ECOLOGICAL BURNING IN THE SIERRA NEVADA: ACTIONS TO ACHIEVE RESTORATION

White Paper by Karina Silvas-Bellanca, Sierra Forest Legacy
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Figure 1. Looking to the Northeast at the Granite Fire (foreground) and Lion Fire (background) on Sequoia National Forest near the Kern Plateau 2009 (Photo courtesy of Scott Williams)

EXECUTIVE SUMMARY

Fire, both naturally ignited and human ignited fires (McKelvey et al. 1996, van Wagtendonk and Fites-Kaufman 2006) in the Sierra Nevada have shaped forest structure and composition for centuries (Skinner and Stephens 2004, Sugihara et al. 2006, van Wagtendonk and Fites-Kaufman 2006). It is a natural and essential process necessary to maintain the long-term ecological function of forest flora and fauna, soil nutrients, forest diseases and pathogens, structural diversity, and composition. Natural fire regimes have been altered as a result of management activities, fire suppression (Stephens et al. 2007), increased development (Sierra Nevada Alliance 2007), and strict air quality regulations, all contributing to an overabundance of live and dead fuels (McKelvey et al. 1996, Sugihara et al. 2006, Reinhardt et al. 2008). Estimates of the annual area burned throughout California prior to the 1800s range from 4.4 to 11.8 million acres (Stephens et al. 2007). In comparison, approximately 5 million acres burned in California from 1994-2004. This is an annual estimate is less than 10% of the historic annual estimate (Stephens et al. 2007).

Sierra Forest Legacy has compiled data from the Forest Service from 2001 to 2008 to evaluate the trends in managed fires[1] on the national forests in the Sierra Nevada. We found that less than 2% of the 11.5 million acres of public lands in the Sierra had been treated with managed fires during this time. As a result of decreased fire, the Sierran ecosystems are at greater risk to uncharacteristic[2], stand-replacing fires in areas that would have historically burned at more frequent intervals with lower intensities.

For many years fires have been suppressed to prevent the destruction of communities and to limit health related hazards from smoke. Smoke is the byproduct of burning, and managed fires tend to produce periodic and low concentrations of smoke whereas uncharacteristic fires can produce heavy concentrations for much longer periods of time (Sugihara et al. 2006). Furthermore, fire suppression often only delays emission outputs rather than actually eliminating them (Peterson and Leenhouts 1997). Continuing to exclude fire poses a great threat to the health and resiliency of the Sierra Nevada. Fire seasons are becoming longer and more severe throughout California (Miller et al. 2009), in response to these conditions, we must increase the pace and scale of managed fire at the appropriate intensity, frequency, and spatial scale while enhancing the support of managed fires at the local, state, and federal levels to restore forest ecosystems and protect communities. Managing fire for its ecological benefits must replace the view that every wildfire is a "catastrophic" event.

Sierra Forest Legacy's goal is to significantly increase the use and support of ecologically appropriate fire at the local, state, and federal levels in the Sierra Nevada. We propose the following key actions to land management agencies in support of this goal: develop a collaborative pilot project; manage the landscape to produce low, moderate, and high severity fire effects; utilize the Forest Service's strategic management response[3] policy in all fire events; ensure adequate staffing year round to accomplish burns; and increase public education for the critical role fire plays in restoration efforts in the Sierra Nevada.

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[1] Managed fire refers to a fire event (human or natural caused) that is managed to benefit resources and communities (i.e. prescribed fire, use fire, broadcast burns, and wildlife habitat enhancement burns, etc).
[2] Uncharacteristic fire refers to fire size and severity that is larger than the historic fire return intervals in a specific vegetation type and geographic position prior to human disturbance (also referred to as wildfires).
[3] "Strategic management response" is an approach recommended in the "2009 QFR Final Report Draft" (http://www.iafc.org/associations/4685/files/wild_QFR2009ReportCommentDraft.pdf) prepared by a team of specialists from U.S. Forest Service, the four U. S. Department of Interior agencies and their state, local, and tribal partners that constitute the wildland fire community. We understand that this has not yet been adopted as a policy, but anticipate that it will be adopted in the near future.

INTRODUCTION

The Sierra Forest Legacy (SFL) is a coalition of over 80 member groups united by an interest in land management on national forests in the Sierra Nevada. The mission of SFL is to engage citizens, communities, and coalition members in the healthy management of Sierra Nevada forest ecosystems to protect and restore the region's unparalleled beauty and natural values. The organization applies the best practices of science, advocacy, and grassroots organizing to safeguard forest lands throughout the Sierra Nevada.

It is the goal of SFL to increase the use of fire that is managed for ecological benefits such as increased native adapted species and increased diversity, as well as goods and services that communities benefit directly from like water quality and wildlife habitat conservation. This white paper identifies the importance of fire as an ecological process and its critical role in the restoration of the Sierra Nevada ecosystem. The use of managed fire to achieve restoration goals is addressed. The amount and extent of managed fire implemented on national forests in the Sierra Nevada was evaluated from 2001 to 2008, to assess efforts to restore fire to the Sierra and to identify barriers land management agencies face in implementation of fire projects. Lastly, the degree that the current program addresses restoration needs is examined, and actions are proposed to increase the level of managed fire implemented in the region.

