



Special Topic: Synthesis for Resource Managers

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Stand Structure in the Sierra de San Pedro Mártir

Background

The forests of the Sierra de San Pedro Mártir (SSPM) in Mexico and in the Sierra Nevada of California offer the unique opportunity to study two similar ecosystems with dissimilar management histories. Both of these areas are located in Mediterranean climates with predominantly yellow (Jeffery) pine and mixed conifer forests and grow on similar soil types. However, these forests have different management histories over the past centuries. The SSPM has had very limited logging and has only recently (1970s) experienced active fire suppression. The Sierra Nevada has had extensive logging and active fire suppression for more than a century (Stephens et al. 2003). Few areas in the Sierra Nevada have been spared from active fire suppression and extensive logging, leaving California without examples of historical (pre-European) conditions. For this reason, the SSPM has been used as a reference forest to help scientists and managers understand what the drier portions of forests in the Sierra Nevada may have looked like without a history of extensive logging and fire suppression (Rivera-Huerta et al. 2016). Researchers can also compare characteristics of the SSPM and the Sierra Nevada to see how the management history has affected forest structure and ecological function (Dunbar-Irwin and Safford 2016).

Description and Management History

The SSPM is part of the Peninsular Mountain Range in northern Baja California, Mexico. 73,000

Management Implications

- The SSPM is an important reference site for resilient forest conditions in yellow pine/mixed conifer forests like the Sierra Nevada.
- The heterogeneous forest structure created by an intact fire regime in the SSPM results in greater resiliency to disturbance.
- The SSPM has been shown to be resistant to disturbances including severe drought, insects, and fire.
- Heterogeneity is not easily captured by a single metric or at any one scale. Management plans that want to incorporate heterogeneity need to take this into account.



Figure 1: Jeffrey pine stand in the SSPM. (Photo by Ian Moore)

hectares of this mountain range fall within the Sierra de San Pedro Mártir National Park. About 17,000 ha of the park are forested (Rivera-Huerta et al. 2016). The SSPM is at the southern edge of the North American Mediterranean climate zone. The area experiences cool, moist winters and warm, dry summers, much like portions of the Sierra Nevada. Most precipitation falls as snow in the winter months, although 10-20% of precipitation occurs in the summer due to monsoonal influences (Dunbar-Irwin and Safford 2016). The soils are mostly granitic in origin, with some metamorphic schist parent material also present (Stephens et al. 2003).

The overstory tree species composition of the SSPM shares many similarities with the Sierra Nevada, especially the drier regions in the southern and eastern Sierra (Dunbar-Irwin and Safford 2016, Fry et al. 2014). Jeffrey pine (*Pinus jeffreyi*), white fir (*Abies concolor*), sugar pine (*Pinus lambertiana*), and lodgepole pine (*Pinus contorta* var. *murrayana*) make up most of the forest cover, with limited amounts of incense-cedar (*Calocedrus decurrens*) and quaking aspen

(*Populus tremuloides*) also present. The most common forest types are Jeffrey pine, Jeffrey pine-mixed conifer, and mixed white fir forests, respectively (Stephens and Gill 2005).

The SSPM was originally populated by the Paipai, Kiliwa, and potentially the Nakipa, according to historical accounts, archaeological evidence, and historical fire regime reconstructions (Stephens et al. 2003). Although the forested portions of the SSPM were not permanently inhabited because of the cold winter climate, the forests were used for foraging and hunting annually and were likely burned intentionally for management purposes on a regular basis (Stephens et al. 2003, Evett et al. 2007). The San Pedro Mártir Mission was established in 1794 and was occupied until 1806, bringing with it the onset of livestock grazing and the decline of the native populations (Stephens et al. 2003). The national park officially banned livestock grazing in 1964 but eliminating livestock in the park has and continues to be a challenge (Stephens et al. 2003). Fire suppression began in a limited capacity in the 1970s. Currently, the park practices a policy of complete fire suppression (Rivera-Huerta et al. 2016). Almost no timber harvesting has occurred within the park (Stephens et al. 2010).

Fire Regime

The fire regime in the mixed conifer and yellow pine forests of the SSPM is typically of low to mixed severity with some instances of higher severity. These higher severity fires typically kill smaller (pole sized) trees and some overstory trees (Minnich et al. 2000, Stephens et al. 2008). The proportion of high severity patches is not correlated to the size of the area burned, indicating that fire behavior is more influenced by fuels rather than weather conditions (Rivera-Huerta et al. 2016). The fire return interval of this area is between 1 and 43 years on individual trees. The mean fire return interval (FRI) for fires recorded between 1521 and 1980 was less than 15 years (Stephens et al. 2003).

