Forest Health Concerns Regarding Red Fir (and All True Firs) Ecosystems

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I. Introduction

a. Potter 1980: red fir is a submontane elevation species that does not commonly the high frequency fire regimes as mixed confiner-pines in lower elevations.

b. General trends: temperatures in the upper elevations of SN are increasing; snow pack is declining but precipitation is increasing**.**

II. Fire Frequency

a. van Wagtendonk and Lutz (2007) found RF fire intervals (Yosemite NP) average between 40-50 years but can vary even up to 90-160 years depending upon type.

b. Meyer (2017) estimates that FRI for central/lower Sierra Nevada can be as low as average ~42 years, particularly in transition zones; varies widely across various study location in the SN.

c. The NFR in red fir ecosystems has not deviated to same degree as lower elevation.

d. Burned area, severity, and frequency is projected to increase significantly in RF ecosystems (Meyer 2017).

III. Density

a. Grows at higher densities (trees per acre) and as a predominant species where it occurs.

b. Oliver and Uzoh 1997 assessed that appropriate SDI for red fir forests could sustain up to 800, most likely due to precipitation at higher elevations. Supporting studies by Zhang et al. (2005) found that no mortality occurred when stands were reduced down to 320 SDI, nearly 70% of max (suggested maximum red fir SDI 1000 (Oliver and Uzoh 1997).

c. At high elevations where it occurs, red fir stands are often the predominant species. Red fir regeneration grow in thick clumps, often shading out pine seedlings trying to grow amongst them. Diversity in red fir ecosystems are primarily by age and size classes that create mosaics. High intensity fires in high elevation is usually small in acreage that openings fill quickly with regeneration.

d. Meyer et al. 2018 found that Rx fire or realignment of NFR would improve RF health. While fire would greatly improve other stand characteristics, it would not improve ratios of unhealthy vs healthy trees.

IV. Precipitation and elevation limitations

a. Felix et al. (1971) assessed that FE-associated mortality was often triggered when California experienced consecutive droughts that occurred longer than 2-3 years. Regardless of prior pathogen infection, increased numbers of trees were attacked by FE as drought continued. In recent decades, mortality across California has consistently coincided with drought periods – most of which were in fir ecotypes (FHM Aerial Detection Surveys). Guarin and Taylor (2005) confirmed that true fir losses were highest even on north-facing slopes when PSDI 2-5 year averages were below average.

b. White and red fir risk ratings are heavily weighted by annual precipitation of sites and basal area. Precipitation (rain or snow) strongly influences whether firs are at a high risk for bark beetle infestation, particularly during drought events. While Red fir occurs at a higher elevations than white, it appears to respond similarly when annual precipitation is below average (FHM aerial detection surveys).

V. Bark beetles and woodborers

a. Most insect activity in RF ecosystems are usually responding to short-term environmental conditions such as drought, fire, vegetation change, or interactions between insects (Potter 1998).

b. Fir engraver (FE)(*Scolytus ventralis*) is the most common damage agent found killing red firs, as well as all true firs in the state. Surges in FE-associated mortality is often triggered by drought events in California. When drought periods extend 2 consecutive years or more, fir engraver is attracted to weakened hosts (Felix et al. 1971, Macias-Samano et al. 1998). High levels of mortality indicate "mass attack" infestations of FE, but hosts may already be declining due to other physiological stressors.

c. FE is one of a complex of damage agents that attack true firs, but is most prolific and commonly found pest. Other damage agents can also cause direct mortality depending upon size, location, prior injuries. FE are highly attracted to trees with prior root disease (Macias-Samano et al. 1998, Goheen and Hansen 1993) or heavy mistletoe infections (Felix et al. 1971).

d. This beetle often works in a complex with other agents, especially on larger diameter trees. FE may dominate a large proportion of the bole, but woodborers in the lower bole, branches, and intermixed in the terminal contribute to gradual mortality of host. However, when populations are high, FE can exclude other agents on selected trees.

e. FE host selection is determined by multitude of criteria, primarily by volatiles released when hosts are under stress (not use of aggregation pheromones typical of bark beetles). This may explain the scattered nature and variable size class selection of FE, as well as localized attacks that are often unsuccessful.

