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Fuel loads, snag abundance, and snag recruitment in an unmanaged Jeffrey pine–mixed conifer forest in Northwestern Mexico

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Abstract

Management of downed woody fuels and snags (standing dead trees) is receiving increasing attention because of their ecosystem values and effects on potential fire behavior. Research has correlated the abundance of many wildlife species with snags and downed woody material but very little information exists of the abundance and arrangement of these forest structures, particularly in unmanaged forests. Conifer forests in northwestern Mexico have not experienced systematic fire suppression or harvesting making them unique in western North America. In 1998, average snag density in Jeffrey pine–mixed conifer forests in the Sierra San Pedro Martir (SSPM) National Park was 3.95 snags/ha but 35% of inventoried plots had no snags. In 2002, average snag density significantly increased to 5.10 snags/ha after a multiple-year drought. Average surface and ground fuel loads were 15.8 and 8.7 t/ha, respectively. High variability characterized all snag and fuel attributes measured in this forest. This high amount of variation is probably the result of the relatively intact frequent surface fire regime and because no harvesting has occurred in the sampled area. The patchy distribution of snags observed argues against the application of uniform targets for snag retention across similar forested landscapes. An improvement in management guidelines would be to manage for snag density and large fuels over moderate spatial scales (hundreds of hectares) instead of on a per hectare basis. Forest fragmentation and diverse ownerships in many western United States forests complicates this recommendation. Conservation of the forests in the SSPM is critical because it is the last landscape-scale, old-growth mixed conifer forest in western North America with a relatively intact frequent fire regime.

Keywords: Sierra San Pedro Martir; Old-growth forest; Wildlife habitat; Fire hazard

1. Introduction

Management of downed woody fuels is receiving increasing attention because of their impacts on potential fire behavior (van Wagtendonk, 1996; Stephens, 1998; Agee et al., 2000; Finney, 2001; Fulé et al., 2001). Currently over 10 million hectares of forests in the western United States (US) have moderate or high fire hazards (NWCG, 2001) and many of them are in need of restoration. High fire hazards have primarily been produced by past harvesting, fire suppression, and livestock grazing (NWCG, 2001). Climate change over the last 100 years could also have influenced current forest structure (Millar and Wolfebden, 1999).

Management of snags and large woody debris has also received increased attention because of their ecosystem values. Snags and downed woody material provide nesting, foraging, and resting habitat for many wildlife species in North America (Scott et al., 1977;

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Thomas et al., 1979; Neitro et al., 1985; Harmon et al., 1986; Bull et al., 1997; Rabe et al., 1998; Laudenslayer, 2002). Snag characteristics have also been studied because attributes such as species, decay condition, and size have been used as indicators of potential habitat for many vertebrate species (Cline et al., 1980; Harmon et al., 1986; Laudenslayer, 2002).

Studies of snag abundance have primarily occurred in managed forested ecosystems (Laudenslayer et al., 1989; Ohmann et al., 1994; Bull et al., 1997; Ganey, 1999; DeLong and Kessler, 2000; Landram et al., 2002). These ecosystems have experienced decades of fire suppression and many have experienced multiple harvests over the last century. Research has correlated the abundance of many wildlife species with standing and downed woody material but very little information exists on the abundance and arrangement of these forest structures, particularly in unmanaged forests (Savage, 1997; Fulé and Covington, 1998; Stephens, 2000; Maloney and Rizzo, 2002).

No information exists on downed woody fuel loads and snag recruitment in unmanaged mixed conifer forests in the western US. The absence of information has occurred because there are no large, coniferous forests in the western US that have not been affected by past management activities, particularly those that once experienced frequent, low–moderate intensity fire regimes.

