Climatic Sensitivities Derived from Tree Rings Improve Predictions of the Forest Vegetation Simulator

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Overview:

- Tree-ring data were used to model the effect of interannual climate variability on large-tree diameter growth for three species (*Pinus ponderosa* Dougl. ex Laws, *Pseudotsuga menziesii* var. glauca Mayr (Franco), and *Picea engelmannii* Parry ex Engelm.) in the Utah variant of FVS.
- Based on out-of-sample validation, we found that tree ring-informed, simplified growth models improved prediction of growth of all three species. Further, growth models that explicitly incorporated the effect of climate variability improved prediction for *Pinus ponderosa* and *Picea engelmannii* in the ten-year time frame of validation. Because of their negative sensitivity to temperature variability, both are projected to grow less in the future because of changing climate.
- This new and reproducible method for combining tree ring and forest inventory to parametrize climate sensitive growth models can be applied to other tree species and variants to assess the impact of changing climate and alternative management scenarios to mitigate those impacts.

Summary:

With forest-based climate mitigation increasingly cited as a way to reduce greenhouse gas emissions, forest management tools that are used to assess and anticipate the impact of alternative management scenarios on carbon storage and sequestration, such as the Forest Vegetation Simulator (FVS), should accurately and precisely represent forest responses to changing climate. An extension of FVS called Climate-FVS (Crookston et al. 2010) relies on estimates of climatic suitability derived from species-level environmental envelopes to modify demographic processes, such as expected tree growth. An alternative approach is to model the direct effect of climate variation on individual tree growth using the responses recorded in annual growth rings. Tree rings sampled at a broad spatial scale can be used to quantify population-level heterogeneity in average growth rate in response to average climate as well as the sensitivity of growth to interannual climate variability. Increment cores collected across the Interior West on Forest Inventory and Analysis (FIA) plots were compiled into a tree-ring data network (DeRose et al. 2017), providing a unique opportunity to use the rich information on climate effects recorded in annual growth rings, complemented by inventory

data from their associated forest plots, to parameterize FVS growth models. This combination of tree-ring and forest inventory data makes it possible not only to build a climate-sensitive version of FVS, but also to look more closely at the representation of tree growth in FVS, including alternative combinations of predictors of tree growth, and how climate might interact with other drivers (e.g., competition).

Key Concepts for FVS Users:

We incorporated the direct effect of climate variation on tree diameter growth by combining tree-ring data with forest inventory data to parameterize a suite of alternative models for three abundant species in Utah, which differed progressively from the current FVS large-tree diameter growth model (fig. 1) in the Utah variant. We validated diameter growth predictions from these models with independent observations. Model performance was quantified using three metrics derived from a regression of observed vs. predicted diameter increment: adjusted R^2 (R^2), root mean square error (RMSE), and slope of the regression model (fig. 2). We then compared predictions of future growth made by the existing large-tree diameter growth model in FVS, i.e., without climate effects, to those of our updated models, including those with climate effects. We found that simpler models of tree growth outperform the current FVS model, and that the incorporation of climate effects improves model performance, in two of three species over a short time span of ten years. The impact of climate change on these two species is negative: diameter growth projected with improved, climate-sensitive models is less than the growth projected by the existing climate-insensitive FVS model. Tree rings can be used to identify and incorporate drivers of growth variation into a stand-level growth and yield model, leading to more accurate predictions under climate change (fig. 3).

Management Applications/Future Directions:

- Our findings may inform forest management aimed at mitigating the impact of changing climate on tree growth. We found that the increased competition within a stand increases climate sensitivities, suggesting that the negative effects of changing climate on tree growth can be moderated by reducing the competition within a stand.
- We detected spatial variation in the sensitivity of tree growth to time-varying climate in calibration. A stronger climate sensitivity (steeper slope of the response to time-varying climate) was found at dryer and warmer than average locations. Our interpretation is that tree growth is limited by soil moisture across all three of the study species and that climate sensitivity increases as soil moisture becomes more limiting.
- The model form for all alternative models was a linear mixed effect model. Future work might consider nonlinear effects, in particular, for climate, to more accurately represent species responses to increasingly novel climatic conditions.
- Further improvements could be made by incorporating more data in calibration to avoid extrapolation, e.g., for small trees. Additional investment in estimating proxy metrics, such as solar radiation, and annually interpolated parameters, namely competition and crown ratio, may also improve model performance.
- Experimentation could be done to understand the mechanism of these effects. For example, we found trees in a drier region of their climatic range are less negatively

impacted by the presence of other trees. The benefit of more or larger neighbors at these sites may reflect facilitation through microclimate effects, but further exploration is needed to verify these effects.

