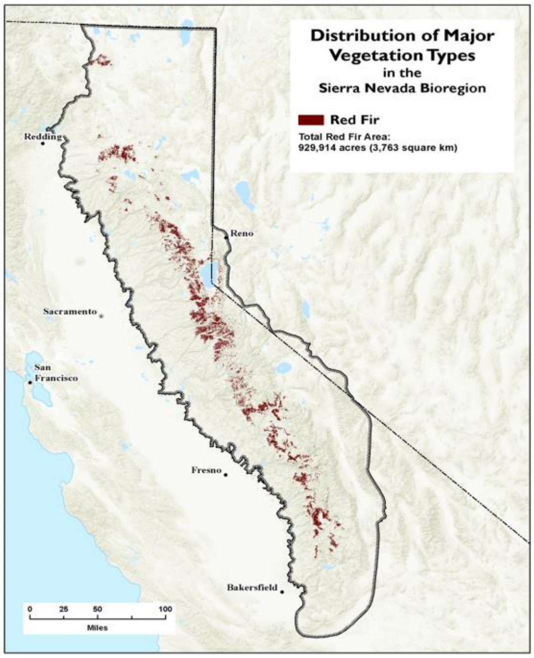
Natural Range of Variation of Red Fir Forests

Becky Estes
USFS, Central Sierra Province Ecologist
Placerville, CA

- Reason for talking to provide the latest science guiding red fir management on forest service lands
- Familiar with GTR 220/237 that provide guidance in mixed conifer forests but only provides anecdotal guidance for red fir
- Concerns red fir: past management, fire exclusion, climate change, increases in pests such as dwarf mistletoe
- General Introduction – thanks to Marc Meyer
- Overview of the presentation – general information, NRV (define), ecological functions (processes) such as fire, wind, volcanism, structure and composition, providing some general recommendations and future plans
- Natural Range of Variability – The ecological conditions and processes with a specific area, period of time, and climate, and the variation in these conditions that would occur without substantial influence from human mechanisms



Distribution of Red Fir

- Red fir (*Abies magnifica*) forests are distributed throughout the Sierra Nevada immediately above the montane mixed-conifer and below the subalpine forest zones
- Red fir forests occupy cool sites with substantial winter snow
- Red fir forest typically occurs on gentle to moderate slopes but also occurs on raised stream benches, terraces, steeper slopes, and ridges
- The second variety, *A. m*. var. *magnifica*, exists in the northern and central Sierra Nevada and has a hidden-bract cone type

Vegetation Classification

- Common associates of red fir include white fir (*Abies concolor*) at lower elevations and lodgepole pine, Jeffrey pine, and mountain hemlock (*Tsuga mertensiana*) at higher elevations (Potter 1994, 1998).
- Western white pine (*P. monicola*) is also a common associate of red fir throughout the Sierra Nevada (Rundel et al. 1988).
- Describe figure

Photos of late-seral red fir forest in the Illilouette Creek Basin of Yosemite National Park. This Illilouette Creek Basin photos were taken in a low-severity burned stand approximately ten years following the Hoover Fire (2001). Image Credit: Marc Meyer, USFS.

Ecological Importance

A total of 169 vertebrate wildlife species use red fir forests for foraging or nesting/denning habitat, including 8 amphibians, 4 reptiles, 104 birds (including 15 waterbirds), and 53 mammals (Mayer and Laudenslayer 1988).

- Red fir forests provide a diverse array of ecosystem services, including watershed protection, erosion control, carbon sequestration, and habitat for a diverse array of species in the Sierra Nevada.
- These forests are particularly important for 28 birds and 26 mammals, including several sensitive and rare species such as American marten (*Martes caurina*)
- Red fir also provides important denning habitat for the northern flying squirrel (*Glaucomys sabrinus*), a keystone and management indicator species in many western forests including the Sierra Nevada (Meyer et al. 2005).
- Red fir provides habitat for several species of arboreal lichens (Rambo 2010, 2012) and a diverse community of ectomycorrhizal fungi (Izzo et al. 2005).