One large forested ecosystem exists in northwestern Mexico where harvesting has never occurred and a policy of large-scale fire suppression was never initiated, the Sierra San Pedro Martir (SSPM), Baja California, Mexico (Minnich et al., 1997; Stephens et al., 2003). This area is composed of mixed conifer forests and shrublands of the Californian floristic province that occur nowhere else in Mexico (Minnich et al., 1997, 2000; Minnich and Franco, 1998). This work was done in the SSPM National Park, the park includes the northern and central areas of the SSPM.

The SSPM is unique within the California floristic province in that its forests are still influenced by lightning-ignited fires that are similar to those that once occurred in many pine-dominated forests in the western US. Median fire return intervals in Jeffrey pine (*Pinus jeffreyi* Grev. and Balf)–mixed conifer forests in the SSPM are shorter than 15 years at all composite scales (Stephens et al., 2003), and this is comparable to past fire frequency in similar forests in California (Skinner and Chang, 1996; Stephens, 2001).

The seasonality of past fires in the SSPM differs from that in California with the majority of fires recorded in the earlywood portion of annual ring, most fires in Californian forests are recorded in the latewood or dormant periods (Stephens et al., 2003; Stephens and Collins, 2004). Limited fire suppression began in the SSPM in the 1970s but this has consisted of one or two 4-person hand crews, mechanized suppression resources are still not available. The SSPM has experienced livestock grazing at varying intensities over the last 200 years (Minnich et al., 1997; Minnich and Franco, 1998; Stephens et al., 2003).

The number of dead trees in mixed white fir forests (Minnich and Franco, 1998) in the SSPM has been tallied in relatively course diameter classes (Maloney and Rizzo, 2002). In this study, 78% of observed tree mortality was explained by the presence of pathogens and bark beetles but no information on snag density, basal area, or recruitment was reported. Minnich et al. (2000) reported average snag densities of approximately 1 ha in all forest types in the SSPM from the analysis of aerial photographs. Another study reported average snag density (9/ha) and basal area (2.64 m^2/ha) in mixed white fir forests in the SSPM (Savage, 1997). Savage (1997) compared tree mortality in the SSPM to similar forests in the San Bernardino Mountains of southern California and found much lower mortality in the Mexican forests over a similar time period.

The objective of this study was to develop information on the abundance and recruitment of snags, and surface and ground fuels in a Jeffrey pine–mixed conifer forest that has few management inputs. This information was compared with similar forests in the western US with different land-use histories. Information from this study can assist in the development of desired future conditions in similar forests in the western US.

2. Methods

2.1. Study location

The study was conducted in the SSPM National Park which is approximately 100 km southeast of

Ensenada, Mexico (UTM 644508, 3430213; latitude 31°37′, longitude 115°59′). The mixed conifer forests of the SSPM are composed of Jeffrey pine, white fir (*Abies concolor*) [Gord. and Glend.] Lindl., sugar pine (*Pinus lambertiana*) Dougl., lodgepole pine (*Pinus contorta* (Grev. and Balf.) Critchf.), and small amounts of incense-cedar (*Calocedrus decurrens*) [Torr.] Floren and quaking aspen (*Populus tremuloides* Mich.).

The most common forest types are Jeffrey pine, Jeffrey pine–mixed conifer, and mixed white fir forests (Minnich and Franco, 1998). Elevation averages 2600 m in the northern SSPM and decreases to 1800 m in the southern portion of the range. The highest mountains are over 3000 m above sea level. The soils of the SSPM are unclassified. The most common parent material is granite with some soils derived from metamorphic quartz shists.

The SSPM is located in southern margin of the North American Mediterranean climate zone (Pyke, 1972; Markham, 1972; Reyes Coca et al., 1990; Minnich et al., 2000), however, weather data from this area are limited. A group of temporary weather stations was installed in this range from 1989 to 1992 and average annual precipitation in the upper plateau (Vallecitos Meadow) was 55 cm (Minnich et al., 2000). The SSPM experienced a severe drought from 1999 to 2003, a similar drought has occurred in the San Bernardino Mountains in southern California (Brett Goforth, personal communication, 2003).

