
- SB 535 Disadvantaged Communities Maps
- CalEnviroScreen 2.0 tool
- ARB Interim Guide on Investments to DACs
- Cal EPA's document outlining possible methodologies for determining DACs

GGRF External Links

- AB 32 Statute
- Air Resources Board AB 32 Overview
- AB 32 Climate Change Scoping Plan
- AB 32 Scoping Plan, Appendix C - Natural and Working Lands Working Paper
- Compliance Offset Protocol U.S. Forest Projects (Forest Offset Protocol)
- Forest Project Protocol

	serve such communities for purposes consistent with the Urban Forestry Act. These projects must demonstrate how GHG will be reduced.			
"Green Innovations" Projects	For urban green infrastructure projects falling within the scope of the Urban Forestry Act of 1978 that are not able to fit in one of the other Urban Forestry Grant Programs above. These projects should be unique and forward-thinking. Projects must show how GHG will be reduced. Selection will be strongly focused on environmental justice communities.	$200,000 - $1,500,000	75/25	RFP

*Note 1: Communities meeting environmental justice criteria as described in the Procedural Guide (Pages 6-7) can qualify for a reduced or waived cost share requirement with proof of status.

Note 2: Educational activities may be undertaken as a portion of each grant type not to exceed 20% of the CAL FIRE share of the budget.

Note 3: Unless otherwise explained above, eligible entities are cities, counties, districts, and 501C(3) non-profit organizations.

GETTING STARTED – A quick guide to the 2014/2015 Urban & Community Forestry Grant Cycle

READ THE PROCEDURAL GUIDE! This document details how the application process works, applicant eligibility requirements and can help you determine which grant category you may be interested in. This guide also details how CAL FIRE USFS grant projects are to be managed.

READ THE REQUEST FOR PROPOSALS (RFP) DOCUMENT! This is your final document after you decide on the grant category you are interested in. The RFP provides specific information about the project types, grant review criteria, matching requirements, and more.

Fill out and electronically submit the **Concept Proposal** following the instructions on the form. Applications are due by November 10, 2014. If you are applying for more than one grant type, please be sure to fill out the appropriate form for each project type.

REMEMBER! You, CAL FIRE Regional Urban Foresters are available to assist you throughout the grant process. Contact them early and often with questions. Contact information can be found on the website listed above or in the Procedural Guide.

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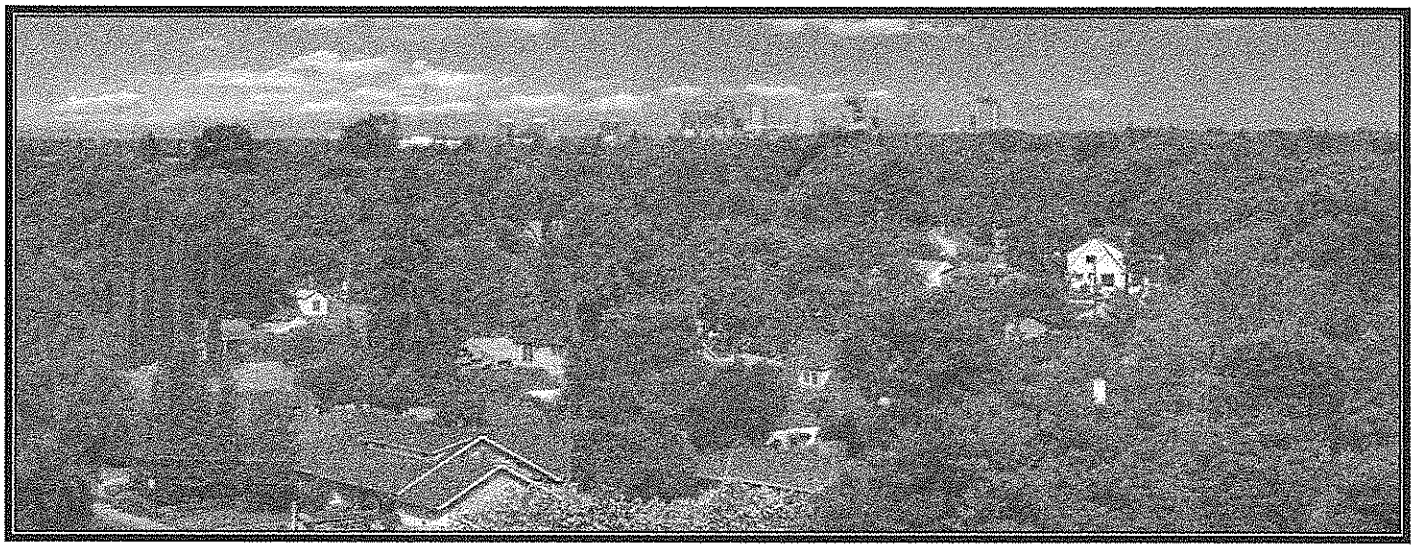
State of California
Department of Forestry & Fire Protection *(CAL FIRE)*
Urban and Community Forestry Program
Greenhouse Gas Reduction Fund Grants

