2

Sierra Cascade Intensive Forest Management Research Cooperative
Proposal 05-01 3-PG Study

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Title: Modeling Carbon Sequestration in Managed Forests Findings from Whitmore Garden of Eden

Executive Summary:

We analyzed above- and belowground biomass in a 21-year-old research plantation typical of many sites in northern California. The Whitmore Garden of Eden installation is the oldest among the most intensively studied pine plantations in the West. Treatments included a control (C = planting and no further treatment), fertilization without vegetation control (F), vegetation control without fertilization (H), and both vegetation control and fertilization combined (HF). Total perennial biomass of planted trees spanned more than a 3-fold difference at 21 years, ranging from 54 Mg/ha (C) to 180 Mg/ha (HF), equivalent to about 27 and 90 Mg carbon/ha. However, perennial biomass differences between extreme treatments disappeared when living understory vegetation on control plots was included (C = 172 Mg/ha, HF = 181 Mg/ha). Of this, between 25% (HF) and 32% (C) occurred belowground, indicating that treatments improving top growth also allocated proportionally less carbon to perennial roots. Untreated plots (C) at 21 years had one-fifth greater total biomass than plots receiving vegetation control (H). However, understory shrubs accounted for two-thirds of the biomass on C plots, and one-quarter of the biomass on F plots because fertilization hastened tree canopy closure and the gradual decline of the understory. Fertilization treatments increased the carbon mass of the forest floor (13.3 and 12.2 Mg/ha for F and HF treatments, respectively; 8.7 and 9.2 Mg/ha for C and H treatments, respectively). Thus, the forest floor is a substantive carbon sink, holding between 9 and 14% of total ecosystem carbon exclusive of soil, and12% to 19% of all aboveground carbon.

Fire behavior simulations calibrated for typical August conditions were applied to each of the treatments from the 10th to the 21st year of plantation development. Throughout this period, simulated flame lengths on C plots exceeded tree heights, leading to complete tree mortality. Fertilization (F) increased the growth of understory shrubs through the first 15 years so that simulated flame lengths exceeded tree heights, producing passive crown fires and 100% plantation mortality. By 21 years, planted pine canopies had closed on F plots and live understory shrubs had declined. Simulated flame lengths were less than tree heights, but heat convection still triggered nearly complete mortality. Fire effects in the H and HF treatments were simulated by surface litter models because these treatments lacked a shrub layer. Simulated flame lengths were always less than 1 m in H and HF treatments and less than average tree heights. However, crown scorch would be sufficient to kill about two-thirds of the trees at age 10. With time, trees grew larger and became more resistant to fire. By 21 years, mortality was projected to be 48% in H treatments, and only 42% in HF.

Additionally, three plots in the H treatment and three in the HF treatment had been thinned at age 10, removing the smallest 50% of the planted trees. Because thinning increased growth rates of the remaining trees, mortality projections from simulated wildfire were less than in the unthinned plots receiving H or HF treatments. Models predicted only surface fires with mortality ranging from a high of 56% to 61% (H and HF) at plantation age 10 years to between 32% and 39% (H and HF) at age 21. Although thinning slash was removed in this study, precommercial materials in operational thinnings sometimes are left on site. If retained, thinning slash creates ground fuels with persistent tinder-dry foliage. Simulated fire occurring two years after thinning and slash retention would produce flame lengths of 2.3 m, creating passive crown fires and nearly complete tree mortality. However, fuel loadings lessen with time. Simulated mortality from later fires fell to 45% by 15 years and to 30% by 21 years. Impacts of wildfire on carbon loss depend on the fraction volatilized during combustion and the fate of dead or dying residual material. Carbon dioxide will be released from residual slash through slow decomposition, but some will remain as inert charcoal. Estimating carbon quantities released as CO_2 or retained as charcoal is beyond the scope of this study.

Assuming fire-free conditions and a future climate similar to that of the present, we projected plantation development for C, F, H, and HF treatments to 50 years using the stand-level process model 3-PG. This model estimates carbon assimilation and allocation based upon leaf area, relative humidity, soil water availability and soil fertility, and accounts for self-thinning.

Understory shrubs dominated total productivity on untreated C plots through the first 21 years of plantation development, but shrubs declined to possible extinction after three decades. By 50 years, total ecosystem forest biomass on untreated plots was projected at 243 Mg/ha. Stands receiving only fertilization (F) showed an initial biomass peak of 201 Mg/ha at 18 years, followed by a decline lasting about a decade. This peak was dominated by understory shrubs that declined rapidly as tree canopies closed. Biomass accumulation began to accelerate by year 22, and total biomass by 50 years was projected to be 376 Mg/ha, mostly in tree stems. Tree stems dominated the biomass throughout the life of the stand where vegetation had been controlled (H), culminating in a total ecosystem biomass of 407 Mg/ha by age 50. Combining vegetation control with fertilization (HF) projected to the greatest gains of all: 487 Mg/ha at 50 years. Thus, 3-PG simulations project carbon accumulations of between 122 and 244 Mg/ha, exclusive of gains to the soil and assuming no incidence of wildfire.

Free of fire, these projections translate conservatively to mean annual carbon sequestration rates of from 2.4 to 4.9 Mg/ha exclusive of soil, offering a broad range of carbon management options. In reality, wildfire is likely. Fuels accumulating from understory shrubs in C and F treatments create a risk of very high mortality from passive crown fires, but H and HF treatments would likely survive. Implications for carbon sequestration are profound. Modeling forest carbon fluxes with a hypothetical fire return interval of 20 years suggests a potential loss of about 50 to 100 Mg carbon/ha over a 50-year span. Lacking understory management, sites with conditions similar to those at Whitmore would probably become fire-susceptible brushfields. Should one or more commercial thinnings occur (unlikely in the C treatment, but a viable option in the H, F, and especially HF treatments), a sizable proportion of carbon would be transferred to long-lived forest products, with only a minor decline in carbon in the residual plantation.