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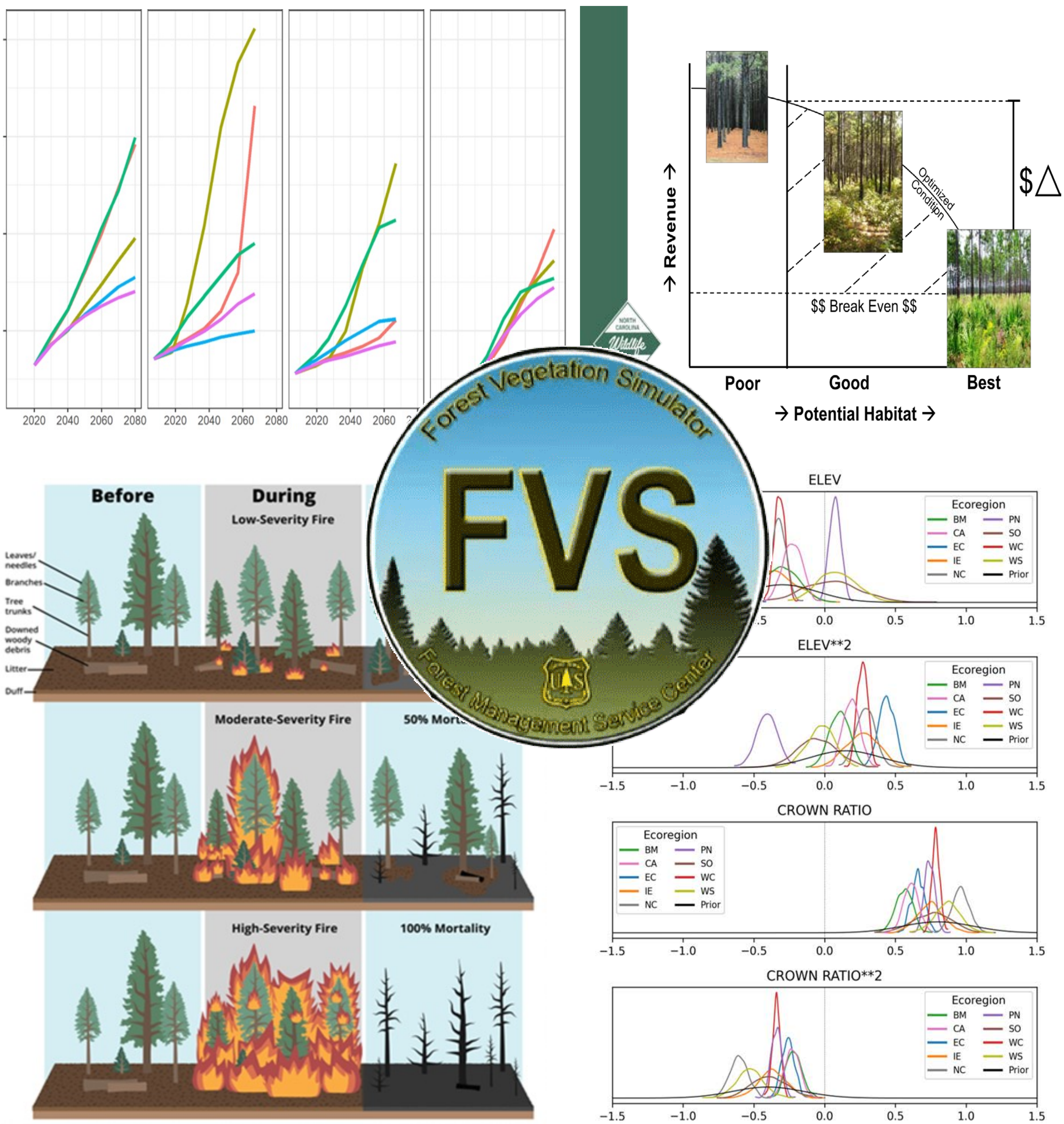
# Sixth Forest Vegetation Simulator (FVS) Conference



Shaw, John D; Battaglia, Mike A.; Castle, Mark, [comps.]. 2024. Sixth Forest Vegetation Simulator Conference; 2023 March 7–9; Fort Collins, CO. Proceedings RMRS-P-81. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. n.p. https://doi.org/10.2737/RMRS-P-81