This dependence on host status makes FE populations vulnerable to rapid declines once environmental conditions change (ex: return to normal precipitation). A similar species, *Scolytus unispinosus* (Kelsey and Joseph 2006) was immediately attracted to Douglas-fir branches experiencing (experimental) water stress within the first two days, compared to those of defoliated branches or logs.

f. Ferrell et al. 1993, Maloney and Rizzo 2002, Egan et al. 2009 found that stands with high fir basal and total stand basal areas account for strong infestation predictability in most cases.
g. Severe drought effects can supersede density-dependent variables creating conditions of positive feedback loops in favor of outbreak (Raffa et al. 2008).

VI. Root disease

a. Pathogens in conifers establish themselves when opportunities arise (ex: fresh cut stumps or mechanical injuries) or conditions are optimal. They can remain on site for decades causing chronic or acute injuries that contribute to gradual host abundance decline in the stand.
b. *Heterobasidion occidentale* (Ho) is the most destructive root disease affecting true firs in California. It is a native pathogen that infects true firs, spruce, giant sequoias, and hemlock. Fir annosus is the disease caused by *Heterobasidion occidentale* (aka the "S" type of *Fomes annosus)*. Lower elevation white fir forest types are experiencing an epidemic of Ho.
c. "Once *Heterobasidion* is introduced into a stand, it is there forever," Dr. Matteo Garbelloto (UC Berkeley). Infection centers can widen by root-to-root contact with similar hosts or spore dissemination. Both Eldorado and Sequoia National Forests have sites where Ho has driven species conversion from fir towards incense cedar (a species immune to Ho).
d. On the westside Sierra Nevada, it is often found in true fir-dominated stands with or without previous logging activity. In areas with continual (ex: alongside roads or campgrounds) and recent (past 50 years) tree removal, conks are often found in residual cut stumps.
e. *H. occidentale* is often associated in trees top-killed or whole tree killed by FE (summarized in Goheen and Hansen 1993). Its presence predisposes trees to FE attack due to weakened vigor and growth (Goheen and Hansen 1993). *H. occidentale* has the potential to kill trees directly without FE, but hosts are often killed by beetles or other damage agents.
f. The incidence of *H. occidentale* is suspected to be higher in California forests than initially surveyed (Slaughter and Parmeter 1989, Mortensen 2011). Anecdotal evidence by FHP and other specialists have found widespread occurrence of the pathogen anywhere hosts are found; particularly in areas with cut stumps.

g. Incidence of root disease doesn't necessarily translate into higher rates of mortality. Rates of mortality of RF appear to be within NRV (Mortensen 2011) but has potential to rise if temperature increases and precipitation decreases due to climate changes (Kliejunas 2000). Host susceptibility increases due to resource stress rather than virulence of pathogen (Kliejunas 2000).
h. Since *H. occidentale* slowly deteriorates the roots and base, they are more vulnerable to windthrow or breakage from snow loading.

VII. Dwarf and True Mistletoes

a. True Mistletoe (*Phoradendron* spp.) infected trees have been shown to be attractive to FE (Felix et al. 1971). True mistletoes photosynthesize, thereby only requiring water from their host. However, true mistletoe is an additional stressor that contributes to host weakening, thereby ratcheting up stress when drought events occur (Felix et al. 1971) and predisposing hosts to FE attack (Maloney and Rizzo 2002). Continual FE attacks and chronic mistletoe infection eventually lead to overall tree distress and mortality.
b. Dwarf mistletoes (DM, *Arceuthobium* spp) of red and white fir are host-specific, parasitic, affecting growth and vigor of infected trees. The most serious pests of mature red fir trees is dwarf mistletoe (*Arceuthobium abietinum* f. sp. *magnificae*). The next rotation of seedlings, saplings and poles growing within drip line (or within twice the radius of the dripline) of larger overstory trees should be primary concern. Mature overstory red firs that are heavily infested with dwarf mistletoes *rain down* on understory with sticky mistletoe seeds. Because this next generation of trees become heavily infested with mistletoes, focus should be on them and not legacy trees. DM rob hosts of water and nutrients; some are systemic. Heavy infections of dwarf mistletoe can significantly draw down vigor of hosts, increasing susceptibility to bark beetle attack.
c. *Cytospora* canker can enter through wounds created by DM, causing branch dieback. DM presence and subsequent *Cytospora* infection probabilities are large unknown, and incredibly difficult to observe. However, the presence of DM alone can be rampant in host trees, causing chronic severe stress.

