The Role of Fuel Breaks in the Invasion of Nonnative Plants

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The Role of Fuel Breaks in the Invasion of Nonnative Plants

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Executive Summary

Fuel reduction projects have become an increasingly important component of state and federal fuels management programs. However, an unintended result of some pre-fire fuel manipulation projects may be the introduction of nonnative invasive plants. The establishment of nonnative plants within fuel breaks is a serious concern because the presence of invasive species in areas treated to reduce fuels could make adjacent wildland areas more susceptible to invasion, particularly following widespread disturbances such as fires.

This report presents the results of a research project investigating the relationship between fuel reduction treatments and the invasion of nonnative plants. Throughout the rest of this document, we will collectively refer to these treatments as *fuel breaks,* although we sampled a range of fuel breaks described variously as fuel breaks, shaded fuel breaks, defensible fuel reduction zones, defensible fuel profile zones, fuel reduction projects, fuel management zones, wildfire protection zones, and community protection zones.

Antelope Border Defensible Fuel Profile Zone (DFPZ),
Plumas National Forest

In **Chapter One** we discuss overall results compiled from 24 separate fuel breaks located across California. These fuel breaks represent a variety of different construction and maintenance methods, and different fire histories. Our primary findings were:

- Fuel breaks may promote nonnative plants.
- Fuel breaks with more canopy and ground cover may be less likely to be invaded.
- Nonnative plants were more abundant adjacent to older fuel breaks and in areas that had experienced more numerous fires.
- Native species may also be promoted by fuel breaks, particularly native annual forbs and grasses.

Our data suggest that fuel breaks provide establishment sites for nonnative plants, and that surrounding areas may be susceptible to invasion, particularly after disturbances such as fire. Fuel break construction and maintenance methods that leave some overstory canopy cover and minimize exposure of bare ground may be less likely to promote nonnative plant invasion.

Etz Meloy fuel break, Santa Monica Mountains National Recreation Area

In **Chapter Two** we evaluate the association between nonnative plants and fuel breaks within vegetation types, including mixed coniferous forest, oak woodland, chaparral, and coastal scrub plant communities. We found that:

- Nonnative abundance and species richness was significantly different among vegetation types: conifer forests had the lowest nonnative cover and richness while coastal sage scrub had the highest.
- Differences in elevation, fire history, grazing, canopy cover, and disturbance history may explain some vegetation type differences.
- Nonnatives were significantly more abundant on fuel breaks in all vegetation types.
- Fuel break construction method was associated with nonnative abundance in all vegetation types.
- Fire and grazing was positively associated with nonnative abundance in all vegetation types with adequate sample sizes to evaluate these factors.

This analysis suggests that although different vegetation types experience varying degrees of invasion by nonnatives, our general recommendations described in Chapter One also may be applied within individual vegetation types. Fuel break construction and maintenance methods that retain some overstory canopy and minimize the exposure of bare ground will likely minimize the probability of nonnative invasion across vegetation types.

In **Chapter Three** we provide a brief summary of each individual fuel break sampled in this study. Each site had a unique history, including various dates of construction and construction methods, different maintenance regimes, varying fire histories, and different land use histories. Our general findings were:

- Individual sites differed greatly in nonnative cover, fire history, and environmental variables.
- Nonnative cover was higher within fuel breaks than in adjacent wildlands at 19 of our 24 study sites.
- Fuel breaks that were not invaded by nonnatives had very deep duff layers, were constructed by methods other than bulldozing, were very young, or had very infrequent maintenance regimes.
- Cheatgrass (*Bromus tectorum*) was the most common nonnative plant species at 8 of our study sites.
- A number of different nonnative species dominated the other 16 sites, suggesting that many nonnative species may be well adapted to take advantage of the disturbed conditions associated with fuel breaks.

Our site level review suggests that fuel breaks may create conditions favorable to a number of different nonnative plant species. The colonization of a fuel break by a particular species may reflect which species has a nearby seed source or is able to disperse into the treated area. Regardless of which nonnative species is of greatest concern in the region, retaining overstory canopy and ground cover will likely be the best way to prevent nonnative invasion on fuel breaks.

When reviewing this report, please remember that our study was observational and additional research using controlled, replicated experiments will be necessary to fully understand the mechanisms that influence nonnative plant invasion within fuel reduction treatments.

Aguanga fuel break, Cleveland National Forest

Acknowledgments

We would like to thank the Joint Fire Science Program for funding this study (project #01B-3-2-08). Sequoia and Kings Canyon National Parks were instrumental in supporting our research. This project would not have been possible without the generous cooperation of the Angeles, Cleveland, Lassen, Los Padres, Mendocino, Plumas, San Bernardino, Sequoia, Shasta-Trinity, Sierra, Six Rivers, and Lake Tahoe Basin Management Area USDA National Forests; the Whiskeytown and Santa Monica National Recreation Areas; the San Luis Obispo District of the California Department of Forestry and Fire Protection; the Bakersfield District of the Bureau of Land Management; the Los Angeles County Fire Department Division of Forestry; and the Orange County Department of Parks, Casper's Wilderness Park. We also want to thank Katie VinZant, Lea Condon, Clara Arndt, Trent Draper, and Elizabeth Martin for their expert field assistance.

Canterbury bells *(Phacelia minor)* in the Cleveland National Forest

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Chapter One: Overall Results

Reduction of hazardous fuels has become a priority for federal, state, local, and private land managers across the United States. High fuel loads resulting from fire suppression, population growth at the wildland-urban interface, and large catastrophic fires have focused unprecedented national attention on pre-fire fuel manipulation projects. As a result, a growing number of federal, state, and local fuel reduction programs have dramatically increased the number of hectares (acres) treated to reduce fuels nationwide, and extended the scope of these projects to include a wider range of vegetation types and treatment prescriptions.

Fuel reduction treatments are generally implemented to change fire behavior, to provide firefighter access, as an anchor point for indirect attack on wildland fires, or to contain prescribed fires (Agee and others, 2000). They range in configuration from narrow linear features along individual ridge lines, to large landscape-scale treatments spanning thousands of acres. The amount of surface and ladder fuels removed within these treatments can vary widely, with reduction of overstory canopy cover ranging from complete to less than 40%.

Here, we will collectively refer to these treatments as *fuel breaks,* although they have been variously termed shaded fuel breaks, defensible fuel reduction zones, defensible fuel profile zones, fuel reduction projects, fuel management zones, wildfire protection zones, and community protection zones. Fuel break construction and maintenance methods have changed over time, and differ according to terrain, vegetation type, and implementing agency (Los Angeles County Fire Department 1962; Omi 1979). For example, fuel break maintenance by aerial application of herbicides and seeding with nonnative grasses was common until the 1970s (Bentley 1967; Clark 1973; Edmunson & Cornelius 1961; San Diego County 1974; US Department of Agriculture 1959, 1960). More recent fuel break construction and maintenance measures include selective thinning, mastication, and increased use of prescribed burning (Farsworth & Summerfelt 2002).

An unintended consequence of large-scale fuel break construction of new fuel breaks, and increased maintenance of existing fuel breaks, may be the establishment of nonnative plant species. A number of studies have documented an association of nonnative plant species with disturbed areas similar to fuel breaks, such as logging sites, roads, trails, and pipeline corridors (e.g., D'Antonio and others, 1999).

These disturbance corridors can promote the invasion of surrounding areas by providing a nearby seed source (Gelbard & Belnap 2003; Parendes & Jones 2000; Tyser & Worley 1992; Zink and others, 1995). Wildland areas adjacent to fuel breaks might be particularly susceptible to invasion following landscape-scale disturbances such as fire, because fire has been shown to promote the invasion of nonnative plants in a number of habitats (D'Antonio 2000). In many cases invading species are well adapted to fire and can invade fire prone ecosystems, particularly when natural fire regimes have been altered through fire suppression, increased anthropogenic ignitions, or by feedback effects with changes in plant species composition (D'Antonio and Vitousek 1992; Keeley 2001).

In this study we evaluated the potential for fuel breaks to function as establishment sites for nonnative plants, and for nonnative species to invade surrounding wildland areas (see Text Box 1-1). The goals of this research were to provide fire and resource managers with information to develop fuels management strategies that both accomplish fuel hazard reduction goals and minimize the potential for nonnative plant invasion.

Text Box 1-1: Our primary research questions were:

- ***Do plant communities differ within fuel breaks compared with adjacent wildland areas?***
- ***What environmental and anthropogenic factors are correlated with the abundance of nonnatives?***
- ***Are nonnative species more abundant in areas adjacent to fuel breaks after disturbances such as fire?***

METHODS

We investigated 24 fuel breaks across the State of California (Figure 1-1). Study sites were located primarily in the Sierra Nevada and coastal mountain ranges, including coastal scrub, chaparral, oak woodland, and mixed coniferous forest vegetation types ranging in elevation from 200 to 2000 m.

The fuel breaks varied in age from those constructed by the Civilian Conservation Corps during the 1930s to fuel reduction projects implemented as recently as 2003. We attempted to include fuel breaks constructed by a variety of different methods such as bulldozers, mechanical equipment, and hand crews. Mechanical equipment included rubber tired and tracked vehicles used for thinning and mastication of forest and chaparral vegetation; hand crews relied primarily on hand tools such as shovels, Pulaskis, McCleods, and other hand line construction tools.

The land use history of each study site was complex, and we could not control for many of the disturbance related factors that may have affected nonnative abundance on the fuel breaks we studied. Additional information about each fuel break is provided in Chapter Three.

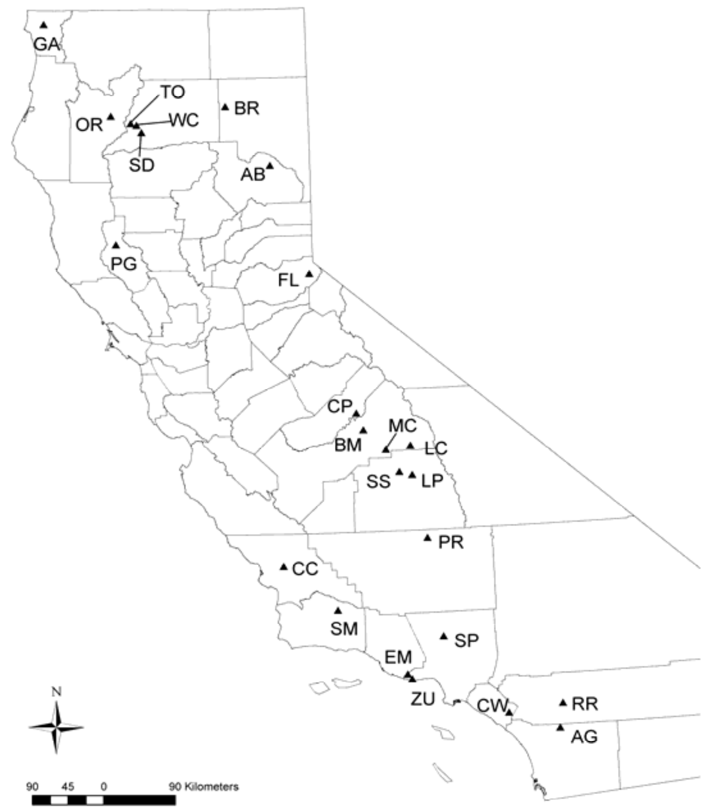


Figure 1-1. Map of 24 fuel breaks study sites across the State of California. Site codes are explained in Table 3-1.

Sampling Protocol

Data were collected during the spring and summer of 2002 and 2003. At each site we established between 8 and 10 transects perpendicular to the fuel break, beginning at the origin nearest a road or urban interface, and continuing at discrete intervals of between 200 and 1500 m, depending on the total size of the treated area. Transects were 50 m in length, extending 10 m towards the center of the fuel break and 40 m into the surrounding vegetation. Two 1 m^2 plots were placed inside the fuel break, and four 1 m^2 plots were placed in the adjacent wildland area at discrete distances of 5, 10, 20, and 40 m from the edge of the fuel break (Figure 1-2).

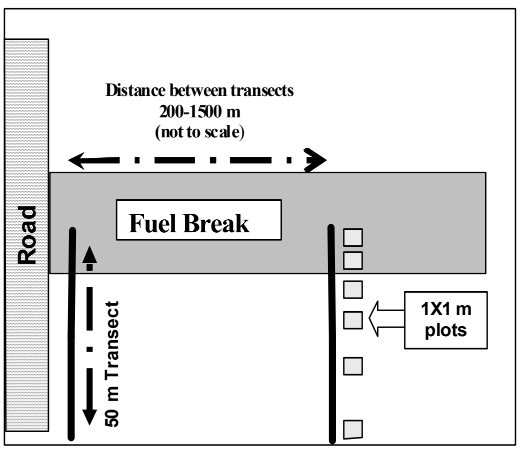


Figure 1-2. Diagram of transect orientation along fuel break and quadrat locations along transects.

We collected a range of data at each fuel break (see Text Box 1-2). We estimated species cover by cover class according to Daubenmire (1959), and estimated the density of each species, including overstory trees and shrubs. All plants were identified according to Hickman (1993). Plant communities were identified according to categories developed by Sawyer and Keeler-Wolf (1995).

Data on fire history was obtained from a state-wide fire perimeter GIS data layer containing fires recorded since 1953 (California Department of Forestry and Fire Protection 2003), and from individual cooperators when available. Information about the distance and density of roads and urban interfaces to our plots was generated from GIS data layers using the ArcView Spatial Analyst extension (ESRI 2000). Information about fuel break age, construction and maintenance methods, and grazing history were obtained from GIS data, environmental and biological assessments, resource management plans, fire incident reports, and agency technical reports. Additional information was collected through personal communications with fuels and fire managers, botanists, range managers, and other staff familiar with each site.

Text Box 1-2. Data Collected:

At each plot:
- Species composition, cover and density
- Ground cover (bare ground, litter, etc.)
- Overstory canopy cover
- Litter and duff depth

At the end points of each transect:
- Soil nitrogen, carbon, moisture
- Slope, aspect, elevation
- Fire and grazing history
- Distance to roads and Wildland Urban Interface (WUI)
- Fuel break age, construction, and maintenance
- Vegetation type

Data Analysis

We used a number of different statistical methods to analyze the data we collected, including paired t-tests, Analysis of Variance (ANOVA), and multiple regressions. Data analysis was performed using SYSTAT version 10 (SPSS 2000). Residuals from each analysis were plotted to identify outliers and evaluate homogeneity of variance (Wilkinson and others, 1996). Percentage values were arcsine square root transformed to improve normality and homogeneity of variance. Sites were not equally distributed across all vegetation types, or with past land use such as grazing and fire history, and some data was missing, so N-values reported for different analyses below may vary.

RESULTS

We identified 736 plant species in our 1 m^2 plots both in and adjacent to 24 separate fuel breaks. Approximately 85% were native, 11% were nonnative, and 4% could not be identified due to dessication, phenology, or lack of plant material. Fifty-one percent of our quadrats contained no nonnative plants. The most frequently occurring nonnative plant was cheatgrass. Our primary findings are summarized in Text Box 1-3, and more detailed results are provided in the sections that follow.

Text Box 1-3. Our primary findings were:

- Nonnative plants had higher relative cover, density, species richness, and diversity within fuel breaks than in adjacent wildlands.
- Some fuel breaks are less likely to support nonnative species, particularly those with more overstory canopy and ground cover.
- Nonnative plants are more abundant adjacent to older fuel breaks and in areas that have experienced more numerous fires.
- Native species diversity was also higher in fuel breaks.
- Both nonnative and native annual forbs and grasses were more abundant in fuel breaks than in adjacent wildlands.
- Nonnative plants were generally more common on fuel breaks, but some species showed no response.
- Native species were generally more common outside fuel breaks, but some species were more abundant in fuel breaks.

1. Nonnative cover, density, and species richness

Absolute and relative nonnative cover, density, and species richness were significantly higher on fuel breaks than in adjacent areas outside of fuel breaks (Figure 1-3).

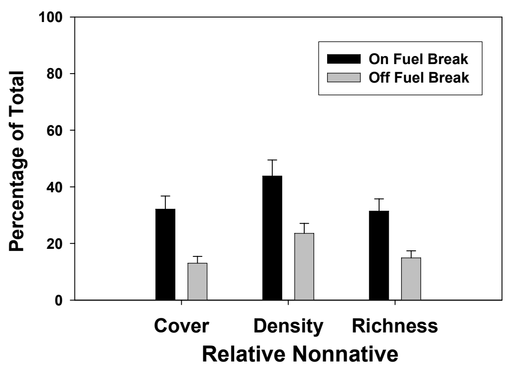


Figure 1-3. MANOVA found that relative nonnative cover, density, and species richness (expressed as the percentage of total plant cover, density, and richness) was significantly higher on fuel breaks compared with sites outside fuel breaks (N= 48, df=3, 44, F= 5.645, $P<0.001$). Error bars indicate + 1 SE.

Nonnatives occurred more frequently on fuel breaks, where they were found in 65% of quadrats, compared with outside of fuel breaks, where only 43% of quadrats contained nonnative plants.

2. Differences among fuel breaks

Elevation, slope, duff depth, overstory canopy, bare ground, litter cover, and rock cover were significantly associated with the presence and abundance of nonnative plant species (Table 1-1).

Table 1-1. Multiple linear stepwise regression analysis of the relationship between environmental variables and relative nonnative plant cover across all quadrats where nonnatives were found.

Effect	Standard Coefficient	Tolerance	T	P
Constant	0.000		29.25	<0.001
Canopy cover (%)	-0.354	0.763	-10.00	<0.001
Elevation	-0.229	0.895	- 7.02	<0.001
Bare ground (%)	-0.129	0.739	- 3.58	<0.001
Slope (%)	-0.097	0.722	- 2.66	0.008
Litter cover (%)	-0.094	0.651	- 2.46	0.014
Transect	0.076	0.741	2.13	0.034
Site	0.067	0.975	2.14	0.032

Notes: Variables with *P (probability)*>0.15 were removed from the model, including rock cover, litter depth, and duff depth (N=754, adjusted multiple r^2=0.281, standard error of estimate=0.225). The T-value is the estimate divided by its standard error.