The forest type selected for this study was Jeffrey pine–mixed conifer. Floristically, this forest is very similar to portions of the eastern Sierra Nevada and southern California mountains (Minnich et al., 1995; Stephens, 2001). Mexican topographic maps were used to select an area with uniform aspects (west, northwest), slopes (0–20%), and soil parent material (granite) to reduce variability in forest structure that could be caused by these abiotic factors. Elevation in the sampled area varied between 2500 and 2600 m and it is approximately 1.2 km west of Vallecitos Meadow in the SSPM National Park.

2.2. Snag and fuel abundance

Measurement of snags, and surface and ground fuel loads was done using a systematic design of plots; the starting point of the grid was selected randomly. Each plot was separated by 200 m and 49 plots were sampled (7×7 grid). This sampling design was selected to assess moderate-scale variability in snags and fuels in Jeffrey pine–mixed conifer forests, rather than individual stand information from random locations throughout the SSPM. The area sampled was approximately 144 ha. Snags were inventoried using 0.4-ha circular plots and diameter at breast height (DBH), height, species, and condition class was obtained for each snag over 2.5 cm DBH. A sampling area of 0.4 ha was selected because it is the recommended plot size in pine-dominated forests that have average snag densities of 2–5 ha (Bull et al., 1990).

Species of snag was determined from bark characteristics; snags without bark were classified as unknown species. The decay classes used by Cline et al. (1980) were recorded for each snag (ratings 1–3 only). Snag plots were inventoried in 1998, 2002, and 2003, and quantile plots were produced to display abundance. The snag plots were measured in 2002 and 2003 to determine if the recent drought had significantly increased tree mortality. Each snag was permanently marked with a steel tag.

Surface and ground fuels were sampled in 1998 at each plot using the line intercept method (van Wagner, 1968; Brown, 1974). Using the plot center that was marked with a steel stake, three transects in random directions were installed. One- and ten-hour fuels were sampled from 0 to 3 m, 100 h fuels from 0 to 5 m, and 1000 h and larger fuels from 0 to 13 m on each transect. Duff and litter depth in cm were measured at 3 and 5 m on each transect.

Surface and ground fuel loads were calculated by using appropriate equations developed for Californian forests (van Wagtendonk et al., 1996, 1998). Coefficients required to calculate all surface and ground fuel loads were arithmetically weighted by the basal area fraction to produce accurate and precise estimates of ground and surface fuel loads (Stephens, 2001).

Descriptive statistics including average snag density, basal area, DBH, condition class, and surface and ground fuel loads by size class were calculated. These values were compared with published information for other areas of mixed conifer and ponderosa pine (*Pinus ponderosa* Laws) forests in the western US.

Table 1
Cumulative percentage of snags by size class and species from Jeffrey pine–mixed conifer forests in the Sierra San Pedro Martir, Mexico, in 1998

Snag size class (cm)	Jeffrey pine	White fir	Sugar pine	Lodgepole pine	Unknown species	Total
DBH > 10	100	88.89	75.00	100	100	93.75
DBH > 20	100	77.78	75.00	100	100	91.25
DBH > 30	87.80	61.11	75.00	100	100	83.75
DBH > 50	73.17	50.00	50.00	0	64.28	62.50
DBH > 75	31.70	27.78	50.00	0	35.71	31.25
DBH > 100	4.87	16.67	0	0	7.14	7.50

2.3. Snag recruitment

A chainsaw was used to extract a wedge from each snag during the 2002 plot inventory. Each wedge was approximately 25 cm long and included approximately 100 annual growth rings. Wedges were sanded and polished to a high sheen (400 grit) so that tree rings could be readily distinguished under a microscope.