Figure 2. Duncan Canyon Fire (2001) 2-years post-fire
Photo courtesy of Don Jacobson

ECOLOGICAL IMPORTANCE OF BURNING

Fire is a natural ecological process in the Sierra Nevada, equal in ecological significance to floods, volcanic eruptions, hurricanes, and other natural disturbances (Lindenmayer and Noss 2006). The pyrogenic vegetation found in the region includes species that tolerate or even require fire to complete their life cycle (Sugihara et al. 2006). Fire effects on above ground structures (Whelan 1995, Agee 2003) and below ground structures (roots) through soil heating (Brown and Smith 2000), changes in light, temperature, moisture, and nutrients (North et al. 2005, Fites-Kaufman et al. 2006). These effects can have both positive and negative outcomes dependant on the intensity and severity of a fire. However, many of the plant communities in the Sierra have evolved with fire over time, and have come to depend on fire (Fites-Kaufman et al. 2006). Some common plant adaptations to fire are listed below (Table 1).

The Sierra Nevada experiences a mixture of fire severities ranging from low to moderate severity in the mixed conifer region (McKelvey and Busse 1996, Collins et al. 2007) to largely high fire severity in chaparral-dominated ecosystems (van Wagtendonk and Fites-Kaufman 2006). The general fire attributes are listed in Table 2 by ecological region and vegetation types common in the Sierra, these are only the general patterns and it is important to note that fire regimes are dynamic at multiple scales. Fire weather can play a very vital role in the extremes that these systems may experience. The amount of fire in each ecosystem is also variable based on slope, aspect, topography, and vegetation. The mixed conifer regions of California, historically, experienced the highest percentage of acres burned in a given year. In a study by Stephens et al. (2007), annual acres burned pre 1800s under range from approximately 682,051 to 1.7 million acres, roughly 6-15 percent of the total land base in the Sierra (Table 3).

Table 1. Common plant adaptations and associated species by ecological zone (Biswell 1989, Howard 1992, Stuart and Sawyer 2001, League 2005, van Wagtendonk and Fites-Kaufman 2006).

Westside - foothill woodland and lower montane	
Sprouting	chamise, yerba santa, California coffeeberry, soap plant, deergrass
Heat enhanced germination	California-lilac, whiteleaf manzanita, buck brush, knobcone pine
Basal sprouting	blue oak, interior live oak, canyon live oak
Thick bark and protective buds	ponderosa pine
Improved establishment with mineral soil	giant sequoia and most other conifer species
Serrotinous cones	giant sequoia, knobcone pine
Thick bark (at maturity)	Douglas-fir, white fir, incense cedar, ponderosa pine
Sprouting from basal burls and root crowns	tanoak, Pacific madrone, California black oak
Upper Montane and Subalpine	
Thick bark (at maturity)	red fir, Jeffrey pine, western white pine, western juniper
Sprouting	quaking aspen, bush chinquapin, mountain whitethorn, huckleberry oak, woolly mule's ear, tufted hairgrass
Serrotinous cones - stimulates seeding	lodgepole pine
Eastside Forest and Woodland	
Thick bark	Jeffrey pine, ponderosa pine, Pinyon pine
Sprouting	quaking aspen, black cottonwood, willow, greenleaf manzanita, sedges

Fire provides many important ecological benefits to the forest including: preparing the seedbed for germination, cycling nutrients and replenishing minerals, modifying conditions promoting wildlife habitat and forage, creating structural heterogeneity, minimizing disease and pathogens, and reducing or increasing fire hazard (Kilgore 1973). Frequent low-moderate severity fires, particularly in the pine and lower to mid-elevation fir and mixed conifer forests, historically produced patchy forests with diverse age classes where extensive crown fires were infrequent. In the absence of fire as a periodic disturbance and the increase of logging for specific *Pinus* species, management in the Sierra Nevada has resulted in second and third growth forests containing higher densities of shade tolerant, and fire-sensitive species such as white fir (*Abies concolor*) and incense cedar (*Calocedrus decurrens*) than occurred historically in the mid-elevation mixed conifer zone (North 2002, Taylor 2002, Fites-Kaufman et al. 2006). In many areas of mixed conifer forest of the Sierra, increased densities that contribute to an increase of surface, ladder fuels and canopy fuels, which are resulting in fire events that are uncharacteristic and increasing in severity (Agee 1993, Miller et al. 2009).

Fire also plays an important role in nutrient cycling and mineralization of soils, although the total effects of fire on the soil's physical and chemical properties can vary with fire intensity and severity (Biswell 1989, Wohlgemuth et al. 2006). Generally, burning of the litter layer to ash allows bound nutrients to be leached into the soil with precipitation (Wohlgemuth et al. 2006). These nutrients available post-fire are converted into new plant growth.

Enhancement and maintenance of wildlife habitat and forage is another key ecological benefit of fire. Some of the burn plans we reviewed on the national forests used a uniform burn pattern emphasizing low severity fire effects for reducing surface and ladder fuels. Burn plans should include emphasis on other key ecological characteristics and biological legacies (Table 4) that a range in fire effects can provide increased wildlife habitat where appropriate. For example, areas of dense high severity fires are important for many cavity-nesting birds, most notably the black-backed woodpecker (*Picoides arcticus*). This woodpecker relies on areas of dense trees that have been burned and are abundant with wood-boring beetles (Hutto 1995, Hutto 2006, Hutto 2008). These beetles provide a food source for the black-backed woodpecker.

Table 2. Fire regime classifications for common vegetation types in the Sierra Nevada (van Wagtendonk and Fites-Kaufman 2006).