Red Fir Forest Function

Fire Regime Description

- Seasonality of Fires
- Fire Pattern
- Fire Size
- Frequency of Fires
- Fire Severity

- Fire Seasonality - In red fir-white fir forests of the southern Cascades, the position of fires on presettlement annual growth rings indicated that 77% of historic fires burned during the late summer and fall, and the remaining 23% of fires burned during the early to mid-summer
- Fire Size/Pattern - These fire patterns indicate a climate-limited fire regime for red fir forests especially at mid- and high-elevations. Climate-limited fire regimes always have sufficient fuel to carry fire, but fire occurrence depends primarily on whether climate or weather is suitable for ignition and fire spread
- Historic Fire Return Interval (FRI) estimates for red fir forests in the Sierra Nevada were highly variable and dependent on several factors, including elevation,

forest type, and geographic location in the region

Pre-European Fire Return Interval (FRI) estimates for red fir forests in the Sierra Nevada

Vegetation Type	Subregion	Mean FRI	Median FRI	Minimum FRI	Maximum FRI
Red fir	CA	40	33	15	130
High elevation red fir	CA	83	66	18	78
Mid elevation red fir	CA	48	16	5	49
Low elevation red fir	CA	27	14	7	61
Red Fir-White fir	Central Sierra	-	12	5	69
Red fir	Central Sierra	-	30	9	92

- Fire return interval - Time in years between two successive fires in a designated area; i.e. the interval between two successive fire occurrences (syn. fire-free interval). Mean FRI - the average period between fires under the presumed historical fire regime; median FRI - an approximation of the center of pre-Euroamerican FRI distributions
- In general, mean and median FRI values increased with elevation and latitude, and intervals tended to be longer in more mesic red fir forest types (e.g., red fir and mountain hemlock)
- Estimates of FRI in the northern Sierra Nevada and southern Cascades (Mean FRI = 50.8 years; range: 9–71 years) were generally greater than FRI estimates for the southern/central Sierra Nevada (Mean FRI = 41.7 years; range: 5–60 years; Table 5), possibly owing to the drier conditions and more xeric red fir types at lower latitudes (Potter 1998).
- Topography - Based on a reconstruction of the annual area burned, mean and maximum FRI estimates for red fir forests in Sequoia and Kings Canyon National Parks tended to be greater on relatively mesic north-facing slopes (mean and maximum FRI = 30 and 50 years) compared to xeric south-facing slopes (mean and maximum FRI = 15 and 25 years; Caprio and Graber 2000, Caprio and Lineback 2002)

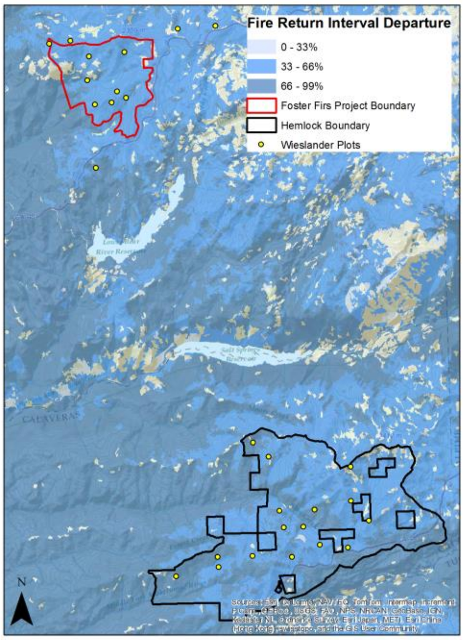
Historic fire rotation estimates for red fir forests in the Sierra Nevada

Location	Forest type	Fire Rotation (years)
Thousand Lakes Wilderness, Southern Cascades	Red fir-white fir	50
Thousand Lakes Wilderness, Southern Cascades	Red fir-mountain hemlock	147
Caribou Wilderness, Southern Cascades	Red fir and other upper montane forests	76
Lassen National Park, Southern Cascades	Red fir-western white pine	76
Yosemite National Park, Central Sierra Nevada	Red fir	163
Yosemite National Park, Central Sierra Nevada	Red fir	96
Sierra Nevada – summary	Red fir	61
Average across studies:		96

Fire rotation—Length of time necessary for an area equal to the entire area of interest (i.e. the study area) to burn (syn. fire cycle). Size of the area of interest must be clearly specified. This definition does not imply that the entire area will burn during a cycle; some sites may burn several times and others not at all.

- In the southern Cascades (pre-1905 period), fire rotation varied from 50 years in red fir–white fir forests to 147 years in red fir–mountain hemlock forests (Bekker and Taylor 2001)
- In Yosemite National Park, contemporary fire rotation estimates based on lightning fires that were allowed to burn under prescribed conditions in red fir forests was 163 years (van Wagtendonk 1985 in van Wagtendonk

and Fites-Kaufman 2006).