The precise year of tree death was determined by cross-dating tree rings in the wedges using standard dendrochronological techniques (Stokes and Smiley, 1977; Swetnam et al., 1985). Most specimens were cross-dated by visually comparing them with a nearby chronology (Stokes et al., 1971) obtained from the International Tree-ring Data Bank (Grissino-Mayer and Fritts, 1998). The program COFECHA was used to facilitate cross-dating of difficult specimens (Holmes, 1983). A chi-square test was used to determine if there was a significant difference ($P < 0.05$) in the number of snags present in 1998 (before the current drought) and 2003.

3. Results

The majority of the snags inventoried in 1998 were Jeffrey pine (52.6%), with fewer from white fir (23.1%), sugar pine (5.1%), and lodgepole pine (1.3%); 17.9% of snags could not be identified to species. Average snag DBH was 57.9 cm (standard error = 3.0) for all species (Table 1). Snag DBH varied from 2.6 to 111.3 cm. The majority of the snags were relatively large (Fig. 1).

Average snag density in 1998 was 3.95 snags/ha (range 0–20 snags/ha, standard error 0.69), 35% of plots had no snags (Fig. 2). Less than average density was recorded on 65% of plots. Greater than 10 snags/ha was recorded in 18% of plots. Average snag basal area was 1.28 m^2/ha (range 0–4.97 m^2/ha, standard error 0.21). Thirty-four percent of total snag basal area was located on the top 5% of plots and 58% was located on the top 10% of plots. Average snag height was 13.0 m (standard error 0.9) and varied from 1.9 to 29.1 m. There was a significant difference in the number of snags present in 1998 compared to 2003 ($\chi^2 = 4.33$, $P = 0.037$).

In 1998, Jeffrey pine snags were equally distributed in the three condition classes (Table 2). There were fewer condition class 1 white fir snags, over two-thirds of the white fir snags were in condition class two (Table 2). Snags that could not be identified to species were dominated by condition class 3. Nineteen more snags were added in 2002 and 2003 (15 Jeffrey pine, 3

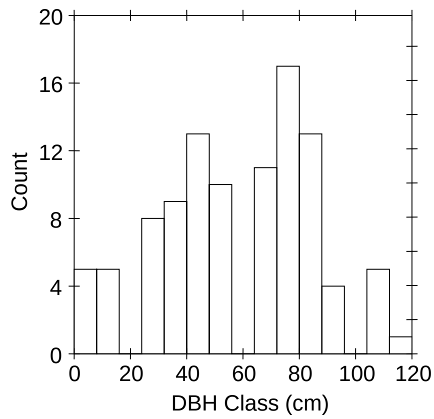

Fig. 1. Snag diameter distribution in 10 cm size classes from Jeffrey pine–mixed conifer forests in the Sierra San Pedro Martir, Mexico, in 2003.

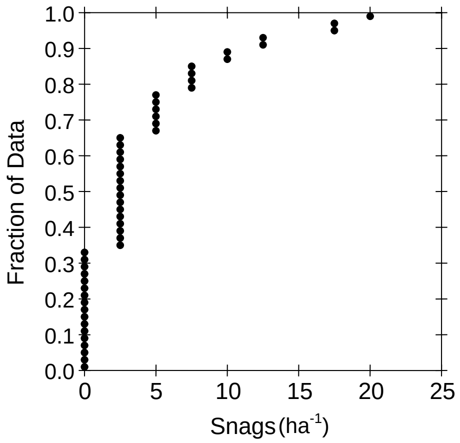

Fig. 2. Snag density (ha^{-1}) distribution from Jeffrey pine–mixed conifer forests in the Sierra San Pedro Martir, Mexico, in 1998.