Vegetation Type	Fire Return Interval[4]	Intensity[5]	Severity[6]	Fire Type[7]
Westside				
Chaparral	Medium	High	High	Crown
Oak woodland/grassland	Short	Low	Low	Surface
Ponderosa pine/ black oak	Short	Low	Low - Moderate	Surface
Douglas-fir and Mixed conifer	Short	Low - Moderate	Low - Moderate	Surface - Mixed
Tanoak-mixed evergreen	Medium	Mixed[8]	Mixed	Mixed
Upper Montane and Subalpine				
Red Fir	Medium	Mixed	Mixed	Mixed
Lodgepole pine	Long	Multiple[9]	Multiple	Multiple
Mountain Hemlock	Long	Low	Low	Surface
Eastside Forest and Woodland				
Jeffrey/Ponderosa Pine	Short	Low	Low	Surface
White fir and mixed-conifer	Medium	Mixed	Mixed	Mixed

Table 3. Estimates of median and high fire return intervals and annual area burned pre-1800s by forest type (Stephens et al. 2007).

Vegetation Type	Period between Fires		Acres burned / year		Percent burned / year	
	MFRI	HFRI	MFRI	HFRI	MFRI	HFRI
Alpine meadow	50	100	14768	7383	0.13	0.06
Cedar/hemlock/Douglas-fir	20	110	99576	18105	0.86	0.16
Mixed conifer	8	20	1705125	682051	14.78	5.91
Red fir	15	50	125377	37613	1.09	0.33
Lodgepole/subalpine	25	60	85005	35420	0.74	0.31
Ponderosa pine/shrub	5	12	334954	139565	2.90	1.21
				Totals	**20.50**	**7.98**

Table 4. Summary of references for the ecological roles of biological legacies on ecosystem recovery and revitalization (Lindenmayer and Noss 2006).

Ecological roles of biological legacies	Reference
Enriches recovering vegetation	Hansen et al. 1991, Lindenmayer and McCarthy 2002
Facilitates survival and population viability of various species in disturbed areas	Hutto 2005, Whelan 1995, Franklin and MacMahon 2000
Provides habitat for species that eventually re-colonize a disturbed site	Lindenmayer et al. 1997, Nappi et al. 2003
Promotes plant and animal re-colonization of disturbed areas	Whelan 1995
Provides a source of energy and nutrients for other organisms	Perry 1994, Hutto 2005
Modifies or stabilizes environmental conditions on disturbed sites	Perry 1994

[4] Fire return interval the length of time between fires. The years associated with the fire return intervals were taken from Sugihara et al. 2006.

[5] Intensity is the rate of energy released from the fire. The amount of heat you would be exposed to per second while standing in from of the fire.

[6] Severity is the magnitude of fire effects on vegetation.

[7] Fire type is the characteristic pattern of fire behavior. Ground, surface, crown, and mixed (combination of all fire types) fire are all fire types.

[8] Mixed refers for low, moderate, and high effects.

[9] Multiple refers to low or high effects.

In contrast, low severity fires can provide good habitat and reduction in surface fuels in the mixed conifer-hardwood habitats of the Sierra Nevada. For example, the winter wren (*Troglodytes troglodytes)* nests in dense understory (Saab and Powell 2005), and relies on more structural diversity. Allowing the forest to experience a range of fire effects promotes increased heterogeneity and can increase wildlife habitat for many different species.

Managed fires on the national forest should focus on creating variable burn patterns and intensities that are specific to the vegetation type. These fires should also promote the development of the full range of biological legacies[10] that are essential in restoring ecosystem function (Table 4). Historic conditions on vegetation heterogeneity and fire regimes can also be used as a reference for resilient and healthy forests to develop desired conditions for the range of effects fire has on the landscape.

Figure 3. Natural post-fire recovery following fire.

COMBINING FIRE WITH MECHANICAL TREATMENTS TO RESTORE THE ECOLOGICAL BALANCE

Today's forests have experienced a change in succession causing shifts within the historic range of variability creating overly dense forest where it may not be appropriate, as a first entry, to reintroduce fire (North et al 2002). In some cases, the dense accumulation of small trees and other ladder fuels needs to be reduced through other, non-fire treatments prior to the reintroduction of fire. This includes hand and mechanical treatments, which are used to mimic mortality in understory burning thus lowering risk of crown fire (North et al. 2002). It is also important to mention that there is no mimic for the ecological benefits gained by fire, and the effects of biomass removal in lieu of fire has not been studied in the Sierra Nevada (SNEP 2006, North et al. 2002). With this being said, mechanized treatments need to be carefully designed to meet conservation and restoration objectives in the short and long term (North et al. 2009). Limiting disturbance in sensitive areas, retaining important forest structure and creating structural heterogeneity (North et al. 2009), and retaining the largest

[10] Biological legacies are organisms, organically derived structures, and organically produced patterns that survive from the pre-disturbance system (Franklin et al. 2000). Examples include thickets of understory vegetation, logs, snags, patches of undisturbed or partially disturbed forest (Lindenmayer and Noss 2006).

trees (North et al. 2009, Stephens et al. 2009) are all important concepts to address when designing mechanical treatments to increase fire resistance.

Mechanized treatments alone can change structure and reduce fuels (Graham et al. 2004, North et al. 2007, Valliant et al. 2009), but in some cases can also increase surface fuel loading (Valliant et al. 2009) if material after treatment is left onsite (Stephens et al 2009). Studies have found fire to be highly effective in reducing surface fuels (Stephens et al. 2009, Valliant et al. 2009), whereas treatments like mastication are considerably less effective (Stephens and Moghaddas 2005) because fuel is rearranged to be on the surface rather than being removed. While such treatments, in theory, are designed to reduce extreme fire effects they can be ineffective because there is a significant delay in decomposition of materials, and under severe weather conditions such as conditions seen in the American River Complex, the available masticated fuel was sufficient to support high severity fire under severe weather conditions (Safford 2008).