Fire Return Interval Departure

- Few fires have burned during the fire suppression time period in red fir forests of the Sierra Nevada
- Most Sierra Nevada red fir forests have missed only one to three fire cycles (i.e., mostly low to moderate FRID), suggesting that the ecological effects of fire suppression in these forests are not as extreme as in the fire-frequent mixed-conifer and yellow pine forests

- Fire Return Interval Departure Condition Class - The departure of current FRI from reference mean FRI in percent
- This absence of fire has led to an increase in FRI and fire rotation in contemporary compared to presettlement red fir forests
- For example, Taylor and Solem (2001) and Taylor (2000) estimated presettlement (1735–1849), settlement (1850–1904), and fire-suppression (1905–1994) fire rotations of 76, 117, and 577 years, respectively, in red fir and other upper montane forests in the southern Cascades.

Fire Severity Percentage

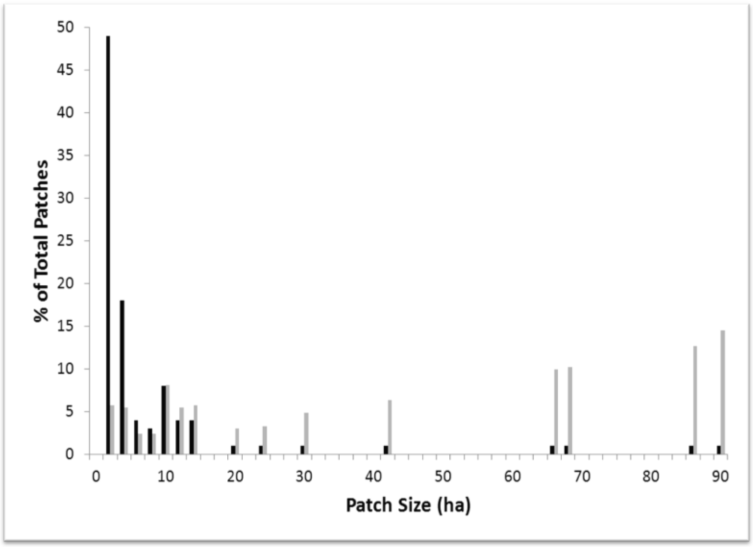
Aggregation/ Group	Locations	Low (%)	Moderate (%)	High (%)	Forest types
Historic estimates (mean)	Southern Cascades and Northern Sierra	49	38	13	Red fir-white fir Red fir-western white pine Red fir
Contemporary reference sites (mean)	Yosemite and Sequoia –Kings Canyon	42	22	8	Red fir Red fir-mixed conifer
LANDFIRE BpS (mean)	Sierra Nevada	62	18	21	Red fir

- Fire regimes of red fir forests in contemporary reference sites have been classified as “mixed” or “moderate” severity
- The proportion of area burned at high severity in contemporary reference sites in Yosemite, Sequoia, and Kings Canyon National Parks averaged 8% (range: <1–15%)
- Re-burned red fir stands in Yosemite National Park tended to burn at higher severity compared to stands not recently burned
- Unmanaged wildfires also tended to burn at greater severity relative to prescribed fires and “wildland fire use” fires across upper and lower montane forests in Yosemite National Park during 1974–2005
- Miller et al. (2009) and Miller and Safford (2008, 2012) examined trends (1984–2004 and 1984–2010, respectively) in percent high severity and high severity fire area for all fires ≥80 ha in the Sierra Nevada and found a marginally significant increase in total area of high severity fire in red fir forests; this pattern was best explained by decreases in spring precipitation

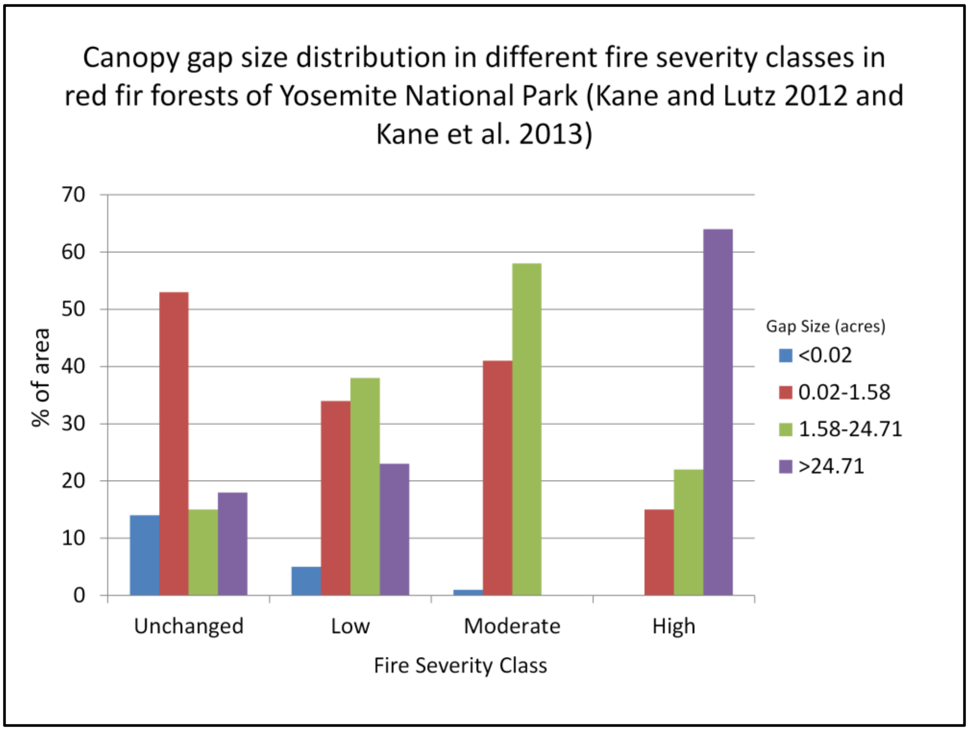
A high severity burned patch in a red fir and Jeffrey pine forest, approximately 20 years following the Rainbow Fire (1992) located within Devils Postpile National Monument. High-severity burned patches were defined as areas exceeding 95% tree mortality with high to complete mortality of vegetation. Image Credit: Marc Meyer, USFS.