Urban Forest Management For GHG Reduction
Request for Proposals
2014/2015
Concept Proposals Due: November 13, 2014



CAL FIRE Urban and Community Forestry will offer workshops on the entire grant application and administration process for all prospective applicants.
Please watch http://www.fire.ca.gov/resource_mgt/resource_mgt_urbanforestry_grants.php for dates, times, and locations of these workshops or contact your Regional Urban Forester (Appendix E of Urban & Community Forestry Grants Procedural Guide for 2014/2015) for details.

Grant programs authorized by:

The California Urban Forestry Act of 1978 (Public Resources Code 4799.06 – 4799.12)

A copy of which can be found at:
http://www.fire.ca.gov/resource_mgt/resource_mgt_urbanforestry.php

Grant funds made available from the following sources:
The California Greenhouse Gas Reduction Fund
and/or
USDA Forest Service Urban & Community Forestry Program Fund

Urban & Community Forestry Greenhouse Gas Reduction Fund Grants: Urban Forest Management Plans 2014-2015

IMPORTANT NOTE:

Please also see and refer to the Urban & Community Forestry Grants Procedural Guide for 2014/2015. This document is available at:

http://www.fire.ca.gov/resource_mgt_urbanforestry_grants.php

or

http://www.ufei.org/grantinfo.lasso

Grant applicants are responsible to meet the requirements of both documents. This RFP document takes precedence in the case of a conflict between the two documents.

Introduction:

The California Department of Forestry and Fire Protection (CAL FIRE) Urban & Community Forestry Program works to optimize the benefits of trees and related vegetation through multiple-objective projects that provide environmental services and cost-effective solutions to the needs of urban communities and local agencies, including, but not limited to, increased water supply, clean air and water, reduced energy use, flood and storm water management, recreation, urban revitalization, improved public health, and producing useful products such as bio-fuel, clean energy, and high quality wood. Such efforts play a significant role in meeting the state's greenhouse gas (GHG) emission reduction targets. CAL FIRE encourages resident participation in the development and implementation of state and local agency and non-profit organization urban forestry programs and projects.

The CAL FIRE Urban & Community Forestry Program has set aside funds to provide grants to organizations that wish to create or implement a "*Urban Forest Management For GHG Reduction*" project. The funding level of each CAL FIRE Urban & Community Forestry grant program may be adjusted based on the applications received and funds available to CAL FIRE for these purposes. Strong preference will be given to communities identified as environmental justice communities utilizing the CalEnviroScreen 2.0 tool that can be found at: http://oehha.ca.gov/ej/ces2.html.

Eligible applicants include cities, counties, qualifying districts, or nonprofit organizations qualified under Section 501(c)(3) of the Internal Revenue Code (PRC 5096.605). Districts include, but are not limited to, school, park, recreation, water, and local taxing districts.

Purpose:

The purpose of this grant program is to fund the development and implementation of urban forest management activities to reduce GHG and to be carried out by a jurisdiction to optimize the benefits of its urban forest. Such activities will be holistic, long term, include the entire jurisdiction, take an ecosystem management approach and may include an inventory, analysis, training and/or educational component. No other practices may be funded by this grant program.