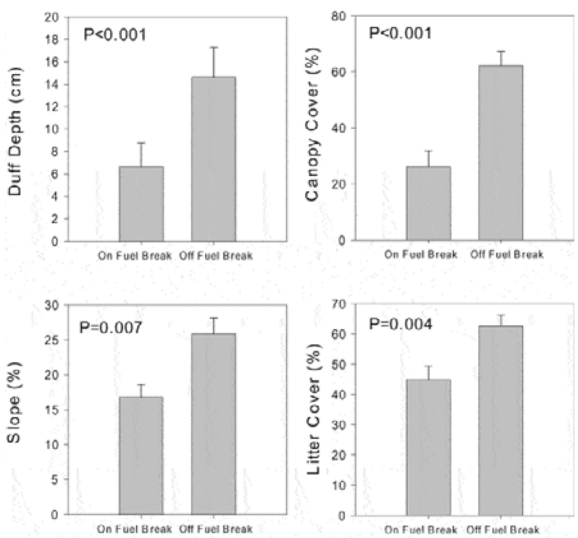


Figure 1-4. MANOVA found that environmental variables associated with nonnative plant presence and abundance were significantly different on and off fuel breaks (N=48, df=4, 43, F=4.165, P=0.002). Error bars indicate + 1 SE. Univariate *P*-values shown on graphs.

Several of these variables were significantly lower in quadrats on fuel breaks (Figure 1-4).

The anthropogenic variables of fuel break construction method, maintenance method, maintenance frequency, fuel break age, and distance to roads were significantly associated with relative nonnative cover on fuel breaks (Table 1-2).

Table 1-2. Multiple linear stepwise regression analysis of the association between anthropogenic variables and relative nonnative plant cover on fuel breaks.

[Data represent plots on the fuel break only, pooled to provide one value per transect]

Effect	Standard Coefficient	Tolerance	T	P
Constant	0.000		14.44	<0.001
Construction Method	-0.631	0.698	13.49	<0.001
Maintenance Frequency	0.221	0.733	4.84	<0.001
Site	0.121	0.821	2.82	0.005
Fuel Break Age	0.084	0.711	1.82	0.071
Maintenance Method	0.068	0.892	1.64	0.103
Distance to Roads	-0.062	0.925	1.53	0.127

Notes: Variables dropped from the multiple stepwise linear regression as not being significant at $P>0.15$ included distance of the fuel break to urban interfaces, prescribed burning, and use of precautions against nonnative invasion such as washing equipment (N=220, adjusted multiple $r^2=0.666$, standard error of estimate= 0.207).

Fuel breaks constructed by bulldozers had significantly higher relative nonnative cover than fuel breaks constructed by hand crews, and fuel breaks thinned mechanically had significantly lower relative nonnative cover than fuel breaks constructed by other means, even with elevation and slope included as covariates (Figure 1-5).

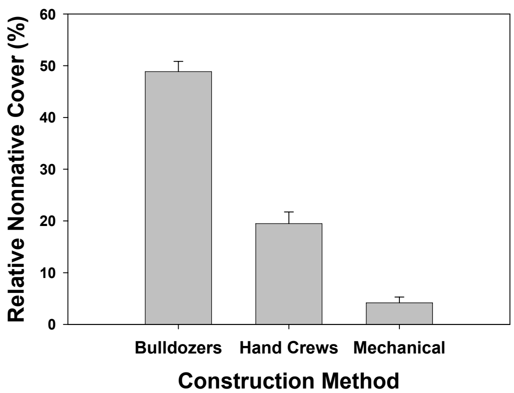


Figure 1-5. Differences in relative nonnative cover with fuel break construction method. Error bars indicate + 1 SE. The effect of construction method was significant based on Analysis of Covariance (ANCOVA) with slope and elevation as covariates (N=220, effect of construction method: df=2, 217, F=118.655, *P*<0.001).

Fuel break constructed by bulldozer, Santa Monica Mountains National Recreation

Environmental variables significantly associated with nonnative cover, including overstory canopy cover, litter cover, duff depth, and bare ground, also varied significantly among fuel breaks constructed by different methods (Figure 1-6). Fuel breaks constructed by bulldozers had the least duff depth, litter cover, and canopy cover of any fuel break construction method.

The presence of nonnatives also was associated with fuel break construction method; 49% of quadrats contained nonnatives on fuel breaks constructed by bulldozers, compared with 20% of quadrats on fuel breaks constructed by hand crews, and only 4% of quadrats on mechanically thinned fuel breaks contained nonnative species.

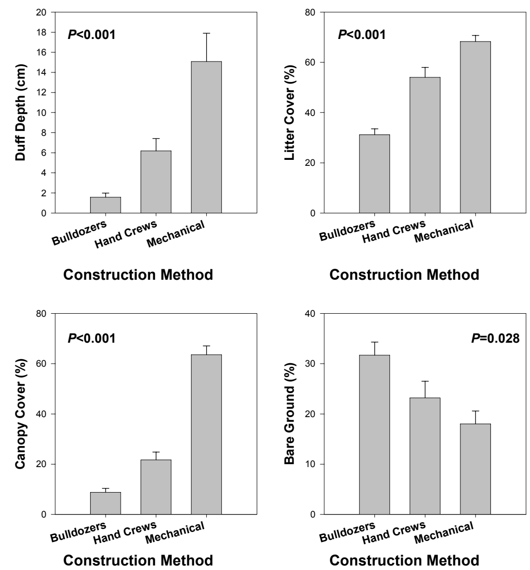


Figure 1-6. Relationship between fuel break construction method and environmental variables significantly associated with nonnatives, including duff depth, litter cover, canopy cover, and bare ground were determined using MANOVA (N=220, df=4, 214, F=11.608, $P<0.001$). Univariate P-values are indicated on graphs. Error bars represent + 1 SE.

This mechanically cleared fuel break in Whiskeytown National Recreation Area maintained some overstory canopy cover and ground cover.

3. Patterns adjacent to fuel breaks

Relative nonnative cover significantly declined with distance from the fuel break, and this effect was more significant with fuel break age category (Figure 1-7).

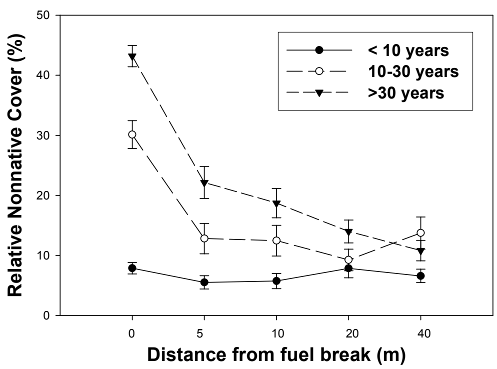


Figure 1-7. Two-way ANOVA found significant differences in relative nonnative abundance with distance from the fuel break and with fuel break age (interaction effect with plot distance nested within transects, N=1543, df=12, 1523, F = 15.377, *P*<0.001). Error bars represent + 1 SE.

The relationship between relative nonnative cover and distance from the fuel break was also influenced by number of fires (Figure 1-8). In the absence of fire, relative nonnative abundance in wildland areas adjacent to fuel breaks did not change with increasing distance from the fuel break. However, in areas that had experienced one or more fires, relative nonnative abundance in wildland areas adjacent to fuel breaks significantly declined with increasing distance from the fuel break.

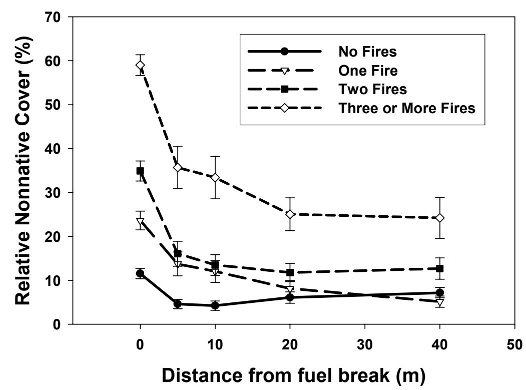


Figure 1-8. Two-way ANOVA found significant differences in relative nonnative cover with distance from fuel break and with the number of fires (interaction effect with plot distance nested within transects, N=793, df=12, 773, F=2.366, *P*<0.001). Error bars represent + 1 SE.

4. Species Diversity

Both native and nonnative species diversity was higher within fuel breaks than in adjacent wildland areas (Figure 1-9), and native and nonnative diversity were significantly positively correlated (Pearson correlation=0.326, *P*=0.024).

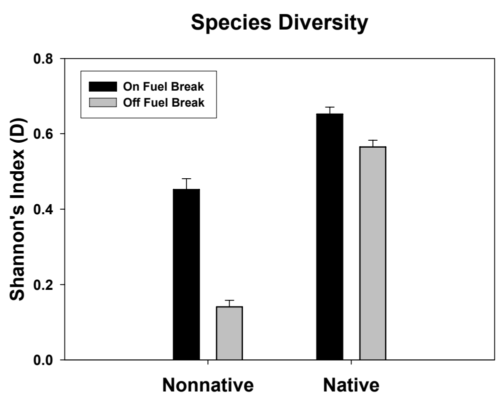


Figure 1-9. Both native and nonnative species diversity was significantly higher on fuel breaks according to paired t-tests. (native species diversity: t=2.983, df=216, *P*=0.003, nonnative species diversity: t=10.284, df=217, *P*<0.001)

Nonnative species diversity at the site level was most strongly correlated with duff depth and elevation, and together these variables explained over half of the variation in nonnative diversity (adjusted multiple R^2=0.521). Duff depth and bare ground were most strongly correlated with native diversity at the site level, although the explanatory power of these variables was lower (adjusted multiple ^{2} = 0.211).

5. Life history types

Fuel breaks were characterized by higher numbers of annual plant species than adjacent wildland areas, including native and nonnative grasses and forbs, which were significantly more common in treated areas than in adjacent wildlands (Figure 1-10). Native perennial forbs and nonnative perennial grasses also were significantly more common on fuel breaks. Native trees, shrubs, and subshrubs were more common outside of fuel breaks. We did not encounter any species of nonnative trees, and only two species of nonnative shrubs and five species of nonnative perennial forbs were sampled in this study.

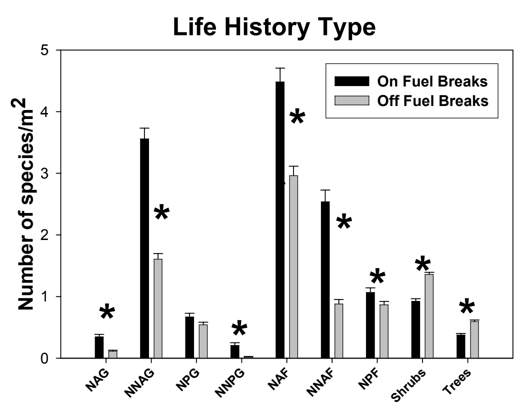


Figure 1-10. Differences between fuel breaks and adjacent wildland areas in the number of species from each life history type were evaluated using paired t-tests (**NAG**=Native annual grass, **NNAG**=nonnative annual grass, **NPG**=native perennial grass, **NNPG**= nonnative perennial grass, **NAF**=native annual forb, **NNAF**= nonnative annual forb, **NPF**= native perennial forb). Error bars indicate + 1 SE. Significantly different means indicated with an asterisk and determined by Bonferroni adjusted method with significance level at *P*=0.006 for nine comparisons.

6. Variation among nonnative species

Of the 79 nonnative species we identified, 21 (26.6%) only occurred on fuel breaks, and 9 (11.4%) were restricted to plots in wildland areas. Of the 32 nonnative species found in 10 or more plots, 17 were statistically equivalent in cover both on fuel breaks and in adjacent wildland areas, and 15 were more common on fuel breaks. Six of the ten most common nonnatives were equally common on fuel breaks and in adjacent wildlands (Table 1-3). The nonnative species we observed were primarily annual grasses and forbs.

Table 1-3. Differences in mean cover on and off fuel breaks of the ten most frequently occurring nonnative plant species.

[Differences between mean cover in wildland areas (OFF), and inside areas treated to reduce fuels (ON) were evaluated using paired t-tests, and significance was determined using Bonferroni adjusted *P* value of 0.005. Species with *no significant difference* in abundance are shown in **bold]**

Scientific Name	# of plots	Mean OFF	Mean ON	P
Bromus tectorum	244	1.4169	1.8157	**0.041**
Bromus madritensis	223	1.9604	2.3	**0.237**
Vulpia myuros	217	1.2763	2.2591	<0.001
Bromus hordeaceus	184	1.1588	2.5721	<0.001
Bromus diandrus	177	1.9572	2.136	**0.570**
Erodium cicutarium	150	0.6409	3.1544	<0.001
Torilis arvensis	122	1.6898	1.4028	**0.313**
Centaurea melitensis	99	1.613	2.375	**0.051**
Aira caryphyllea	82	1.303	1.876	**0.229**
Avena barbata	79	0.816	2.645	<0.001

7. Variation among native species

Of the 551 native species observed in this study, 142 (25.8%) only were found outside of fuel breaks, while 108 (19.4%) only occurred inside fuel breaks. Of the 178 native species that were found in ten or more plots, 46 were statistically more common outside of fuel breaks, 12 species were more common inside fuel breaks and 111 native species did not differ in abundance in fuel breaks compared with adjacent wildland areas. Native species that were more common on fuel breaks were found in all vegetation types and represented a range of life history types, including annual grasses, annual forbs, perennial forbs, subshrubs, and shrubs (Table 1-4).

Both native and nonnative species may be found on fuel breaks, such as this one in the Sierra National Forest.

Table 1-4. Native species that were significantly more common on fuel breaks, based on paired t-tests.

[Life history abbreviations are **AG**=annual grass, **AF**=annual forb, **PF**= perennial forb, **SS**=subshrub, and **S**=shrub. Vegetation type abbreviations are **CF**=coniferous forest, **OW**=oak woodland, **CH**=chaparral, and **CS**=coastal sage scrub. Significance assessed with Bonferonni adjusted *P* value of 0.002 for 10 comparisons]

Scientific Name	Life History	Vegetation Type	P
Vulpia microstachys	**AG**	**CF, OW, CH**	**<0.001**
Lupinus bicolor	**AF**	**OW, CH, CS**	**<0.001**
Lotus strigosus	**AF**	**CH, CS**	**0.002**
Lotus argophyllus	**PF**	**CF, CH**	**0.001**
Epilobium brachycarpum	**AF**	**CF, OW, CH**	**<0.001**
Trifolium albopurpureum	**AF**	**OW, CH, CS**	**0.001**
Lotus purshianus	**AF**	**CF, OW, CH**	**0.001**
Lotus wrangelianus	**AF**	**CH, CS**	**0.002**
Eriophyllum lanatum	**SS**	**CF, OW,**	**0.002**
Micropus californicus	**AF**	**OW, CH,**	**0.002**
Arctostaphylos glandulosa	**S**	**CH**	**0.001**
Madia glomerata	**AF**	**OW, CH**	**0.001**

DISCUSSION

Pre-fire fuel manipulations, such as fuel breaks, are an important component of fire management programs, particularly in areas where prescribed fire or wildland fire use is impractical. Our study demonstrates that fuel breaks have the potential to promote the establishment and spread of nonnative plants. The management implications of our findings are summarized in Text Box 1-4.

Text Box 1- 4. Some management implications of our findings are:

- Fuel breaks may promote nonnative plants.
- Fuel breaks with more canopy and ground cover may be less likely to be invaded.
- Nonnative plants are more abundant adjacent to older fuel breaks and in areas that have experienced more numerous fires.
- Native species may also be promoted by fuel breaks, particularly native annual forbs and grasses.
- Managers will have to balance maintaining natural disturbance regimes against the potential risk of nonnative invasion.

Blacks Ridge DFPZ, Lassen National Forest

1. Canopy and ground cover

We found that fuel breaks had significantly less overstory canopy, litter cover, and duff depth than adjacent wildland areas. These environmental variables were significantly associated with nonnative species presence and abundance. Removing overstory canopy within fuel breaks may benefit nonnative plants by reducing competition with natives and changing light, nutrient, and water levels (Berlow and others, 2003; McKenzie and others, 2000; Parendes & Jones 2000). Removing litter and duff and disturbing soils on fuel breaks could provide sites for nonnative plant establishment, stimulate seed germination, eliminate native seed banks, and disrupt soil profiles (Burke & Grime 1996; D'Antonio 1993; Hobbs & Atkins 1988). Removing litter and duff also may change the physical characteristics of the soil, such as temperature, moisture, and nutrient availability, in ways that benefit nonnative plants (Parker and others, 1993; Reynolds and others, 2001; Shaw & Diersing 1990). These findings suggest that fuel break construction and maintenance strategies that retain some overstory canopy and ground cover may reduce the establishment and widespread invasion of nonnative plants.

Fuel breaks might be constructed and maintained to retain overstory canopy and ground cover. We found that fuel breaks constructed by selective thinning had significantly lower nonnative cover and higher canopy and ground cover than those constructed by bulldozers. Fuel breaks with on-site chipping or mastication of fuels had deeper layers of litter cover and less exposed bare ground, which may have reduced nonnative germination and establishment at these sites. Increasing the time between fuel break maintenance might allow ground and canopy cover to increase and also lower the probability of nonnative invasion.

Altering the type of machinery used to construct and maintain fuel breaks might also influence patterns of invasion by nonnative plants. We found that even in relatively uninvaded vegetation types such as coniferous forests, use of bulldozers significantly increased the abundance of nonnative plants. Bulldozers have large blades specifically designed to remove surface soil layers, and may be more likely to introduce nonnative seeds into fuel breaks by disrupting soil seed banks and transporting seeds between sites.

