Evaluating Long-Term Seedling Growth Across Densities Using Nelder Plots and FVS in the Black Hills

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Overview:

- Although site preparation through herbicide or scalping resulted in significantly different tree sizes at age 12, by age 45 no differences in height or diameter could be detected.
- Implementing small-tree density management can increase tree diameters by 2.5-3 times their unthinned counterparts by age 45.
- The Forest Vegetation Simulator, Central Rockies variant, underpredicted age 12 heights by 0–45 percent, with accuracies improving to ±10 percent at age 45.
- For predicted diameters at age 12, the model underpredicted by 33-76 percent with these errors narrowed at age 45 to ±5 percent at the greatest planting densities and still underpredicted the open-grown diameters by 35 percent.

Summary:

Management and modeling of small-tree growth can affect decision-making for a range of treatment plans. Accurately representing this critical component of stand development is important for evaluating treatment alternatives from fuel hazard reduction to harvest scheduling. In the Black Hills of South Dakota and Wyoming, USA, favorable growing conditions and prolific seed crops often coincide, resulting in abundant natural ponderosa pine (*Pinus ponderosa* var. *scopulorum* Dougl. Ex Laws.) seedling establishment. This study seeks to quantify the influence of planting density and site preparation on small-tree development through 45 years of ponderosa pine growth in the Black Hills Experimental Forest. Using three Nelder plots (fig. 1) with 16 densities from 296 to 11,132 trees ha^{-1} and two site-preparation strategies, the analysis characterizes the effects of density and site preparation on average tree size at 12 and 45 years following planting. Additionally, simulations from the Forest Vegetation Simulator Central Rockies variant (FVS-CR) initiated from bare ground are used to evaluate the model's ability to represent early stand development until age 45. Our results demonstrate that both herbaceous vegetation and tree density affect tree size, but their influences varied with the tree development stage (fig. 2). Through the first 12 years of field observations, site preparation had the strongest effect on diameter and height growth, with a weaker effect from planting density. By age 45, the effect of planting density strengthened (fig. 2), with the lowest planting density trees approximately 2.5–3 times larger in QMD than the densely grown trees. Additionally, at age 45, site preparation no longer influences QMD or height. The FVS-CR predictions of age 45 height were

within 10 percent of the field observed values (fig. 3). However, age 45 predictions of QMD varied from ±5 percent at the greatest planting densities to 35 percent underprediction for the most open-grown condition.

Key Concepts for FVS Users:

The validation of the FVS-CR variant revealed key ideas for improving model reliability:

- FVS-CR's underprediction range for age 45 QMD of 0 to 35 percent as a function of planting density suggests the model fails to capture the intensity or timing of density-induced competition in these even-aged growth trials.
- The presence of relatively small errors in FVS-CR estimates of height across densities 45 years into the simulation, but QMD underpredictions that are dependent on planting density suggests that the Black Hills large-tree growth equation underrepresents the effect of stand density on diameter growth.
- Given the observed underestimation, FVS's growth multipliers could allow users to increase growth rates in the small-tree growth model such that diameters and heights might be unbiasedly predicted by the time they enter the large-tree growth model. However, because prediction bias varied across planting density, it is unlikely that calibration through FVS's multipliers would be able to improve growth rate predictions for more than a small range of densities at a time.

Management Applications/Future Directions:

- Generally, FVS-CR projections at age 12 captured most heights (73 percent) in the Scalped treatment within the USDA Forest Service's Common Stand Exam expectations, however, only 2.1percent of predicted QMD values met the <0.25 cm error standard.
- By age 45, predictions from FVS-CR nearly meet the Common Stand Exam Extensive standard for height on every tree in the Scalped treatment. Although improved, only 12.5 percent of predicted diameters are within the standard, and all of these trees were grown at the greatest planting densities.
- Modeling small-tree growth can impact management decision-making for a range of activities, such as fuel treatment effectiveness and sustainable harvest scheduling:
  - Underprediction of age 12 diameter will reduce ladder fuel biomass estimates and result in overpredicting the post-treatment period of effective fuel hazard reduction.
- The underprediction of tree height and diameter growth rates in stands with high regeneration densities during the first 12 years could delay the scheduling of precommercial thinning and lead to loss of growth or stand stagnation.