Key fire research suggests that thinning of the intermediate sized trees and the reduction of surface and ladder fuels is most effective (Agee et al. 2000, Agee and Skinner 2005, Stephens et al. 2009). Further, the combination of mechanical treatments and fire yields the best results for manipulation of stand characteristics and reduction of surface and ladder fuels (Stephen and Moghaddas 2005, Stephens et al 2009, Valliant et al. 2009). Fire is an ecological tool that will reduce surface and ladder fuels, increase forest resiliency, improve biodiversity, improve wildlife habitat by providing key structures (i.e., snags, downed logs, cavities, and patches of burned forest), and restore an essential ecological process to the ecosystem.

MANAGED FIRES AND AIR QUALITY

There is no doubt that fire is important to California's ecosystems; and there is no doubt that it also has the potential to harm human health and welfare. One of the many challenges land managers and air quality regulators face is how to find the appropriate balance in protecting human health and welfare with the need to maintain and restore ecological integrity (Ahuja 2006). Collaborative efforts between local, state, tribal, and federal agencies have been moving toward better smoke management strategies with the Prescribed Fire Incident Reporting System (PFIRS) this system was designed to help prevent standard violations for National Ambient Air Quality Standards, reduce the nuisance calls, and support cooperative meetings between local air pollution control districts and land managers to better strategize for upcoming burns. This is a positive step forward to increasing the pace and scale of fire in the Sierra.

One of the major revisions currently in progress is focused on the Environmental Protection Agency's (EPA) 1998 Interim Air Quality Policy on Wildland and Prescribed Fires. The 1998 communication policy is being revised to better reflect the "exception events" rule in an effort to aid local air districts in implementation of the rule. Currently there is no fire policy guidance from the EPA on how to implement exceptional events, which leaves the rule open for a wide array of interpretation. The update could potentially provide more flexibility for land managers to use managed fire to better achieve the Region's current direction for ecological restoration. However, it is unclear if these revisions will be beneficial, restrictive, or neutral in the application of "exception events."

With the uncertainty of the revisions to the 1998 Interim Air Quality Policy on Wildland and Prescribed Fires, the restrictions on air quality remain one of the biggest impediments to using managed fire in the Sierra Nevada. Whether the ignition source is naturally ignited or human ignited fires, smoke will be a byproduct. What we do know from emission data is that uncharacteristic fires tend to produce more significant amounts of emissions that exceed the health standards when compared with managed fires (Ahuja 2006, van Wagtendonk and Fites-Kaufman 2006). There is a choice to be made, accept periodic low concentrations of smoke with managed fires or accept the heavy concentrations produced by uncharacteristic wildfire (van Wagtendonk and Fites-Kaufman

2006). This is a choice that was previously understood before the era of fire suppression, and from eye-witness accounts (Merriam 1989, quoted in Morford 1993 and Stephens et al. 2007), "Of the hundreds of persons who visit the Pacific slope in California every summer to see the mountains, few see more than the immediate foreground and a haze of smoke which even the strongest glass is unable to penetrate."

MANAGED FIRE IN THE SIERRA NEVADA: TODAY'S PROGRAM

Managed fire is used to varying degrees on the national forests in the Sierra Nevada. To better understand the extent and variability of the program in the region and among national forests, we requested information from the eleven national forests[11] pertaining to all managed fires (excluding pile burns) 2001-2008. We evaluated the amount of managed fire implemented in the Sierra Nevada based on written documentation and the FACTs database.[12] For the purposes of evaluating the data, we separate managed fires into two categories: controlled burning and beneficial use fire. Controlled burning includes practices such as prescribed burning, broadcast burning, controlled burn, understory burn, jackpot burning, and wildlife habitat enhancement burns. Beneficial use fire is defined as naturally ignited fires from lightening strikes that are allowed to burn until they fall out of the prescription set by the Forest Service (also referred to as wildland use fire), or wildfire that had fuels benefits.

Figure 4. An understory managed fire in a mixed conifer stand, and note the smoke output. Photo from Forest Service website.

Our results indicate that controlled fire was implemented on a yearly basis, but not by all forests (Figure 5 and 6). The average rate of success for implementation of acres proposed in a given year was 76 percent. With the exception of 2008, all years had 50 percent or greater success of accomplishing more than half of the acres proposed. The decrease in accomplishment may be attributed to an inadequate burn window (more than two consecutive burn days) or work force limitations.

[11] The request included the Carlson and Bridgeport Ranger Districts on the Humboldt-Toiyabe National Forest.

[12] There were some issues with the written documentation corresponding to the FACTs database. Some of the acres reported were not consistent throughout the documents provided.

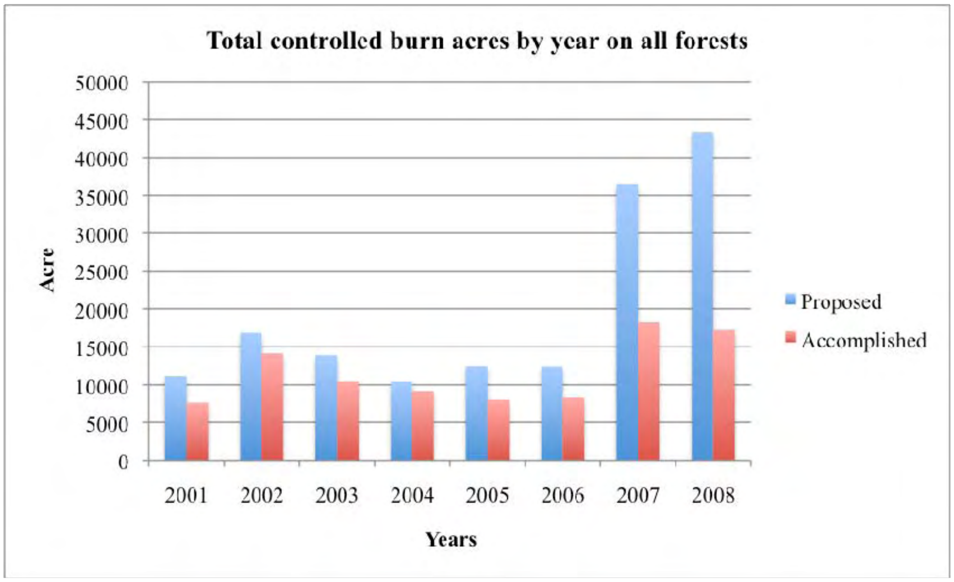

Figure 5. Acres proposed and accomplished as reported by all forests from 2001-2008.