The presence of overstory canopy cover and ground cover in a fuel break may be more important to preventing nonnative species invasion than employing specific methods of fuel break construction. For example, we might have expected that fuel breaks built by hand crews would be the least disturbed, but instead we found that these fuel breaks had significantly lower overstory canopy cover, litter cover, and duff depth than fuel breaks constructed by mechanical equipment. This result is consistent with the emphasis of hand crews on exposing bare mineral soil to construct effective fire lines. These fuel breaks had significantly higher cover of nonnatives than fuel breaks constructed by mechanical thinning.

2. Fuel break age and fire history

We found that nonnative cover decreased with distance from the fuel break, suggesting that fuel breaks act as sources of nonnative plant propagules in the invasion of adjacent areas. Fuel breaks may act as nonnative seed reservoirs because they support higher numbers of nonnative plants, and they also receive external inputs of seeds through vehicles, equipment, or humans traveling on them (Lonsdale & Lane 1994; Schmidt 1989; Tyser & Worley 1992).

Wildland areas adjacent to fuel breaks were more likely to be invaded by nonnative species when the wildlands had been subject to recurrent fires. Numerous studies have found that fire can promote nonnative plant invasion, even in fire adapted vegetation types (Brooks and others, 2004; Keeley 2001). Increased fire frequencies can kill native plants in fire prone ecosystems because native species develop life histories in response to specific fire frequencies; these native species may be extirpated when fires occur more frequently (Keeley & Fotheringham 2003; Moreno & Oechel 1991). The establishment of nonnative annual grass species, the most common nonnatives in our study, has been found to alter fuel characteristics such that fires become less intense and more frequent in many areas (Brooks and others, 2004; D'Antonio & Vitousek 1992; Keeley 2001). Reduced fire intensity on fuel breaks may increase the survivorship of nonnative seeds (Keeley & Fotheringham 2003). The establishment of nonnatives in fuel breaks could lead to feedback effects with fire that increase the abundance of nonnatives in fuel breaks and promote the invasion of surrounding areas.

We found nonnative plant abundance on fuel breaks and in adjacent wildlands continued to increase with fuel break age. Although some authors have suggested that dispersal does not limit alien plant abundance in later stages of invasion (e.g., Wiser and others, 1998), we found that fuel breaks may continue to provide inputs of alien propagules even after periods of 30 years. Giessow (1997) found a similar pattern in fuel breaks 80 years of age and older in coastal scrub habitats in southern California.

Post-fire regeneration along the Rouse Ridge fuel break, San Bernardino National Forest

3. Native species

Fuel management treatments may also promote native plants, particularly native annual forbs. Other studies have found that the native annual forbs respond positively to disturbances such as grazing (Hayes & Holl 2003) and fire (Safford & Harrison 2004). Annual plants may be better able to colonize disturbed areas because of their short life cycles and dormant seed banks. Six of the twelve native species that were more abundant on fuel breaks than in adjacent wildlands were in the Fabaceae family, which is known to have long-lived seed banks (Auld 1996; Holmes & Newton 2004).

We found that native and nonnative diversity were significantly correlated. Although it has been suggested that native diversity should be negatively related to nonnative diversity because diverse native plant communities may be more resistant to invasion by nonnative plant species, our results support the idea that natives and nonnatives respond similarly to habitat conditions such as heterogeneity, resource availability, and disturbance history (Levine & D'Antonio 1999; Stohlgren and others, 2003).

Disturbance related variables, including fire number, overstory canopy cover, and duff depth significantly influenced both native and nonnative plant species at our study sites, and both native and nonnative diversity was most strongly negatively related to the depth of the duff layer. The depth of duff and litter layers have been found to be important indicators of plant species richness, probably by controlling plant establishment and germination (Battles and others, 2001; Facelli 1991; Hayes & Holl 2003; Xiong & Nilsson 1999). Our data suggest that deep duff layers suppress both native and nonnative plant species.

Although many native trees and shrubs were more common outside of fuel breaks, there were native trees and shrubs that were either more common in fuel breaks, or equally common within fuel breaks and outside of fuel breaks. This may reflect selective application of treatments to avoid specific tree and shrub species of interest, such as Ponderosa pines (*Pinus ponderosa)*. Some shrub species may have adaptations such as stump sprouting that would allow them to persist in treated areas. Pine and other tree seedlings may be able to utilize germination sites and high light availability created in fuel breaks.

Many native species, particularly annual forbs, require periodic disturbance to persist in natural ecosystems. The best management regime for maintaining native plant diversity is likely one that restores natural disturbance processes of the frequency, intensity, and duration with which native species evolved.

It is important to emphasize that the relative abundance of nonnative species was significantly higher on fuel breaks, indicating that native plants represented a smaller proportion of the total plant community on fuel breaks. Land managers may have to weigh the benefits of maintaining natural disturbance regimes to restore some ecosystem processes against the potential risks of promoting nonnative invasives.

This study was observational, and there were many environmental and anthropogenic factors that we could not control for. Research using controlled, replicated experiments will be necessary to fully understand the mechanisms that influence nonnative plant establishment within pre-fire fuel manipulation projects and invasion into adjacent wildland areas. Here we have identified potentially important variables influencing patterns of nonnative abundance with respect to fuel breaks and suggested ways that the probability of nonnative invasion might be minimized. If these methods are strategically implemented as part of a long-term fuel reduction program, it may be possible to both achieve fuel management goals and reduce the probability of nonnative plant invasion on fuel breaks and in surrounding wildland areas.

Rouse Ridge fuel break, San Bernardino National Forest

Chapter Two: Vegetation Type Differences

INTRODUCTION

We examined fuel breaks in a number of different plant communities throughout the California floristic province. Each study site was dominated by different plant species, which we classified into four major vegetation types; mixed coniferous forest, mixed oak woodland, chaparral, and coastal scrub communities.

We found that a number of variables differed significantly among these four vegetation types. For example, the relative cover of nonnative plants was lowest in coniferous forests, greater in oak woodlands, even higher in chaparral vegetation types, and the highest in coastal scrub vegetation types (Figure 2-1).

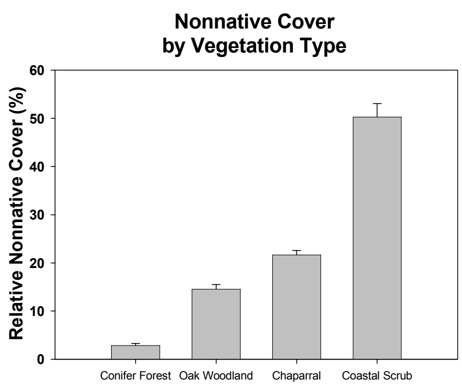


Figure 2-1. ANOVA indicated relative nonnative cover differed significantly among vegetation types (N=1543, df=3, 1539, F=150.7, P<0.001). Error bars represent + 1 SE.

Nonnative species richness was also significantly different among vegetation types. Coniferous forests had the lowest numbers of nonnative species of any vegetation type, followed by oak woodlands and chaparral. Coastal scrub vegetation types had the highest nonnative species richness of any vegetation type we studied (Figure 2-2).

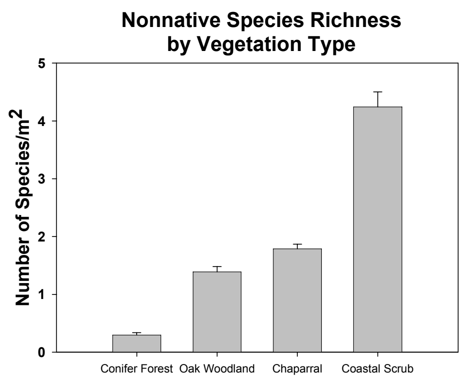


Figure 2-2. ANOVA found significant differences in nonnative species richness among vegetation types (N=1543,df=3, 1539, F = 124.726, P<0.001). Error bars represent + 1 SE.

Many environmental variables also varied among vegetation types. For example, the depth of the duff layer was highest in coniferous forests, lower in oak woodlands and chaparral vegetation types, and duff depth was lowest in coastal scrub vegetation types (Figure 2-3).

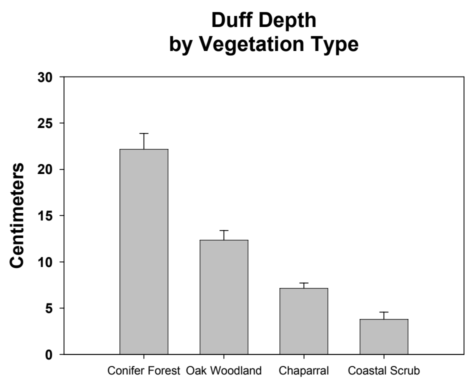


Figure 2-3. ANOVA found significant differences in duff depth among vegetation types (N=1498, df=3, 1493, F=31.955, $P<0.001$). Error bars represent + 1 SE.

Other environmental variables such as overstory canopy cover were significantly different in some vegetation types but not in others (Figure 2-4). Canopy cover was similarly high in coniferous forest and oak woodland plant communities, but lower in chaparral and coastal scrub vegetation types.

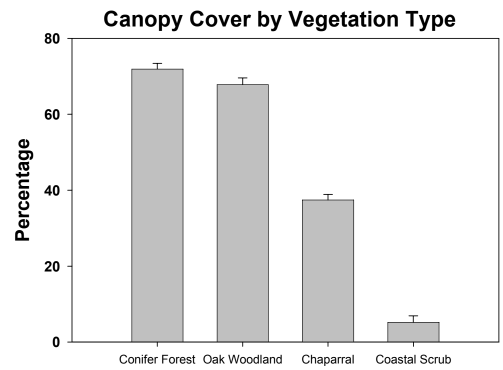


Figure 2-4. ANOVA on canopy cover found significant differences among vegetation types (N=1502, df=3, 1498, F=60.203, $P<0.001$).
Error bars represent + 1 SE.

Relative nonnative cover was much higher on fuel breaks in all vegetation types (Figure 2-5).

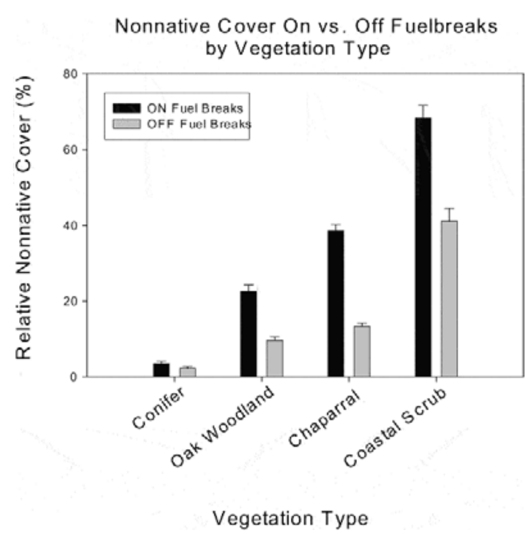


Figure 2-5. ANOVA determined that relative nonnative cover was significantly higher ON fuel breaks compared with OFF fuel breaks in all vegetation types (interaction effect: N=1543, df=3, 1535, F = 27.699, $P<0.001$).
Error bars represent + 1 SE.

Environmental variables that were significantly related to nonnative cover were associated with fuel breaks in each vegetation type. For example, duff depths were significantly higher outside of fuel breaks in each vegetation type (Figure 2-6). Plots on fuel breaks had significantly lower canopy cover in each vegetation type as well (Figure 2-7).

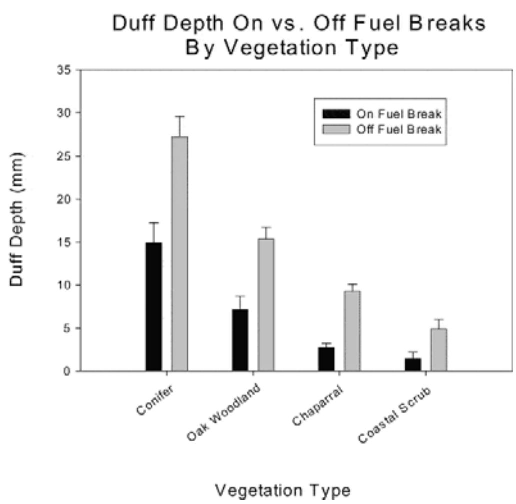


Figure 2-6. ANOVA found that duff depth was lower on fuel breaks within each vegetation type (interaction effect of vegetation type and position on or off fuel break: N=1498, df=3, 1490, F=29.72, P<0.001). Error bars represent + 1 SE.

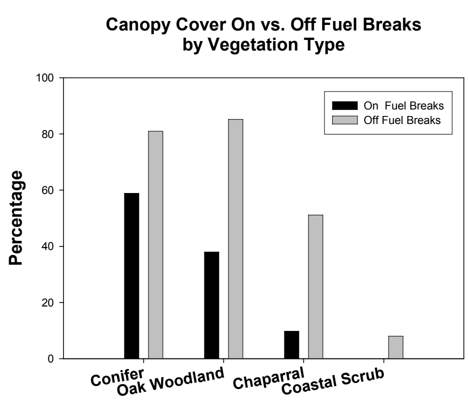


Figure 2-7. ANOVA found canopy cover was significantly lower on fuel breaks in each vegetation type (interaction effect of vegetation type and position on or off fuel break N=1502, df=3, 1494, F=19.116, P<0.001). Error bars represent + 1 SE.

These general results suggest that different vegetation types vary in abundance of nonnative plants, as well as environmental variables such as canopy and ground cover. However, despite these differences, the general pattern we found of increased nonnative abundance on fuel breaks, and associated patterns of decreased canopy cover and duff depth were evident within each vegetation type.

These results suggest that nonnative species may respond to fuel breaks in similar ways across vegetation types. Patterns of nonnative abundance within individual vegetation types are discussed in more detail below.

CONIFEROUS FOREST

There were six fuel breaks which contained mixed coniferous forest vegetation types, typically dominated by Ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*Pinus jeffreyi*), incense cedar (*Calocedrus decurrens*) and white fir (*Abies concolor*).

Coniferous forest vegetation type in the Plumas National Forest

Coniferous forest sites included the McKenzie Ridge fuel break in the Sequoia National Forest, the Pilot Grove fuel break in the Mendocino National Forest, the Fallen Leaf Lake fuel break in the Lake Tahoe Basin Management Area, portions of the Palos Ranches fuel break in the Sequoia National Forest, the Antelope Border defensible fuel profile zone in the Plumas National Forest, and the Blacks Ridge defensible fuel profile zone in the Lassen National Forest.

Our study sites within mixed coniferous forest vegetation types ranged in elevation from 1194 to 2017 m, and were constructed by mechanical thinning, hand crews, and bulldozers. These sites ranged in age from 1 to 42 years, and had experienced between 0 and 2 fires. At the time of our study, most of these sites were being grazed, and had been subject to logging in the past 50 years.

Coniferous forests had the lowest relative nonnative cover of the four vegetation types we identified (mean = 4.0% of total plant cover). This vegetation type was also characterized by significantly greater duff depths than other vegetation types, while canopy cover and litter depth were equivalent to oak woodlands, but higher than chaparral and coastal scrub habitats. We identified a total of 185 plant species in our 1m^2 plots in coniferous forest sites.

We found that fuel break construction method was significantly associated with relative nonnative cover in coniferous forests. Fuel breaks that had been constructed by bulldozers had significantly higher relative nonnative cover than sites constructed by other means. However, in coniferous forests, mechanically constructed fuel breaks and those constructed by hand crews had statistically similar cover of nonnative species (Figure 2-8).

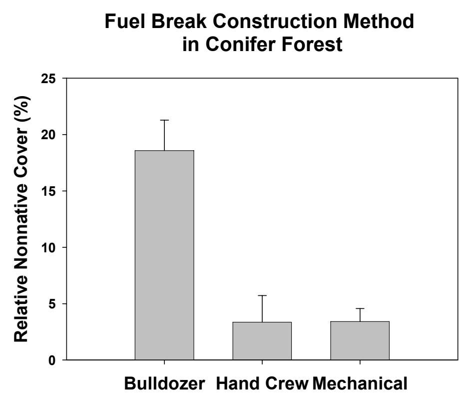


Figure 2-8. ANOVA found significant differences in relative nonnative cover among different construction methods in coniferous forests (N=39, df=2, 35, F=5.30, P=0.01). Error bars represent + 1 SE.

Coniferous forest vegetation types were the only plant communities where there was not a significant decline in relative nonnative cover outside of the fuel break when only unburned sites were considered. However, this pattern was significantly altered at sites that had experienced one or two fires (Figure 2-9). Conversely, areas that had experienced one or two fires had a significant increase of relative nonnative abundance, particularly in plots located closer to fuel breaks.

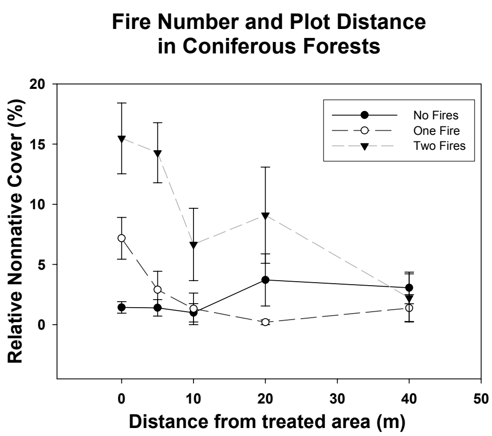


Figure 2-9. ANOVA found a significant interaction effect between fire number and distance from the fuel break on relative nonnative cover in coniferous forests (N=339, df=12, 325, F=3.789, *P* <0.001). Error bars represent 1 SE.

MIXED OAK WOODLANDS

We sampled nine fuel breaks that included mixed oak woodland vegetation types. These sites were typically dominated by black oak (*Quercus kelloggii*), canyon live oak (*Quercus chrysolepis*), and tan oak (*Lithocarpus densiflorus*) species.

Oak woodland vegetation type
in the Shasta Trinity National Forest

Fuel breaks within oak woodland plant communities included the Shepard Saddle and Lookout Point fire lines in Sequoia and Kings Canyon National Parks, the Oregon fire line in the Shasta Trinity National Forest, the Gasquet fuel break in the Six Rivers National Forest, the Cascadel Point and Burrough Mountain fuel breaks in the Sierra National Forest, the Shasta Divide fuel break in Whiskeytown National Recreation Area, the Pilot Grove fuel break in the Mendocino National Forest, and the Sierra Pelona fuel break in the Angeles National Forest.