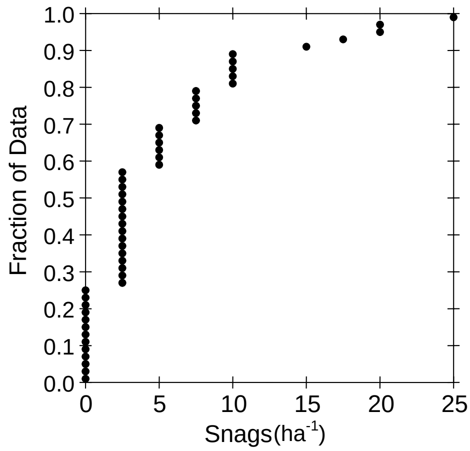

Fig. 3. Snag density (ha^{-1}) distribution from Jeffrey pine–mixed conifer forests in the Sierra San Pedro Martir, Mexico, in 2003.

white fir, 1 lodgepole pine) and this changed the condition class distribution of Jeffrey pine snags to 50% class 1, 27% class 2, and 23% class 3.

Average snag density in 2003 was 5.10 snags/ha (range 0–25 snags/ha, standard error 0.80), 26% of plots had no snags (Fig. 3). Less than average density was recorded on 71% of plots. Ten percent of the plots had a snag density greater than 10 snags/ha. Average snag basal area was 1.67 m^2/ha (range 0–6.45 m^2/ha, standard error 0.25). Average snag DBH was 58.1 cm (standard error = 2.7) for all species. Snag DBH varied from 2.6 to 111.3 cm.

Surface and ground fuels were measured using 147 planar transects. Average total surface fuel loads were 15.8 t/ha (range 0.01–159.74 t/ha, standard error 3.91) (Table 3). Average ground fuel loads were 8.7 t/ha (range 0.43–23.91 t/ha, standard error 0.83) (Table 3). Ground fuels consisted of only litter (average depth of 1.6 cm, range 0–10.0 cm), no duff was recorded.

Total surface fuel load was less than the average load in 73% of plots. Surface fuel load was greater than 18.4 t/ha on 24% of plots and greater than 36.8 t/ha on 8% of plots. Average 1000-h fuel load was 13.64 t/ha (Table 3). Thirty-seven percent of plots had no 1000-h fuels, 67% had less than the average load, and 22.4% of plots had greater than 20 t/ha. Fifty-six percent of 1000-h fuels are found on 10% of the plots, 75% are located on 20% of the plots. Eighty-one percent of the 1000-h fuel load was from rotten materials, the remaining 19% was from sound wood.

The snag year of death varied from 1910 to 2002 and 89% of snags sampled in 2002 were dated (Fig. 4). Missing rings occurred on most snag wedges and specific years were predictable as a subset of those indicated as very narrow rings by the San Pedro Martir chronology (Stokes et al., 1971). Additionally, ring-width patterns for most specimens followed the San Pedro Martir chronology closely, thus facilitating cross-dating. The sapwood of some snags (11% of

Table 2
Percentage of snags by condition class from Jeffrey pine–mixed conifer forests in the Sierra San Pedro Martir, Mexico, in 1998

Snag condition	Jeffrey pine	White fir	Sugar pine	Lodgepole pine	Unknown species
Some needles and small branches attached, rating 1	31.7	23.5	25.0	100	0
No needles, most small branches absent, stubs formed as the tips of large limbs broke, rating 2	36.6	64.7	25.0	0	21.4
Most branches broken off, only stubs of the largest limbs remain, rating 3	31.7	11.7	50.0	0	78.6

Table 3
Surface and ground fuel loads from Jeffrey pine–mixed conifer forests in the Sierra San Pedro Martir, Mexico

Fuel class	1 h	10 h	100 h	1000 h	Total dead and down	Litter
Average (t/ha)	0.11	0.85	1.20	13.64	15.80	8.69
Maximum (t/ha)	0.89	6.98	8.80	156.41	159.74	23.91
Minimum (t/ha)	0	0	0	0	0	0.43
Standard error	0.03	0.16	0.27	3.84	3.91	0.83

those sampled in 2002) was eroded, and therefore, the year of death could not be determined. The oldest outside ring of an eroded snag was 1814, other snags with eroded sapwood had outer ring dates of 1817, 1841, 1938, and 1948.

