Appendix 2 PROGRESS REPORTS – FUNDED PROPOSALS

PROPOSAL 1

Balderston Plantation Revisited: Does Vegetation Control or Fertilization Really Matter?

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Weed control is synonymous with plantation success in summer-dry California, and fertilization can improve 5-year volume growth by an average of 44% when combined with weed control (Powers *et al.* 1988). However, response to either treatment definitely varies by site quality (Powers and Reynolds 1999). Both weed control and fertilization make sizable demands on capital, but most reports of weeding or fertilization studies rarely cover more than 5 years. If investment is made early in the life of the stand--and if a response is obtained—two fundamental questions emerge: (1) "How long does it last?" (2) "How does it vary with site quality?" Fortunately, Balderston Plantation provides an excellent chance to address both questions.

Background.

The Setting. Balderston Plantation was established in 1967 at 3200 feet elevation on the Eldorado National Forest near Georgetown, CA. The site formerly supported a brush-field of whiteleaf manzanita that established in the wake of a 1947 wildfire. In 1966, brush and some topsoil were bulldozed into windrows set roughly a chain apart preparatory to planting with ponderosa pine. While this site preparation method was common throughout California and southwestern Oregon, Balderston Plantation has two unusual attributes.

Balderston plantation straddles two contrasting soil types separated by a draw. To the west are soils of the Mariposa series (fine-loamy, mixed, mesic Ruptic-Lithic-Xerochreptic Haploxerults) weathered from slate formed from 200 million-year-old marine sediments. Site index is about 35 feet at 50 years. To the east are younger soils of the Cohasset series (fine-loamy, mixed, mesic Ultic Haploxeralfs) formed from a 50,000-year-old volcanic mudflow. Site index on the Cohasset soil is about 76 feet at 50 years--twice that of the Mariposa. Mariposa soil is moderately deep, but is infertile and stony. The Cohasset is deep with very few stones, and is relatively fertile. Because these contrasting soil types occur side-by-side on comparable aspects and elevations, because they were planted simultaneously, and because they receive the same precipitation (53 inches annually), the site is ideal for examining how soil type influences stand development and response to silvicultural treatment. The second unusual characteristic of Balderston Plantation is that it represents the West's first statistically valid field experiment involving factorial combinations of weed control and nitrogen fertilization.

Research History. In 1974 the entire plantation (then 8-years old) was choked with brush. Survival (640 trees/acre) was high, but growth was disappointing. I was asked to assess why the plantation was doing poorly. Trees on the Cohasset side were at or above the level of the thick understory of manzanita and deerbrush, but color was poor and trees weren't doing well. Those on the Mariposa side were even worse. Only a few trees were above the manzanita canopy, and all trees were yellow. Chemical analyses of the needles of even the best trees revealed a severe nitrogen deficiency on the Mariposa soil (0.8% N) and a borderline deficiency on the Cohasset (1.1% N). In 1975 Eldorado National Forest personnel and I installed 36 tenth-acre treatment plots, 18 on each soil type. The 18 plots consisted of 3 replications of brush removal treatments (none vs. complete removal by hand) crossed with 3 levels of fertilization with urea (0, 200, and 400 lbs N/acre). These six treatments were repeated three times on each soil type.

Both 1st year (Powers and Jackson 1978) and 5th year findings (Miles and Powers 1988) were dramatic. On the Mariposa soil, brush control alone nearly doubled 1st-year height growth and needle weight, and 5-year volume growth was tripled. Although trees were extremely deficient in N at the start of the experiment, fertilization had no effect if brush remained. Once brush was removed, tree volume growth on the Mariposa soil was increased 162% by 200 lbs N/acre and 255% by 400 lbs N. Results on the more fertile, deeper Cohasset soil were less spectacular. First-year responses were nil. Needle mass was increased only 35% by brush removal, and height growth was unaffected by any treatment. But differences strengthened over 5 years. Volume growth was doubled simply by brush control. It also increased more than 50% simply by fertilization with 200 lbs N/acre, and growth was tripled when brush control and fertilzation were combined. Fertilizing with 400 lbs N/acre did not improve growth further, regardless of brush.

Subsequent Treatments. By 1980 the study had completed its planned life span of 5 years, but the plots still had demonstration value. After the 1986 growing season, when the trees were 20 years old and 11 years past treatment, Gary Fiddler's Silviculture Development Unit restaked the plots and applied a second round of treatments. One of the three replicates received no further treatment. On the Mariposa side, the second of three reps originally receiving brush control was weeded again. The third remaining replicate received brush removal plus 200 lbs N/acre (regardless of whether it had been fertilized previously). On the Cohasset side, one replicate was left untreated, another was thinned, and a third was thinned and fertilized with 200 lbs N/acre. Thinning was from below to about 267 trees/acre, leaving trees at about a 13-foot spacing. Nothing further was done with the plots.