What was the approximate size of this high severity patch? 9 acres in size

Frequency distribution of stand-replacing patch sizes (black bars) and proportion of total stand-replacing patch area by size class (gray bars) within the Hoover (2001) and Meadow (2004) fires from Collins and Stephens (2010).



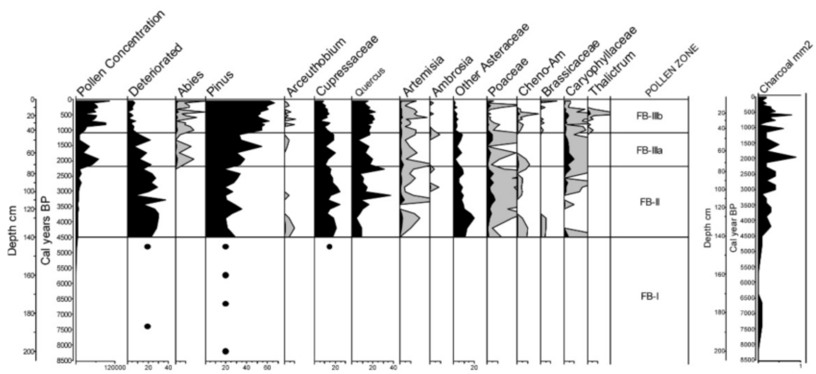
- In the Illilouette Creek Basin of Yosemite National Park, the mean patch size of stand-replacing, high-severity burned patches (>95% tree mortality) following the Hoover Fire (2001) and Meadow Fire (2004) was 9.1 ha (3.6 acres) (median = 2.2 ha (1 acre); Collins and Stephens 2010).
- Most (>60%) of the stand-replacing patches in their study were ≤4 ha (<2 acres) in size, but a few large patches accounted for ~50% of the total stand-replacing patch area (Figure 7).



- In another study using LiDAR to examine structural patterns in burned stands of Yosemite National Park, the frequency distribution of canopy gap sizes in red fir forest generally shifted toward the right (increased gap sizes) with increasing fire severity (Kane et al. 2013; Figure 8).
- In addition, the majority (>60%) of canopy gaps were greater than 10 ha (4 acres) in size within high severity burned red fir stands.
- Very little historic information available detailing precise patch sizes
- Miller et al. (2012) found that lower and upper montane forests (including red fir forest) had a mean patch size of 10.4 acres (median = 1.11 acres; range: 0.22–2469 acres) in Yosemite National Park, but a mean patch size of 22.2 to 40.8 acres (median = 1.11 to 1.56 acres; range: 0.22 to 11473 acres) in the Sierra Nevada national forests.
- The average size of high-severity patches tended to be smaller following prescribed fires (4.5 acres) and wildland fire use fires (5.7 acres) compared to wildfires (16.8 acres) in lower and upper montane forests of Yosemite National Park (van Wagtendonk and Lutz 2007).

Dwarf Mistletoe

- Dwarf mistletoe has been a persistent component of Sierra Nevada red fir forests for the past 3000 years, likely fluctuating with changes in canopy cover and density (Anderson and Davis 1988, Brunelle and Anderson 2003).



Dwarf Mistletoe

Past Occurrence: 45% of trees in Sierra Nevada red fir stands were infected with dwarf mistletoe in the early 1950s, especially in older and denser forests and often associated with Cytospora canker (California Forest Pest Council 1960, Scharpf 1993).