Climate is also an important factor in the fire regime in the SSPM. The climate is influenced by the El Niño Southern Oscillation (ENSO) annually and the Pacific Decadal Oscillation (PDO). The years that are warm and wet have less fire activity during that year. However, these warm, wet years

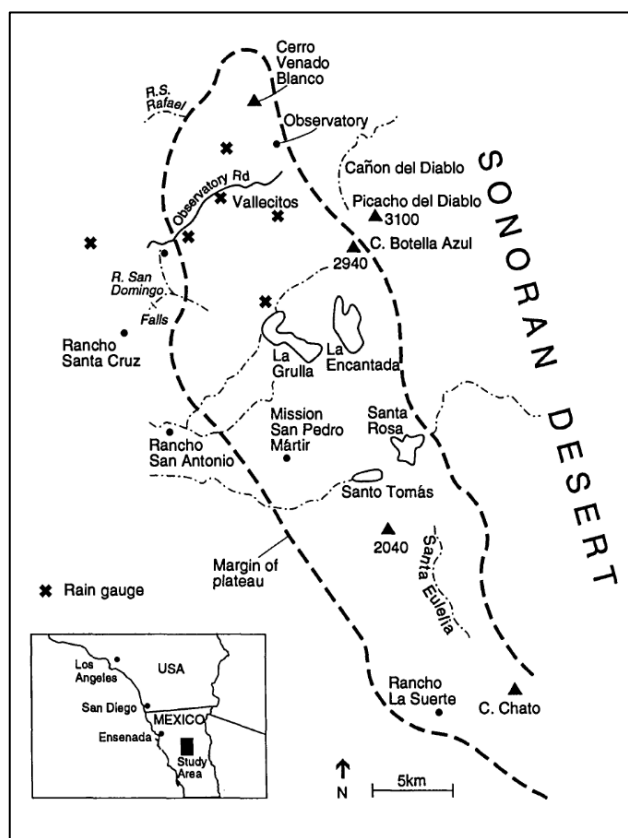


Figure 2: Map of the SSPM. (Adapted from Minnich et al. 2000)

can also cause more growth in plants and create future conditions that allow fires to spread in the cooler drier years. This variation in climate, driven by the ENSO and PDO, leads to different patterns in forest fuels and a highly varied fire regime. Overall, the fire regime is influenced by both the current climate and the climate in years prior (Skinner et al. 2008).

In the 1800s the seasonality and frequency of fire in the SSPM shifted. This coincided with the establishment of the San Pedro Mártir Mission in 1794. With the mission, the forest saw the beginning of livestock grazing and the decline of native populations (Stephens et al. 2003). Until the 1800s, records also indicate that there were many ignitions in the early summer (May and June). The phytolith (microfossils derived from grasses that provides historical vegetation data) and climate data show that there was not a substantial change in climate or understory grasses during this time. Without climate or fuel changes, this suggests that changes to human activity were the likely cause in the fire regime changes (Evetts et al. 2007). Additionally, there had been archaeological evidence of native people using the area seasonally; thus, human-caused fire may have been a substantial component of the fire regime in the SSPM (Stephens et al. 2003). Utilizing fire as a tool and a cultural practice has long tradition for Indigenous people throughout North America.

Over the last thirty years, the implementation of fire suppression has caused some changes to the fire regime. Though most metrics still fall within the historic range of variation, the mean size of high severity patches has increased (Rivera-Huerta et al. 2016). If fire suppression continues, these forests may begin to look more like Sierra Nevada forests and may have increased risk from disturbances such as severe fire and drought.

Forest Fuels

Plant materials other than living trees are also an important consideration for ecosystem function and fire behavior. Plant materials that affect fire include surface fuels (e.g. needles and twigs), coarse woody debris (CWD) (e.g. logs and large dead branches), and snags (e.g. standing dead trees). Understanding the metrics of how these materials are distributed in the SSPM can serve as

a proxy for historical values in western pine forests like the Sierra Nevada, before the era of fire suppression. Overall, fuels and snags in the SSPM show a very heterogeneous distribution across the landscape.