Fuel breaks in oak woodland vegetation types spanned a wide range of elevations, including sites from 200 to 1400 m. They included fuel breaks constructed by mechanical thinning, hand crews, and bulldozers, and ranged in age from 1 to 82 years. Oak woodland sites had experienced between 0 and 3 fires. At the time of our study, about half (6 of 13 transects) of these sites were being grazed.

Oak woodlands had the second lowest relative nonnative cover of the four vegetation types we identified (mean = 25.0% of total plant cover), as well as the second lowest nonnative species richness. We identified a total of 313 plant species in our oak woodland sites. Oak woodlands had significantly higher species richness (at the 1m2 scale) than other vegetation types. Oak woodlands were comparable to coniferous forests in canopy cover, litter cover, and bare ground, but had significantly lower duff depth and litter depth than coniferous forest vegetation types. Oak woodlands had higher duff depth, litter depth, canopy cover, and litter cover than either chaparral or coastal scrub vegetation types.

We found that fuel break construction method was significantly associated with relative nonnative cover in oak woodland vegetation types (Figure 2-10). Fuel breaks that had been constructed by selective thinning and mastication in oak woodlands had significantly lower relative nonnative cover than fuel breaks constructed by other means.

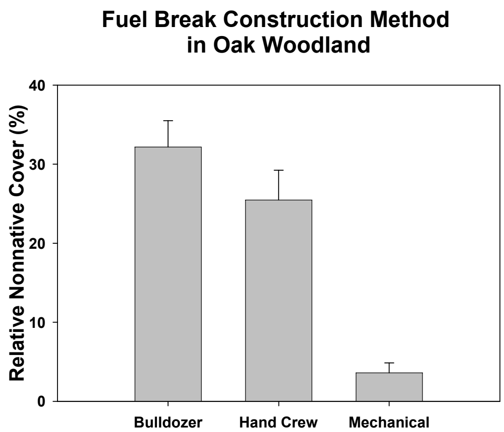


Figure 2-10. ANOVA found significant effect of construction method on relative nonnative cover in oak woodlands (N=57, df=2, 54, F=20.432, *P*<0.001). Error bars represent + 1 SE.

Relative nonnative cover in oak woodland vegetation types was significantly higher in areas that had experienced more numerous fires, and in plots that were closer to fuel breaks (Figure 2-11).

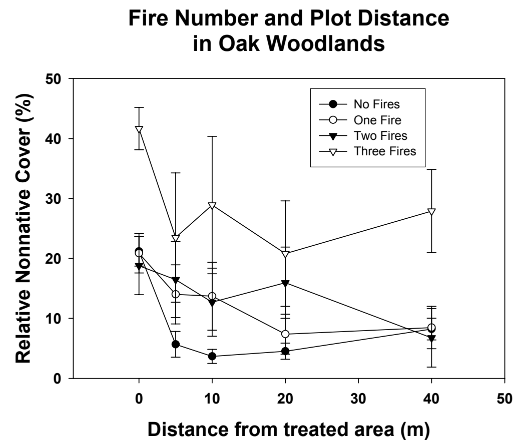


Figure 2-11. ANOVA found significant effects of fire number and distance from the fuel treatment on relative nonnative cover in oak woodlands (N=385, number of fires, df=3, 365, F=11.827, *P*<0.001; distance, df=4, 365, F=6.588, *P*<0.001). Error bars represent + 1 SE.

Relative nonnative cover also was significantly greater in oak woodland vegetation types that had been grazed, and this effect was significant at distances up to 40 m from the fuel break (Figure 2-12).

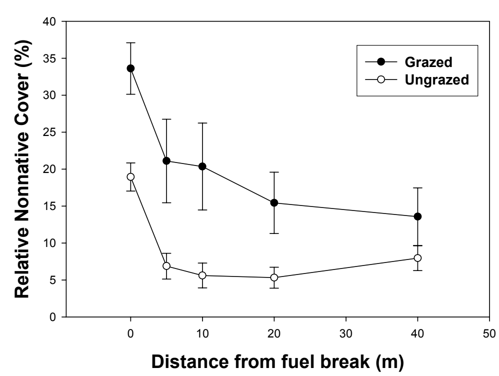


Figure 2-12. ANOVA found significant effect of grazing and distance from the fuel treatment on relative nonnative cover in oak woodlands (N=385, grazing effect: df=1, 375, F=29.991, *P*<0.001, plot distance effect: df=4, 375, F=13.018, *P*<0.001). Error bars represent + 1 SE.

CHAPARRAL

We studied 15 fuel breaks that contained chaparral vegetation types, typically dominated by chamise (*Adenostoma fasciculatum*), manzanita species (*Arctostaphylos spp.*), and scrub oak species (*Quercus spp.*).


Chaparral vegetation type in the Mendocino National Forest

Fuel breaks located in chaparral type plant communities included the Shepard Saddle, Lewis Creek, and Lookout Point fire lines in Sequoia and Kings Canyon National Park, the Oregon fire line in the Shasta Trinity National Forest, the Tower fire line and Whiskey Creek fuel breaks in the Whiskeytown National Recreation Area, the Pilot Grove fuel break in the Mendocino National Forest, the Sierra Pelona fuel break in the Angeles National Forest, the Calf Canyon Fuel Break administered by the Bakersfield District of the Bureau of Land Management, the Palos Ranches fuel break in the Sequoia National Forest, the Etz Meloy and Zuma Ridge fuel breaks in the Santa Monica National Recreation Area, the Sierra Madre Ridge in the Los Padres National Forest, the Rouse Ridge fuel break in the San Bernardino National Forest, and the Aguanga fuel break in the Cleveland National Forest.

Chaparral study sites ranged in elevation from 300 to 1600 m, and included fuel breaks constructed by mechanical thinning, hand crews, and bulldozers. These sites ranged in age from 1 to 51 years, and included areas that had experienced between 0 and 4 fires. About half (17 of 32 transects) of these sites are currently being grazed.

Chaparral had the second highest relative nonnative cover of the four general vegetation types we identified (mean=39.0% of total plant cover). Chaparral sites had significantly more exposed bare ground than any other vegetation type, and less ground cover than oak woodland or coniferous forest vegetation types. However, ground and canopy cover were significantly higher in chaparral than in coastal scrub vegetation types. We identified a total of 438 plant species in our $1m^2$ plots in chaparral vegetation types. Species richness at the $1m^2$ scale was statistically similar to coniferous forest and coastal scrub vegetation types.

We found that fuel break construction method was significantly associated with differences in relative nonnative cover in chaparral vegetation types (Figure 2-13). Fuel breaks constructed by bulldozers had significantly higher relative nonnative cover than fuel breaks constructed by other means.

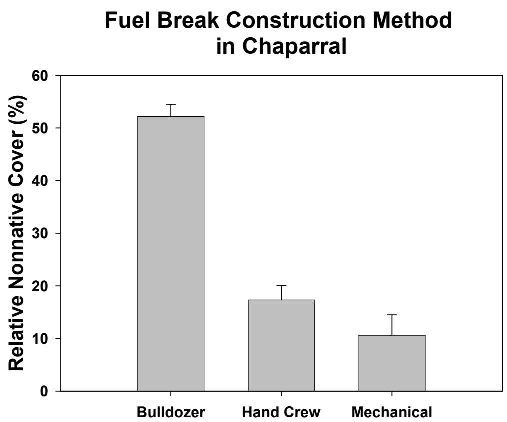


Figure 2-13. The effect of construction method on relative nonnative cover in chaparral vegetation types. ANOVA found significant differences (N=108, df=2, 105, F=58.294, *P*<0.001). Error bars represent + 1 SE.

Wildland areas adjacent to fuel breaks in chaparral vegetation types were more likely to have higher relative nonnative cover when they had experienced grazing or recurrent fires (Figures 2-14 and 2-15). There was a significant interaction effect between fire number and distance from the fuel break, while there was no interaction between grazing and distance from the fuel break. Distance to the fuel break was an important factor at all chaparral sites, and plots closer to fuel breaks had higher relative nonnative cover, even when those sites had experienced multiple fires or had been grazed.

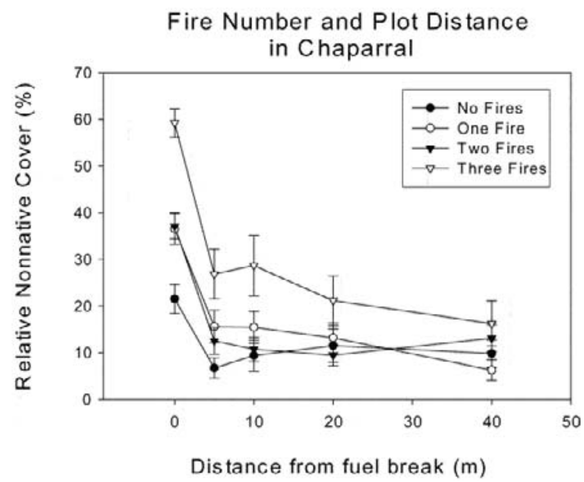


Figure 2-14. The effect of fire number and distance from the fuel treatment on relative nonnative cover in chaparral. ANOVA found significant interaction effect (N=720, df =12, 700, F=13.030, *P* <0.00), main effect of fire number (N=720, df=2, 700, F=15.365, *P*<0.001) and main effect of plot distance from fuel break (N=720, df=4, 700, F=48.314, *P*<0.001).
Error bars represent + 1 SE.

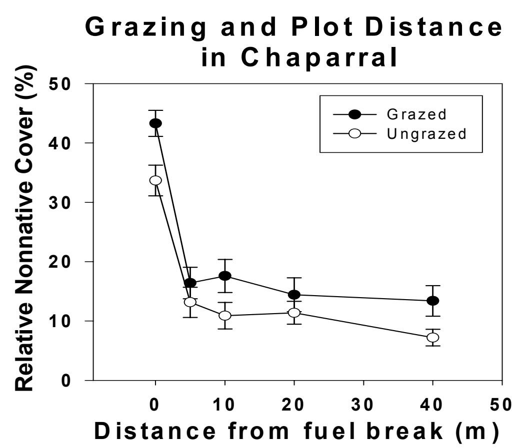


Figure 2-15. The effect of grazing and distance from the fuel treatment on relative nonnative cover in chaparral. ANOVA found significant main effects (grazing: N=719, df=1, 710, F=11.723, *P*<0.001, plot distance: N=719, df=4, 710, F=52.187, *P*<0.001). Error bars represent + 1 SE.

COASTAL SCRUB

There were only three fuel breaks that contained coastal scrub vegetation types, typically dominated by California sage (*Artemisia californica*), black sage (*Salvia mellifera*) and California buckwheat (*Eriogonum fasciculatum*).

Coastal scrub vegetation type in Casper's Wilderness Park

Coastal scrub plant communities were found at the Oso Ridge fuel break in Casper's Wilderness Park, Zuma Ridge fuel break in the Santa Monica National Recreation Area, and on a small portion of the Rouse Ridge fuel break in the San Bernardino National Forest.

Coastal scrub study sites were limited in elevation to below 700 m. All of these fuel breaks were constructed by bulldozers, and ranged in age from 19 to 55 years. We did not sample any unburned areas in coastal scrub vegetation types; all fuel breaks sampled had experienced between 1 and 5 fires.

Coastal scrub vegetation types had the highest relative nonnative cover of the four vegetation types we identified (mean=68.3% of total plant cover). Coastal scrub sites had significantly less duff depth, litter depth, canopy cover, and litter cover than other vegetation types.

We identified a total of 108 plant species in our $1m^2$ plots at the three coastal scrub study sites we sampled in this study. Native species richness at the $1m^2$ scale was statistically similar to coniferous forest and chaparral vegetation types. While many of the coastal scrub sites we sampled had experienced one or more fires during the past 50 years, very few of these sites were grazed. Therefore, we were not able to evaluate the effect of grazing within coastal scrub vegetation types; we found that fire number had no effect on relative nonnative cover. However, relative nonnative cover declined significantly with distance from the fuel breaks in coastal scrub vegetation types (Figure 2-16).

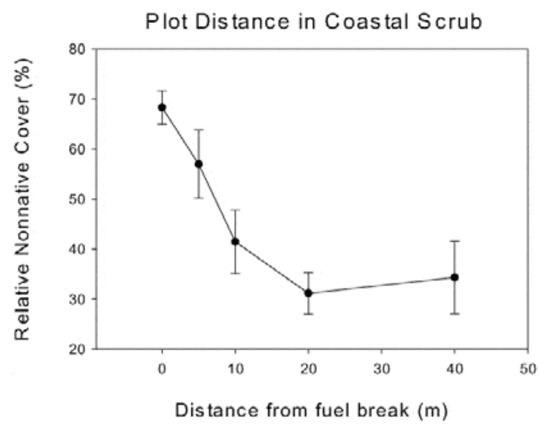


Figure 2-16. ANOVA found significant effect of distance from the fuel treatment on relative nonnative cover in coastal scrub vegetation types (N=95, df=4, 90, F=5.695, *P*<0.001). Error bars represent + 1 SE.

DISCUSSION

We found significant differences in relative nonnative cover and nonnative species richness among vegetation types. Vegetation type has been found to be among the most important factors influencing nonnative plant abundance, either because of the life history characteristics of the dominant plant community, or because of the association of different vegetation types with specific resources, such as soil nutrients or water availability (Aragon & Morales 2003; D'Antonio 1993; Larson and others, 2001; Mack 1989; Stohlgren and others, 2001).

The effect of vegetation type on nonnative abundance may be related to elevation. Our study sites in coniferous forests occurred at relatively high elevations (above 1000 m) and had the lowest relative cover of nonnatives. Conversely, the coastal scrub plant communities we sampled were located at relatively low elevations (generally below 300 m), and had the highest relative nonnative cover. Elevation has been found to be strongly negatively correlated with nonnative plant invasion in California, and most nonnative plants are not adapted to the climate at high elevations (Keeley and others, 2003; Schwartz and others, 1996).

The chaparral and oak woodland vegetation types we sampled in this study spanned a wide range of elevations (400–1600 m). We found that chaparral plant communities had higher nonnative plant cover and species richness than oak woodland sites. The difference in nonnative abundance between oak woodland and chaparral vegetation types may reflect differences in land use and disturbance history (Keeley 2000). For example, the chaparral sites we sampled had experienced more frequent fires than oak woodland sites. Chaparral sites also had significantly less duff depth and canopy cover, and more exposed bare ground than oak woodland sites.

Despite the strong influence of vegetation type on nonnative abundance and species richness, we found that a number of variables, including fuel break construction method, distance to the fuel break, fire number, and grazing still had significant effects on nonnative abundance when evaluated within individual vegetation types separately. This suggests that although important, vegetation type alone does not determine the abundance of nonnatives. We found that fuel breaks appear to promote nonnative abundance in all vegetation types, and this pattern may be compounded by more numerous fires or by grazing.

Text Box 2-1: Summary of Findings Vegetation Type Differences

- Nonnative abundance and species richness differed among vegetation types.
- Elevation, fire, grazing, and disturbance history may have explained some differences among vegetation types.
- Nonnatives were significantly more common on fuel breaks in all vegetation types;
- Environmental variables such as canopy cover and duff depth were significantly lower outside of fuel treatments in all vegetation types.
- Fuel break construction method altered nonnative abundance in all vegetation types where it could be examined.
- Fire and grazing were associated with higher abundance of nonnatives in most vegetation types.

Chapter Three: Site Specific Results

INTRODUCTION

We sampled 24 different fuel breaks in this study, representing a wide range of vegetation types, construction and maintenance regimes, and grazing and fire histories. Table 3-1 provides a brief overview of the different fuel breaks sampled in this study.

Table 3-1. Selected characteristics of fuel breaks included in this study ordered from lowest to highest elevation.

[A range is shown for some variables because there were multiple transects on each fuel break, and individual transects often varied in year of construction, fire history, construction method, and vegetation type. Abbreviations are: NF = National Forest; SMNRA = Santa Monica National Recreation Area; WNRA = Whiskeytown National Recreation Area; CDF = California Department of Forestry and Fire Protection; BLM = Bureau of Land Management; SEKI = Sequoia and Kings Canyon National Parks, LTBMU= Lake Tahoe Basin Management Unit; MT= mechanical thinning, BD= bulldozer, HC= hand crews, CF=Coniferous Forest, OW=Oak woodland, CP=Chaparral, CS=Coastal Scrub]

Site Code	Site Name	Managing Agency	Elev. (m)	Year Constructed	Number of Fires	Construction Method	Vegetation Type	Grazing or Logging	UTM X, Y
GA	Gasquet	Six Rivers NF	202	1995	0-1	MT	OW	None	420382E 4631797N
ZU	Zuma Ridge	SMNRA	244	1952	3-5	BD	CS/CP	None	885589E 3774442N
CW	Oso Ridge	Casper’s Park	273	1963	2-3	BD	CS	None	1007681E 3730835N
WC	Whiskey Creek	WNRA	390	2001-2003	0	MT	CP	None	537636E 4499983N
TO	Tower	WNRA	447	1980	1-4	BD	CP	Grazed	530298E 4502212N
CC	Calf Canyon	CDF and BLM	474	1965-2002	1-3	BD	CP	None	723242E 3921383N
SD	Shasta Divide	WNRA	492	1985	0	BD	OW	None	543785E 4490521N
EM	Etz Meloy	SMNRA	652	1957	2-3	BD	CP	None	879828E 3780738N
OR	Oregon	Shasta-Trinity NF	922	2001	0	BD	OW	None	505186E 4511552N
SS	Shepard Saddle	SEKI	983	1960	2-3	BD	CP/OW	Grazed	869150E 4045923N

Site Code	Site Name	Managing Agency	Elev. (m)	Year Constructed	Number of Fires	Construction Method	Vegetation Type	Grazing or Logging	UTM X, Y
BM	Burrough Mtn	Sierra NF	1109	1935	1	HC	OW	Grazed	823660E 4100650N
AG	Aguanga	Cleveland NF	1189	1974	0-2	HC	CP	Grazed	1072233E 3711374N
PG	Pilot Grove	Mendocino NF	1194	1960	1-2	BD	CP/OW/CF	Grazed	511751E 4343359N
CP	Cascadel Point	Sierra NF	1294	1920	2-3	HC	OW	Logged	814871E 4122622N
RR	Rouse Ridge	San Bernardino NF	1298	1984	1-2	BD	CS/CP	Grazed	1075390E 3743619N
SP	Sierra Pelona	Angeles NF	1302	1960	1-2	BD	OW/CP	Grazed	925013E 3831072N
LC	Lewis Creek	SEKI	1461	1981	0-2	HC	CP	None	882984E 4080437N
BR	Blacks Ridge	Lassen NF	1533	2002-2003	0-1	MT	CF	Grazed Logged	649479E 4524209N
SM	Sierra Madre	Los Padres NF	1535	1962-1966	0-2	BD	CP	Grazed	791673E 3864508N
PR	Palos Ranches	BLM	1544	1977-2001	0	HC/BD	CF/CP	Logged	904704E 3959471N
LP	Lookout Point	SEKI	1579	1997	0	HC	OW/CP	None	885263E 4042110N
AB	Antelope-Border	Plumas NF	1590	2001	0	MT	CF	Grazed Logged	705805E 4447632N
MC	McKenzie Ridge	Sequoia NF	1646	1960	0-2	MT	CF	Grazed Logged	852223E 4075163N
FL	Fallen Leaf	LTBMU	1899	1995	0	MT	CF	Grazed	755427E 4305872N

Many of the variables we measured differed greatly among fuel breaks. For example, mean relative nonnative cover ranged from 0 to over 50% (Figure 3-1). Native species richness also varied among sites ranging from between almost 2 to over 6 species per m^2 (Figure 3-2).