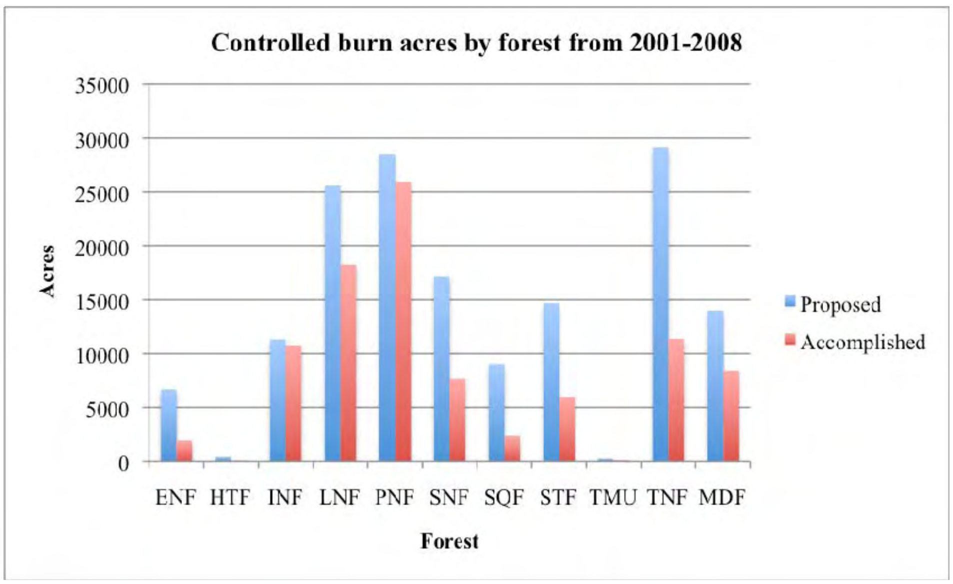

Figure 6. Reported acres proposed and accomplished by forest from 2001-2008.

Beneficial use fire or wildfire with fuels benefits occurred on each of the national forests with the exception of Eldorado National Forest and Lake Tahoe Basin Management Unit during the period of review. Wildfire with fuel benefits was reported in the FACTs database for Tahoe National Forest in 2008 and Plumas National Forest in 2007. The area of beneficial use fire for the national forests in the region for any given year ranged from 0 acres to nearly 45,000 acres (Figure 7). From 2001-2008, 119,203 acres were accomplished with beneficial use fire. This amounts to a little more than 1 percent of national forest land being managed with beneficial use fire (Table 5). The Sequoia National Forest has treated the most amount of land with beneficial use fire totaling about 40,000 acres during the seven-year period.

During the seven year period, slightly less than 2 percent of national forest lands are been treated with managed fire (Table 5), totaling 212,360 acres. In comparison, the historic estimates of annual area burned in within the mixed conifer region of California ranged 276,136 to 1.7 million acres annually (Stephens et al. 2007). Using the conservative high fire return interval of 20 years for the mixed conifer region, about 12 percent of the mixed conifer region in California was being burned (Stephens et al. 2007, Table 4); currently 4.7 percent of our lands in the national forests are being managed with fire. In order for fire to play an important role in restoration it will need to be maintained as a frequent and dynamic process (Webster and Halpern 2010).

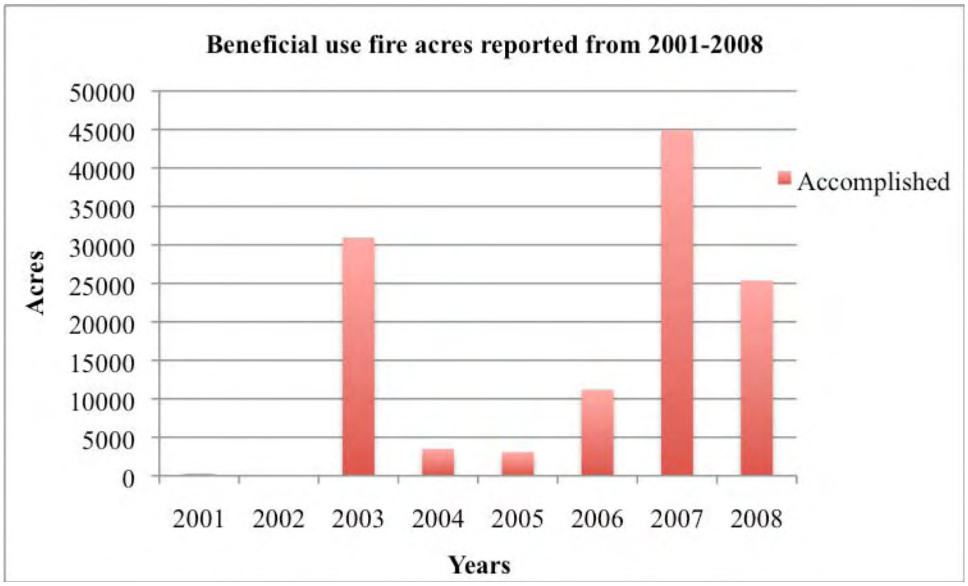

Figure 7. Beneficial use fire acres reported from 2001-2008 for all forests.