## Abstract

The Forest Vegetation Simulator (FVS) is a forest dynamics modeling system with geographic variants covering forested areas of the contiguous United States. FVS was developed in the early 1980s and is used throughout the United Sates for predicting forest development and the effects of alternative forest management actions. FVS variants are also used in Canada and Europe. The Sixth Forest Vegetation Simulator (FVS) Conference, held March 7-9, 2023, in Fort Collins Colorado, consisted of 29 offered presentations and two invited panel discussions organized into three main topic areas: Model Development (day 1), Project Application (day 2), and Model Evaluation (day 3). Presenters were invited to provide summaries of their presentations for inclusion in the proceedings, resulting in 21 submissions. Presentations represented a wide range of users—academic institutions, non-governmental organizations, Forest Service Research and the National Forest System, Natural Resources Canada, State agencies, and private consultants. The diversity of attendees was even greater, with the addition of members from other federal agencies, tribal governments, and forest industry. Many presentations described the use of FVS at the stand and landscape scales, and one of the panel discussions focused on carbon management and climate. Other topics including model calibration, growth and yield modeling, integration of tree-ring data, wildlife habitat management, testing effects of treatment alternatives, and general forest planning. Other presentations covered user interaction with the latest version of FVS and access to Forest Inventory and Analysis data. The conference concluded with a lively discussion on the future of FVS development.

***Keywords***: forest management, forest planning, growth and yield, vegetation dynamics, habitat modeling, carbon inventory, landscape dynamics, fire, fuels, climate change, economics, tree-rings

***Cover:*** Images from the cover pages and papers in these sections: upper left—Model Development, Weiskittel et al.; upper right—Project Application, Phillips et al.; lower right—Model Evaluation, Diaz and Ettl; and lower left—Project Application, Urbanski et al.

## Compilers

**John D. Shaw** is a Research Forester with the USDA Forest Service, Rocky Mountain Research Station in Riverdale, UT. Dr. Shaw has been collaborating with the FVS staff for more than 25 years, starting with development of the first web-based tutorial for FVS, initially designed to support undergraduate students in silviculture and forest management at Utah State University. Currently, he is responsible for the translation and distribution of Forest Inventory and Analysis (FIA) data in FVS-ready format and is a member of the FVS Steering Team as the FIA representative.

**Mike A. Battaglia** is a Research Forester with the USDA Forest Service, Rocky Mountain Research Station in Fort Collins, CO. Dr. Battaglia's research focuses on developing and implementing innovative management strategies to enhance forest resiliency to disturbance. Within his research, he utilizes FVS to simulate and test different management strategies. Furthermore, Dr. Battaglia generates long-term data sets to aid in the evaluation and development of FVS.

**Mark Castle** is a Biometrician with the FVS Staff, USDA Forest Service Washington Office—Forest Management, Range Management, and Vegetation Ecology. He received a B.S. in Geographic Science from James Madison University in 2012 and an M.S. in Forest Resources with an emphasis in forest biometrics from the University of Maine in 2017. He started on the FVS staff in October 2017 and continues to develop, maintain, and support the FVS software.

## Acknowledgments

Funding for this publication was provided by the Forests Inventory and Monitoring Program of the Rocky Mountain Research Station (RMRS), and the Forest Management, Rangeland Management and Vegetation Ecology staff, both part of the U.S. Department of Agriculture, Forest Service. The conference organizing committee included Erin Smith-Mateja, Mike Battaglia, Mark Castle, Lance David, Matt Diskin, John Shaw, Michael Shettles, Michael Van Dyck, and Daniel Wagner. Their efforts along with those of all the presenters, authors, and reviewers made this conference and proceedings a success. The compilers are particularly grateful to Patricia Cohn, RMRS Publications, for guiding us through the publication process and producing professional conference proceedings, and the many reviewers who gave feedback on earlier drafts.

