Ninety-Two Years of Tree Growth and Death in a Second-Growth Redwood Forest[1]

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Extended Abstract

Mature second-growth redwood (*Sequoia sempervirens* (D. Don) Endl.) forests are an important and uncommon resource in the redwood region. Development of second-growth redwood forests beyond rotation age is not well understood. Continuous long-term data are especially lacking, considering that the maximum possible age of second-growth stands is now over 150 years. Two observation plots established in 1923 in the Arcata Community Forest provide a unique opportunity to examine the long-term development of second-growth redwood forest.

Dr. Woodbridge Metcalf of UC Berkeley established two 0.4 ha (1 ac) plots on land that was logged in approximately the 1880s. Metcalf and associates tagged and measured all trees every 10 years from 1923 to 1963. Dr. Rudolf Becking of Humboldt State University spearheaded another remeasurement in 1990, but no publication ever resulted from Metcalf or Becking's work. The Metcalf and Becking surveys collected diameter at breast height (DBH; 1.37 m, 4.5 ft) and species for all trees, and height for only some trees. We surveyed the plots using modern methods (precise stem mapping confirmed with LiDAR data, height measurements with laser rangefinders and LiDAR data, crown volume measurements, multiple diameter measurements of buttressed tree bases, and others) and assembled a complete dataset from 1923 to 2015. We utilized new allometric models for Sitka spruce (*Picea sitchensis* (Bong.) Carrière), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and second-growth coast redwood to predict tree-level quantities such as total biomass and leaf area from functional DBH, diameter at top of buttress, height, and crown volume (Sillett and Iberle, unpublished). The hierarchical sampling methods used to obtain the datasets for these models and the model construction are similar to methods described in Sillett et al. (2015) and Van Pelt et al. (2016).

Both plots approximately doubled in total basal area over the study period, ending at 124 m^2 ha^{-1} (538 ft^2 ac^{-1}) in Plot 1 and 142 m^2 ha^{-1} (624 ft^2 ac^{-1}) in Plot 2. Redwood is becoming more dominant in the plots, especially beginning around 80 years in stand age. This trend is apparent for proportion of basal area (fig. 1, bottom) and is also reflected in estimated variables (total mass, wood volume, and others). Stem density decreased over the study period, from 435 to 282 trees per hectare (TPH) (176 to 114 trees per acre, TPA) in Plot 1 and 596 to 356 TPH (240 to 144 TPA) in Plot 2. The non-redwood species are slowly dropping out of the plots, while redwood numbers stabilized in the last 50 years due to ingrowth (fig. 1, top). Causes of mortality were not recorded during surveys, other than notable windthrow events between 1943 and 1963 (stand age of 63 and 83 years). These disturbances dominate the net growth trajectory in the twenty-year period, as seen in the plateau in total basal area (fig. 1).

The only similar long-term dataset for second-growth redwood forest is Dr. Emanuel Fritz's "Wonder Plot" in Mendocino County, famous for a high rate of tree growth (Allen et al. 1996, Fritz 1945, Gerhart 2006). Established by a collaborator of Metcalf, also in 1923, this pure redwood forest on an alluvial plain provides an interesting comparison with this study's mixed-species forests located further north in Humboldt County. Stem density in the Wonder Plot is higher than the Metcalf plots around 60 years in stand age, but steeply drops to similar levels by 130 years (fig. 1, top). Tree growth in the Wonder Plot outpaced the Metcalf plots by a large margin, with approximately one-

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and-a-half times the basal area at equivalent stand ages. However, a windthrow event in 1998 all but erased that margin. The most recent Wonder Plot survey found a total basal area that will be nearly equivalent to Metcalf plot totals if their growth trend continues (fig. 1, bottom). Nevertheless, the higher growth rate of the Wonder Plot is unsurprising considering the highly productive alluvial site chosen by Fritz.