Surface fuels

Surface fuels (the accumulation of newly fallen needles and small sticks) are the main driver of fire spread (Agee and Skinner 2005). The surface fuel load is held in balance by deposition from the overstory and removal by decay, fire, or other processes. Surface fuel deposition in the SSPM is significantly affected by precipitation and forest structure characteristics including basal area, canopy cover, and tree density (Fry et al. 2018). Much like fuels, the forest structure also varies considerably across the landscape. While there is much variation, the average surface fuel load is 15.8 metric tons (tonnes)/hectare (ha) (Stephens 2004, Fry and Stephens 2010).

The variation in surface fuels interacts with fire in a feedback loop; since fire requires fuel to spread, where a fire occurs depends on surface fuels and surface fuel loads depend on recent fire activity. This relationship means that surface fuel patch heterogeneity leads to fires that consume areas of high fuel load, and low fuel loads can stop a fire. This results in a patchwork of fire intensity and area burned across the landscape (Minnich et al. 2000). Fires, having consumed surface fuels, then help maintain patch heterogeneity of surface fuels (Stephens et al. 2008). Understanding the links between surface fuels, overstory structure, and fire, as well as the importance of heterogeneity in this system, can help guide management plans in other forests.

Course Woody Debris (CWD)

Course woody debris refers to the larger pieces of wood and logs on the forest floor. CWD can support a variety of wildlife species and ecosystem processes. Consumption of CWD by fire can lead to patches of high nutrient availability, which are ideal sites for tree growth and regeneration. Thus, the arrangement of CWD can influence the overstory patch dynamics of a forest (Stephens and Fry 2005). Due to the low severity fire regime in the SSPM, most CWD is in later stages of decay. Average CWD loads in the SSPM were found to be 15.7 tonnes/ha but ranged from

0 to 154.5 tonnes/ha with many areas having none (Stephens et al. 2007). The importance of maintaining a heterogenous or patchy structure, is again illustrated, this time regarding CWD. The variation in this measurement also illustrates that using the average of a metric may misrepresent the larger picture by not recognizing the far ends of the distribution. When designing management goals, managing for heterogeneity may be more representative than aiming for averages. If management goals do use the average, the authors recommend this should only be done over larger scales (hundreds of hectares) (Stephens 2004).

Snags

Snags have important value for several wildlife species. They also serve as relics of mortality events and can provide clues to how a forest has responded to past disturbances or stresses. Snag density in the SSPM ranges from 1-6 snags/ha (Minnich et al. 2000). Between 1998 and 2002 average snag density increased from 3.95 snags/ha to 5.10 snags/ha (1.6 snags/acre to 2.1 snags/acre) due to a multi-year drought (Stephens et al. 2004). While these increases are significant, snag density was found to be 2.6 times higher in similar forests of the eastern Sierra Nevada (Dunbar-Irwin and Safford 2016). Additionally, Maloney and Rizzo (2002) found 78% of mortality in the SSPM was due to insects and pathogens and only 6% was due to fire. The low snag densities, even after the moderate increase from the drought, indicate that the forest structure of the SSPM is able to buffer against the lethal effects of drought, insects, disease, and fire.

Spatial Patterns

Researchers have used a variety of metrics to capture the heterogeneity of the SSPM's forest structure (Table 1). These statistics highlight the high variability in forest structure and the low tree densities, especially when compared to fire-excluded forests in the Sierra Nevada. Dunbar-Irwin and Safford (2016) found that average live tree density and basal area were significantly lower in the SSPM and that average DBH (a measurement of tree size) was significantly higher in the SSPM compared to the eastern Sierra Nevada. Overall, this means that on average, the forests of the SSPM had both fewer and larger

trees compared to the eastern Sierra Nevada forests.

Table 1: Compilation of various forest structure metrics used by different authors to characterize the SSPM. All metrics are averages with ranges in parentheses.

Authors	Live tree density (trees/ha)	Live tree basal area (m ² /ha)	Live tree DBH (cm)	Canopy cover (%)
Stephens and Gill 2005	145.3 (30-320)	19.9 (5.7-50.7)	32.6 (2.5-112)	25.3 (14.0-49.5)
Fry and Stephens 2010	151.9 (30-450)	20.1 (5.7-50.7)		26.8 (0-56)
Dunbar-Irwin and Safford 2016	187.9 (0-600)	22.5 (0-46)	39.1 (7.5-146.7)	24.9

