Ecosystem Responses to Variable-Density Thinning for Forest Restoration in Mill Creek[1]

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Background

Variable-density thinning (VDT) has promise as a forest restoration tool that accelerates development of old-growth redwood (*Sequoia sempervirens* (D.Don) Endl.) forest characteristics (O'Hara et al. 2010) but can lead to bear damage in north coastal California (Hosack and Fulgham 1998, Perry et al. 2016). Three novel VDT prescriptions (O'Hara et al. 2012) were tested across an extensive area at the Mill Creek addition of Del Norte Coast Redwoods State Park, near Crescent City, in Del Norte County, California. This area is primarily composed of young, crowded forests dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) regenerating after a history of industrial forest management. These forests were once dominated by large, widely-spaced redwood and Douglas-fir, and are located in a watershed that plays an important role in protecting old-growth forest located downstream in Jedediah Smith Redwoods State Park. The even-aged stands prioritized for VDT had been regenerated between 1982 and 1992, and prior to treatment had around 1300 stems ha^{-1} averaging 15 cm diameter at breast height (DBH; 1.37 m) of which 2/3 were Douglas-fir.

Each stand was assigned one of four experimental prescriptions replicated five times throughout the ownership and monitored in large sample plots. Three plots were established in each stand soon after treatment (within 1 year of the treatment date). All plots were then re-measured 4 years after establishment. We summarized tree- and stand data from the 60 monitoring plots in 20 stands receiving one of four treatments: low-density thin to 6.1 m spacing (LDT), high-density thin to 4.9 m spacing (HDT), localized release (LR), and no-thin control (C). Specifically, we calculated averages for each monitoring plot, and compared these averages among the four treatments. Our objectives were to compare the effectiveness of VDT treatments at promoting redwood dominance, redwood tree growth, and stand structural complexity. We also compared incidences of bear damage and depth of slash following each thinning treatment and over the same time period in unthinned control stands.

Structural (Tree-Size) Diversity

After treatment, trees of all species combined were tallest and largest on average (10.2 m height (HT); 17.5 cm DBH) after HDT. Trees in LR stands (9.55 m HT; 16.8 cm DBH) were taller but slightly smaller in DBH than the LDT stands (9.26 m HT; 16.9 cm DBH). Trees in unthinned control stands were smallest on average (6.87 m HT; 14.8 cm DBH). Structural diversity in terms of tree-size variability after thinning was greatest after LR, where standard deviation of tree DBH in each plot averaged 6.32 cm. LDT and HDT had equivalent, intermediate levels of tree-size variability (s.d. 5.86 and 5.90 cm, respectively), and controls the lowest average s.d. of tree DBH (4.90 cm).

Species Composition

Proportion of stand basal area (BA) in each species gave tree species composition after treatment. Redwood represented 29 percent of stand BA in unthinned control stands, 37 percent after HDT, 44

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percent after LR, and 46 percent of stand BA after LDT. Douglas-fir represented 66 percent of stand BA in unthinned control stands, 60 percent after HDT, 50 percent after LR, and 48 percent of stand BA after LDT.

Tree Diameter Growth

From the 8366 tree records for all tree species in all plots, 1696 tree records were excluded from growth (DBH and BA increment) calculations. Excluded were trees with damaged tops, bear damage, and/or missing or estimated DBH data. Among 2282 tree records for redwood trees without damage, the average redwood tree DBH increment over 4 years after treatment ranged from 0.42 cm yr^{-1} in unthinned controls up to 0.73 cm yr^{-1} and ranked LR > HDT ≈ LDT > Control. Tree BA increment over 4 years after treatment ranged from 13.1 cm^2 yr^{-1} in unthinned controls up to 25.4 cm^2 yr^{-1} and ranked LR > HD > LD > Control. These undamaged redwood trees were slightly larger on average, immediately following LR and HDT treatments, than the undamaged redwood trees giving dbh increment data in LDT and Control treatments, suggesting that BA increments would give a better indication of differences in post-treatment growth than dbh increment. Tree BA growth of the 50 largest redwood/ha and 50 largest Douglas-fir/ha, presumably a big part of the future restored old-growth overstory, ranked LR > LD > HD > C for redwood and HDT > LDT > C ≈ LR for Douglas-fir where localized release favored redwood while restricting Douglas-fir growth.