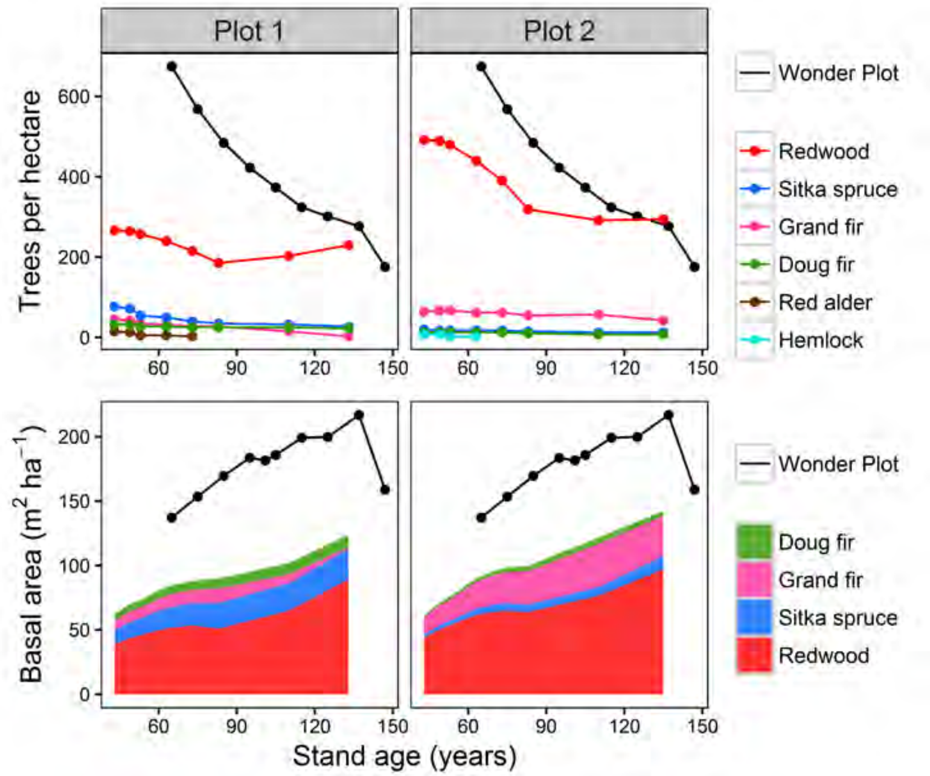

Figure 1—Basal area and stem density over time in the Metcalf plots in Arcata, California. The Wonder Plot in Mendocino, California, a pure redwood stand, is presented for comparison (data from Gerhart 2006). All three plots are 0.4 ha (1 ac).

Our application of allometric models predicting total mass and leaf area also allow for comparison to old-growth coast redwood plots described in detail by Van Pelt et al. (2016). We selected four plots from Van Pelt et al. (2016) for comparison, two in Redwood National Park and two in Prairie Creek Redwoods State Park, which are the closest geographically and ecologically to the Metcalf plots. At approximately 135 years of stand age, both Metcalf plots are remarkably close to their old-growth counterparts in leaf area index of trees alone. Unsurprisingly, the Metcalf plots are far behind the old-growth plots in total aboveground tree mass, with the old-growth plots being between three and four times heavier (fig. 2). While the second-growth forests have similar photosynthetic capacity after 135 years of growth, the trees in old-growth forests have been applying that capacity for many centuries and storing the energy in decay-resistant heartwood.

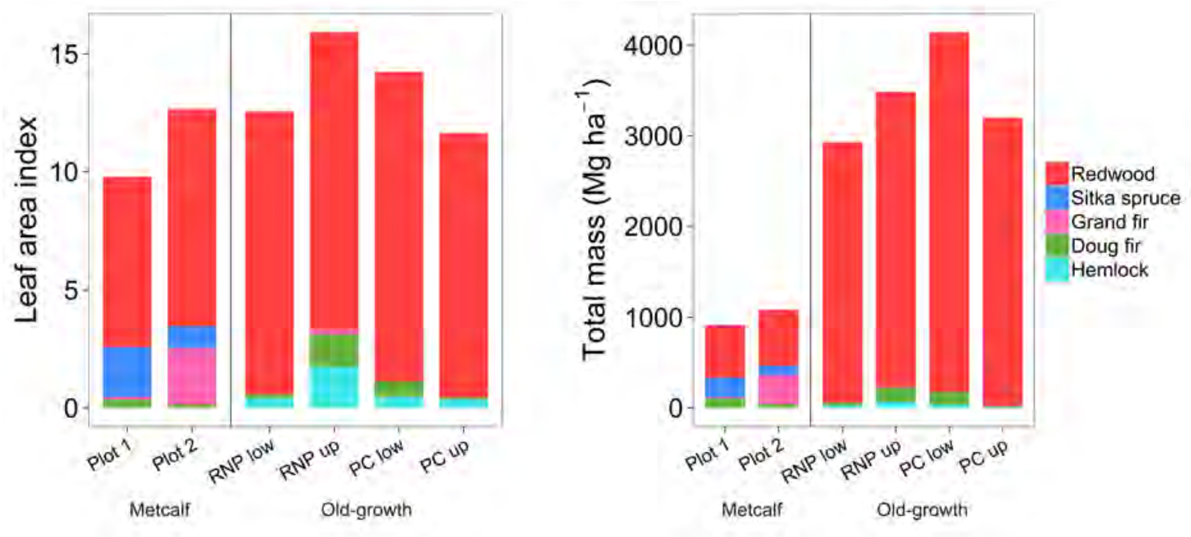

Figure 2—Total tree mass and leaf area index of the Metcalf plots (Arcata, CA) at ~135 years of stand age compared with two lowland and two upland plots in old-growth forest from Van Pelt et al. (2016) in Redwood National Park (RNP) and Prairie Creek Redwoods State Park (PC).

The Metcalf plots have shown strong growth over the study period, although not approaching the rates achieved by Fritz's Wonder Plot. This is despite heavy human use within and around the plots, even predating the establishment of the city park in 1955, according to survey notes. The undergrowth is clearly reduced by formal and social trails in the plots, particularly in the upper plot, and soil compaction is likely. Nevertheless, the Metcalf plots are a rare long-term example of northern second-growth coast redwood forest dynamics and can serve as a benchmark for comparison. Restoration of old-growth forest attributes in second-growth forests through silvicultural manipulation is of increasing interest, as seen in the Silviculture section of these proceedings. Our results from relatively unmanaged conditions can be compared to such studies, especially as treated stands move beyond rotation age. The large non-redwood component occupying growing space in the Metcalf plots, as well as the exceptional example of growth in the Wonder Plot, indicate opportunities for acceleration of second-growth redwood forests toward old-growth characteristics.

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