# Sixth Forest Vegetation Simulator (FVS) Conference

## Proceedings of the conference held at the Fort Collins Hilton Fort Collins, Colorado

***March 7-9, 2023***

Compiled by:
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Sponsored by:
USDA Forest Service, Washington Office Forest Management, Rangelands Management, and Vegetation Ecology

USDA Forest Service, Rocky Mountain Research Station, Inventory and Monitoring

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# Sixth Forest Vegetation Simulator Conference Summary

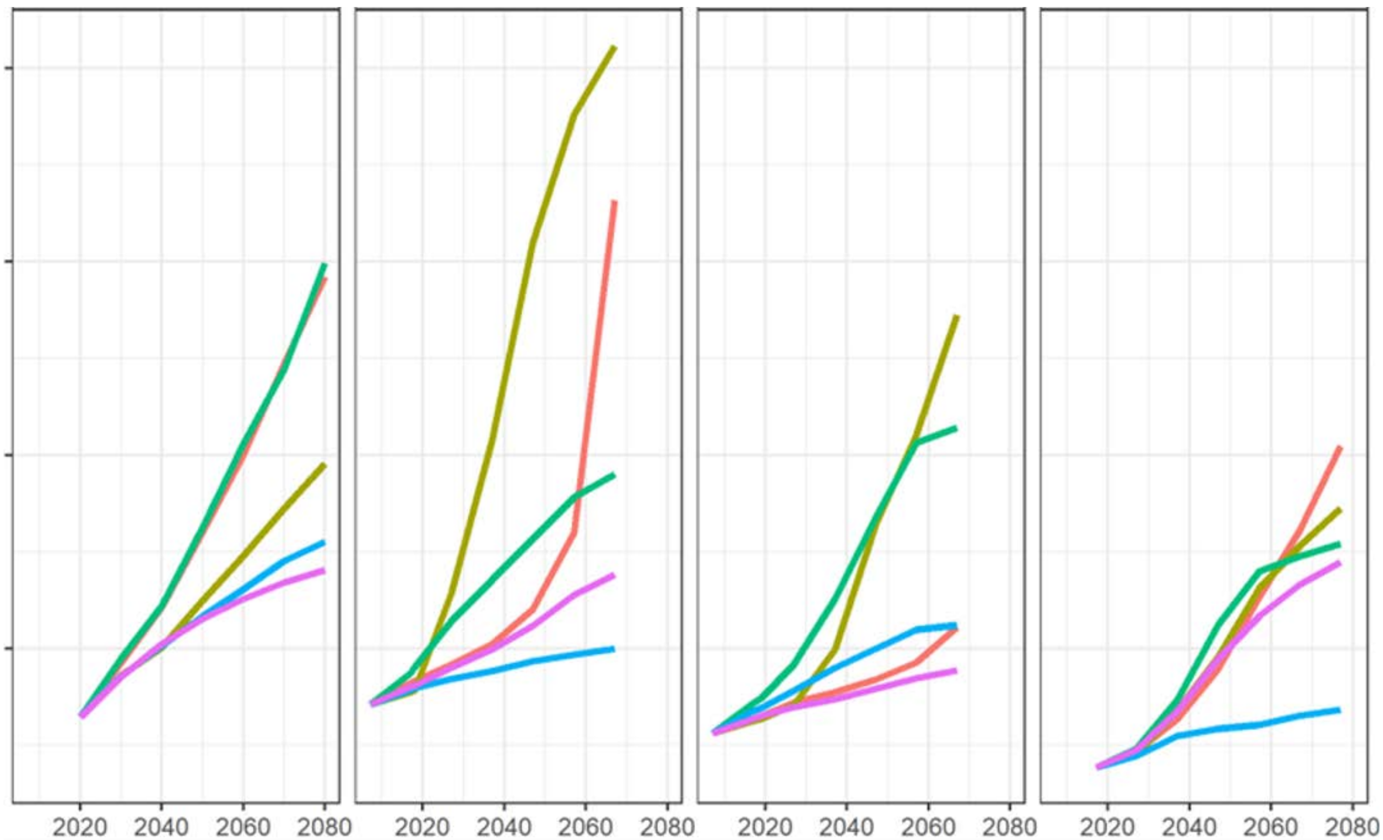
The Forest Vegetation Simulator (FVS) Conference took place March 7-9, 2023, at the Hilton Fort Collins, Fort Collins, CO. This was the sixth FVS Conference, the series dating back to the first conference in 1997. There were close to 90 attendees at the conference, one-third were from the U.S. Department of Agriculture, Forest Service, and the other two-thirds were from non-governmental organizations, including timber industry and carbon consultants, State and local agencies, universities, and other federal agencies. Attendees were from across the U.S., along with a few participants from Canada. Troy Heithecker, Associate Deputy Chief for the National Forest System, provided the keynote address.