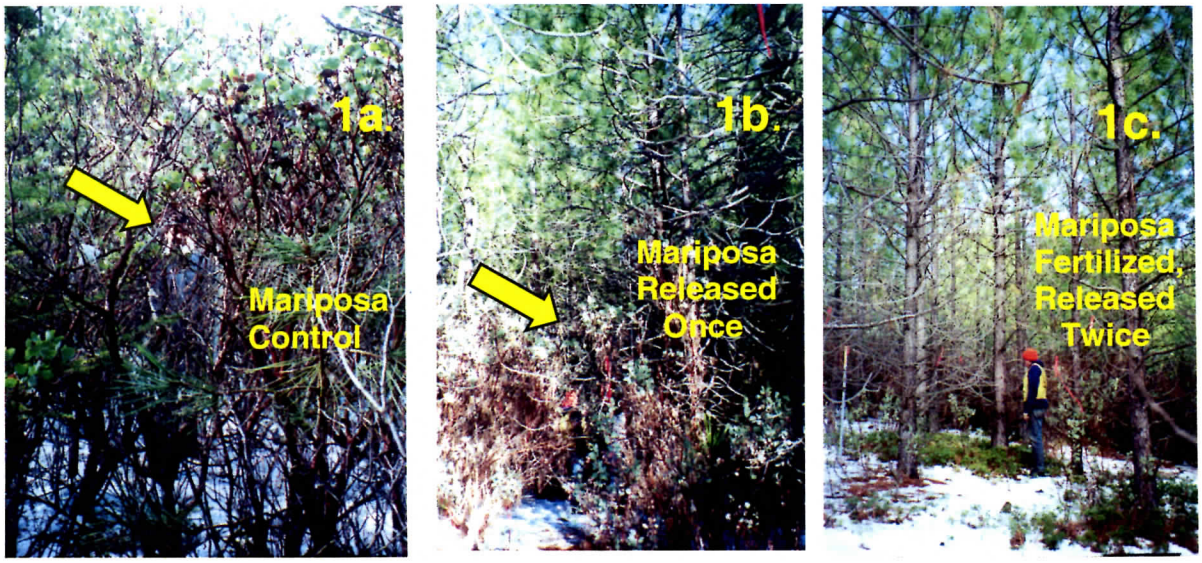
Year 2000. We returned to each 0.1-acre plot in November 2000--25 years after the original treatments. Trees were now 33 years old and all but two plots remained in good condition. We laid out 0.05-acre measurement plots within each treatment plot. Each measurement plot tree was tallied for DBH, and every 3rd tree was measured for current and past heights at intervals back to 1980 (the last measurement following the original treatments). Heights and DBHs were converted to inside bark cubic foot stem volumes (Oliver and Powers 1978). Volume:DBH equations were fit by regression and compared

for each treatment and soil type. These equations were used to estimate standing tree volume for each treatment plot and results expanded to volumes per acre.

Findings.

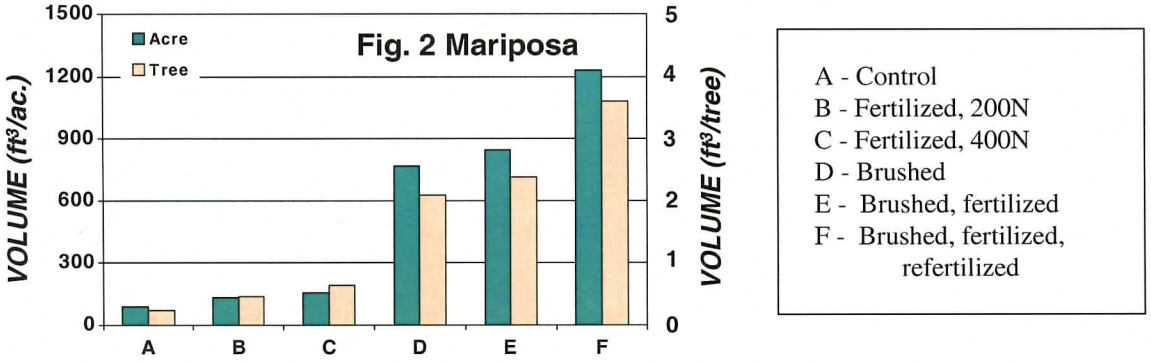
General. Comparing tree volume and DBH trends for each plot indicated that a single general equation fit all trees on a given soil type, but that the equations differed by soil type.