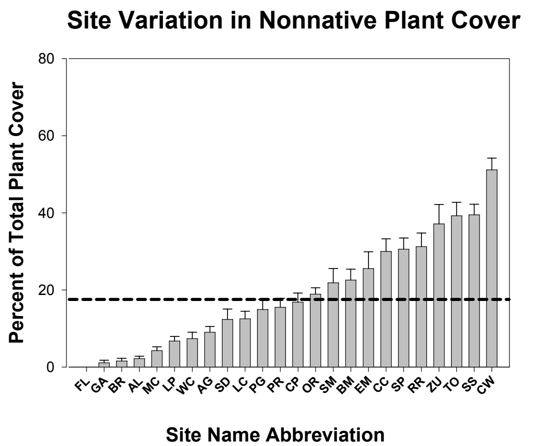


Figure 3-1. Variation in relative nonnative plant abundance between fuel breaks. N=1543. The mean value of 18% is shown as a dashed line. Error bars indicate + 1 SE.

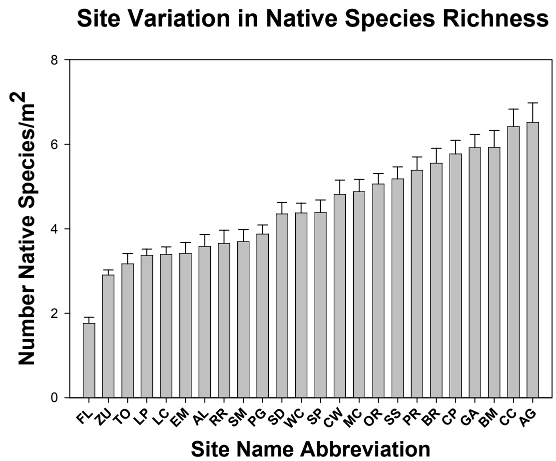


Figure 3-2. Variation in mean native species richness among fuel breaks. N=1543. Error bars indicate + 1 SE.

We found that duff depth and canopy cover together explained over 70% of the variation in relative nonnative cover (R^2=0.721, P<0.001). These environmental variables also varied considerably among sites. Duff depth ranged from less than 2 cm to over 50 cm (Figure 3-3). Overstory canopy cover ranged from 5 to 88% as shown in Figure 3-4.

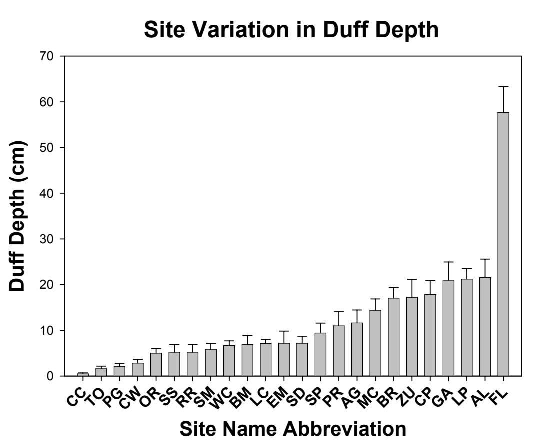


Figure 3-3. Variation in duff depth among fuel breaks. N=1543. Error bars indicate + 1 SE.

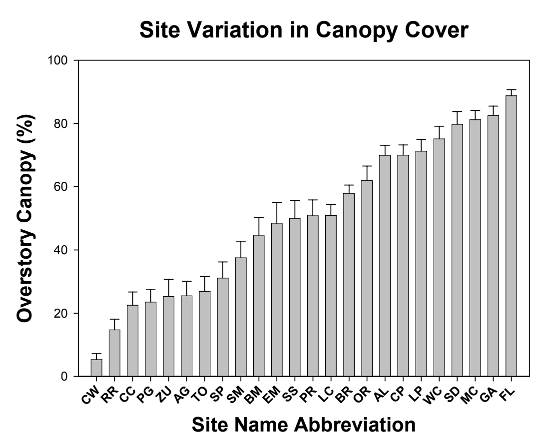


Figure 3-4. Variation in canopy cover among fuel breaks. N=1543. Error bars indicate + 1 SE.

We have described some of the factors that may explain differences in relative nonnative cover among fuel breaks, including construction methods and environmental factors (Chapter One), and the potential role of vegetation type (Chapter Two). In this chapter we focus on patterns observed at individual sites. A description of each fuel break is given separately below, arranged from lowest to highest elevation. Only a general description of the location of each study site is provided here. See Figure 1-1 for general location of each site. More specific information, including GIS shapefiles of plot locations, is available upon request.

This fuel break near Lake Tahoe had the highest duff depth and overstory canopy of any of our sites.

Gasquet Shaded Fuel Break, Six Rivers National Forest

The Gasquet shaded fuel break is located in the Six Rivers National Forest near the town of Gasquet in the Smith River National Recreation Area of Del Norte County. This shaded fuel break was constructed in 1995 by mechanical thinning and prescribed burning. Only two transects at the Gasquet fuel break contained nonnative plants, and these were located within the perimeter of the 1996 Panther Fire.

Gasquet shaded fuel break,
Six Rivers National Forest

The Gasquet shaded fuel break is located in a tan oak and Douglas fir (*Pseudotsuga menziesii*) forest. Other dominant species include incense cedar (*Calocedrus decurrens*) and black huckleberry (*Vaccinium ovatum*). Our plots on the Gasquet shaded fuel break were located predominately on the Jayel soil series. These are moderately deep, well drained soils formed in material weathered from serpentinized peridotite.

We identified 60 plant species in our $1m^2$ plots at the Gasquet shaded fuel break. Only 3 of these species were nonnative. The most common nonnative plant in our plots was Scotch broom (*Cytisus scoparius*).

Nonnative plants occupied 12% of the total plant cover at the Gasquet shaded fuel break in plots where they occurred, which represented only 10% of all plots. The mean relative nonnative cover (1%) on the Gasquet shaded fuel break was much lower than the mean (18%) of the 24 sites in our study. Relative nonnative plant cover was not significantly higher on the Gasquet fuel break than in the adjacent wildland off of the fuel break (Figure 3-5).

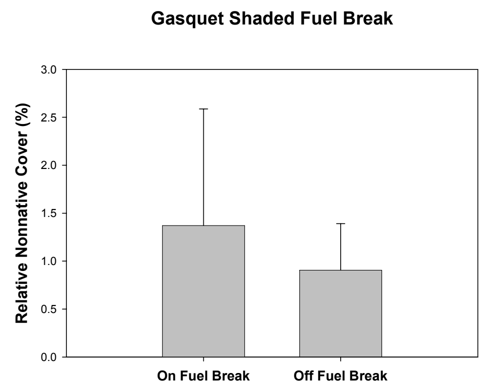


Figure 3-5. ANOVA did not find significant differences in relative nonnative abundance on the Gasquet fuel break compared to outside of the fuel break. (N=62, df=1, 60, F=0.022, *P*=0.883). Error bars indicate + 1 SE.

Santa Monica Mountains National Recreation Area

We sampled two fuel breaks in the Santa Monica Mountains National Recreation Area, near the city of Thousand Oaks in Los Angeles County. These were the Zuma Ridge and Etz Meloy fuel breaks.

The Etz Meloy fuel break was constructed in 1957 by bulldozers, and was maintained by bulldozers on an annual or biennual rotation by the Los Angeles County Fire Department until 1985. Portions of this fuel break were also maintained by goat grazing on an experimental basis. The Etz Meloy fuel break is not currently maintained. The area around the fuel break burned in the 1993 Green Meadows fire.

Etz Meloy fuel break, Santa Monica Mountains National Recreation Area

The Etz Meloy fuel break is located in a chaparral habitat, dominated by black sage (*Salvia mellifera*), bigpod ceanothus (*Ceanothus megacarpus*), and redshank (*Adenostema sparsifolium*). Our plots were located primarily on soils from the Hambright series. These are shallow, well drained soils formed in material weathered from basic igneous rocks.

We found 49 species in our 1m^2 plots at the Etz Meloy fuel break, including 13 nonnatives. The most common nonnative species in our plots on the Etz Meloy fuel break was red brome (*Bromus madritensis*).

The Zuma Ridge fuel break was constructed in 1952 by bulldozers. The fuel break was maintained by bulldozers on an annual or biennial rotation by the Los Angeles County Fire Department until 1985. Our plots along the Zuma Ridge fuel break were located in areas that have burned up to five times between 1935 and 1995.

Zuma Ridge fuel break, Santa Monica Mountains National Recreation Area

The Zuma Ridge fuel break is located in a coastal scrub type plant community, dominated by bigpod ceanothus, California encelia (*Encelia californica*), and purple sage (*Salvia leucophylla).* Our plots were located primarily on sandy soils classified as beaches. We identified 51 plant species in our 1m^2 quadrats at the Zuma Ridge fuel break, including 17 nonnative species. The most common nonnative species on the Zuma Ridge fuel break was wild oats (*Avena fatua).*

Nonnative plants were found in 100% of our 1 m^2 plots on both the Etz Meloy and Zuma Ridge fuel breaks, while nonnatives were only present in 22% and 45% of plots outside of these fuel breaks, respectively. Nonnative plant cover was significantly higher on both the Etz Meloy and Zuma Ridge fuel breaks than in the adjacent wildland. Zuma Ridge had higher nonnative plant cover than Etz Meloy both on and off the fuel break (Figure 3-6).

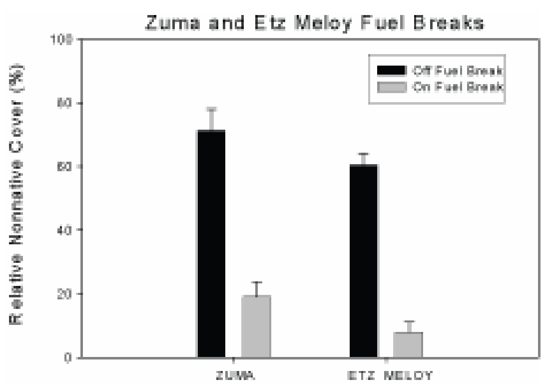


Figure 3-6. ANOVA found significant differences between nonnative abundance on the Zuma Ridge and Etz Meloy fuel breaks compared with adjacent wildlands. (Difference between fuel breaks, N=106, df=1, 102, F=6.528, P=0.012; and position on or off fuel breaks, N=106, df=1, 102, F=103.8, P<0.001). Error bars represent + 1 SE.

Oso Ridge Fuel Break, Casper's Wilderness Park

The Oso Ridge fuel break is located within Casper's Wilderness Park, near the town of San Juan Capistrano, in Orange County. Casper's Wilderness Park is administered by the Orange County Parks and Recreation Department. The Oso Ridge fuel break was constructed in the 1960s by bulldozers, and has been maintained annually. A number of fires have occurred in the vicinity of this fuel break, including the 1993 Ortega fire.

Oso Ridge fuel break,
Casper's Wilderness Park

The Oso Ridge fuel break is located in a coastal scrub plant community, dominated by California sage, black sage, and California buckwheat. Our plots on Oso Ridge were located primarily in the Alo soils series. The Alo series consist of moderately deep, well drained soils formed in material weathered from shale or sandstone on mountains.

We identified 80 species in our 1m^2 quadrats along Oso Ridge, including 18 nonnative species. The Oso Ridge fuel break had the highest relative cover (51%) of nonnative plant species of the 24 sites in our study. The most common nonnative was black mustard (*Brassica nigra*). Nonnative species were found in 100% of our plots both on and off the Oso Ridge fuel break. Nonnative plant cover was significantly higher on the Oso Ridge fuel break than in the adjacent wildland off of the fuel break (Figure 3-7).

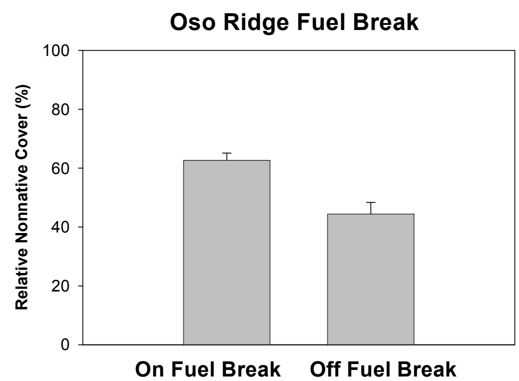
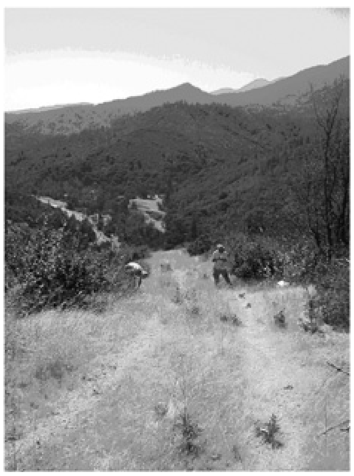


Figure 3-7. ANOVA found significant differences in relative nonnative abundance on the Oso Ridge fuel break compared with adjacent wildlands (N=60, df=1, 58, F=4.812, *P*=0.032). Error bars represent + 1 SE.

Whiskeytown National Recreation Area

We studied three separate fuel breaks within the Whiskeytown National Recreation Area, located west of the town of Redding in Shasta County. These included the Tower fire line, the Shasta Divide fuel break, and the Whiskey Creek fuel break.

The Tower fire line was constructed in 1980 by bulldozers to contain the Tower wildfire. The fire line has not been maintained and was seeded with native plants after 1980. At the time we conducted our sampling in 2002, the area surrounding the Tower fire line had experienced four separate fires since 1959, the most recent in 1999. This area was burned again during the 2004 French fire.



Tower fire line, Whiskeytown National Recreation Area

The Tower fire line is located in a chaparral type plant community dominated by chamise (*Adenostoma fasciculatum*), interior live oak (*Quercus wislizenii*), and yerba santa (*Eriodictyon californicum*). Our plots were located primarily on Boomer soils series. These are very deep, well drained soils that formed in material weathered from metavolcanic rock. We identified 51 species in our $1m^2$ plots at the Tower fire line, 19 of which were nonnative. The most common nonnative species on the Tower fire line was foxtail fescue (*Vulpia myuros)*.

The Shasta Divide fuel break was constructed in 1985 by bulldozers and prescribed burning. The fuel break has been periodically maintained by prescribed burning and hand crews. The Shasta Divide fuel break is located primarily in an oak woodland vegetation type dominated by canyon live oak (*Quercus chrysolepis*), black oak (*Quercus kelloggii*), and whiteleaf manzanita (*Arctostaphylos viscida*). We identified 56 species in our $1m^2$ plots at the Shasta Divide fuel break, 10 of which were nonnative. The most common nonnative species on the Shasta Divide fuel break was foxtail fescue.

Shasta Divide fuel break, Whiskeytown National Recreation Area

The Whiskey Creek shaded fuel break was created in 2001 and 2003 by selective thinning and prescribed burning. Fuels were masticated and remain on the ground within the fuel break. The Whiskey Creek shaded fuel break is located in a chaparral habitat dominated by whiteleaf manzanita, black oak, and chamise. Our plots were located primarily on Boomer soils at this site, which are very deep, well drained soils that formed in material weathered from metavolcanic rock.

We identified 56 species in our 1m^2 plots at the Whiskey Creek fuel break, 8 of which were nonnative. The most common nonnative species on the Whiskey Creek shaded fuel break was barren brome (*Bromus sterilis*).

Whiskey Creek fuel break,
Whiskeytown National Recreation Area

The Whiskey Creek and Shasta Divide fuel breaks had lower mean relative nonnative cover (7% and 12%, respectively) than most other sites in our study (18%) including the Tower fire line (39%). Relative nonnative cover was higher on the fuel break than in the adjacent wildland at all three sites in the Whiskeytown National Recreation Area, and this effect differed among fuel breaks (Figure 3-8).