The three days were filled with 29 presentations and two panel discussions. The presentations ranged from the use of FVS at the stand level to large, landscape-level projects; and projects showing management effects and time on fire risk, carbon, wildlife habitat, or more traditional stand metrics such as volume and density. Presentations also included the use of FVS using the standard FVS interface, the FSVEG Spatial Data Analyzer, and the R-FVS API. The R-FVS API provides advanced users more flexibility for connecting to other programs and processes outside of the standard user interface. Presentations also covered evaluation and validation of the FVS models. The two panel discussions focused on Carbon and Future FVS Development. There was significant interest in ways to continue including the latest science in FVS; finding ways to keep the FVS code as open source (to allow for collaboration in development); as well as discussions on how to provide continued support and additional staffing for such a widely-used model.

The three-day conference was an overall success. Participants shared through formal talks and informally during the breaks. Discussions included modeling problems and solutions; desires for future advancements in stand dynamics modeling; and examples of project applications to help decision makers make informed decisions for management on the ground.

More information can be found on the Forest Service FVS web page: https://www.fs.usda.gov/fvs/

# Model Development



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

Wade T. Tinkham[1*], Mike A. Battaglia[1], Chad M. Hoffman[2]

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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.

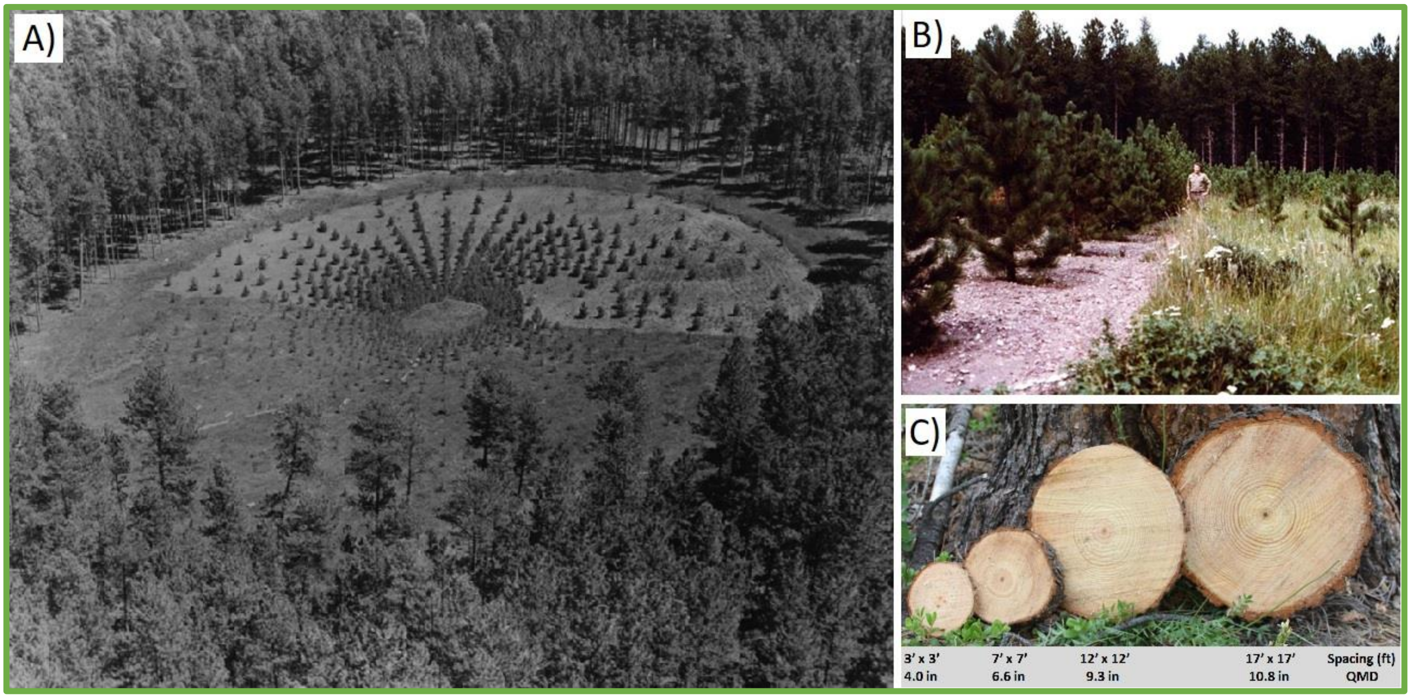


**Figure 1—**Overview of the Nelder Plot design (A) where the radiating spokes can be seen extending from the center of the site, with increasing density the further along each spoke. Additionally, from the aerial photo (A) the application of herbicide can be seen in the upper half of the image with 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.