Other studies have attempted to quantify the spatial complexity of the SSPM's forest structure. The SSPM is characterized by patterns of large individual trees, clusters of trees, and canopy gaps (Figure 3). By comparing stem maps from the SSPM and fire-excluded sites in the southern Sierra Nevada, one study found a higher proportion of trees in large patches, higher densities of single trees in small size classes, and greater overall uniformity in the Sierra Nevada sites (Fry et al. 2014). The authors also found that there were lower snag densities and snag sizes in

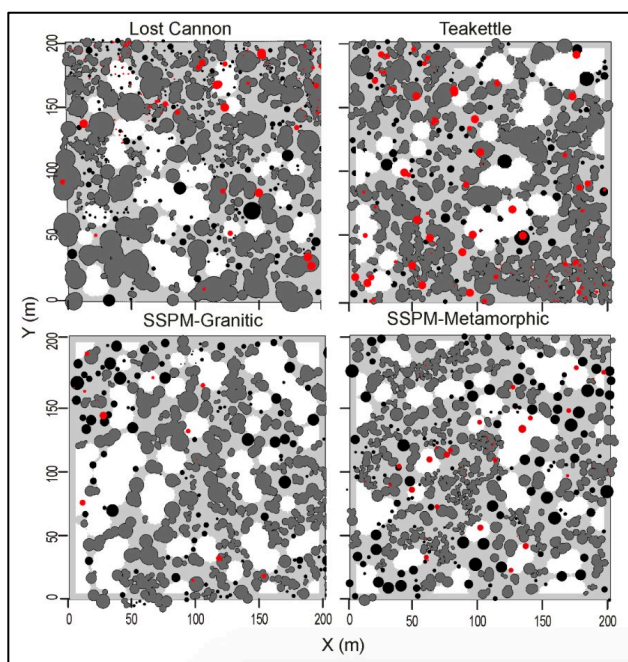


Figure 3: Stem maps comparing the southern Sierra (top row) and the SSPM (bottom row). The stem maps include patches (gray), individual trees (black), canopy gaps (white), and snags (red). (Adapted from Fry et al. 2014)

the SSPM, and that there was no difference in average canopy gap size between regions (Fry et al. 2014).

These fine-scale spatial patterns have important effects on forest resilience. Variability in overstory vegetation results in a heterogeneous fuels structure (Fry and Stephens 2010), which reduces the probability of crown fire and perpetuates diverse fire effects (Churchill et al. 2013). In addition, low tree densities and the presence of canopy gaps provide resistance and resilience to drought, insects, and pathogens (Dunbar-Irwin and Safford 2016; Maloney and Rizzo 2002; Stephens et al. 2008).

As an example of compared resistance between the SSPM and the Sierra Nevada forests, both forests have recently experienced the effects of a severe drought. This drought impacted the forests of southern California from 1999-2002, centered around the Lake Arrowhead area of the San Bernardino National Forest. Due to past forest management actions including fire suppression, this forest has many more trees per acre than the SSPM. With more trees per acre, it made it more difficult for the trees to get water to survive and defend themselves from the bark beetles. This resulted in millions of killed trees from bark beetle attacks and drought.

The same drought impacted the forests 200 miles south in the Sierra San Pedro Martir (SSPM) but with drastically different results. Here the drought and beetle disturbance only caused 0.5 trees/acre to die. Then in 2003, the year after the intense drought ended in 2002, a wildfire burned in the SSPM. Even with this succession of events, about 80% of the trees survived (Stephens et al. 2008). This forest demonstrated incredible resilience to these stressors, something that conifer forests in California also once had. Creating forests with conditions more aligned to those in the SSPM (Stephens, 2004, Stephens and Gill 2005, Fry et al. 2014) would enable them to better deal with drought, fire, and climate change.

Conclusion

Due to the similar climate, vegetation, and soils, the Sierra de San Pedro Mártir can act as a reference site for pre-European, resilient forests in the mixed conifer/ yellow pine forests of the

western US/ California. By comparing forests like the Sierra Nevada that have experienced extensive logging and fire suppression, differing results in forest structure and resilience can be identified. The characteristics of SSPM forest structure, including tree density, clustering, canopy cover, and fuel arrangement, all share one common trait: a high degree of variability. This variability is a result of different patches that assemble to create a heterogeneous landscape. The structure of this forest creates an ecosystem that is resistant and resilient to drought, high-severity fire, insects, and disease. The SSPM can help guide management decisions in mixed conifer/ yellow pine forests of the western US/ California that wish to return forests to historical (pre-European) conditions or prepare them for a changing climate and an uncertain future.

Authors

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