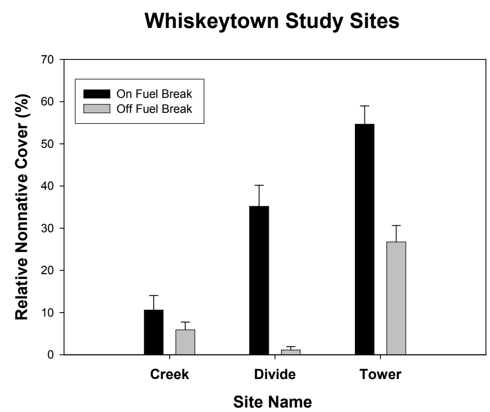


Figure 3-8. ANOVA found a significant interaction between position on and off the fuel break and site (N=173, df=2, 167, F=11.743, $P<0.001$). Error bars represent + 1 SE.

Calf Canyon Fuel Break, Bakersfield BLM and San Luis Obispo CDF

The Calf Canyon fuel break is located near the town of Santa Margarita in San Luis Obispo County. This fuel break is managed by the Bakersfield District of the Bureau of Land Management (BLM), and maintained by the San Luis Obispo Unit of the California Department of Fire and Forestry (CDF). This fuel break was first constructed in 1965 using bulldozers, and has been maintained periodically by hand crews. The areas adjacent to the fuel break burned during the 2002 Highway 58 fire.

Calf Canyon fuel break,
San Luis Obispo CDF and BLM.

Calf Canyon is a chamise dominated chaparral habitat. Other shrub species we observed at Calf Canyon included wedgeleaf ceanothus (*Ceanothus cuneatus*) and black sage. Our plots at Calf Canyon were located primarily on Cieneba soils. These are very shallow, somewhat excessively drained soils that formed in material weathered from granitic rock.

Calf Canyon had the second highest species richness of our 24 study sites; we identified 97 species in our $1m^2$ plots at Calf Canyon, 21 of which were nonnative. The most common nonnative species was cheatgrass (*Bromus tectorum*).

The Calf Canyon fuel break had higher mean relative nonnative cover (30%) than the mean (18%) of 24 sites in our study. Nonnative plants were found in 100% of our $1m^2$ plots on Calf Canyon fuel break, and in 76% of plots outside the fuel break. Nonnative plant cover was significantly higher on the Calf Canyon fuel break than in the adjacent wildland (Figure 3-9).

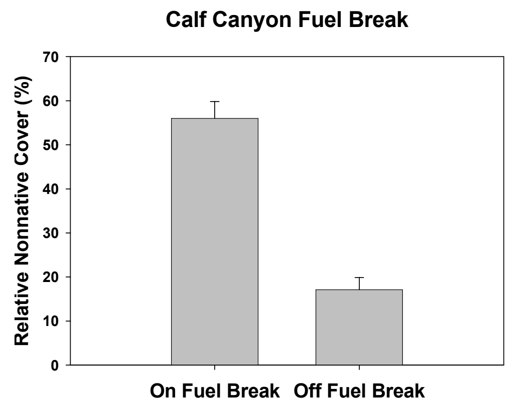


Figure 3-9. ANOVA found significant differences in relative nonnative abundance on the Calf Canyon fuel break compared with adjacent wildlands (N=60, df=1, 58, F=55.639, $P<0.001$). Error bars represent + 1 SE.

Sequoia and Kings Canyon National Park

We studied three fuel breaks at Sequoia and Kings Canyon National Parks, the Shepard Saddle fire line, the Lookout Point fire line, and the Lewis Creek fire line. All of our plots in Sequoia and Kings Canyon were located primarily on soils of the Holland series. These are very deep, well drained soils that formed in material weathered from granitic rock.

The Shepard Saddle fire line is located near Sequoia National Park's southwestern boundary near the town of Three Rivers in Tulare County. This fire line was constructed in 1960 by bulldozers, and has not been maintained. Areas in the vicinity of this fire line were burned during the 1996 Kaweah fire. Unlike most other areas in Sequoia National Park, the Shepard Saddle fire line is occasionally subject to grazing. The Shepard Saddle fire line includes black oak woodlands and chaparral habitats.

The most common nonnative species on the Shepard Saddle fire line was soft chess (*Bromus hordeaceus)*. We observed 80 species in our 1m^2 plots on Shepard Saddle, including 20 nonnative species.

Shepard Saddle fire line in
Sequoia National Park

The Lookout Point fire line is located in the Mineral King area of Sequoia National Park in Tulare County. This fire line was constructed in 1997 by hand crews to contain the Redwood fire. The Lookout Point fire line is located in oak woodland and chaparral habitats, dominated by canyon live oak (*Quercus chrysolepis*) and indian manzanita (*Arctostaphylos mewukka*). The most common nonnative species on the Lookout Point fire line was cheatgrass. We observed 42 species in our 1m^2 plots at Lookout Point, including three nonnative species.

The Lewis Creek fire line is located in the Cedar Grove area of Kings Canyon National Park, Fresno County. This fire line was constructed in 1981 by hand crews, in preparation for a prescribed burn. Portions of the Lewis Creek fire line were burned in the 1980 Lewis Creek fire. The Lewis Creek fire line is located in a chaparral habitat, dominated by whiteleaf manzanita, wedgeleaf ceanothus, and birchleaf mountain mahogany (*Cercocarpus betuloides*). The most common nonnative plant found on the Lewis Creek fire line was cheatgrass. We observed a total of 55 species in our 1m^2 plots at Lewis Creek, three of which were nonnative.

Shepard Saddle had much higher relative nonnative cover (39%) than either the Lookout Point or Lewis Creek fire lines (6% and 12% respectively). Relative nonnative plant cover was significantly higher on the Shepard Saddle and Lookout fire lines than in the adjacent wildland areas. However, there was no difference in relative nonnative plant cover on the Lewis Creek fire line compared with adjacent wildlands (Figure 3-10).

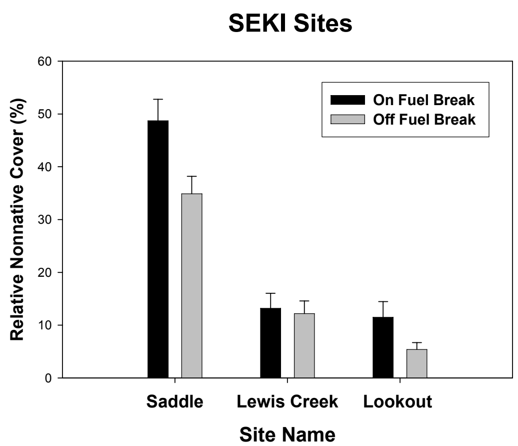


Figure 3-10. ANOVA found significantly higher relative nonnative abundance on the Shepard Saddle and Lookout Point fire lines compared with adjacent wildlands, but this pattern did not emerge on the Lewis Creek fire line (interaction between site and position on fuel break, N=173, df=2, 167, F=41.113, $P<0.001$). Error bars represent + 1 SE. Significance assessed with Bonferroni adjusted P value of 0.015 for 3 post-hoc comparisons.

Sierra National Forest

We studied two fuel breaks in the Sierra National Forest, the Burrough Mountain fuel break and the Cascadel Point fuel break. The Burrough Mountain fuel break is located in the Sierra National Forest near the town of Toll House in Fresno County. The Cascadel Point fuel break is located east of the town of North Fork in Madera County.

The Burrough Mountain fuel break was first constructed in 1935, and has been maintained regularly through clearing and prescribed burning. This fuel break is located in mixed oak woodland. The most common tree species we observed included interior live oak, black oak, and California buckeye (*Aesculus californica*). Our plots on the Burrough Mountain fuel break were located on soils from the Ahwahnee, Chaix, and Holland series. These are deep, well to somewhat excessively well drained soils formed in material weathered from igneous rock such as granite and granodiorite.

The Burrough Mountain fuel break had the highest site level species diversity of any of our study sites. We detected over 100 species in our 1m^2 plots at Burrough Mountain. Twenty of these species were nonnative. The most common nonnative plant we encountered at this site was tocalote (*Centaurea melitensis*).

Burrough Mountain fuel break,
Sierra National Forest

The Cascadel Point fuel break is not currently maintained, although prescribed burning was conducted in the vicinity of the fuel break in 1980. The Cascadel Point fuel break is located within a mule deer winter range habitat area and is currently excluded from cattle grazing.

The fuel break is located in a mixed oak woodland, characterized by black oak (*Quercus kelloggii*), ponderosa pine (*Pinus ponderosa*), canyon live oak (*Quercus chrysolepis*), and whiteleaf manzanita (*Arctostaphylos viscida*). Our plots at Cascadel Point were located primarily on soils of the Holland series. These are very deep, well drained soils that formed in material weathered from granitic rock.

The most common nonnative plant in our plots on the Cascadel Point fuel break was field hedge parsley (*Torilis arvensis*). We recorded 80 species in our 1m^2 plots on the Cascadel Point fuel break, 20 of which were nonnative.

Cascadel Point fuel break,
Sierra National Forest

The Burrough Mountain fuel break had higher mean relative nonnative cover (23%) than the mean (18%) of 24 sites in our study, while the Cascadel Point fuel break had slightly lower mean relative nonnative cover (17%). Nonnative plants occurred in 100% of the plots on the Burrough Mountain fuel break, and 53% of plots in the adjacent wildland. Nonnative plants occurred in 75% of the plots on the Cascadel Point fuel break, and 56% of plots in the adjacent wildland.

Nonnative plant cover was significantly higher on both the Burrough and Cascadel Point fuel breaks than in the adjacent wildlands, and there were also significant differences between fuel breaks (Figure 3-11).

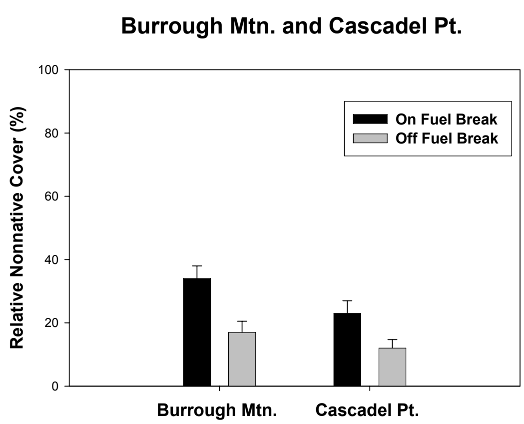


Figure 3-11. ANOVA found significant differences between fuel breaks (N=110, df=1, 106, F=4.674, *P*=0.033), and with position on or off fuel break (N=110, df=1, 106 F=18.772, *P*<0.001). Error bars represent + 1 SE.

Aguanga Fuel Break, Cleveland National Forest

The Aguanga fuel break is located in the Cleveland National Forest, near the town of Oak Grove in San Diego County. This fuel break was constructed in 1974 by hand crews, mechanical thinning, and prescribed fire. It has been maintained on an approximately five year rotation by hand crews and prescribed burning. Portions of the fuel break were most recently prescribed burned in 2003.

Aguanga fuel break, Cleveland National Forest

The Aguanga fuel break is located in a chaparral vegetation type, dominated by chamise, red shank, and cupleaf ceanothus (*Ceanothus greggii*).

The most common nonnative species on the Aguanga fuel break was red brome. We identified 80 species in our $1m^2$ plots at this site, 9 of which were nonnative. The Aguanga fuel break had lower mean relative cover (9%) than the mean (18%) of 24 sites in our study. Nonnative plants occurred in 80% of plots on the Aguanga fuel break, and 40% of plots in the adjacent wildland.

Relative nonnative cover was significantly higher on the Aguanga fuel break than in the adjacent wildland area (Figure 3-12).

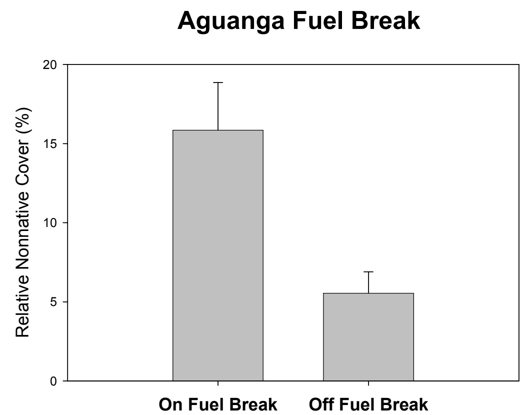


Figure 3-12. ANOVA found significant differences in relative nonnative abundance on the Aguanga fuel break compared with adjacent wildlands (N=60, df=1, 58, F=14.016, P<0.001). Error bars represent + 1 SE.

Pilot Grove Fuel Break, Mendocino National Forest

The Pilot Grove fuel break is located in the Mendocino National Forest near Clear Lake in Lake County. This fuel break was constructed in 1960 by bulldozers, and has been maintained by prescribed burning on an approximately five-year rotation. The area surrounding this fuel break was burned during the 1996 Forks fire.

Pilot Grove fuel break,
Mendocino National Forest

The Pilot Grove fuel break includes a range of plant communities, including ponderosa pine forest, black oak woodlands, and chaparral habitats dominated by chamise. Portions of the fuel break were historically seeded with grasses, including Harding grass (*Phalaris aquatica)*. Our plots on the Pilot Grove fuel break were located primarily on soils from the Neuns series. These are moderately deep, well drained soils that formed in slope alluvium and colluvium from metamorphosed igneous and sedimentary rocks.

We identified 78 species in our 1m^2 plots at Pilot Grove, 17 of which were nonnative. The most common nonnative species on the Pilot Grove fuel break was foxtail fescue. Nonnatives were detected in 80% of the quadrats on the Pilot Grove fuel break, and only 20% of those outside the fuel break. The Pilot Grove fuel break had slightly lower mean relative nonnative cover (15%) than the mean (18%) of 24 sites in our study. Nonnative plant cover was significantly higher on the Pilot Grove fuel break than in the adjacent wildland off of the fuel break (Figure 3-13).

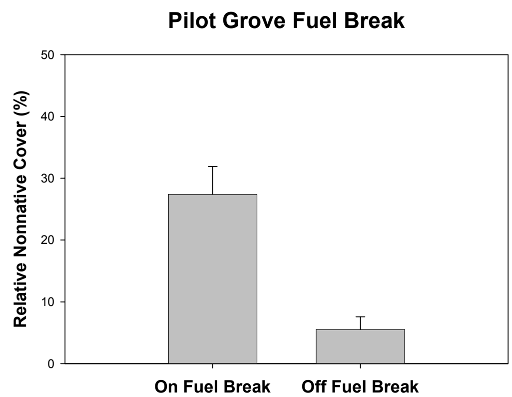


Figure 3-13. ANOVA found significant differences in relative nonnative abundance on the Pilot Grove fuel break compared with adjacent wildlands, (N=70, df= 1, 68, F=29.807, $P<0.001$). Error bars represent + 1 SE.

Rouse Ridge Fuel Break, San Bernardino National Forest

The Rouse Ridge fuel break is located east of the town of Hemet, Riverside County, in the San Bernardino National Forest. This fuel break was constructed in 1984 by bulldozers and prescribed burning. Portions of the fuel break were prescribed burned again during 2002 and 2003.

Rouse Ridge fuel break,
San Bernardino National Forest

The Rouse Ridge fuel break is located primarily in a chaparral vegetation type dominated by chamise, California buckwheat, and birchleaf mountain mahogany (*Cercocarpus betuloides*). Soils on the Rouse Ridge fuel break were primarily of the Chawanakee and Goulding series. Both series are shallow, somewhat excessively drained soils. The Chawanakee is formed in material weathered from granitic rock, while the Goulding series is formed in material weathered from metavolcanic or metasedimentary rocks.

We identified 81 species in our 1m^2 plots at Rouse Ridge, 16 of which were nonnative. The most common nonnative species on the Rouse Ridge fuel break was cheatgrass.

Nonnative species occurred in 65% of plots outside the fuel break, and 90% of plots on the fuel break. The mean relative nonnative cover at the Rouse Ridge study site (31%) was higher than the mean (18%) of 24 sites in our study. Nonnative plant cover was significantly higher on the Rouse Ridge fuel break than in the adjacent wildland (Figure 3-14).

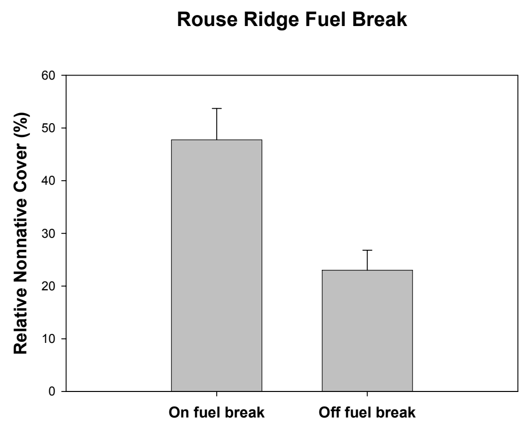


Figure 3-14. ANOVA found significant differences in relative nonnative abundance on the Rouse Ridge fuel break compared with adjacent wildlands (N=60, df=1, 58, F=12.195, P=0.001).
Error bars represent + 1 SE.

Sierra Pelona Fuel Break, Angeles National Forest

The Sierra Pelona fuel break is located in the Angeles National Forest east of the City of Santa Clarita, Los Angeles County. The Sierra Pelona Fuel Break was constructed in the 1960s by bulldozers. The fuel break has been annually maintained by cattle grazing, and is periodically prescribed burned.

Sierra Pelona fuel break,
Angeles National Forest

The Sierra Pelona fuel break occurs in oak woodland and chaparral type plant communities, dominated by scrub oak (*Quercus berberidifolia*), canyon live oak, chamise, and California buckwheat. Our plots on the Sierra Pelona fuel break were located on the Gaviota series. These consist of shallow, well drained soils that formed in material weathered from hard sandstone or meta-sandstone. The most common nonnative species we observed on the Sierra Pelona fuel break was cutleaf filaree (*Erodium cicutarium).* We identified 71 species in our 1m^2 plots at the Sierra Pelona fuel break, 16 of which were nonnative.

Nonnative species were found in 75% of plots in the wildland area, and 100% of plots on the fuel break. The Sierra Pelona fuel break had higher relative cover of nonnative plant species (31%) than the mean (18%) of 24 sites in our study.