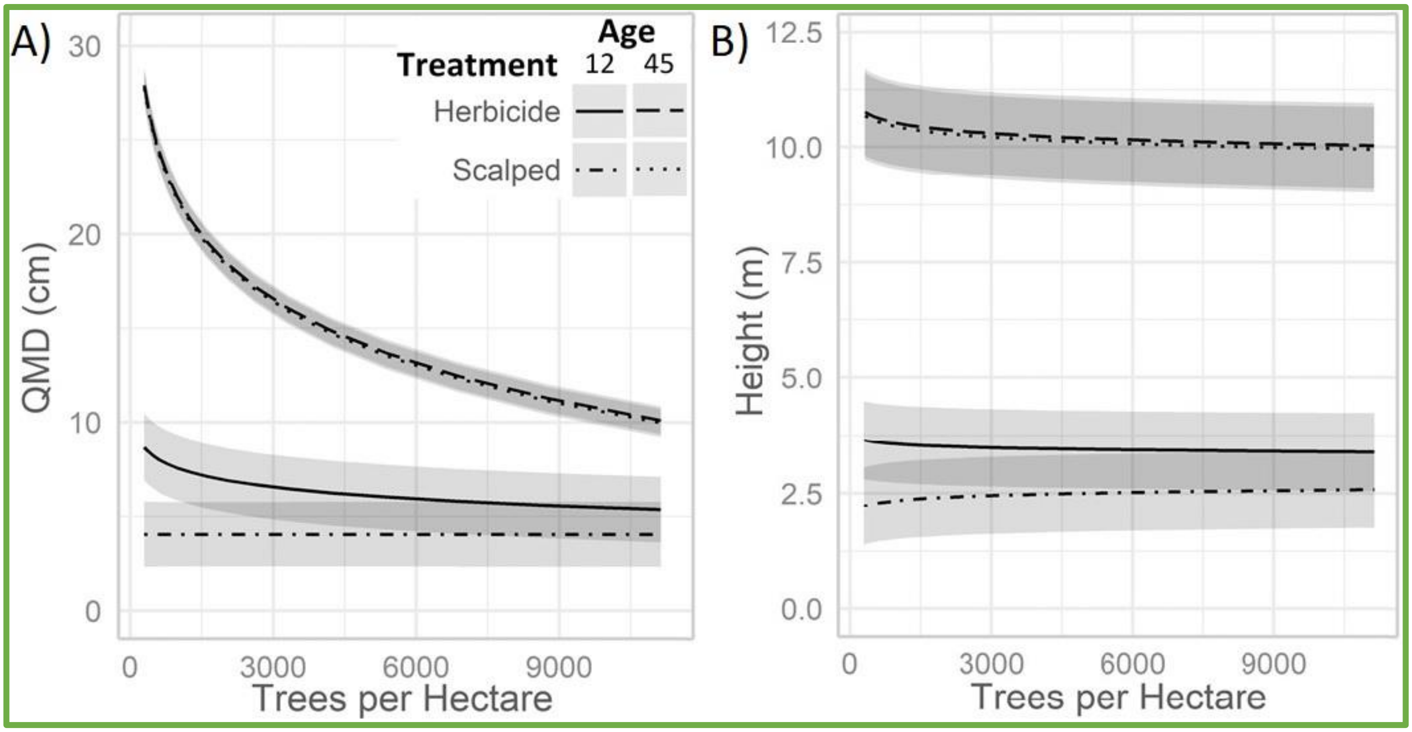


**Figure 2**—The influence of planting density and site preparation on (A) quadratic mean diameter (QMD) and (B) total height at 12 and 45 years after planting. Modeled as generalized mixed-effects models using a gamma distribution and site as a random effect.