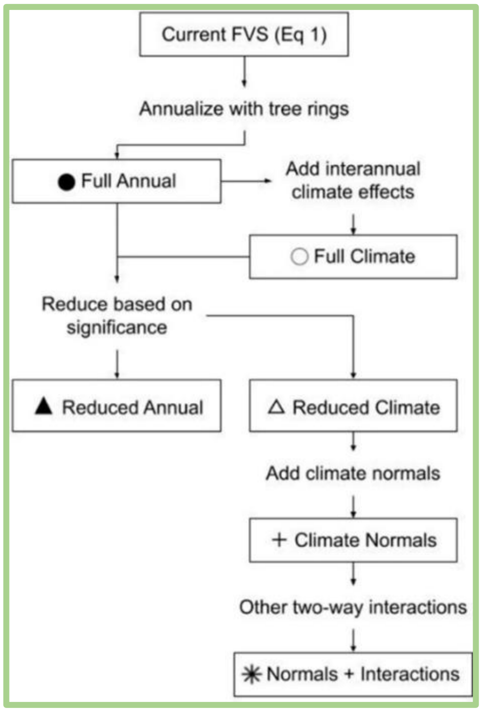

Figure 1—Alternative diameter growth models progressively diverged from the current large-tree diameter growth model in FVS. First, tree rings were used to convert the model to a one-year time step (annualization), creating the Full Annual model. Second, interannually varying climate variables were added as predictors, creating the Full Climate model. Third, full models were reduced based on significance, creating the Reduced Annual and Reduced Climate models. From the Reduced Climate model, the Climate Normals model was created by adding climate normals (i.e., 30-year average) as a predictor and their significant interactions with interannual climate predictors, which was then used to create the Normals + Interactions model by adding all other significant two-way interactions.