Project Rating Criteria:

All content of this RFP and the accompanying "Urban & Community Forestry Grants Procedural Guide for 2014/2015" document may be utilized for rating purposes. See below for specific information that will be utilized to rate projects.

Conditions:

All of the following conditions must be met for a proposed urban forestry management plan to be eligible for a grant:

- Grant requests must be for doing tree inventory work and/or establishing a new management plan or updating an existing inventory or management plan as well as associated mapping and analysis.
- The project will lead to sequestration of significant amounts of GHG and/or avoid emissions of significant amounts of GHG over a 40 year period (see "GHG Tracking and Reporting" below).
- The applicant must be a city, county, or district.
- The amount requested must be between $150,000 and $750,000.
- An applicant may only submit one application for this grant program in this fiscal year.
- Applicants must show proof of an existing urban forest/street tree protection system (city ordinance, general plan element, etc.).
- Applicants must show proof of having an existing urban forester, arborist, or other qualified position responsible for urban forest resources or have such a professional under contract.
- A project must be located in, or immediately adjacent to, an "urban area" or "urban cluster" as defined by the U.S. Census Bureau. (http://www.census.gov/geo/www/ua/2010urbanruralclass.html)
- The applicant has complied (and will comply) in all respects with all applicable local and county ordinances, and all applicable state and federal laws and regulations, including the California Environmental Quality Act (CEQA).
- An inventory must be completed before developing a management plan.
- The management plan must be a long term (40-50 year), holistic document, not solely a maintenance plan.
- There shall be a provision for periodic review of the management plan.
- Inventory data collected must follow the criteria set forth in Appendix G of the *Urban & Community Forestry Grants Procedural Guide.*
- Applicants must demonstrate how they will implement and utilize the inventory, analysis, and/or Management Plan.
- Applicants must agree to refer to the Management Plan as a guiding policy document in an ordinance, a general plan element or another binding, enforceable way as approved by CAL FIRE staff.
- An education component may be included but must not be more than 20% of the project budget.
- Applicants must provide an electronic and printed copy of all grant products to CAL FIRE Urban & Community Forestry at the conclusion of the grant.
- CAL FIRE's Urban and Community Forestry Program and the funding source must be acknowledged in any documents or other media produced.

Desirable Concept Proposal Attributes:

- The project will take place in a CalEnviroScreen 2.0 identified community.
- The project will serve a CalEnviroScreen 2.0 identified community.
- The project will commit the jurisdiction to a systematic strategy for long term management of

its entire urban forest resource.

- The project will produce a product or products that will be widely available for public consumption.
- The product produced will be compatible with the jurisdiction's other policies and ordinances and will not conflict with any state or federal laws or regulations.
- The project will have a provision for periodic review and adjustment of the plan utilizing public opinion and the most current science and information available.
- The project has an educational component and develops public awareness of the need for expanding and managing urban forest resources.
- The inventory and analysis will be used to inform the management plan.
- The plan will be implemented and is somehow tied to a city ordinance or general plan element or other acceptable enforceable mechanism.
- The planning process will perform mapping and analysis that leads to a well-informed plan or will utilize existing maps and analysis for the same.
- The plan is referred to in a Climate Action Plan or similar plan.

Ineligible Projects:

- No practices other than those described above may be funded by this grant program without prior written approval by CAL FIRE.
- Projects that will supplant a locally funded budget item rather than supplement it.

Ineligible Costs:

This grant cannot finance any undertaking or complete any practice designed to supplant rather than supplement existing local agency activities. Such ineligible practices shall consist of any request that CAL FIRE furnish grants to take the place of a regular or ongoing fiscal commitment to a program or project by a local government. Any practices that are required as mitigation of any kind may not be financed by this grant program. Additionally, costs other than those explicitly stated as eligible costs above may not be paid for by this grant program.

For projects that include an Urban or Community Forestry education program, no more than 20% of grant funds may be used towards each of these activities. These activities as part of the overall project can be shown as project match dollars by the applicant.