Relative nonnative plant cover was significantly higher on the Sierra Pelona fuel break than in the adjacent wildland (Figure 3-15).

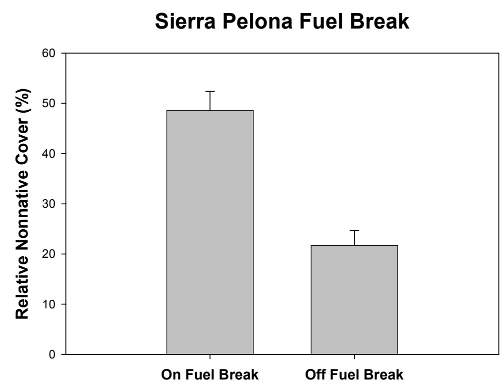


Figure 3-15. ANOVA found significant differences in relative nonnative abundance on the Sierra Pelona fuel break compared with adjacent wildlands (N=60, df=1, 58, F=25.518, *P*<0.001).
Error bars represent + 1 SE.

Blacks Ridge Defensible Fuel Profile Zone, Lassen National Forest

The Blacks Ridge Defensible Fuel Profile Zone (DFPZ), a shaded fuel break, is located in the Eagle Lake Ranger District of the Lassen National Forest, near the town of Little Valley in Lassen County.

Blacks Ridge DFPZ,
Lassen National Forest

This shaded fuel break was constructed as part of the Herger-Feinstein Quincy Library Group Forest Recovery Act, Bill HR 858, passed in 1997. The entire Blacks Ridge DFPZ is planned to occupy almost 3642 hectares (ha) (9000 acres), including thinning and group selection treatments. As of 2003 when we collected data, much of this DFPZ had not yet been constructed. We collected data on two portions of the DFPZ, where almost 101 ha (250 acres) had been treated to reduce fuels using mechanical thinning and prescribed burning between 2002 and 2003.

The Blacks Ridge DFPZ is located in a ponderosa pine forest. Other common species we observed in our plots at the Blacks Ridge DFPZ included mountain mahogany (*Cercocarpus ledifolius*), mahala carpet (*Ceanothus prostratus*), and mule’s ear (*Wyethia mollis*). Our plots on the Blacks Ridge DFPZ were located on Trojan and Holland soils. Trojan soils are very deep, well drained soils that formed in colluvium and residuum derived from volcanic rocks or from schist and argillite. Holland soils are very deep, well drained soils that formed in material weathered from granitic rock.

We identified 60 species in our 1m^2 plots at Blacks Ridge DFPZ, three of which were nonnative. The most common nonnative plant we found was cheatgrass. Nonnative species were found in 18% of plots in the untreated wildland area, and only 8% of plots within the DFPZ. The Blacks Ridge DFPZ had the third lowest relative cover of nonnative plant species (1.6%) of 24 sites in our study.

Nonnative plant cover was not statistically different in the treated area of the Blacks Ridge DFPZ compared to the adjacent wildland (Figure 3-16).

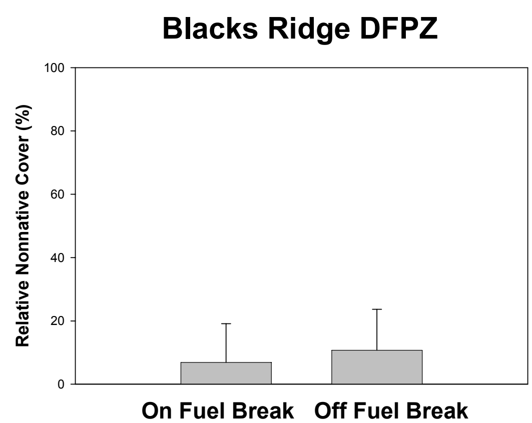


Figure 3-16. ANOVA found no difference in relative nonnative abundance on the Blacks Ridge DFPZ compared with adjacent wildlands (N=80, df=1, 78, F=25.518, *P*=0.1430). Error bars represent + 1 SE.

Sierra Madre Ridge Fuel Break, Los Padres National Forest

The Sierra Madre Ridge fuel break is located in the Los Padres National Forest, southwest of the Cuyama Valley, in Santa Barbara County. This fuel break was constructed in 1964 by bulldozers. The fuel break has been maintained regularly, initially through the use of herbicides and mechanical clearing, and more recently through prescribed burning.

Sierra Madre Ridge fuel break,
Los Padres National Forest

The Sierra Madre Ridge fuel break is located in a scrub oak habitat, dominated by Tucker's oak (*Quercus john-tuckeri*), and scrub oak. The most common nonnative species on the Sierra Madre Ridge fuel break was cheatgrass. Our plots were located on Aramburu and Lodo soils. The Aramburu series are moderately deep, well drained soils that formed in material weathered from shale or sandstone. The Lodo series consists of shallow, somewhat excessively drained soils that formed in material weathered from hard shale and fine grained sandstone.

We identified 80 plant species in our 1m^2 plots at the Sierra Madre Ridge, 11 of which were nonnative. Nonnative species occurred in 20% of plots outside the fuel break and 100% of plots within the fuel break. The Sierra Madre Ridge fuel break had slightly higher relative nonnative cover (22%) than the mean (18%) of 24 sites in our study.

Nonnative plant cover was significantly higher on the Sierra Madre Ridge fuel break than in the adjacent wildland (Figure 3-17).

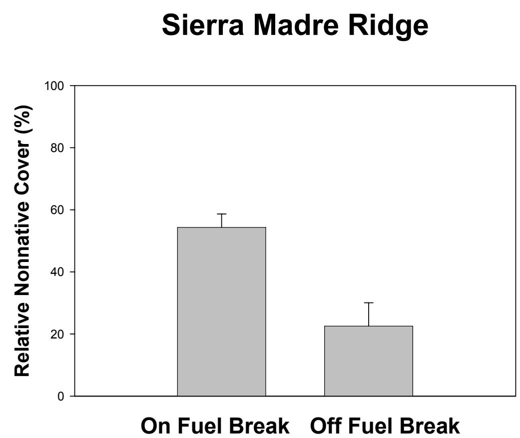


Figure 3-17. ANOVA found significantly higher relative nonnative abundance on the Sierra Madre Ridge fuel break compared with the adjacent wildland (N=60, df=1, 58, F= 133.226, P<0.001). Error bars represent + 1 SE.

Palos Ranches Fuel Break, Sequoia National Forest and BLM

This fuel break is located west of the town of Wofford Heights in Kern County. The fuel break consists of two separate portions, the Shirley portion and the Palos Ranches portion, constructed and managed by separate agencies, the USDA Forest Service and the Bureau of Land Management. The Shirley portion is located within the Sequoia National Forest. This portion of the fuel break was constructed in 1977 by mechanical thinning. The fuel break is located in a mixed conifer forest dominated by incense cedar, white fir, and black oak. The only nonnative plant found on the Shirley portion of the fuel break was cheatgrass.

Palos Ranches fuel break, BLM

The Palos Ranches portion of the fuel break is located on land managed by the Bakersfield District of the Bureau of Land Management. This portion of the fuel break was constructed by bulldozers and hand crews in 1998 and 2001 for use during a prescribed burn. The Palo Ranches portion of the fuel break is located in a chaparral habitat, dominated by wedgeleaf ceanothus, birchleaf mountain mahogany, and greenleaf manzanita (*Arctostaphylos patula*). The most common nonnative species on the Palos Ranches portion of the fuel break was cheatgrass.

Soils on both portions of the Palos Ranches fuel break were predominately Walong series. The Walong series consists of moderately deep, well drained soils that formed in material weathered from granitic rocks.

We identified 85 species in our 1m^2 plots on the entire Palos Ranches fuel break, including both the Palos Ranches and Shirley portions. Eight of these species were nonnative. Nonnative species were found in 50% of our plots outside the fuel break and 70% of our plots within the treated area. The Palo Ranches fuel break had slightly lower relative nonnative cover (16%) than the mean (18%) of 24 sites in our study.

Nonnative plant cover was significantly higher on the Palo Ranches fuel break than in the adjacent wildland (Figure 3-18).

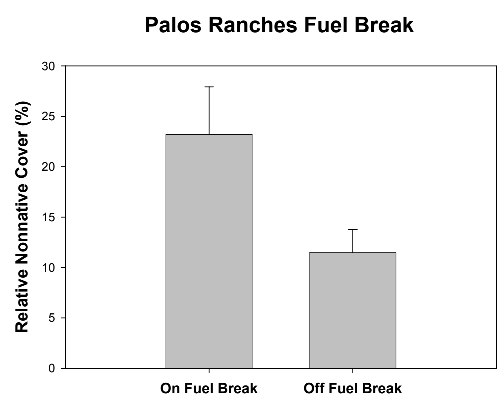


Figure 3-18. ANOVA found significant differences in relative nonnative abundance on the Palos Ranches fuel break compared with adjacent wildlands (N=60, df=1, 58, F=5.094, *P*=0.028).
Error bars represent + 1 SE.

Antelope Border Defensible Fuel Profile Zone, Plumas National Forest

The Antelope Border Defensible Fuel Profile Zone (DFPZ), a shaded fuel break, is located in the Plumas National Forest in the vicinity of the Antelope Recreation Area, Plumas County. This fuel reduction project was implemented as part of the Herger-Feinstein Quincy Library Group Forest Recovery Act, HR 858, passed in 1997. The entire Antelope Border DFPZ consists of 34 units, varying in size from 5 to 50 ha (11 to 127 acres). For this study we collected data on units 11 and 12, totaling about 40 ha (100 acres) in size. These units were constructed in 2001 using mechanical thinning and prescribed burning.

Antelope Border DFPZ,
Plumas National Forest

The Antelope Border DFPZ is located in a ponderosa pine forest. Other common species we observed included antelope bitterbrush (*Purshia tridentata*) and mahala carpet. Soils on the Antelope Border DFPZ were from the Chaix and Cagwin series. The Chaix series consists of moderately deep, somewhat excessively drained soils that formed in material weathered from acid intrusive igneous rock, mainly granite or granodiorite. The Cagwin series consists of moderately deep, somewhat excessively drained soils that formed in material weathered from granite.

The most common nonnative plant we encountered in our study plots at the Antelope Border DFPZ was cheatgrass. We identified 59 species in our 1 m^2 plots at the Antelope Border DFPZ, three of which were nonnative. Nonnative species occurred in 26% of our plots outside the fuel break and only 4% of our plots within the treated area.

The Antelope Border DFPZ had much lower relative nonnative cover (2%) than the mean (18%) of 24 sites in our study. Relative nonnative plant cover tended to be higher outside of the Antelope Border DFPZ (*P*=0.076), (Figure 3-19).

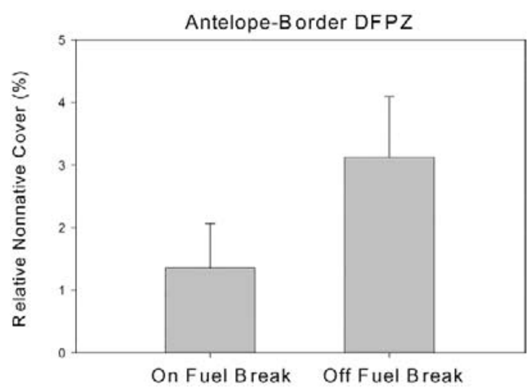


Figure 3-19. ANOVA found no significant differences in relative nonnative abundance within the Antelope Border DFPZ compared with adjacent untreated areas (N=80, df=1, 78, F=3.237, *P*=0.076). Error bars represent + 1 SE.

Fallen Leaf Lake Shaded Fuel Break, Lake Tahoe Basin Management Unit

The Fallen Leaf Lake shaded fuel break is located within the Lake Tahoe Basin Management Unit of the USDA Forest Service, near Lake Tahoe in El Dorado County. This shaded fuel break was constructed in 1995 by mechanical thinning and prescribed burning. The Fallen Leaf Lake shaded fuel break is located at an elevation of 2000 meters, the highest of any of our study sites. This site also had the greatest duff depth (57 cm) of any area we sampled.

Fallen Leaf Lake shaded fuel break, Lake Tahoe Basin Management Unit

The Fallen Leaf Lake shaded fuel break is located in a mixed coniferous forest. Dominant trees species include white fir, canyon live oak, incense cedar, and Jeffrey pine. Soils at this fuel break were predominately from the Meeks series, a deep, well or somewhat excessively drained soil that formed in material weathered from glacial outwash.

We did not find nonnative plants in any of our $1m^2$ plots at Fallen Leaf Lake. We identified 21 native species at the Fallen Leaf fuel break.

Oregon Fire Line, Shasta Trinity National Forest

The Oregon fire line is located in the Shasta Trinity National Forest near the town of Weaverville in Trinity County. This fire line was constructed by bulldozers in 1980 to suppress the Oregon fire.

Oregon fire line, Shasta Trinity National Forest

The Oregon fire line is located in an oak woodland, dominated by Oregon white oak (*Quercus garryana*). Other common species found in the vicinity of the Oregon fire line include grey pine (*Pinus sabiniana*) and greenleaf manzanita. Soils at the Oregon fire line were from the Musserhill series. The Musserhill series consists of moderately deep, well drained soils formed in materials weathered from weakly consolidated conglomerate.

We identified 60 species in our $1m^2$ plots at the Oregon fire line, 11 of which were nonnative. The most common nonnative plant we found on the Oregon fire line was field hedge parsley.

The Oregon fire line had slightly higher mean relative nonnative cover (19%) than the mean (18%) of 24 sites in our study. Nonnative species occurred in 78% of plots outside the fire line and 90% of plots within the fire line.

Nonnative plant cover was significantly higher on the Oregon fire line than in the adjacent wildland (Figure 3-20).

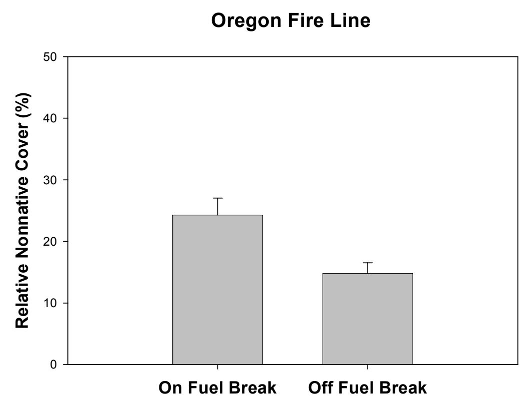


Figure 3-20. ANOVA found significant differences in relative nonnative abundance within the Oregon fire line compared with adjacent untreated areas (N=70, df=1, 68, F=7.190, *P*=0.009). Error bars represent + 1 SE.

McKenzie Ridge Fuel Break, Sequoia National Forest

The McKenzie Ridge fuel break is located in the Sequoia National Forest, west of Grant Grove in Kings Canyon National Park, Fresno County. This fuel break was constructed in the 1960s by mechanical thinning. It has been periodically maintained by prescribed burning, thinning, and discing. Portions of the McKenzie Ridge fuel break were burned in the 2001 Highway fire. The fuel break is located in a mixed conifer forest, dominated by incense cedar, ponderosa pine, and black oak. Our plots on McKenzie Ridge were found in Holland and Jocal soil series. The Holland series consists of very deep, well drained soils that formed in material weathered from granitic rock. The Jocal series consists of deep and very deep, well drained soils formed in material weathered from metasedimentary rocks.

We identified 58 species in our $1m^2$ plots at McKenzie Ridge, 10 of which were nonnative. The most common nonnative plant we found on the McKenzie Ridge fuel break was cheatgrass. Nonnative species occurred in only 5% of plots outside the fuel break and 31% of plots within the fuel break. The McKenzie Ridge fuel break had much lower relative nonnative plant cover (4%), than the mean (18%) of 24 sites in our study.

Relative nonnative plant cover was significantly higher in plots on the McKenzie Ridge fuel break than outside of the fuel break (Figure 3-21).

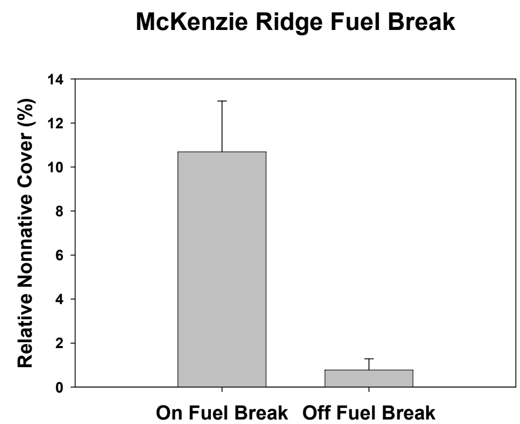


Figure 3-21. ANOVA found significant differences in relative nonnative abundance on the McKenzie Ridge fuel break compared with adjacent untreated areas (N=81, df=1, 79, F=42.771, P<0.001). Error bars represent + 1 SE.

DISCUSSION

The 24 fuel breaks described in this chapter occurred across a wide range of vegetation types, soil series, elevations, and climates. Each site had a unique history, including various dates of construction, different construction and maintenance regimes, varying fire histories, and different land use histories. Despite this variation, we found that 19 of the 24 fuel breaks had significantly higher relative nonnative cover than the adjacent wildland areas. The six fuel breaks where nonnative cover was similar on the fuel break and in the adjacent wildland were the Blacks Ridge DFPZ, the Antelope Border DFPZ, the Lewis Creek fire line, the Cascadel Point fuel break, and the Gasquet shaded fuel break. These sites had several common characteristics (Table 3-2). None of them were constructed by bulldozers, and they had either never been maintained or had very long (i.e. 20 year) maintenance rotations. All of these sites, except the Lewis Creek fire line, had significantly deeper duff depths on the fuel break than the mean (11 cm) of all sites studied.

Table 3-2. Characteristics of fuel breaks where relative nonnative cover did not differ between plots on the fuel break and plots in the adjacent wildland area.