Mariposa. Figures 1a, 1b, 1c show the range of plantation conditions on the Mariposa soil type. After 33 years of brush development, tree survival had declined from the original planting density of 680 stems/acre to 268. Survival was 23% higher where brush had been removed at age 9. On plots with no previous treatment (the control), trees averaged only 16 feet tall and many were below the mean brush height of 8.2 feet (Fig. 1a). In all respects the plots had become brushfields. Where brush had been removed in 1975 without further treatment (Fig. 1b), trees were twice as tall (34 feet). Although a significant brush understory had reinvaded, these plots now resembled a minimally-tended tree plantation. Plots receiving both initial fertilization and brush control *and* subsequent thinning and fertilization now supported trees averaging 36 feet tall. These plots had the appearance of a well-managed plantation (Fig. 1c). (Arrows indicate heights of crewmembers standing in brush.)

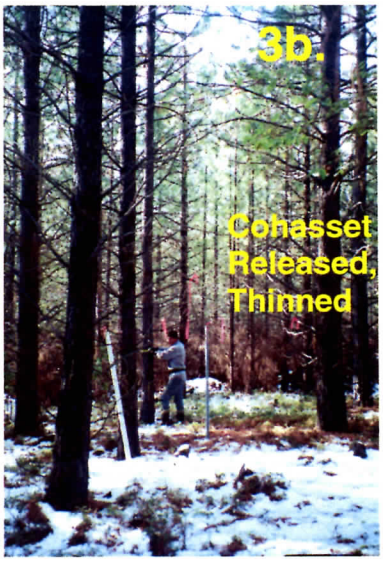


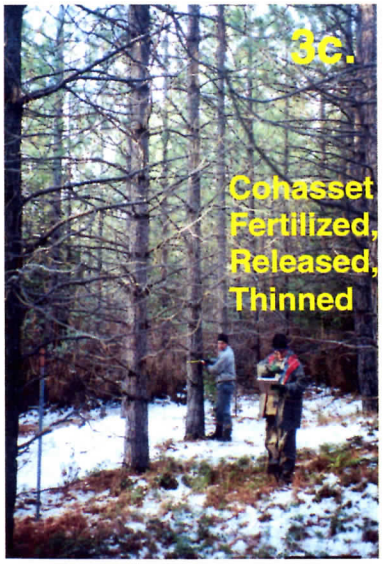
Retreatment in 1986 split the three replicate plots into separate, individual treatments, precluding analysis by inferential statistics. Spatial variation among plots caused further variability, but six distinct patterns in standing volume were apparent (Fig. 2). Plots lacking brush control had stand volumes varying between 88 and 157 ft^3/acre, with volume rising slightly with increasing N fertilization. Compared with the control treatment, brush removal in 1975 (year 9) led to standing volumes at age 33 that were nearly 9-fold greater (768 ft^3/acre) than controls—almost precisely the standing volumes predicted by Oliver and Powers (1978) yield tables. Mean stand diameters are 2.7 inches on control plots and 6.9 inches where trees had been released from brush 25 years earlier. Plots receiving both fertilization and brushing in 1975 showed an additional 10% volume

response (846 ft^3/acre). The best response appeared in plots receiving both fertilization and brushing in 1975 and refertilization and brushing in 1986. There, standing volumes averaged 1228 ft^3/acre at 33 years—14-times greater volume than on the untreated controls and about what one would expect if the stand were 10-years older or 20 feet higher in site index. Mean stand diameter for the retreated plots averaged about 8 inches (Fig. 1c). Except for plots without brush control, no differences were apparent between plots receiving 200 or 400 lbs N/acre.

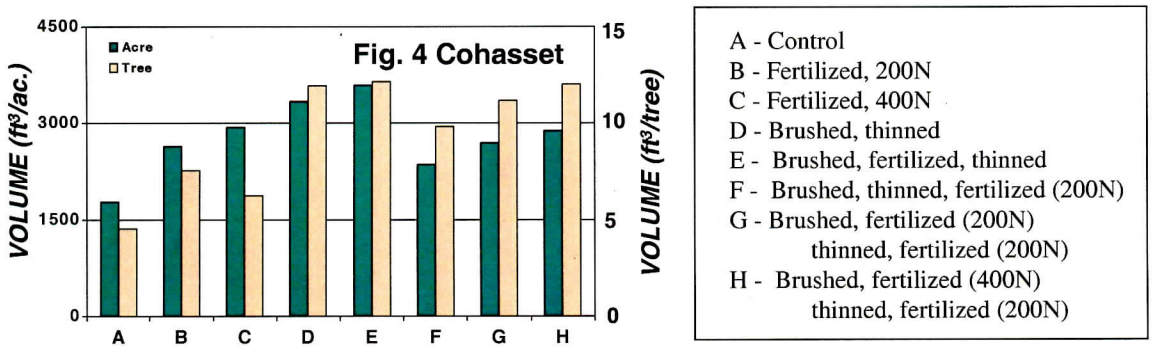


Cohasset. Responses on the Cohasset soil contrasted strongly with those on the Mariposa. Survival was greater (407 trees/acre) and stand development had progressed further. Tree crowns had closed on control plots and understory vegetation was almost completely dead (Fig. 3a). Tree heights averaged 44 feet and diameters 7.3 inches on control plots and as much as 50 feet and 8.8 inches on those receiving N. Trees released from brush competition in 1975 and thinned in 1986 averaged 10.2 inches DBH and 52 feet in height (Fig. 3b). Those fertilized and released in 1975 and thinned a decade later averaged 11.1 inches in DBH and 58 feet in height (Fig. 3c).