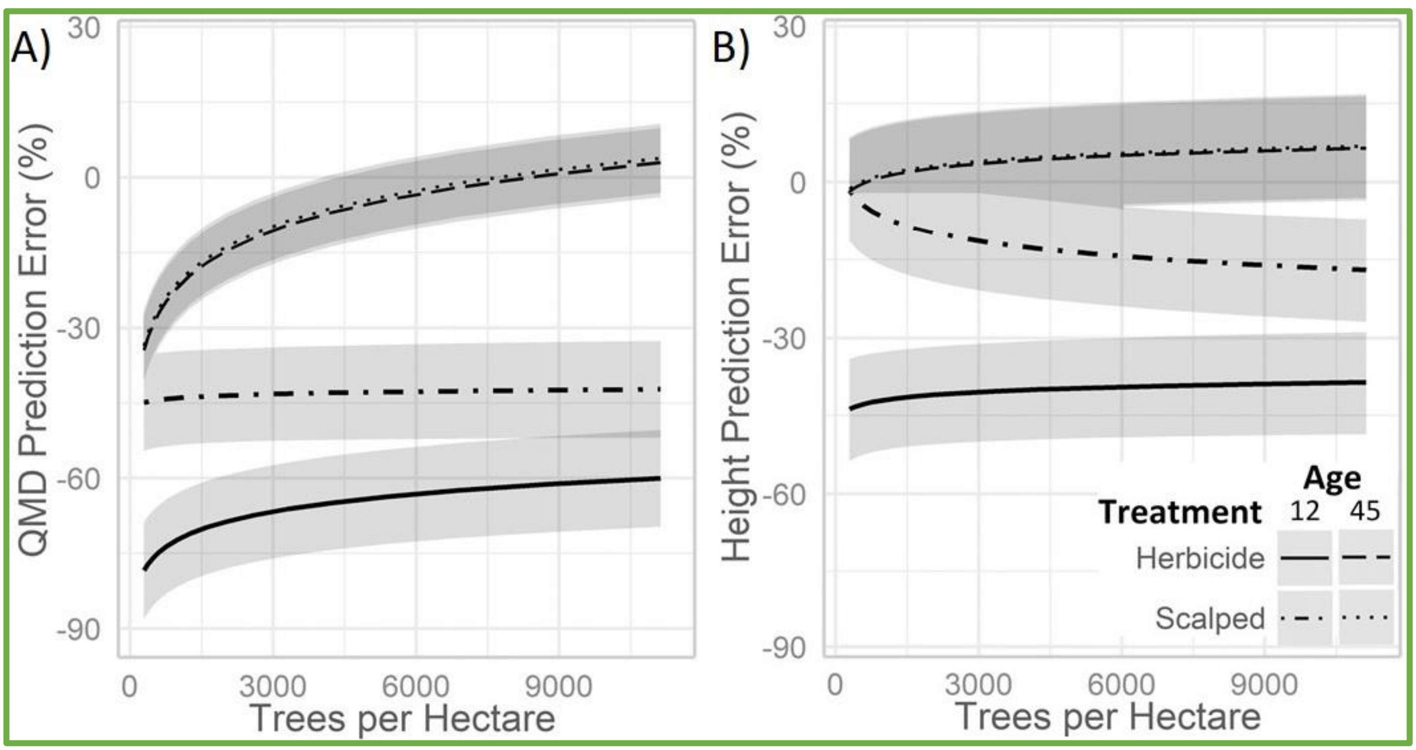


**Figure 3**—Accuracy of Forest Vegetation Simulator Central Rockies variant at predicting (A) quadratic mean diameter (QMD) and (B) total height at ages 12 and 45 from bare ground simulations. Values below zero represent model underpredictions and values above zero are over-predictions. Modeled as generalized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

# Utilizing FVS Growth Predictions for Reforestation in Northern California

Katherine E. A. Wood[1,2,*], Christopher E. Looney[2], and Jianwei Zhang[2]

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**Overview:**

- We leveraged 20 years of growth data from the Garden of Eden experimental plots in Northern California, evaluating the effect of FVS variant, age, competing vegetation control, fertilizer, and site index on top height, basal area, and quadradic mean diameter of ponderosa pine trees.
- FVS bare ground predictions were most accurate for top height in control plots (fig. 1). Growth predictions did not often align with each site's geographic variant. Furthermore, the best fit models for top height, basal area, and quadratic mean diameter included sites with competing vegetation control (herbicide), grown to 20 years old, and with high site index (fig. 2).
- Top height FVS predictions can be accurately used with or without intensive management. However, basal area and quadratic mean diameter predictions are most accurate when planning to use competing vegetation control and to grow stands for at least 20 years.