Cost share:

These grants are to share the cost of eligible urban forestry projects. The proportion of the project's cost funded by CAL FIRE Urban & Community Forestry shall not be greater than 75%. Matching requirements (25%) for state funds may be met with in-kind activities or materials related to the project, as well as with any state funding source related to the project that is not the same as the state source of funding awarded by CAL FIRE. USDA Forest Service funds granted by the Urban and Community Forestry Program can be matched by non-USDA Forest Service federal funding.

For example:

Total Project = $1,000,000.00
CAL FIRE Request = $750,000.00
Minimum match required = $250,000.00

Important Notes on Cost Share:

Projects taking place in environmental justice communities as identified using CalEnviroScreen 2.0 criteria will be eligible to have their cost share requirement completely waived by CAL FIRE. This request must be made during the concept proposal process by checking the appropriate box on the form.

Projects that will serve a CalEnviroScreen 2.0 will be eligible to have increased cost share of up to 90% of project costs with a 10% matching contribution in the form of material, services, equipment, or funds from any non-state source. Such communities must be able to prove they meet the criteria. Please see Procedural Guide for further details.

GHG Tracking and Reporting

The State of California requires that grant projects track their carbon sequestration and avoided emissions, as well as any emissions a project may have. CAL FIRE has worked with the California Air Resources Board (CARB), the USDA Forest Service (USFS), and other partners to develop a methodology and tools for meeting these reporting requirements.

For application purposes, estimates of carbon emissions and reductions must be as accurate as possible. Any deviation from the suggested tool and methodology below must be explained, and prior approval for the deviation must be approved by CAL FIRE.

Reporting must be done for each grant project progress reporting period (quarterly).

If improved tools become available during the project period, grantees may request CAL FIRE to approve an updated tool or methodology to increase accuracy or reduce costs with the same accuracy. Increased cost and/or reduced accuracy will not be approved.

Many projects may have a tree planting component, even if that is not the focus of the project. The suggested tool for tree planting is the USDA Forest Service Urban Tree Carbon Calculator. This tool can be found at the following web page:

http://www.fire.ca.gov/resource_mgt/resource_mgt_urbanforestry.php

Projects must project their GHG reductions and emissions for a minimum of 40 years. Direct sequestration of GHG and any avoided GHG emissions resulting from co-benefits of the project may be taken into consideration. When reporting, the projected direct sequestration must be reported separately from the avoided emissions. In addition, any emissions associated with the project must be reported. A net GHG benefit must result when taking these three reported numbers into account.

See for example:

CO2 Stored By Trees	-24,089	metric tonnes (t)
CO2 Avoided Emissions By Trees	-29,158	t
CO2 Emitted By Project	+1,000	t
Total CO2 Reduction	**-52,247**	**t**

For other project considerations, applicants must identify the tools that will be utilized to meet the project GHG reporting requirements above, and provide a justification. All calculations must be clearly shown.

Application Process:

The first step is to complete a Concept Proposal. If your Concept Proposal is selected, you will be asked to complete a Project Application. The Concept Proposal can be found at:

http://www.fire.ca.gov/resource_mgt_urbanforestry_grants.php
or
http://www.ufei.org/grantinfo.lasso

- Concept proposals must be submitted electronically in the provided format by November 13, 2014.
- Email or electronic submissions other than in the provided format will not be accepted unless alternative arrangements are made with Urban & Community Forestry Program staff at least two weeks prior to the deadline.
- Do not send unsolicited materials. Doing so will result in rejection of the application.
- In the case of technical difficulties or an inability to utilize the online format, please contact your CAL FIRE Regional Urban Forester for authorization to use alternative grant submittal procedures (see *"Urban & Community Forestry Grants Procedural Guide for 2014/2015"* Appendix E).
- Late submissions will be rejected. No exceptions. Late is defined as: after 11:59 PM PST on the due date according to CAL FIRE's email system.

Using the submit button at the end of the form field will submit the concept application electronically. Before clicking to submit your concept application, please print a copy for your records and go to the file menu in your current version of Adobe Acrobat Reader (http://get.adobe.com/reader/) and select the "save a copy" option. This will allow applicants to retain a copy of the application for their records.

Information required on the Concept Proposal shall include:

Complete the online application and follow the format, directions about size limitations etc. Failure to fully complete the form will result in rejection of the application.