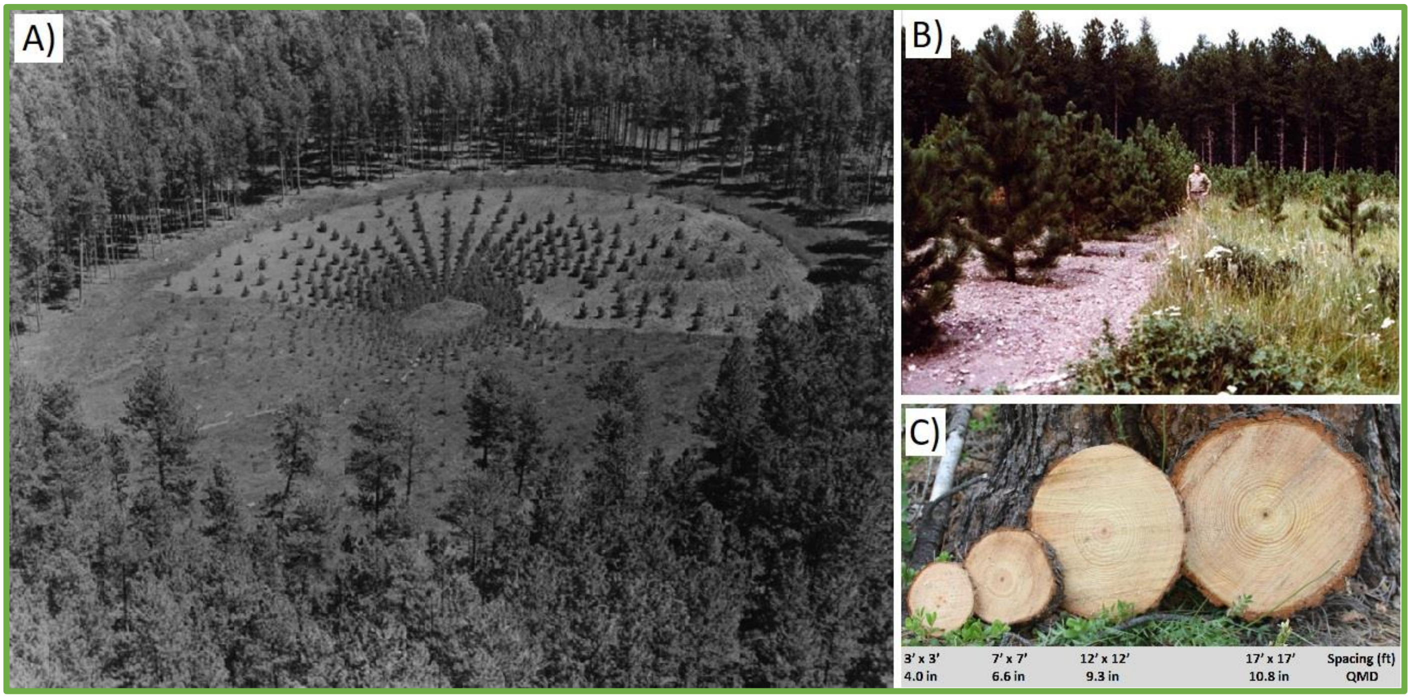

Figure 1—Overview of the Nelder Plot design (A) where the radiating spokes can be seen extending from the center of the site, with increasing density the further along each spoke. Additionally, from the aerial photo (A) the application of herbicide can be seen in the upper half of the image with the lower half having seedlings planted with scalps. The short-term effects of site preparation (B) can be seen at age 12 with the herbicide trees being much larger than the scalped trees due to each competition with herbaceous vegetation. The cumulative effects of density (C) resulted in stem diameters at age 45 that were 2.5–3 times larger in the most open-grown trees compared to the narrowest planting spacing.