Volume growth was substantially greater on the Cohasset soil than on the Mariposa, but treatment differences were more erratic (Fig. 4). Control plot volumes averaged 1784 ft^3/acre, 20-times those on the Mariposa control, and greater than the best treatment on Mariposa. Fertilization was effective on the Cohasset soil, even without brush control. Volumes were increased by 48% with 200 lbs N/acre and by 65% with 400 lbs N/acre. Simple brush removal at age 8 doubled net volume growth over the control--even though brush-free plots had been thinned in 1986 and the controls had not. The standing volume of 3344 ft^3/acre is about what is expected for unthinned plantations of that site quality, spacing, and age (Oliver and Powers 1978). Combining brush control with fertilization had little further effect. Where plots were refertilized and thinned, growth also followed this stair-step progression of 0N < 200N < 400N and the volume of the average tree was twice that of control plot trees. Surprisingly, net volume growth was consistently less on plots that had been refertilized in 1986 than on those fertilized only once. Further checking of stocking indicates that plots fertilized only once had 22% higher stocking (293 trees/acre compared with 240 trees/acre). Lower stocking density partially explains why trees on twice-fertilized plots produced less volume.



Conclusions.

Mariposa. Despite a severe N deficiency and a linear response to N fertilization, volume production remained low if brush was present (Fig. 2), and what remains is a dense brushfield. Weak fertilization response indicates the immense influence of soil moisture in controlling forest development on droughty sites (in this case, droughty from high stone content and a high density of aggressive shrubs). Brush removal early in the life of the plantation reduced tree mortality and permitted the development of a reasonably productive, young forest. Plots free of shrub competition responded positively to N fertilization, but differences between 200 and 400 lbs N/acre were not apparent by age 33. Nor was the 25-year response to N particularly impressive (a volume increase of only 10% over brush control, alone). This is because thinning improved moisture availability temporarily so that trees could respond to fertilizer N. But once stand growth had increased sufficiently or understory brush had reinvaded, moisture again limited production. Retreating such plots in 1986, 10 years after the original treatments, did boost growth substantially (382 ft^3/acre more than those treated only once).

Cohasset. Because Cohasset soils are less stony and have greater water holding capacities than Mariposa soils, brush competition does not threaten plantation survival. By age 33, trees in control plots averaged 390 stems/acre and had shaded out all but a few shrubs (Fig. 3a). The consequence, however, is a fuel ladder of dead brush averaging more than 9 feet tall that merges with dead lower limbs of the trees (Fig. 3a). Although brush competition is not as serious on this productive soil, early brush control stimulated volume growth considerably. Brushed plots were thinned to two-thirds the stocking of those with brush. Even so, net volume production easily compensated for fewer stems per acre, and average volume per tree was doubled (Fig. 4). Despite better native fertility of the Cohasset soil, fertilization at 400 lbs N/acre produced a volume response nearly that of brush removal. Fertilization combined with brush removal substantially improved growth, but the effect diminished as standing volume exceeded 3000 ft^3/acre. Because of variability in stocking of individual plots, it wasn't clear whether benefits from refertilization exceeded those from a single fertilization a decade earlier.

Conclusions are:

- A forest will *not* develop in 33 years on droughty sites without brush control.
- Even on extremely infertile sites, response to fertilization is blocked by brush competition if the site is droughty.
- With early brush control, a stand *will* develop.
- Fertilization response is possible on droughty sites if brush is controlled, but follow-up treatments may be needed for the greatest volume response.
- On better sites, a stand will develop even without brush control.
- Trees on better sites will shade out understory brush by age 33, but an extremely hazardous fuel ladder will persist. On poorer sites, it takes longer.
- Growth on better sites can be improved by either brush control or fertilization.
- Better sites give a far-greater return in volume production than poorer sites for the same silvicultural investment.
- Regardless of site quality, silvicultural investments made early in the life of the plantation will carry for periods of at least 25 years.

The Balderston study exemplifies the long-range value of well-designed experiments. However, the 0.1 acre treatment plots now support trees approaching 60 feet tall. This means that many trees were affected by conditions on adjoining areas (walls of brush, brush-free clearings). This "edge effect" from small plot size tends to reduce the differences between treatments and suggests that results reported here probably are conservative. Plot size and long-term value are important considerations for field experiments yet to be designed by the Cooperative.

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