4. Discussion

High variability characterized all snag and fuel attributes measured in this Jeffrey pine–mixed conifer forest in the SSPM. This high amount of variability is probably the result of the relatively intact frequent surface fire regime (Stephens et al., 2003) and because no harvesting has ever occurred in this forest. The high variability in surface fuel loads would produce equally diverse fire behavior and effects, and this would probably maintain high spatial heterogeneity if the forest continues to burn under a low-intensity fire regime.

Because of declining populations of some old-growth associated wildlife species such as Californian (*Strix occidentalis occidentalis*) and Mexican (*Strix occidentalis lucida*) spotted owls, management guidelines have been developed for the abundance of snags and downed woody material in forests in the western US (Thomas et al., 1990; USDI, 1995; Verner et al., 1992). Many of these guidelines call for average characteristics (such as snag density) to be created at the stand level, replicated for all stands across very large spatial scales. The California spotted owl is reported to inhabit the forests of the SSPM (Minnich et al., 1997), but their distribution may be limited to denser forests near perennial streams. Therefore, uniform snag densities across all stands may not be appropriate for meeting habitat requirements in these or similar forests.

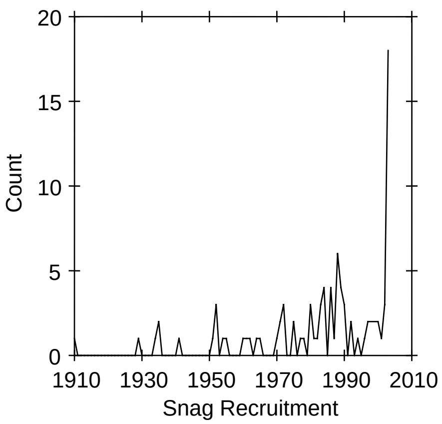

Fig. 4. Snag recruitment dates from Jeffrey pine–mixed conifer forests in the Sierra San Pedro Martir, Mexico, in 2003.

Current management standards in US Forest Service lands in the southwestern US (Arizona and New Mexico) require 4.9 and 7.4 snags/ha in ponderosa pine and mixed conifer forests, respectively, with a minimum DBH of 46 cm and minimum snag height of 9 m (Ganey, 1999). In the Lake Tahoe Basin of California and Nevada, old-growth forest structure is reported to have a minimum of 5 snags/ha that are >76 cm DBH (mean snag density of 16/ha). The forest series included in this recommendation include Jeffrey pine, mixed conifer, white fir, and red fir (*Abies magnifica* A. Murr.) (Barbour et al., 2002).

Jeffrey pine–mixed conifer forests in this study had similar snag densities as those reported in Ganey (1999) and are the lower range of Barbour et al. (2002) recommendation, but in 1998 there were no snags in 35% of plots, and after a severe drought that significantly increased snag abundance, there were still zero snags on 28% of plots. Average snag density of 5/ha is similar to that found in other pine-dominated forests before harvesting or fire suppression (Table 4) but this density was produced by approximately 60% of the inventoried area in this study.

Table 4
Snag characteristics from pine-dominated coniferous forests in western North America

Forest type	Snag size definition	Average density (ha^{-1})	Forest history	Location
Ponderosa pine	DBH > 20 cm, height > 2 m tall	5 (median)	Fire suppression, past harvesting	North-central Arizona (Ganey, 1999)
Mixed conifer	DBH > 20 cm, height > 2 m tall	24 (median)	Fire suppression, past harvesting	North-central Arizona (Ganey, 1999)
Jeffrey pine	DBH > 1 cm	109	Fire suppression	Lake Tahoe Basin, CA, NV (Barbour et al., 2002)
Mixed conifer	DBH > 1 cm	37	Fire suppression	Lake Tahoe Basin, CA, NV (Barbour et al., 2002)
Mixed conifer	DBH > 2.5 cm	60	Fire suppression	Southern Sierra Nevada (Stephens and Finney, 2002)
Jeffrey pine–white fir	DBH > 4 cm, height > 1.4 m tall	41	Fire suppression	San Bernardino Mountains, CA (Savage, 1997)
Jeffrey pine–white fir	DBH > 4 cm, height > 1.4 m tall	59	Fire suppression	San Bernardino Mountains, CA (Savage, 1997)
Mixed conifer	DBH > 30.5 cm	5	No fire suppression or harvesting	Northern and central Sierra Nevada, CA (Stephens, 2000)
Mixed white fir	DBH > 4 cm, height > 1.4 m tall	9	No fire suppression or harvesting	La Corona Arriba, Sierra San Pedro Martir, Mexico (Savage, 1997)
Jeffrey pine–mixed conifer	DBH > 2.5 cm	5	No fire suppression or harvesting	This work