[A range of values is given where individual transects at the same site vary. NA, not applicable, is given for maintenance frequency of fuel breaks that have not yet been maintained. Cm, centimeter]

Site Name	Construction Method	Maintenance Frequency	Age (years)	Vegetation Type	Number of Fires	Duff Depth (cm)
Blacks Ridge	Mechanical	NA	0-1	Coniferous Forest	0	21.6
Antelope Border	Mechanical	NA	1	Coniferous Forest	0	17.0
Lewis Creek	Hand Crews	20 yrs	21	Chaparral	0-2	7.1
Cascadel Point	Hand Crews	20 yrs	80	Oak Woodland	2-3	17.9
Gasquet	Mechanical	NA	7	Oak Woodland	0-1	21.0

In addition to sharing common features, these sites also differed from each other in several ways. They included three of the four vegetation types we identified, and they had experienced a range of fire histories.

It is likely that a number of factors, including construction method and maintenance history as well as propagule availability and chance may explain the lack of an association between nonnative abundance and position relative to the fuel break that we observed at these sites.

Continued monitoring would help determine if a pattern of increasing nonnative abundance appeared over time on these fuel breaks. Time since construction was strongly associated with nonnative abundance when we evaluated all of the fuel breaks together (See Figure 1-7 from Chapter 1).

Cheatgrass was the most common nonnative species at eight of our study sites, and was both the most abundant and frequent species across all of our sites. This result supports the findings of others that cheatgrass is both widespread and common in California (Bossard and others, 2000).

Foxtail fescue was the most common nonnative at three of the sites, red brome was the dominant nonnative at two sites, and field hedge parsley was the most common nonnative at two sites. The other nine study sites had different dominant nonnative species. The lack of one dominant nonnative at all sites suggests that fuel breaks may create conditions favorable to a number of different nonnative plant species or that local and site-specific factors may dictate differences between nonnatives in fuel breaks. The colonization of a fuel break by a particular species may reflect which species has a nearby seed source or is able to disperse into the treated area.

Most of the common nonnatives encountered in this study are known to respond favorably to disturbance. Four of the five most common nonnatives were annual grasses from the genus *Bromus.* These annual grasses have been found to readily colonize disturbed sites across a wide range of environments (Bossard and others, 2000). These grasses have also been found to alter fuel conditions in the habitats they invade, and contribute to changes in fire behavior and frequency to the detriment of the native plant community (D'Antonio & Vitousek 1992). The establishment of these species in fuel breaks may have serious implications for native plant communities and fire regimes in the areas they invade (Brooks and others, 2004).

Text Box 3-1: Summary of Site Specific Findings:

- Individual sites differed greatly in nonnative cover, fire history, and environmental variables.
- Nonnative cover was higher within fuel treatments than adjacent wildlands at 19 of our 24 study sites.
- Sites without significant differences in nonnative cover in and out of fuels breaks were characterized by higher duff depths, construction methods other than bulldozing, and were newly constructed or had very infrequent maintenance.
- Cheatgrass was the most common nonnative plant species at 8 of our study sites.
- A number of different species assumed dominance at the other 16 sites, suggesting that many nonnative species may be well adapted to take advantage of the conditions provided by fuel treatments.

Chapter Four: Summary

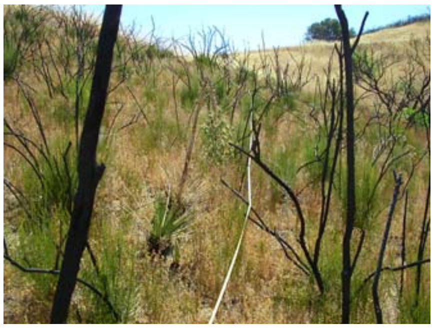
Some litter cover and overstory canopy were retained on the Whiskey Creek fuel break in Whiskeytown National Recreation Area.

We found that fuel breaks have the potential to promote the establishment and spread of nonnative plants. However, fuel breaks with more canopy and ground cover may be less likely to be invaded. Varying construction methods to retain more litter cover, minimize the exposure of bare ground, and retain some canopy cover might reduce nonnative germination and establishment on fuel breaks. Increasing the time between fuel break maintenance also could allow ground and canopy cover to increase and also lower the probability of nonnative invasion.

Even in relatively uninvaded vegetation types such as coniferous forests, the use of bulldozers significantly increased the abundance of nonnative plants. Bulldozers have large blades specifically designed to remove surface soil layers, and may be more likely to introduce nonnative seeds into fuel breaks by disrupting soil seed banks and transporting seeds between sites.

Bulldozers were used to construct this fuel break in the Mendocino National Forest.

We found that nonnative cover decreased with distance from the fuel break, suggesting that fuel breaks act as sources of nonnative plant seeds during the invasion of adjacent areas. Wildland areas adjacent to fuel breaks were more likely to be invaded by nonnative species when the wildlands had been subject to recurrent fires. Nonnative plant abundance on fuel breaks and in adjacent wildlands continued to increase with fuel break age.



Recent burn adjacent to the Calf Canyon fuel break maintained by the San Luis Obispo Unit of CDF

Native species may also be promoted by fuel breaks, particularly native annual forbs and grasses. We found that native and nonnative diversity were significantly correlated. Many native species, particularly annual forbs, require periodic disturbance to persist in natural ecosystems. The best management regime for maintaining native plant diversity is likely one that restores natural disturbance processes of the frequency, intensity, and duration with which native species evolved. However, these disturbances may also promote nonnative plants. Land managers will have to weigh the benefits of maintaining natural disturbance regimes to native plant communities against the potential risks of promoting nonnative invasives.

Native grasses were abundant on this fuel break in the Sierra National Forest.

We found significant differences in relative nonnative cover and nonnative species richness among vegetation types. Vegetation type has been found to be among the most important factors influencing nonnative plant abundance, either because of the life history characteristics of the dominant plant community or because of other factors such as elevation land use and disturbance history (Keeley 2000).

The Oso Ridge fuel break, and other coastal scrub sites, supported high numbers of nonnative plants.

Despite the strong influence of vegetation type on nonnative abundance and species richness, we found that a number of variables, including fuel break construction method, distance to the fuel break, fire number, and grazing still had significant effects on nonnative abundance when evaluated within individual vegetation types separately. This suggests that although important, vegetation type alone does not determine the abundance of nonnatives. We found that fuel breaks appear to promote nonnative abundance in all vegetation types, and this pattern may be compounded by more numerous fires or by grazing.

The 24 fuel breaks we sampled had unique histories, including various dates of construction, different construction and maintenance regimes, varying fire histories, and different land use histories. Despite this variation, we found that 19 of the 24 sites had significantly higher relative nonnative cover within fuel breaks than in adjacent wildland areas.

At most sites, such as the Tower fire line, there was a significant increase in nonnative abundance on the fuel break.

Cheatgrass was the most common nonnative species at eight of our study sites. Cheatgrass was both the most abundant and frequent species across all of our sites, suggesting that this species is widespread and common in California. However, the other sixteen study sites had twelve different dominant nonnative species. The lack of one dominant nonnative at all sites suggests that fuel breaks may create conditions favorable to a number of different nonnative plant species or that local conditions may dictate nonnative occurrence. The colonization of a fuel break by a particular species may reflect which species has a nearby seed source or is able to disperse into the treated area.

Cheatgrass was the most common nonnative species at our sites.

This study was observational, and there were many environmental and anthropogenic factors for which we could not control. Research using controlled, replicated experiments will be necessary to fully understand the mechanisms that influence nonnative plant establishment within pre-fire fuel manipulation projects and invasion into adjacent wildland areas. Here we have identified potentially important variables influencing patterns of nonnative abundance with respect to fuel breaks and suggested ways that the probability of nonnative invasion might be minimized. If these methods are strategically implemented as part of a long term fuel reduction program, it may be possible to both achieve fuel management goals and reduce the probability of nonnative plant invasion on fuel breaks and in surrounding wildland areas.

Oso Ridge fuel break,
Casper's Wilderness Park

Summary of our findings:

- Fuel breaks may promote nonnative and native plants.
- Fuel breaks with more canopy and ground cover may be less likely to be invaded.
- Nonnative plants are more abundant adjacent to older fuel breaks and in areas that have experienced more numerous fires.
- Native species may also be associated with fuel breaks, particularly native annual forbs and grasses.
- Cheatgrass was the most common nonnative plant species at eight of our study sites.
- A number of different species assumed dominance at the other 16 sites, suggesting that many nonnative species may be well adapted to take advantage of the conditions provided by fuel breaks.

Literature Cited

Agee, J., B. Bahro, M. Finney, P. Omi, D. Sapsis, C. Skinner, J. v. Wagtendonk, and C. P. Weatherspoon. 2000. The use of shaded fuelbreaks in landscape fire management. Forest Ecology and Management **127**:55-66.

Aragon, R., and J. M. Morales. 2003. Species composition and invasion in NW Argentinian secondary forests: effects of land use history, environment and landscape. Journal of Vegetation Science **14**:195-204.

Auld, T. D. 1996. Ecology of the Fabaceae in the Sydney region: fire, ants and the soil seedbank. Cunninghamia **4**:531-551.

Battles, J. J., A. J. Shlisky, R. A. Barrett, R. C. Heald, and B. H. Allen-Diaz. 2001. The effects of forest management on plant species diversity in a Sierran conifer forest. Forest Ecology and Management **146**:211-222.

Bentley, J. 1967. Conversion of chaparral areas to grassland: techniques used in California. Pacific Southwest Research Station, USDA Forest Service, Berkeley, California, USA.

Berlow, E. L., C. M. D'Antonio, and H. Swartz. 2003. Response of herbs to shrub removal across natural and experimental variation in soil moisture. Ecological Applications **13**:1375-1387.

Bossard, C. C., J. M. Randall, E. Marc, and C. Hoshovsky. 2000. Invasive plants of California's wildlands. University of California Press, Berkeley, California, USA.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience **54**:677-688.

Burke, M. J. W., and J. P. Grime. 1996. An experimental study of plant community invasibility. Ecology **77**:776-790.

California Department of Forestry and Fire Protection. 2003. Fire Perimeters, Sacramento, California, USA.

Clark, K. P. 1973. Fuelbreaks, fire and brushlands. Environmental Southwest:1-2.

D'Antonio, C. 2000. Fire, plant invasions, and global changes. Pages 65-93 *in* H. A. Mooney, and R. J. Hobbs, editors. Invasive species in a changing world. Island Press, Covelo, California, USA.

D'Antonio, C. M. 1993. Mechanisms controlling invasion of coastal plant communities by the alien succulent *Carpobrotus edulis*. Ecology **74**:83-95.

D'Antonio, C. M., T. L. Dudley, and M. Mack. 1999. Disturbance and biological invasions: direct effects and feedbacks. Pages 413-452 *in* L. R. Walker, editor. Ecosystems of disturbed ground. Elsevier, New York, New York, USA.

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics **23**:63-87.

Daubenmire, R. F. 1959. A canopy-coverage method of vegetation analysis. Northwest Science **33**:43-64.

Edmunson, G., and D. Cornelius. 1961. Promising grasses for southern California fuel breaks. Pacific Southwest Forest and Range Experiment Station, Berkeley, California, USA.

ESRI. 2000. ArcView. ESRI Limited, Redlands, California, USA.

Facelli, J. M. 1991. Plant litter: its dynamics and effects on plant community structure. Botanical Review **57**:1-32.

Farsworth, A., and P. Summerfelt. 2002. Flagstaff interface treatment prescription: results in the wildland-urban interface. Fire Management Today **62**:13-18.

Gelbard, J. L., and J. Belnap. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. Conservation Biology **17**:420-432.

Giessow, J. 1997. Effects of fire frequency and proximity to firebreak on the distribution and abundance of non-native herbs in coastal sage scrub. Biology. San Diego State University, San Diego, California, USA.

Hayes, G. F., and K. D. Holl. 2003. Cattle grazing impacts on annual forbs and vegetation composition of mesic grasslands in California. Conservation Biology **17**:1694-1702.

Hickman, J. C., editor. 1993. The Jepson manual: higher plants of California. University of California Press, Berkeley, California, USA.

Hobbs, R. J., and L. Atkins. 1988. Effect of disturbance and nutrient addition on native and introduced annuals in plant communities in the western Australian wheatbelt. Australian Journal of Ecology **13**:171-180.

Holmes, P. M., and R. J. Newton. 2004. Patterns of seed persistence in South African fynbos. Plant Ecology **172**:143-158.

Keeley, J. E. 2000. Chaparral. Pages 204-253 *in* M. Barbour, and W. Billings, editors. North American Terrestrial Vegetation. Cambridge University Press, Cambridge, UK.

Keeley, J. E. 2001. Fire and invasive species in mediterranean-climate ecosystems of California. Pages 81-94 *in* K. Galley, and T. Wilson, editors. Fire conference 2000: the first national congress on fire ecology, prevention, and management. Tall Timbers Research Station, San Diego, California, USA.

Keeley, J. E., and C. J. Fotheringham. 2003. Impact of past, present, and future fire regimes on north American mediterranean shrublands *in* T. T. Veblen, W. L. Baker, G. Montenegro, and T. W. Swetnam, editors. Fire and climatic change in temperate ecosystems of the western Americas. Springer, New York, New York, USA.

Keeley, J. E., D. Lubin, and C. J. Fotheringham. 2003. Fire and grazing impacts on plant diversity and alien plant invasions in the southern Sierra Nevada. Ecological Applications **13**:1355-1374.

Larson, D. L., P. J. Anderson, and W. Newton. 2001. Alien plant invasion in mixed-grass prairie: effects of vegetation type and anthropogenic disturbance. Ecological Applications **11**:128-141.

Levine, J., and C. M. D'Antonio. 1999. Elton revisited: a review of evidence linking diversity and invasibility. Oikos **87**:15-26.

Lonsdale, W. M., and A. M. Lane. 1994. Tourist vehicles as vectors of weed seeds in Kakadu National Park, northern Australia. Biological Conservation **69**:277-283.

Los Angeles County Fire Department. 1962. A fuel break has been tested. Los Angeles County Fire Department, CDF, USDA Forest Service, Los Angeles, California, USA.

Mack, R. M. 1989. Temperate grasslands vulnerable to plant invasions: characteristics and consequences. Pages 155-179 *in* J. A. Drake, H. A. Mooney, F. d. Castri, R. H. Groves, F. J. Kruger, M. Rejmanek, and M. Williamson, editors. Biological invasions: a global perspective. Wiley and Sons, New York, New York, USA.

McKenzie, D., C. B. Halpern, and C. R. Nelson. 2000. Overstory influences on herb and shrub communities in mature forests of western Washington, USA. Canadian Journal of Forest Research **30**:1655-1666.

Moreno, J., and W. Oechel. 1991. Fire intensity effects on germination of shrubs and herbs in southern California chaparral. Ecology **72**:1993-2004.

Omi, P. 1979. Planning future fuelbreak strategies using mathematical modeling techniques. Environmental Management **3**:73-80.

Parendes, L. A., and J. A. Jones. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. Conservation Biology **14**:64-75.

Parker, I. M., S. K. Mertens, and D. W. Schemske. 1993. Distribution of seven native and two exotic plants in a tallgrass prairie in southeastern Wisconsin: the importance of human disturbance. American Midland Naturalist 130:43-55.

Reynolds, S. A., J. D. Corbin, and C. M. D'Antonio. 2001. The effects of litter and temperature on the germination of native and exotic grasses in a coastal California grassland. Madroño **48**:230-235.

Safford, H. D., and S. Harrison. 2004. Fire effects on plant diversity in serpentine vs. sandstone chaparral. Ecology **85**:539-548.

San Diego County. 1974. Fuel reduction and brushland management in San Diego County, California. Watershed Resources Advisory Commission, County of San Diego, USA.

Sawyer, J. O., and T. Keeler-Wolf. 1995. A manual of California vegetation. California Native Plant Society, Sacramento, California, USA.

Schmidt, W. 1989. Plant dispersal by motor cars. Vegetatio **80**:147-152.

Schwartz, M. W., D. J. Porter, J. M. Randall, and K. E. Lyons. 1996. Impact of nonindigenous plants. Pages 1203-1226. Sierra Nevada Ecosystem Project: Final Report to Congress, vol. II. University of California, Centers for Water and Wildland Resources, Davis, California, USA.

Shaw, R. B., and V. E. Diersing. 1990. Tracked vehicle impacts on vegetation at the Pinon Canyon maneuver site, Colorado, USA. Journal of Environmental Quality **19**:234-243.

SPSS. 2000. Systat. SPSS, Chicago, Illinois, USA.

Stohlgren, T. J., D. T. Barnett, and J. T. Kartesz. 2003. The rich get richer: patterns of plant invasions in the United States. Frontiers in Ecology and the Environment **1**:11-14.

Stohlgren, T. J., Y. Otsuki, C. A. Villa, M. Lee, and J. Belnap. 2001. Patterns of plant invasions: a case example in native species hotspots and rare habitats. Biological Invasions **3**:37-50.

Tyser, R. W., and C. A. Worley. 1992. Alien flora in grassland adjacent to road and trail corridors in Glacier National Park, Montana (USA). Conservation Biology **6**:253-262.

US Department of Agriculture. 1959. Four Corners- a cooperative fuel break demonstration project. Pacific Southwest Forest and Range Experiment Station, Berkeley, California, USA.

US Department of Agriculture. 1960. Trabuco Oaks, a cooperative fuel break demonstration project. Pacific Southwest Forest and Range Experiment Station, Berkeley, California, USA.

Wilkinson, L., G. Blank, and C. Gruber. 1996. Desktop data analysis with SYSTAT. Prentice Hall, Upper Saddle River, New Jersey, USA.

Wiser, S. K., R. B. Allen, P. W. Clinton, and K. H. Platt. 1998. Community structure and forest invasion by an exotic herb over 23 years. Ecology **79**:2071-2081.

Xiong, S., and C. Nilsson. 1999. The effects of plant litter on vegetation: A meta-analysis. Journal of Ecology **87**:984-994.

Zink, T. A., M. F. Allen, B. Heindl-Tenhunen, and E. B. Allen. 1995. The effect of a disturbance corridor on an ecological reserve. Restoration Ecology **3**:304-310.