The project description should include a description of the project, the number and job nature of the people involved in the project and the source of funds, materials, equipment or services to be provided by the applicant. Provide your proposed budget following the format provided in the concept proposal form.

Project Timeline:

Projects Completed By	December 31, 2019
Projects Closed By *No Reimbursement Possible After this date*	June 1, 2020

Note: Please see *Urban & Community Forestry Grants Procedural Guide for 2014/2015* for reporting requirements for this grant program.

What happens after submitting a Concept Proposal?

(Please see APPENDIX H of the *Urban & Community Forestry Grants Procedural Guide for 2014/2015* for a CAL FIRE Urban & Community Forestry Program Grant Process Flow Chart).

Concept Proposal Review and Filing

Upon receipt of a Concept Proposal for an urban forestry project grant, CAL FIRE Urban & Community Forestry staff or a designee of the CAL FIRE Urban & Community Forestry Program Manager shall review it for conformance with the California Urban Forestry Act of 1978 (Public Resource Code 4799.06 to 4799.12), The California Code of Regulations (Title 14, Division 1.5, Chapter 9.7), this Request For Proposals, and the *Urban & Community Forestry Grants Procedural Guide*. Such review may include an inspection of the project area, if applicable.

If the Concept Proposal is found incomplete in a material way or the proposed project is not eligible for a grant, the applicant will be informed that the Concept Proposal is ineligible. Only when a Concept Proposal is complete and the project is deemed eligible for a grant, will CAL FIRE Urban & Community Forestry staff file the Concept Proposal.

Notification of Application Status

CAL FIRE Urban & Community Forestry staff shall notify each applicant whose Concept Proposal has been filed and reviewed of the status of its proposal within ten working days of the completion of review.

(1) For those Concept Proposals that have ranked high enough in the initial review, CAL FIRE shall notify the applicant and invite them to submit a Project Application for a grant for the project. Invitation for a Project Application is NOT a guarantee of funding. Once a Project Application is submitted, CAL FIRE Urban & Community Forestry staff will notify the applicant if a grant will be awarded as the circumstances allow. The applicant may then either withdraw their Project Application or complete the negotiations and execute a grant agreement. When the grant agreement is executed, the Director of CAL FIRE will make the grant funds available to the recipient in the manner and at the times specified in the agreement. Do not begin work on a project prior to receiving a fully executed grant agreement. Doing so may result in the project being ineligible for reimbursement.

(2) For those Concept Proposals that are eligible but for which there are no existing funds due to ranking, CAL FIRE shall notify the applicant that they will be invited to submit a Project Application if funds become available during the fiscal year.

Administration: To receive a grant, successful applicants must enter into a grant agreement with CAL FIRE. Grant recipients must agree to complete their project and allow for periodic inspections. In return, CAL FIRE agrees to share the cost of the project.

Technical Assistance: For technical assistance in preparing the Concept Proposal, the applicant should contact the CAL FIRE Regional Urban Forester located in the area nearest to the proposed project (see *Urban & Community Forestry Grants Procedural Guide* APPENDIX E):

Request for Record Review:
Within ten days of the receipt of notice that the application has been denied the applicant may request that the Director of CAL FIRE personally reconsider the decision of rejection. The request shall identify the applicant and the proposed project, and shall briefly state the applicant's reasons for requesting reconsideration. The Director shall consider the application and all of the correspondence from interested parties in reviewing the decision.

Final Decision by the Director of CAL FIRE:
If the Director finds that the decision to reject the application conforms to these guidelines and the Urban Forestry Act, the Director shall uphold the decision. If the Director finds that the decision to reject the application does not conform to these guidelines or the Act, the Director may approve the application.

Federal Affiliation

This program is made possible through a cooperative relationship with the USDA Forest Service.

In accordance with Federal law and U.S. Department of Agriculture policy, this institution is prohibited from discriminating on the basis of race, color, national origin, sex, age or disability. (Not all prohibited bases apply to all programs.)

To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, Room 326-W, Whitten Building, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410 or call (202) 720-5964 (voice and TDD). USDA is an equal opportunity provider and employer.