**Summary:**

- In California, climate change, dramatically manifested in the increasing severity and extent of wildfires, is renewing interest in tools to guide silvicultural treatments for reforestation. Managers often face difficult decisions regarding the potential use of herbicides, which are commonly an essential competing vegetation control method for assuring reforestation success in the region. Young stand fertilization may also help quickly achieve forest resilience and resistance to reburns.
- The Forest Vegetation Simulation (FVS) is a commonly used tool for silvicultural planning on National Forest System lands in the region. However, regional FVS variants currently lack a way to integrate the effects of vegetation control or young stand fertilization.
- We leveraged 20 years of growth data from the Garden of Eden experimental plots in Northern California. Six study sites represent a gradient of site quality, from the poorest to the best, within the natural range of the ponderosa pine forest type in the Coast Ranges, Klamath Mountains, southern Cascades, and Sierra Nevada. The experimental plots have a factorial experimental design, with two levels of fertilization (applied or

not applied) and two levels of vegetation control (complete or none). Treatments were applied for the first several years of growth.

- We compared FVS bare ground simulations to measured growth data (top height, basal area, and quadratic mean diameter) at 10 and 20 years old. We also compared FVS models using the Inland California (CA), Northern California Klamath Mountain (NC), and Western Sierra Nevada (WS) variants.
- With this dataset, we evaluated potential benefits and trade-offs of competing vegetation control and fertilization for reforestation success. In addition, we plan on developing a simple workflow for managers to incorporate these treatments into planning.

**Key Concepts for FVS Users:**

- FVS bare ground simulations (density = 681 trees/acre, 100 percent survival, uniform spatial distribution, no sprouting) accurately predicted top height (fig. 1), but not basal area and quadratic mean diameter for the Garden of Eden experimental plots.
- Growth predictions did not align with their geographic variant. Top height was most accurately predicted by the Inland California (CA) variant, which overlays the geographic location for most of the study sites. Basal area and quadratic mean diameter were best predicted by the Northern California Klamath Mountains (NC) variant, which does not correspond with any of the study sites' geographic location.
- The most accurate FVS predictions for top height, basal area, and quadratic mean diameter were for plots with competing vegetation control (herbicide), grown to 20 years old, and in high quality (high site index) sites (fig. 2).

**Management Applications/Future Directions:**

- For California forest managers not planning to use competing vegetation control in their reforestation management plans, utilizing top height predictions from FVS bare ground simulations will most accurately reflect actual growth data in the field (compared to basal area and quadratic mean diameter). Additionally, focusing efforts in areas with high site indices and growing stands to at least 20 years old will also increase FVS model accuracy. Accurate top height estimates are important as indicators of susceptibility to crown scorch during reburns.
- For managers planning to use competing vegetation control in their reforestation management plans, top height, basal area, and quadratic mean diameter can accurately be used to predict growth. However, it is important to note that the FVS bare ground simulations will accurately predict growth only with competing vegetation control and when stands are grown for at least 20 years. Assuring the accurate prediction of basal area and quadratic mean diameter would be important for anticipating effects on carbon stocks and stem fire resistance.

- Our next steps are to re-evaluate the models, calibrate them with 5-year height and mortality data, and bin site indices. Furthermore, we plan on creating an updated scientific guidance and decision support tool for California national forest managers to aid the planning and monitoring of silviculture treatments using FVS.

