An FIA-based Imputation Procedure to Account for Natural Tree Regeneration Post-treatment in FVS

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Overview:

- Natural tree regeneration is an important component of forest development that can affect stand growth, mortality, and alter the severity of natural disturbances (e.g., wildfire) over time. Silvicultural treatments and/or natural disturbances typically increase stand-level resource availability that can stimulate pulses of natural tree regeneration.
- Only a select few FVS variants include natural tree regeneration (full establishment) models. Partial establishment models exist but rely on the user to specify the degree of tree establishment by species that will occur. Failure to account for natural tree regeneration after tree harvest or natural disturbance can lead to unrealistic FVS simulation results over time.
- We present a simple FIA-based imputation procedure that can be used to add the midpoint (average) of expected natural tree regeneration into FVS simulations after tree harvest and/or natural disturbances. Our imputation procedure is geared toward forest ecosystems dominated by obligate seeding conifer tree species in western North America.

Summary:

FVS simulations that do not account for natural tree regeneration after silvicultural treatments that harvest trees, or natural disturbances that kill trees, may overestimate tree growth and underestimate tree mortality, stem density, and ladder fuel development over time. The Westside Fire- and Carbon-Oriented Forest Management Modeling (FCOMM) project aims to quantify fire resistance across forests of western Oregon, Washington, and northwestern California using FVS simulation of business-as-usual management practices (i.e., silvicultural treatments) across >10,000 FIA conditions. Given that abundant tree regeneration post-harvest can reduce the long-term effectiveness of silvicultural treatments aimed at enhancing stand-level fire resistance, accounting for natural tree regeneration within FCOMM FVS simulations is paramount. To address this issue, a natural tree regeneration imputation procedure was adapted from prior research methods (Vandendriesche 2010) using field-observed natural tree regeneration (average small sapling density; 1-3" diameter) measurements across thousands of FIA conditions (stands) and a range of forest structure condition classifications (percent canopy cover * overstory quadratic mean diameter [QMD] classes) as the imputation basis. Two distinct imputation procedures were developed for

comparison, based on shade-tolerance groups (aggregated species responses) and species-specific responses. We present the imputation procedure logic and FVS simulation results from its application across 3,799 West Cascades (WC) variant stands, nested within the FCOMM study area.

Key Concepts for FVS Users:

- Modeling natural tree regeneration is a hard science problem, hence the general lack of full establishment models available across FVS variants.
- Our imputation procedure is a relatively simple method to account for the midpoint (average) of expected natural tree regeneration after tree harvest and/or disturbance in FVS.
- Unlike many previously developed tree regeneration estimation methods developed for FVS, our methods work entirely via keyword file (kcp) scripts. This can allow users to easily augment the methods to fit their specific needs by adjusting the kcp scripting as needed.
- The empirical FIA sample used as the basis of the imputation procedure is user-defined, can be drawn from thousands of data points (FIA plots), and can be customized to represent regeneration responses at the FVS variant, defined geographic area, or forest type level(s).
- Imputation procedure results (number of small saplings by species imputed after simulated tree harvest or disturbance in FVS) can be tracked by the user via predefined variables in the FVS_COMPUTE table.

Management Applications/Future Directions:

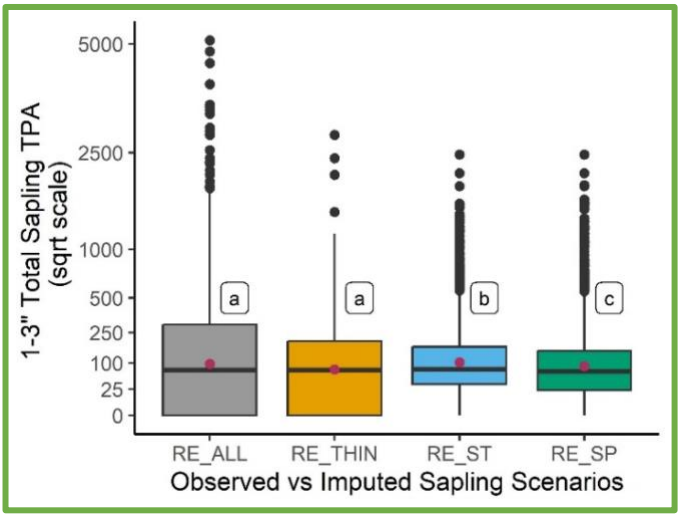
- When evaluating the effectiveness of silvicultural treatments over time in FVS, accounting for natural tree regeneration can improve the validity of simulation results. Ultimately, FVS should include full establishment regeneration models across a wider range of variants. In the meantime, stopgap methods (like those presented here) should be leveraged by FVS users.
- While our methods impute the midpoint (average) of empirical observations, natural tree regeneration can be highly variable across sites (e.g., 0 to >5,000 saplings per acre). Much of that variability can be explained by climate and topography (i.e., site productivity). Our methods could be improved by scaling (multiplying) the imputation response using a measure of site productivity at the stand level.
- While our methods are currently applied via keyword file (kcp) scripts, they could also be applied via popular programming languages like R. Past tree regeneration estimation methods applied in FVS have often used programming languages that fell out of use or required external programs that became unsupported. Future methods should prioritize user-customizability and ease of useability.
- Knowledge of tree species' regenerative capacity and functional traits within a study area should guide what imputation procedure is used. Aggregating species into groups based on shade-tolerance is a popular approach applied in our methodology, among others, yet species with similar shade-tolerances can exhibit variability in other

functional traits that influence regeneration responses. When this is known to be true, the species-specific approach may be a better application.