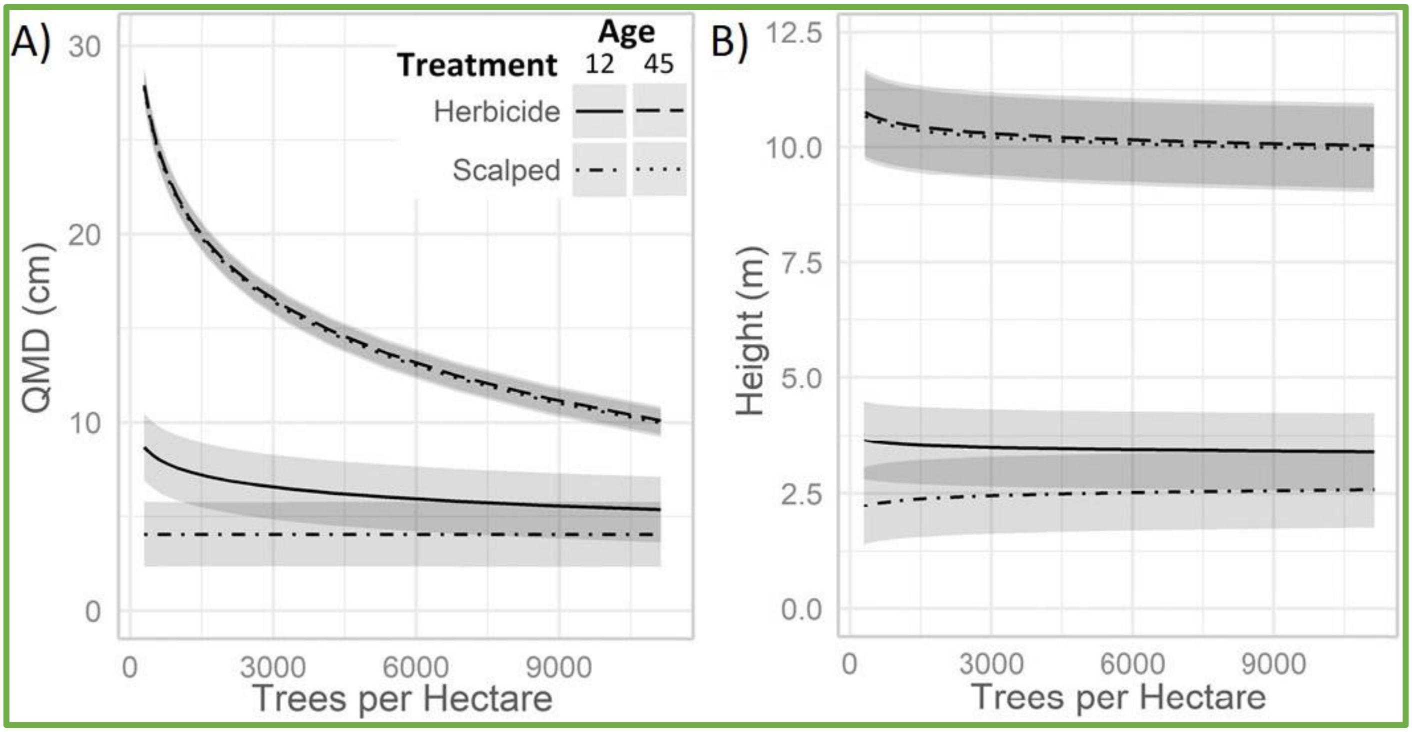

Figure 2—The influence of planting density and site preparation on (A) quadratic mean diameter (QMD) and (B) total height at 12 and 45 years after planting. Modeled as generalized mixed-effects models using a gamma distribution and site as a random effect.