Table 5. Percentage of national forest lands treated with controlled or beneficial use fires from 2001-2008. Percentages are based on a land base of 11,535,000 acres (USDA Forest Service 2001).

Year	Land treated with controlled fire (%)	Land treated with beneficial use fire (%)
2001	0.07	0.002
2002	0.12	0.000
2003	0.09	0.268
2004	0.08	0.030
2005	0.07	0.027
2006	0.07	0.097
2007	0.16	0.389
2008	0.15	0.220
Total	**0.81%**	**1.03%**

BARRIERS TO BURNING

There are many barriers that land managers face in implementing their current burn programs. Some of the limitations were identified in a survey completed by the San Joaquin Valley Air Pollution Control District in 2009. Land managers were asked what changes (not limited to changing air district burn policy or lack of funding) could be made that would increase prescribed burning. A major priority for all managers was education on topics such as the ecological role of fire and the need for greater tolerance for short duration smoke events associated with managed fires. In addition to education, monitoring was a high priority in areas where burns are being conducted in order to evaluate the impacts of smoke and air quality thresholds. Other barriers identified were internal to the Forest Service. Forest Service managers cited staffing and timing issues (e.g., fire crews being sent out of the area during ideal weather conditions for burning, and the lack of dedicated burn crews); liability in burning; lack of qualified staff (e.g., type one burn bosses) to burn larger areas; risk to communities; limits on burn days; and forest location (e.g., proximity to community or smoke dispersion patterns).

The only way to address these issues is to collaborate. The barriers to burning for ecological benefit must be addressed by the Forest Service, air quality districts, conservation groups, and the public to ensure we can effectively restore the national forests to their historic resilient and healthy condition.

MANAGED FIRE IN THE SIERRA NEVADA: ACTIONS FOR RESTORATION

It is Sierra Forest Legacy's belief that we can coexist with fire and meet both ecological and social needs. As stewards, we must work collaboratively towards a common and shared understanding of the role that fire plays in the Sierra Nevada both ecologically and culturally. We propose the following actions in support of this goal:

- Develop a collaborative pilot project among the Forest Service, air quality control districts, conservation groups and the public to implement burning on a larger landscape scale that will closely mimic fire behavior and fire return intervals associated with different slope positions, aspect, and slope steepness, and create diversity among species (Sherlock 2007, North et al. 2009). A critical objective of this collaboration would be increased outreach to the public about the level of burning needed to restore resilience to the Sierra. We propose the development of a 5-year project that allows 10,000 acres per year within a 100,000 to 150,000-acre project area for a total of 50,000 acres treated with fire. For an area of this size we understand that some mechanical treatment may be necessary to reintroduce fire and recommend utilization of the findings from North et al. (2009) in the development of this project. This collaborative process should include the following (Kaufman et al. 2009):

    i. Strive to understand the nature, degree, and extent of human impacts on conserving the role of fire in ecosystems at multiple scales, including any effects of traditional relationships between people and fire.
    ii. Use knowledge, both scientific and traditional, to more completely integrate native fire regimes into the design needs of human developments and land uses.
    iii. Proactively engage and partner with diverse stakeholders in all fire management, land use, conservation planning, and development activities.
    iv. Identify key barriers to conserving the role of fire in ecosystems or abating fire as a threat to ecosystem functions, including ecologically inappropriate fire and land use policies, lack of funding, capacity, or expertise, and lack of knowledge about fire's ecological roles on the part of the public and decision-makers.
    v. Develop and implement collaborative, innovative solutions that take advantage of partnerships, shared resources, and expertise across landscapes, countries, and regions.
    vi. Sustain the effectiveness of collective action through adaptive learning processes that engender trust, relationship building, and commitment to sustainable living.

- Include desired condition statements in forest plans and other planning documents that provide discussion of low, moderate, and high severity fire effects in the context of the landscape; and recognize the ecological benefits of these effects on forest ecosystems at the appropriate pace and scale. Plans should also incorporate a long-term strategy to reintroduce fire as the primary ecological process in the Sierra Nevada, to enhance and maintain the ecosystems. Further, the National Parks program provides a unique opportunity to learn from fire playing its natural role with limited human intervention. This is an opportunity to learn and adapt management for the uncertainties of climate change (Webster and Halpern 2010).

- Utilize the Forest Service’s strategic management response policy in all fire events. This policy will allow for the more effective use of managed fire to achieve ecological benefits.

- Create and support dedicated crews for burning to ensure experience and availability to implement increased levels of managed fire during the fall and spring. This is necessary to ensure burn windows are used to the greatest extent when given the opportunity.

- Increase public education on the critical importance of fire in the Sierra Nevada and the reduced levels of smoke generally associated with managed fires. The focus for this education should be the acceptance of occasional smoke in the short term, in order to reduce extreme levels of smoke during fire season.

Figure 8. Sunset Lookout, Plumas National Forest has only been treated with fire, resulting in a forest that can carry natural fire. Photo courtesy of Jim Brobeck.

References

Agee, J. K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C., USA.

Agee, J. K. 2003. Monitoring postfire tree mortality in mixed-conifer forests of Crater Lake, Oregon, USA. Natural Areas Journal 23:114–120.