Reference Sites: Dwarf mistletoe incidence in white fir was 50% (range: 17–100) in the relatively active fire regime landscapes of the Sierra San Pedro Martir in Baja, Mexico (Maloney and Rizzo 2002).

- Based on these studies and reports, dwarf mistletoe occurrence in Sierra Nevada red fir forests is generally similar between historic (1600–1960) and current (1960–2005) periods.

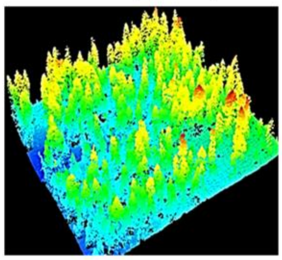
Dwarf Mistletoe

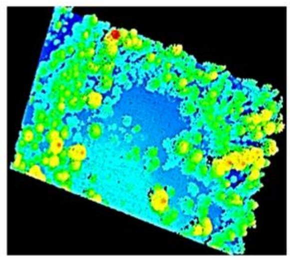
- Recent trends (1983–2012, Forest Inventory and Analysis plots) indicate that the impacts of dwarf mistletoe, Cytospora canker, and other pathogens in red fir forests may be increasing in the Sierra Nevada.
- These findings are driven by recent increases in temperature, drought stress, and climatic water deficit (California Forest Pest Council 2011, Mortenson 2011, van Mantgem and Stephenson 2007).

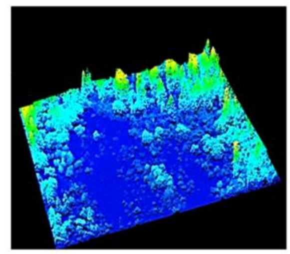
Red Fir Forest Structure

Landscape-scale canopy structural classes derived from LiDAR in burned and unburned red fir forests of Yosemite National Park (Kane et al. 2013)