VIII. Management, Restoration, Resiliency

a. As with most native damage agents, mitigation of associated injury/mortality, decreases in their prevalence, and prevention of outbreaks are recommended management objectives.
b. Resiliency strategies can aim to balance the levels of infection/mortality with conditions that are more aligned within NRV. Increasing spacing between infected and non-infected hosts can interfere with pathogen dispersion and

allowing for growth of shade-intolerant species that provide buffers between hosts and increase stand diversity (Maloney and Rizzo 2002).

c. In Yosemite NP, the prevalence of root disease in the Valley has become a chronic hazard tree issue (Rizzo and Slaughter 2001). *H. occidentale* along with other native diseases have caused property damage and human mortality. This is a high-risk hazard and safety concern to personnel and public.

d. The main objective of preventing new infection centers or mitigating mortality due to H. *occidentale* is to reduce gradual (large) fuel loading (Goheen and Hansen 1993). Regeneration, growth, then mortality of firs in root disease centers can create stagnant conditions that prevent pine establishment, reducing species diversity. The accumulation of dead trees can lead to high severity burn conditions which can destroy all seed source in the area rather than being selective.

e. There is a proven (Graham 1971; Smith 1970) and cost-efficient means of disease mitigation. Kleijunas (1989) summarized the existing literature on borax effectiveness. Mitigation methods are described in the R05 Heterobasidion root disease web page at: http://www.fs.usda.gov/detail/r5/forest-grasslandhealth/insects-diseases/?cid=stelprdb5329386 . The actual Regional Policy is described in the FSH FSH 3409.11 at https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5329399 . *Webpage provides links to commonly asked questions about the treatment. FHP is available not only to find answers to other questions, but to provide training in the application of these preventative measures.*

f. Egan et al. 2009 suggests thinning against fir to favor pine component will reduce FE-associated as well as total mortality in stands, especially during times of drought.

g. Almost all options will involve the removal of the heavily DM infected seedlings, saplings, and poles. Subsequent restoration of the *micro site* (a circle equal to twice the dripline radius of the heavily infested legacy trees). Some of options for replacing these heavily infested next generation trees are listed below. A project could include in a variable ratio more than one of these options. Ideally a project would involve several of these options in a mixed ratio.

    1. After cutting, piling, and burning infested small trees, some sites could be left to naturally regenerate.
    2. After cutting piling and burning the infested small trees, tractors could be brought in to scarify the micro site back to mineral soil, to provide an environment more suitable for the establishment of natural regeneration.
    3. After clearing the micro site, with or without site prep, it could be hand planted with local red fir seedlings.

4. After clearing the micro site, with or without site prep, it could be hand planted with seedlings of other species that have a minor presence in the overall site. This would be done only to maintain bio-diversity and no attempt at overall species conversion would ever be attempted.
5. After clearing the micro site, with or without site prep, a small percentage of sites could be established with seedlings from a seed source originating from a lower elevation than the local seed source. This would be done to evaluate if assisted migration of seed sources of red fir or other species. One of the "other species" that FHP would like to see tried in this option would be western white pine.

h. When it comes to dealing with the heavily dwarf mistletoe infested legacy trees at the center of these micro-sites there are three major options. FHP would anticipate that all projects would incorporate a mix of at least two options:

- A significant number of large wolf trees will be left to preserve their wildlife value. Such trees have significant wildlife value and the wildlife biologists will be asked to provide guidelines on the number of such trees to retain. Mistletoe infested trees have a role to play in the ecosystem and FH objective of every project should be to improve the overall health of the stand. *Eliminating all heavily infested trees would not improve the overall stand health*.
- Any large wolf tree that threatens a, road, trail, structure will be felled and if possible harvested to defray the cost of site improvements.
- Wildlife guidelines will be used to determine how many wolf and or heavily mistletoe infested trees will be left to complement the number of snags in the project. These future snags will be ringbarked and left to become snags. However, ring barking will only be done after the microsites have been re-established.