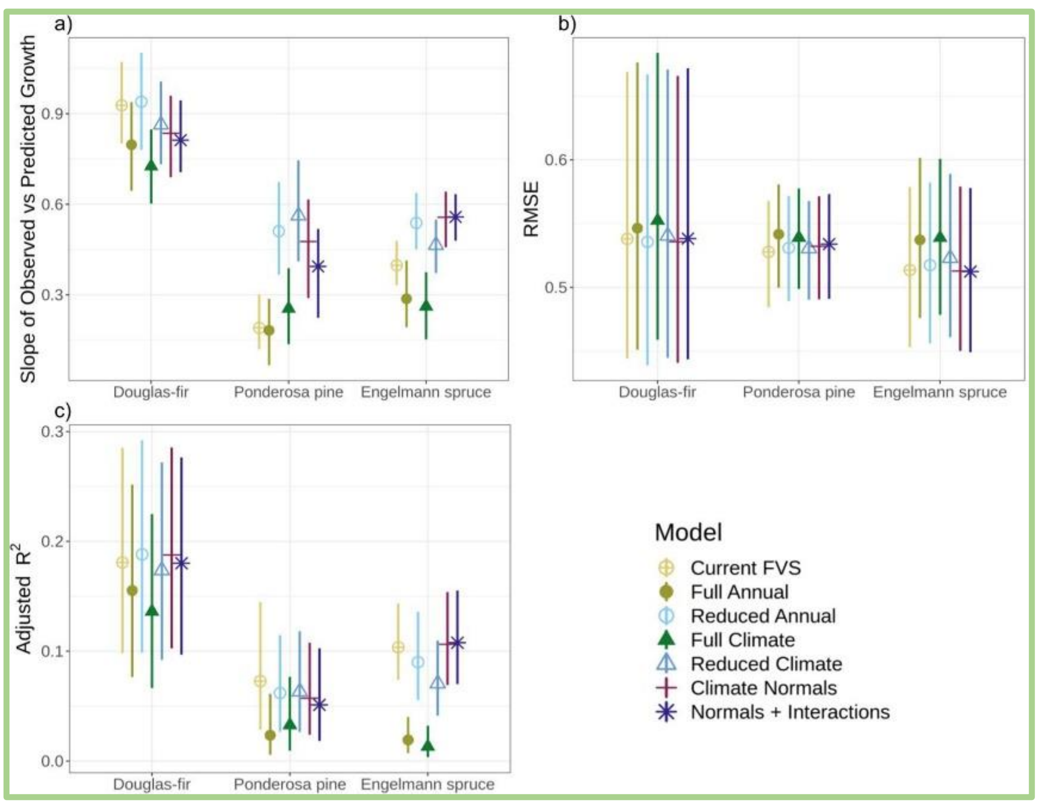

Figure 2—Validation of six alternative diameter growth models for Douglas-fir, ponderosa pine, and Engelmann spruce. Model performance is assessed in terms of adjusted R^2, root mean square error (RMSE), and the slope of the linear regression of observed vs. predicted diameter growth increment. Confidence intervals for adjusted R and RMSE were derived from bootstrapping.

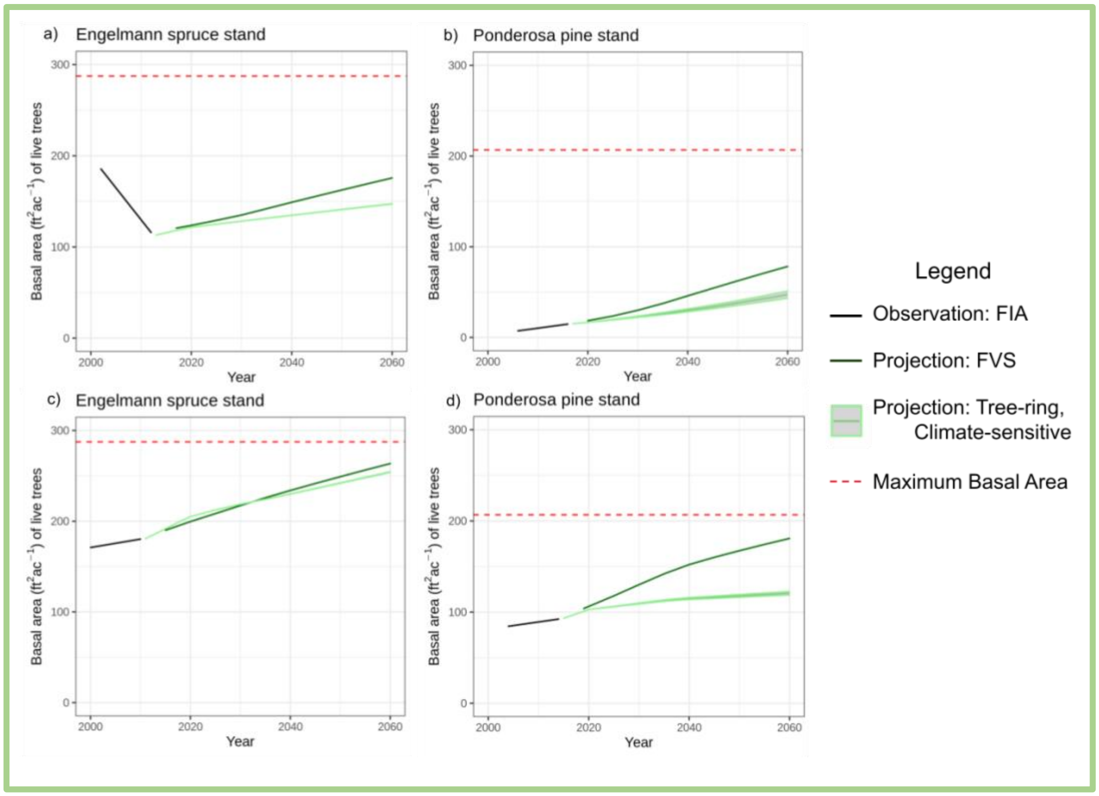

Figure 3—Observed and projected basal area (ft^2ac^{-1}) of live trees with and without the effect of climate. Total basal area (ft^2ac^{-1}) of live trees in pure Engelmann spruce or ponderosa pine stands in Utah as observed by the Forest Inventory and Analysis (FIA) program (black line), modeled without the effect of climate by the Forest Vegetation Simulator (FVS; dark green line), or modeled with the effect of climate by a tree-ring-informed model based on FVS (light green line) with species-specific maximum basal area (dashed red line).

References:

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