Canopy-Gap	Clump-Gap	Open-Patch

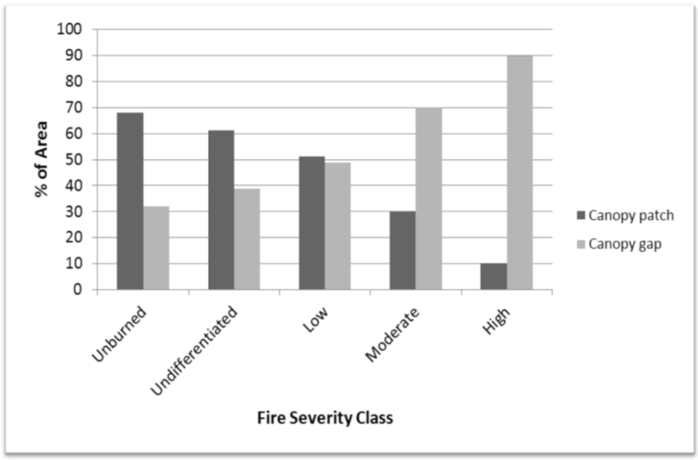




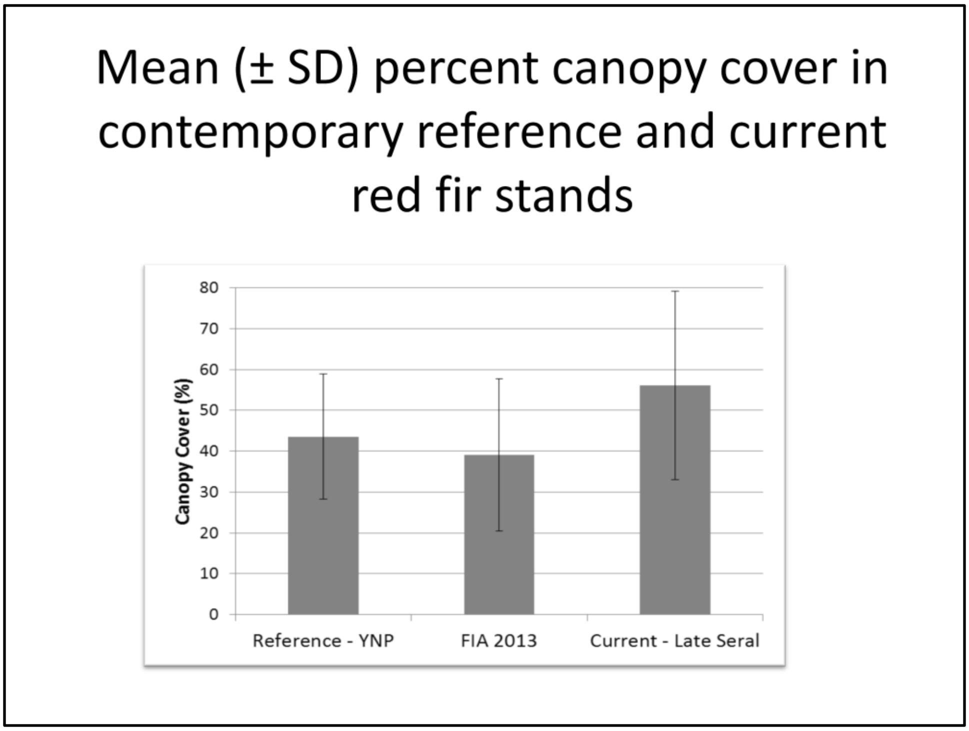


Continuous canopy was punctuated by frequent and small gaps	Tree clumps and canopy gaps alternated and neither dominated	Trees were scattered across large open areas

Percent of landscape occupied by canopy patches or gaps in burned and unburned red fir forest landscapes of Yosemite National Park (Kane et al. 2013)



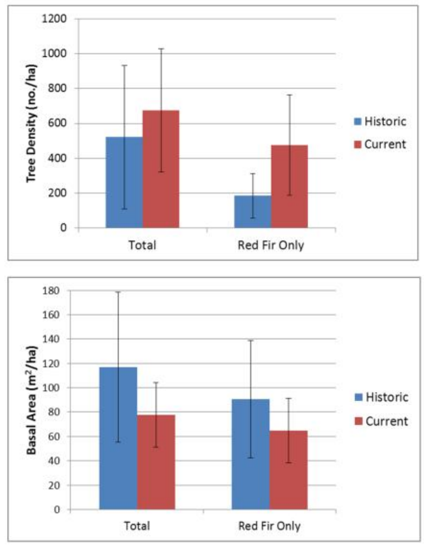
- Overall, the proportion of the landscape containing canopy patches decreased and the proportion of canopy gaps increased with increasing fire severity in red fir stands of Yosemite National Park
- These results suggest that in the absence of fire over the past century, current red fir forests landscapes have: (1) shifted from a spatially-heterogeneous partially-open canopy to a closed canopy structure, and (2) experienced substantial canopy ingrowth that led to a reduction in the portion of canopy gaps (Kane et al. 2013).



- Historic mean canopy cover is estimated as a product of LiDAR-derived canopy cover values from Yosemite National Park (YNP) for each fire severity class (based on data presented in Figure 13) and fire severity class estimates based on reference sites and models presented in Table 7.
- Current red fir forests are represented by Forest Inventory and Analysis data (FIA 2013; includes logged and unlogged stands) and current late-seral (unlogged) stands based on 13 studies presented in Table 8.
- Error bar for contemporary reference stands are based on canopy cover estimates for red fir forests of YNP exclusively and does not represent the full range of variation in canopy cover for the entire assessment area.
- These combined results suggest that modern unburned red fir forest landscapes have considerably more cover in the lower strata, lower canopy base heights, greater canopy bulk density, and reduced dominant tree heights than either contemporary reference landscapes that burned at low-

severity or presettlement reference stands.

Mean (± SD) tree densities (top graph) and basal area (bottom graph) in historic and current unlogged red fir forests of the Sierra Nevada



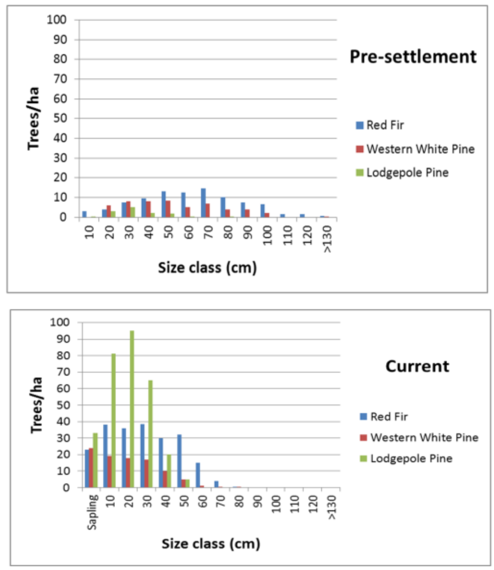
- Average tree densities (all species pooled) were similar between historic and current red fir forests based on a broad comparison of all unlogged stands across the entire assessment area (Table 8, Figure 18).
- Basal area averaged 43% greater in historic reference than modern red fir forests, but most modern forests were within the historic range of variation

Average total and relative red fir tree densities, basal area (BA), and tree diameter in historic and current red fir stands