Agee J. K. and Skinner, C. N. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management 211: 83–96. doi:10.1016/J.FORECO.2005.01.034

Ahuja, S. 2006. Fire and air resources. Pages 444-465. In: Fire in California's ecosystem. Sugihara, N. G., van Wagtendonk, J. W., Shaffer, K. E., Fites-Kaufman, J., and Thode, A. E., editors. Berkley and Los Angeles, California: University of California Press.

Biswell, H. H. 1989. Prescribed burning in California wildlands vegetation management. Berkeley and Los Angeles, California: University of California Press.

Brown, J. K. and Smith, J. K. 2000. Wildland fire in ecosystems: effects on flora and fauna. RMRS GTR-42, vol. 2. USDA Forest Service, Rocky Mountain Research Station, Ogden, Utah, USA.

Collins, B. M., Kelly, M., van Wagtendonk, J. W., and Stephens, S. L. 2007. Spatial patterns of large natural fires in Sierra Nevada wilderness areas. Landscape Ecology 22:545–557

EPA. 2007. Treatment of data influenced by exceptional events: Final rule. Federal Register 72(55): 13560-13581.

Fites-Kaufman, J, Bradley, A. F., Merrill, A. G. 2006. Fire and plant interactions. Pages 94-117. In: Fire in California's ecosystem. Sugihara, N. G., van Wagtendonk, J. W., Shaffer, K. E., Fites-Kaufman, J., and Thode, A. E., editors. Berkley and Los Angeles, California: University of California Press.

Franklin, J. F. and MacMahon, J. A. 2000. Message from the Mountains. Science 288:1183-1185.

Graham, R. T., McCaffrey, S., and Jain, T. B. (tech. eds.) 2004. Science basis for changing forest structure to modify wildfire behavior and severity. Gen. Tech. Rep. RMRS-GTR-120. Fort Collins, Colorado: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Hansen, A. J., Spies, T. A., Swanson, E. J. and Ohmann, J. L. 1991. Conserving biodiversity in managed forests. Lessons from natural forests. Bioscience 41:382-392.

Howard, J. L. 1992. Arctostaphylos viscida. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2009, July 20].

Hutto, R. L. 1995. The composition of bird communities following stand-replacement fires in northern Rocky Mountains (U.S.A.) conifer forests. Conservation Biology 9(5):1041-1058.

Hutto, R. L. 2006. Toward meaningful snag-management guidelines for postfire salvage logging in North American conifer forests. Conservation Biology 20(4):984-993.

Hutto, R. L. 2008. The ecological importance of severe wildfires: some like it hot. Ecological Applications 18(8):1827-1834.

Kaufmann, M. R., Shlisky, A., Brooks, J. J., Kent, B. 2009. Coexisting With Fire: Ecosystems, People, and Collaboration. Gen. Tech. Rep. RMRS-GTR-227. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Kilgore, B.M. 1973. The ecological role of fire in Sierran conifer forests: Its application to national park management. Journal of Quaternary Research 3(3):496-513.

League, K. R. 2005. Ceanothus cuneatus. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2009, July 20].

Lindenmayer, D. B., Cunningham, R. B., and Donnelly, C. E. 1997. Tree decline and collapse in Australian forests: implications for arboreal marsupials. Ecological Applications 7:625-641.

Lindenmayer, D. B. and McCarthy, M. A. 2002. Congruence between natural and human forest disturbance – an Australian perspective. Forest Ecology and Management 155:319-335.

Lindenmayer, D. B. and Noss, R. F. 2006. Salvage logging, ecosystem processes, and biodiversity conservation. Conservation Biology 20(4):949–958.

McKelvey, K. S. and Busse, K. L. 1996. Twentieth century fire patterns on Forest Service lands. In: Sierra Nevada Ecosystem Project: Final report to Congress. Davis, California: University of California, Wildland Resource Center.

McKelvey, K. S., Skinner, C. N., Chang, C. , Erman, D. C., Husari, S. J., Parsons, D. J., van Wagtendonk, J. W., and Weatherspoon, C. P., 1996. An overview of fire in the Sierra Nevada. In: Sierra Nevada Ecosystem Project: Final report to Congress. Davis, California: University of California, Wildland Resource Center.

Miller, J. D., Safford, H. D., Crimmins, M., and Thode, A. E. 2009. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and Southern Cascade mountains, California and Nevada, USA. Ecosystems 12:16–32.

Nappi, A., Drapeau, P., Giriouux, J. F., and Savard, J. F. 2003. Snag use by foraging Black-backed woodpeckers (*Picoides artious*) in a recently burned eastern boreal forest. Auk 120:505-511.

North, M., Oakley, B., Chen, J., Erickson, H., Grey, A., Izzo, A., Johnson, D., Ma, S., Marra, J., Meyer, M., Purcell, K., Rambo, T., Rizzo, D., Roath, B., and Schowalter, T. 2002. Vegetation and ecological characteristics of mixed-conifer and red fire forests at the Teakettle Experimental Forest. Gen. Tech. Rep. PSW-GTR-180. Albany, California: U. S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

North, M. P. 2002. The Teakettle Experiment. Gen. Tech. Rep. PSW-GTR-183. Albany, California: U. S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

North, M., J. Innes, and H. Zald. 2007. Comparison of thinning and prescribed fire restoration treatments to Sierran mixed-conifer historic conditions. Canadian Journal of Forest Research 37: 331–342.