Table 1—Fifteen strata (regeneration forest structure; RGNST; Vandendriesche 2010) are defined and coded based on varying thresholds of FVS computed stand-level canopy cover and overstory tree size. For example, code 21 is a stratum containing stands with 10-40 percent canopy cover and an overstory quadratic mean diameter (QMD) of 5-10 inches. RGNST stratum represent the influence of forest structure on tree competition and resource availability that influences natural tree regeneration responses. Empirically observed mean small (1-3" diameter) sapling density is calculated by RGNST class and species group from the FIA sample and programmed into a lookup table in FVS. After simulated tree harvest in FVS, each stand's post-harvest RGNST class is assessed and used to reference, from the programmed lookup table, the expected density (trees per acre) of saplings, by species, that will be imputed into the stand roughly 10 years post-harvest. The expected number of saplings for imputation is finally adjusted down based on the residual small sapling density in the stand post-harvest.

Canopy Cover Class (%)	Overstory QMD (") Size Class				
	0-5	5-10	10-15	15-20	>20
10-40	11	21	31	41	51
40-70	12	22	32	42	52
>70	13	23	33	43	53

Figure 1—Boxplots (maroon dot in box is the mean) comparing the distribution of empirically observed small (1-3” diameter) sapling density (trees per acre; TPA) across all WC variant stands (RE_ALL; n = 3799), stands that experienced a thinning treatment 10-20 years prior to FIA measurement (RE_THIN; n = 179), and the shade-tolerance (RE_ST; n = 3799) and species-specific (RE_SP; n = 3799) imputation approaches 10 years after a simulated thinning treatment. A Wilcoxon rank sum test with Bonferroni correction for multiple pairwise comparisons did not find statistical differences (α = 0.05) in small sapling density between the RE_ALL and RE_THIN groups (letter a) but did find differences between the imputation approaches and empirical observations (letters b, c). Median and mean values were very similar across groups, however.



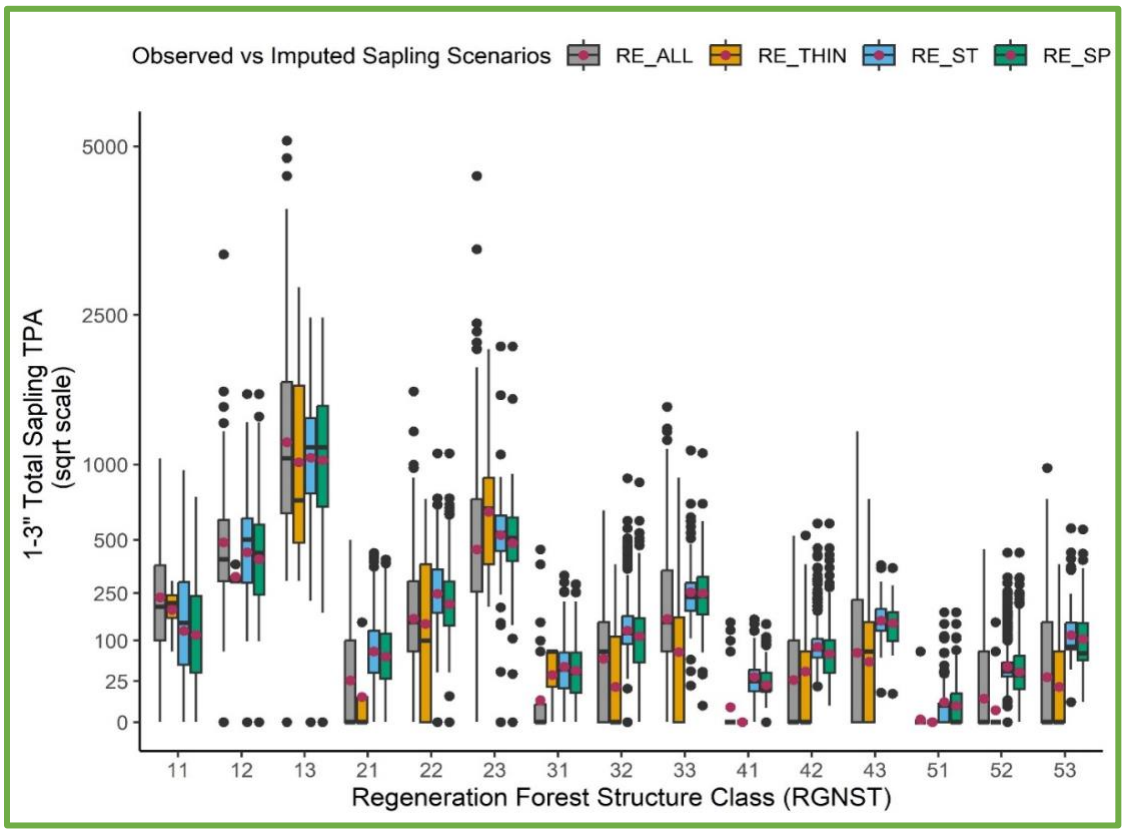


Figure 2—Boxplots (maroon dot in the box is the mean) comparing the distribution of empirically observed small (1-3” diameter) sapling density (trees per acre; TPA) across all WC variant stands (RE_ALL; n = 3799), stands that experienced a thinning treatment 10-20 years prior to FIA measurement (RE_THIN; n = 179), and the shade-tolerance (RE_ST; n = 3799) and species-specific (RE_SP; n = 3799) imputation approaches 10 years after a simulated thinning treatment, stratified by regeneration forest structure class (RGNST). The shade-tolerance and species-specific approaches (RE_ST; RE_SP) exhibited similar distributions, with variable deviation from empirically observed mean values (RE_ALL; RE_THIN) depending on RGNST class. Generally, imputation approaches underpredicted tree establishment in young forests (RGNST < 21) and overpredicted in older forests (RGNST > 21).