	Tree Density (no/ha)[2]			BA (m^2/ha)			Mean DBH (cm)	No Stands
Historic (pre-1950) red fir stands:								
	Total	Red fir	% red fir	Total	Red fir	% red fir		
Mean	609	388	71	117	91	79	76	>10
SD	379	363	18	61	48	17	2	—
Contemporary (post-1950) red fir stands:								
Mean	658	472	74	72	54	74	31	229
SD	363	284	19	22	20	16	8	—
Contemporary (2013) FIA red fir stands:								
Mean	527	254	49	41	21	51	20	342
SD	537	—	—	25	—	—	—	—

- The average size of trees (red fir, western white pine, and lodgepole pine) in red fir–western white pine forests was greater in presettlement than contemporary stands (Table 8).

Size class distribution of presettlement and current secondary-growth red fir–western white pine stands in the Lake Tahoe Basin



- The density of larger-diameter red fir trees in Sierra Nevada red fir forests was often greater in historic than contemporary periods.
- Dolanc et al. (in review) compared extensive historic (early 1930s) and modern (USFS Forest Inventory and Analysis; FIA) forest inventories in the northern and central Sierra Nevada and found that the density of large (>60 cm dbh) red fir trees had declined by 40% (68 to 41 trees/ha) and the density of smaller (10–30 cm dbh) red fir trees had increased by approximately 60% over a 70-year time period.
- Size class distribution in red fir forests have shifted to smaller size classes between historic and current periods.
- Patterns of increased mortality rates in large diameter trees were also apparent in late-seral forests in the southern Sierra Nevada (Smith et al. 2005, van Mantgem and Stephenson 2007) and throughout the western United States (van Mantgem et al. 2009).
- In most cases, these changes in the density of red fir trees were attributed to recent increases in temperature and climatic water deficit (Dolanc et al. 2012, in press; van Mantgem et al. 2009).

Climatic Changes

- Recent climate trends indicate that the mean annual and monthly temperatures have increased in the upper elevations of the Sierra Nevada, especially within the past 30 year
- The annual number of days with below-freezing temperatures at higher elevations has declined, resulting in a 40–80% decrease in spring snowpack over the last 50 years in the northern and central Sierra Nevada (Moser et al. 2009).
- Snowpack (snow water equivalent) on April 1 in the southern Sierra Nevada has increased 30–110% over the same period (Moser et al. 2009), possibly owing to the relatively higher elevation terrain of the region (Safford et al. 2012a).
- Precipitation has remained stable or steadily increased over the past several decades in the higher elevations of the Sierra Nevada (Safford et al. 2012a).