North, M., B. Oakley, R. Fiegener, A. Gray, and M. Barbour. 2005. Influence of light and soil moisture on Sierran mixed-conifer understory communities. Plant Ecology 177: 13–24

North, M., Stine, P., O'Hara, K., Zielinski, W., and Stephens, S. 2009. An ecosystem management strategy for Sierran mixed-conifer forests. Gen. Tech. Rep. PWS-GTR-220. Albany, California: U. S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Perry, D. A. 1994. Forest ecosystems. Johns Hopkins Press. Baltimore, Maryland.

Peterson, J. and Leenhouts, B. 1997. What Wildland Fire Conditions Minimize Emissions and Hazardous Air Pollutants and Can Land Management Goals Still be Met? [Online]. Available: http://www.westar.org/Docs/Fire/emissi11.pdf

Reinhardt, E. D., Keane, R. E., Calkin, D. E., and Cohen, J. D. 2008. Objectives and considerations for wildland fuel treatment in forested ecosystems of the interior western United States. Forest Ecology and Management 256:1997-2006.

Saab, V. A. and Powell, H. D. W. 2005. Fire and avian ecology in North America: Process influencing pattern. Studies in Avian Biology 30:1-13.

Safford, H. 2008. Report on fire severity in fuel treatments. American River Complex Fire, Tahoe National Forest. Vallejo, California: U. S. Department of Agriculture, Forest Service, Pacific Southwest Region.

Sandberg, D. V., Ottmar, R. D., Peterson, J. L., and Core, J., 2002. Wildland Fire in Ecosystems: Effects of Fire on Air. In. Gen. Tech. Rep. RMRS-GTR-42 vol.5. Ogden, Utah: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Sherlock, J. W. 2007. Integrating stand density management with fuels reduction. In: Powers, R. F., tech. ed. Restoring fire-adapted ecosystems: proceedings of the 2005 national silviculture workshop. Gen. Tech. Rep. PWS-GTR-203. Albany, California: U. S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Sierra Nevada Alliance 2007. Dangerous development – Wildfire and rural sprawl in the Sierra Nevada. http://www.sierranevadaalliance.org/publications/db/pics/1190122868_27040.f_pdf.

SNEP. 1996. Sierra Nevada ecosystem project: final report to Congress, vol I-III. Centers for Water and Wildland Resources, University of California, Davis, California, USA.

Skinner, C. N. and Stephens, S. L. 2004. Fire in the Sierra Nevada. In: Proceedings of the Sierra Nevada science symposium. Murphy, Dennis D. and Stine, Peter A., editors. Gen. Tech. Rep. PSW-GTR-193. Albany, California: U. S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Stephens, S. L. and Moghaddas, J. J. 2005. Experimental fuel treatment impacts on forest structure, potential fire behavior, and predicted tree mortality in a California mixed conifer forest. Forest Ecology and Management 215: 21-36.

Stephens, S. L., Moghaddas, J. J., Edminster, C., Fiedler, C. E., Haase, S., Harrington, M., Keeley, J. E., Knapp, E. E., McIver, J. D., Metlen, K., Skinner, C. N., Youngblood, A. 2009. Fire treatment effects on vegetation structure, and potential fire severity in western U.S. forests. Ecological Applications 19(2): 305-320.

Stephens, S. L., Martin, R. E., and Clinton, N. E. 2007. Prehistoric fire area and emissions from California's forests, woodlands, shurblands, and grasslands. Forest Ecology and Management 251(3): 205-216.

Stuart, J. D. and Sawyer, J. O. 2001. Trees and shrubs of California. Berkeley, California: University of California Press.

Sugihara, N. G., van Wagtendonk, J. W., and Fites-Kaufman, J. 2006. Fire as an ecological process. In: Fire in California's ecosystem. Sugihara, N. G., van Wagtendonk, J. W., Shaffer, K. E., Fites-Kaufman, J., and Thode, A. E., editors. Berkeley and Los Angeles, California: University of California Press.

Taylor, A. H. 2002. Identifying forest reference conditions on early cut-over lands, Lake Tahoe Basin, USA. Ecological Applications 14(6): 1903-1920.

USDA Forest Service 2001. Final environmental impact statement. Sierra Nevada forest plan amendment. Vallejo, California: U. S. Department of Agriculture, Forest Service, Pacific Southwest Region.

Vaillant, N. M., Fites-Kaufman, J., and Stephens, S. L. 2009. Effectiveness of prescribed fire as a fuel treatment in Californian coniferous forests. International Journal of Wildland Fire 18: 165-175.

Vaillant, N. M., Fites-Kaufman, J., Reiner, A. L., Noonan-Wright, E. K., and Dailey, S. N. 2009. Effects of fuel treatments on fuels and potential fire behavior in California, USA, National Forests. Fire Ecology 5(2): 14-29.

van Wagtendonk, J. W. and Fites-Kaufman, J. 2006. Sierra Nevada Bioregion. In: Fire in California's ecosystem. Sugihara, N. G., van Wagtendonk, J. W., Shaffer, K. E., Fites-Kaufman, J., and Thode, A. E., editors. Berkley and Los Angeles, California: University of California Press.

Webster, K. M. and Halpern, C. B. 2010. Long-term vegetation responses to reintroduction and repeated use of fire in mixed-conifer forests of the Sierra Nevada. Ecosphere 1(5):1:27.

Whelan, R. J. 1995. The ecology of fire. Cambridge studies in ecology. Cambridge, United Kingdom: Cambridge University Press.

Wohlgemuth, P. M., Hubbert, K., and Arbaugh, M. J. 2006. Fire and physical environment Interactions: soil, water and air. Pages 75-93. In: Fire in California's ecosystem. Sugihara, N. G., van Wagtendonk, J. W., Shaffer, K. E., Fites-Kaufman, J., and Thode, A. E., editors. Berkley and Los Angeles, California: University of California Press.