Bear Damage

We noticed virtually no bear damage while overseeing the thinning and assume all bear damage happened after treatment. Most damage was recorded in the first measurement, when monitoring plots were installed, within 1 year of treatment (not immediately after). Additional damage was noted during the second assessment 4 years later. Among 3230 redwood trees in all plots sampling all treatments, 24 percent to 26.5 percent were damaged after thinning treatments whereas only 8.2 percent were damaged in unthinned control plots over the same period. More Douglas-fir were damaged after LDT (20 percent) than HDT (13.8 percent) and LR (12.8 percent), and very few were damaged in unthinned stands (1.1 percent). Bears mainly damaged redwood and Douglas-fir; damage was only noted for 19 other conifer trees (assortment of five species) and one tanoak (*Notholithocarpus densiflorus* (Hook. & Arn.) P.S. Manos, C.H. Cannon, & S.H. Oh) in the sample of 8366 trees in 60 plots across all treatments.

Slash (Fuel Bed) Depth

Treatment-wide averages calculated for 4,686 measurements of fuel depth in 58 monitoring plots indicated that LR generated the deepest fuel beds (averaging 0.98 m). LDT had an intermediate fuel depth (0.85 m) and HDT the shallowest fuel beds (0.72 m), but that variability in fuels among measurement locations were equally variable under each treatment. Mortality within unthinned control plots was contributing some fuel load (0.12 m) measured after 4 years of monitoring. Fuel beds were decreasing in depth by 24 percent to 37 percent over the 4 years since treatment, with HDT exhibiting the greatest decrease; possibly due to more smaller/fewer large trees cut decaying and breaking down more quickly.

Recommendations for Adaptive Management

These results inform adaptive management, guiding ongoing restoration of thousands of hectares of crowded young forest at Mill Creek. Outcomes from each VDT treatment differed in terms of species composition, structural diversity, tree growth, incidences of bear damage, and fuel load from cut wood and debris, across the wide range of sites and stands included in this landscape-scale manipulative experiment at Mill Creek. LDT enhanced redwood tree growth and resulted in the greatest shift in species composition in favor of redwood. Tree-size development and variability were both enhanced by the LR treatment. Assuming such changes are desirable, LR appeared to garner most benefit overall by enhancing redwood dominance, accelerating redwood growth, and promoting structural heterogeneity in terms of tree-size variability (fig. 1). LR was most efficient to implement (0.79 ha/person/day) > HDT (0.56 ha/person/day) > LDT (0.53 ha/person/day), demonstrating that promoting complex stand conditions can be accomplished at a cost competitive with more traditional forest management PCT treatments that resemble HDT.

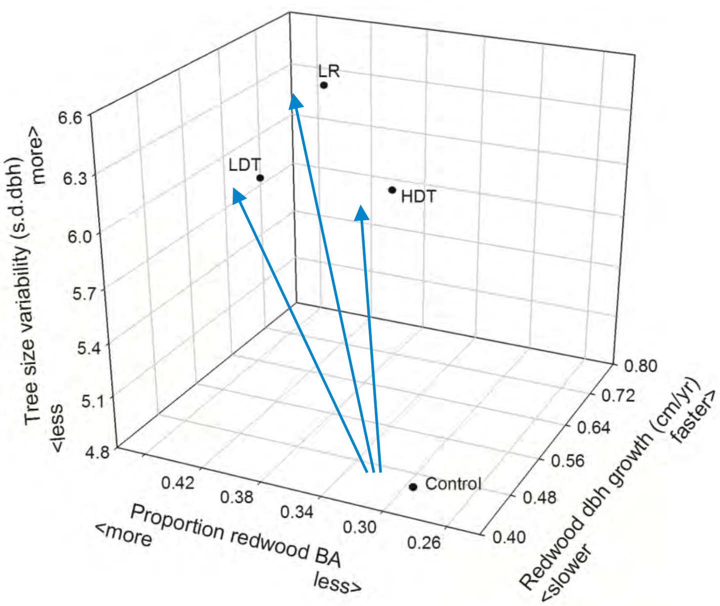

Figure 1—Stand attributes after variable density thinning compared with unthinned control stands. Averages based on data from 60 plots in 20 stands receiving one of four treatments: low-density thin to 6.1 m spacing (LDT), high-density thin to 4.9 m spacing (HDT), localized release (LR), and no-thin control stands at Mill Creek.

Variable slash accumulation averaging up to a meter depth, including thick patches and areas without slash, can be expected. The slash will settle and decay quickly, but could be treated in specific locations such as fuel breaks and strategically-placed defensible spaces. In anticipation of bear damage and loss of trees after any thinning operation, we could design thinning prescriptions where additional trees are retained to compensate for loss or damage (e.g., 25 percent extra redwood and 20 percent Douglas-fir after heavier thinning).

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