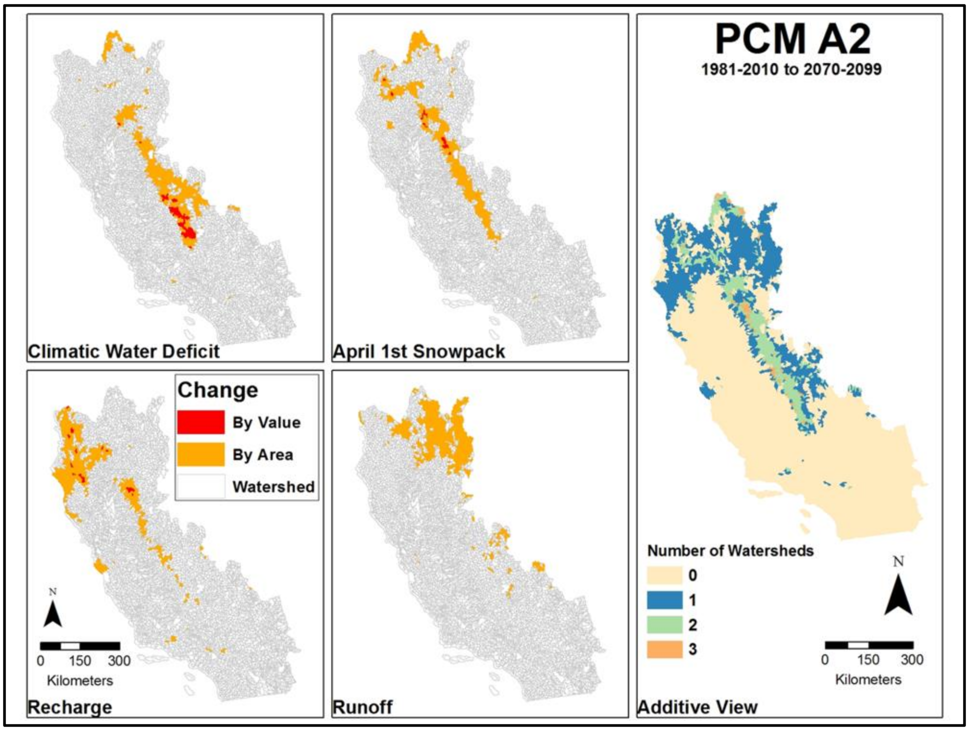
Predicted Future Fire Trends

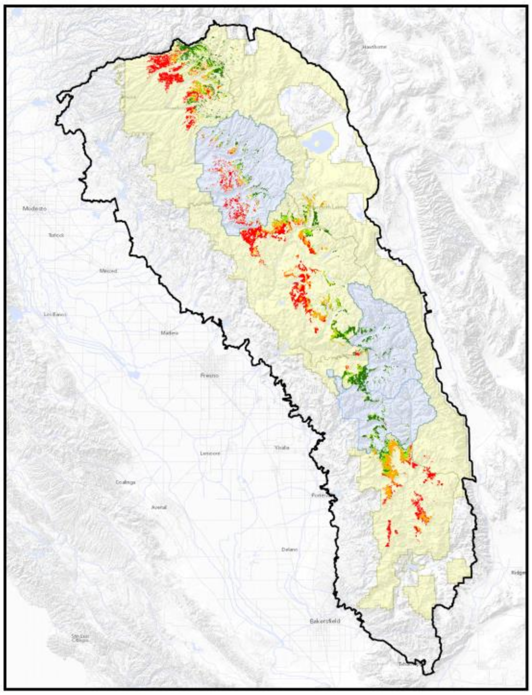
- Projections of future fire frequency, probability, and total burned area are expected to increase in the coming decades.
- Projections of future climate suggest that fire severity or intensity may increase in many parts of the Sierra Nevada during the mid-21st century, especially in high-elevation forests such as red fir (Lenihan et al. 2003, 2008)

Climatic Water Deficit

- Modeled climatic water deficit (Deficit) averages for red fir forests in Yosemite National Park was projected to be 24% greater in the near future (2020–2049; Deficit = 157 mm) compared to the present (1971–2000; Deficit = 126 mm; Lutz et al. 2010), indicating an increasing trend of moisture stress in red fir forests.
- This value will be compounded at low elevations where red fir grades into white fir/mixed conifer

Climatic Water Deficit -


PCM A2
1981-2010 to 2070-2099
Climatic Water Deficit
April 1st Snowpack
Change
By Value
By Area
Watershed
N
0 150 300
Kilometers
Recharge
Runoff
Number of Watersheds
0
1
2
3
N
0 150 300
Kilometers
Additive View



Future projections (end of century: 2070–2099) of red fir forest climate exposure in the southern Sierra Nevada based on the **PCM** model (warmer and similar precipitation).

Figure 26 – Future projections (end of century: 2070–2099) of red fir forest climate exposure in the southern Sierra Nevada based on the **PCM** model (warmer and similar precipitation). Levels of climate exposure indicate bioclimatic areas that are projected to be: (1) inside the 66th percentile (Dark Green), (2) in the marginal 67–90th percentile (Light Green), (3) in the highly marginal 90–99th percentile (Yellow), or (4) outside the extreme 99th percentile (Red) for the current bioclimatic distribution. Areas in green are suggestive of climate refugia for red fir forests by the end of the century.

Conclusions

- Fire regimes in red fir forests have changed significantly, as fire return intervals and fire rotations have generally lengthened during much of the 20th century due to fire suppression activities
- Total burned area has increased since 1984
- Future fire frequency, annual burned area, and fire severity are projected to increase in red fir forests with climate change.

Conclusions

- The incidence of pathogens and insects, such as dwarf mistletoe and Cytospora canker, likely have not changed considerably from historic (1600–1960) to contemporary (1961–2005) periods.
- Recent (2006-2012) and future projects point toward increases in tree mortality in red fir forests associated with pathogens, insects, and moisture stress

Conclusions

- A considerable shift in the tree size class distribution to smaller diameters, greater homogenization of forest structure at both stand and landscape scales, and a decrease in the density of large-diameter red fir trees.
- These changes have likely occurred primarily as a result of 19th century logging within secondary-growth stands and recent climatic warming.

Conclusions

- Climate envelope models consistently project a substantial loss (average: 82%) or high climate vulnerability of red fir forests in the assessment area by the end of the 21st century.
- This suggests that the greatest changes in Sierra Nevada red fir forests during the 21st century will occur as a consequence of climate change.


Questions??
Link to NRV Documents:
http://www.fs.usda.gov/detail/r5/plants-
animals/?cid=stelprdb5434436