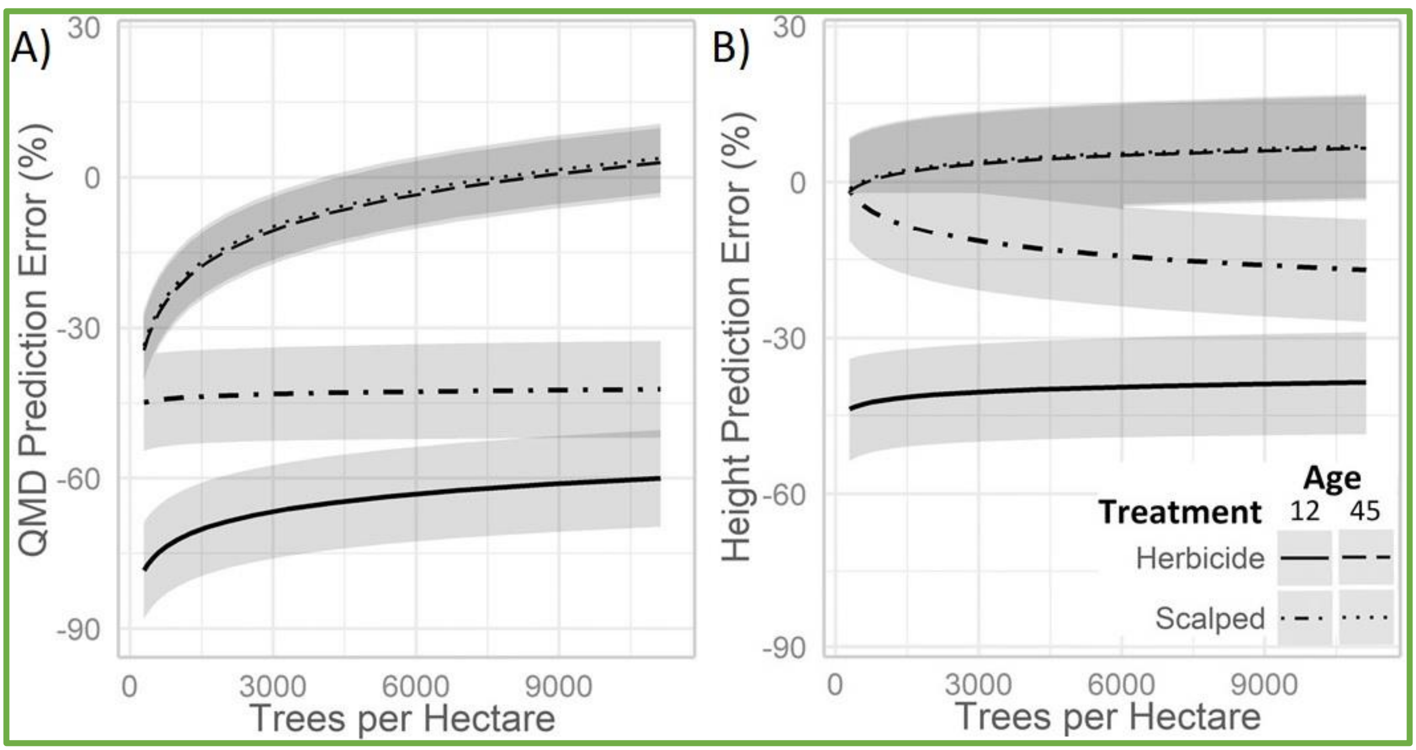

Figure 3—Accuracy of Forest Vegetation Simulator Central Rockies variant at predicting (A) quadratic mean diameter (QMD) and (B) total height at ages 12 and 45 from bare ground simulations. Values below zero represent model underpredictions and values above zero are over-predictions. Modeled as generalized mixed-effects models using a poisson distribution and site as a random effect.