Many western forests that have experienced fire suppression and harvesting have almost 10 times the snag density as forests in the SSPM, but there are exceptions (Table 4). Differences in the minimum DBH used to define a snag (Table 4) complicate the comparisons.

The majority of snags in the SSPM have large diameters, 85% have a DBH $>$ 30 cm, and 63% have a DBH $>$ 50 cm (Table 1; Fig. 1). There are very few small, dead trees in the SSPM (only 7% with DBH $<$ 10 cm). This is in contrast to ponderosa pine and mixed conifer forests in Arizona and California, where current snag populations are dominated by small snags (Ganey, 1999; Barbour et al., 2002). Fire suppression has increased tree density and canopy cover in many western US forests and the resulting competition has probably contributed to the high number of small dead tress.

Snag populations in the study area were dominated by snags in the early and mid-decay classes (Table 2) and this is the first study to report such information from forests without large-scale fire suppression or harvesting. Snag populations in ponderosa pine forests in central Arizona are dominated by the later decay classes and this may indicate an unbalanced age structure in snag populations (Ganey, 1999).

Average surface fuel loads are relatively low (15.8 t/ha) in the Jeffrey pine–mixed conifer forests in the SSPM but there is great variation (range 0.01–159.74 t/ha). Seventy-three percent of individual plots had surface fuel loads that were below the 49 plot mean. Approximately 25% of plots had moderate fuel loads (18.4 t/ha) and a few (8% of plots) had relatively high surface fuel loads of 36.8 t/ha. Thousand-hour fuels were equally patchy with over one-third of plots having no 1000-h fuels and 22% of plots having greater than 20 t/ha.

Average 1–100 h fuel loads in eastern Sierra Nevada Jeffrey pine forests that have experienced 100 years of fire suppression are 3.13 t/ha (Stephens, 2001), average 1–100 h fuel loads from this study is 2.16 t/ha (Table 3). The fine fuel loads from these forests are similar even though they have experienced very different management histories. Fine fuels would accumulate slowly in relatively dry, unproductive, pine-dominated forests and this probably explains why the differences are small. In a more mesic, west-slope mixed conifer forests in the southern Sierra Nevada that has experienced 100 years of fire suppression, average 1–100 h fuel load was much greater (8.52 t/ha) (Stephens and Finney, 2002). Similar high fuel loads in mixed conifer forests in the western Sierra Nevada have been reported (Blonski and Schramel, 1981).

In contrast to the small difference in fine fuel loads between floristically similar forests in the SSPM and eastern Sierra Nevada, 1000-h fuel loads were different. In the eastern Sierra Nevada, Jeffrey pine forests with 100 years of fire suppression had an average 1000-h fuel load of 1.78 t/ha (Stephens, 2001), in the SSPM these fuels averaged 13.64 t/ha (Table 3). Very few large, down trees were present in the eastern Sierra Nevada and this can be partially explained by local firewood collecting. The eastern Sierra Nevada location is within easy walking distance of several cabins and firewood has probably been collected for many years.

In the SSPM, firewood collection has not occurred but frequent fires occurred until 1960 (Stephens et al., 2003). The high amount of heterogeneity in SSPM fuel loads (both surface and ground) probably results in fires that are very patchy. Such fires would only burn a portion of the forest and this would allow some large fuels to persist. The forested area sampled in the eastern Sierra Nevada was relatively small (Stephens, 2001), so comparisons of large fuel loads should be interpreted with caution.

Average ground fuel loads in the two forested areas were also substantially different (SSPM—8.69 t/ha, eastern Sierra Nevada—28.38 t/ha). The Jeffrey pine forests in the eastern Sierra Nevada had large amounts of duff (Stephens, 2001), ground fuels in the SSPM only included litter. Fire suppression has increased ground fuel loads in the eastern Sierra Nevada. Mean litter depth in mixed white fir forests in the SSPM was also small, averaging 0.92 cm (Maloney and Rizzo, 2002).

The forests in the SSPM have relatively low fuel loads and snag densities (Tables 3 and 4) and are not in need of salvage harvesting (removal of dead or dying trees). Such operations could significantly increase potential fire behavior by leaving activity fuels on the forest floor (Stephens, 1998) and the creation of pine stumps could increase the spread of root pathogens. Indeed, the resiliency of the forests in the SSPM is probably the direct result of them being relatively intact with few management interventions.

5. Conclusions

In many western US forests, the achievement of wildlife habitat improvement and fire hazard reduction goals are frequently not complementary, especially in xeric pine-dominated forests that once experienced frequent, low–moderate-intensity fire regimes. It is common for wildlife habitat goals to require relatively high, uniform woody fuel loads and snag densities at large spatial scales. When these are combined with ignitions and severe fire weather, large high-severity wildfires can be produced (Stephens, 1998; Fulé et al., 2001).

Snag dynamics in forests with intact surface fire regimes are uncertain. In the SSPM forests investigated in this work, forest fuels (surface and ground) had high amounts of variability. This high variability and relatively low fuel loads would result in surface and ground fires that would leave many areas unburned within the perimeter of a fire. Fires burning under modal weather conditions (in contrast to severe fire weather) would have modest behaviors (flame lengths, rates of spread) and spotting would be limited because of higher relative humidities and low wind speeds. Low and variable fuel loads coupled with most fires burning under modal fire weather conditions would probably allow snags to remain in these forests for decades.

In contrast to SSPM forests with a relatively intact fire regime, most forests in the western US have been significantly modified by fire suppression. This has increased fuel loads and fuel continuity. When fire is reintroduced into these forests, the high horizontal fuel continuity results in the majority of the area burning within a fire perimeter, even under modest fire weather. Many snags are old and are in the latter stages of decay in western US forests (Ganey, 1999; Barbour et al., 2002) and this increases their susceptibility to spot-fire ignitions. When fire is reintroduced in these conditions it will consume the majority of old, decayed snags but will create new snags from direct fire effects and the interaction with bark beetles (*Dendroctonus* and *Ips* spp.). The habitat value of the new snags will probably be significantly different than those before the fire.

The patchy distribution of snags observed in this study argues against the application of uniform targets for snag retention across similar forest landscapes. An improvement in management guidelines would be to manage for snag density and large fuels over moderate spatial scales (hundreds of hectares) instead of on per hectare basis. This would enable managers to meet standards by maintaining high snag densities and large fuel loads over only a portion of the forested landscape.

Many mixed conifer, Jeffrey pine, and ponderosa pine forests in the western US have been fragmented by roads, urban development, recreational use, fire suppression, and past forest harvesting. Land ownership is commonly diverse including multiple private, federal, and state entities. This further complicates the management for rare or endangered species because it can limit the number and size of areas with high-quality habitat. The SSPM currently does not have these limitations, but if fire suppression or harvesting is maintained or initiated, respectively, the ecosystems in this mountain range will face similar challenges. Conservation of the forests in the SSPM is critical because it is the last landscape-scale, old-growth mixed conifer forest in western North America with a relatively intact frequent fire regime.

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