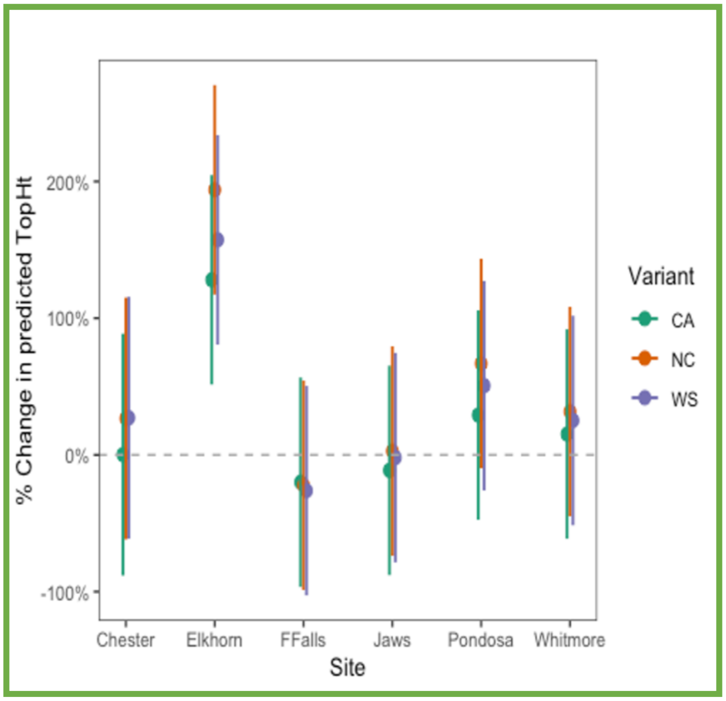


**Figure 1—**Percent difference in predicted top height between FVS bare ground simulations and measured data from the Garden of Eden experiment. Data are pooled from stands at both 10 and 20 years old. Top height was accurately predicted by FVS for 5 of 6 sites, across the 3 tested variants (Inland California [CA], Northern California Klamath Mountains [NC], and Western Sierra Nevada [WS]).

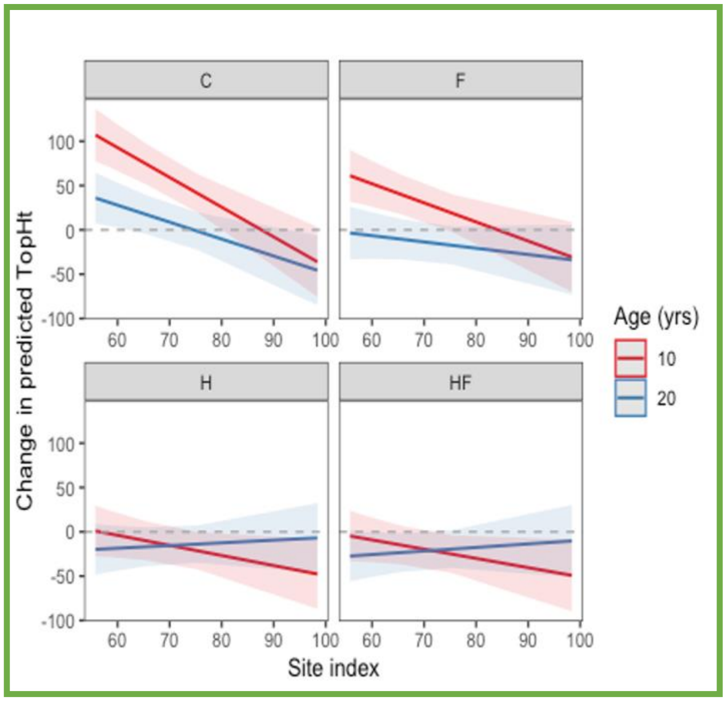


**Figure 2—**Percent difference in predicted top height between FVS bare ground simulations and measured data from the Garden of Eden experiment. The best fit model was for the Inland California (CA) variant:
*top height = age × SI + age × trt + SI × trt,*
where SI = site index and trt = treatment.

# 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:**

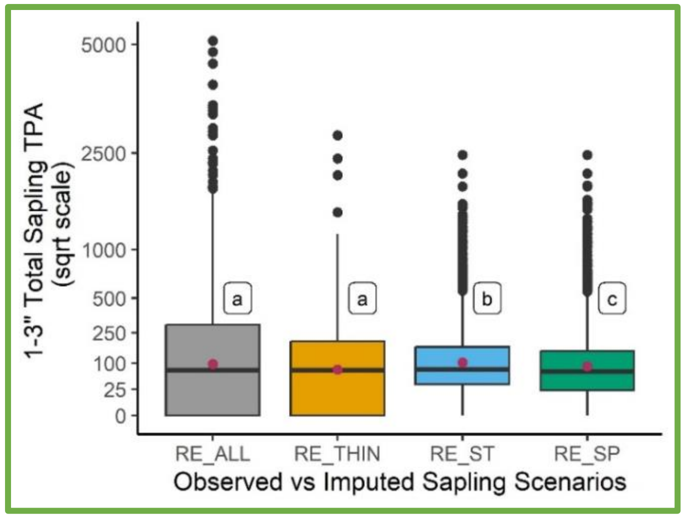
- When evaluating the effectiveness of silvicultural treatments over time in FVS, accounting for natural tree regeneration can improve the validity of simulation results. Ultimately, FVS should include full establishment regeneration models across a wider range of variants. In the meantime, stopgap methods (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.



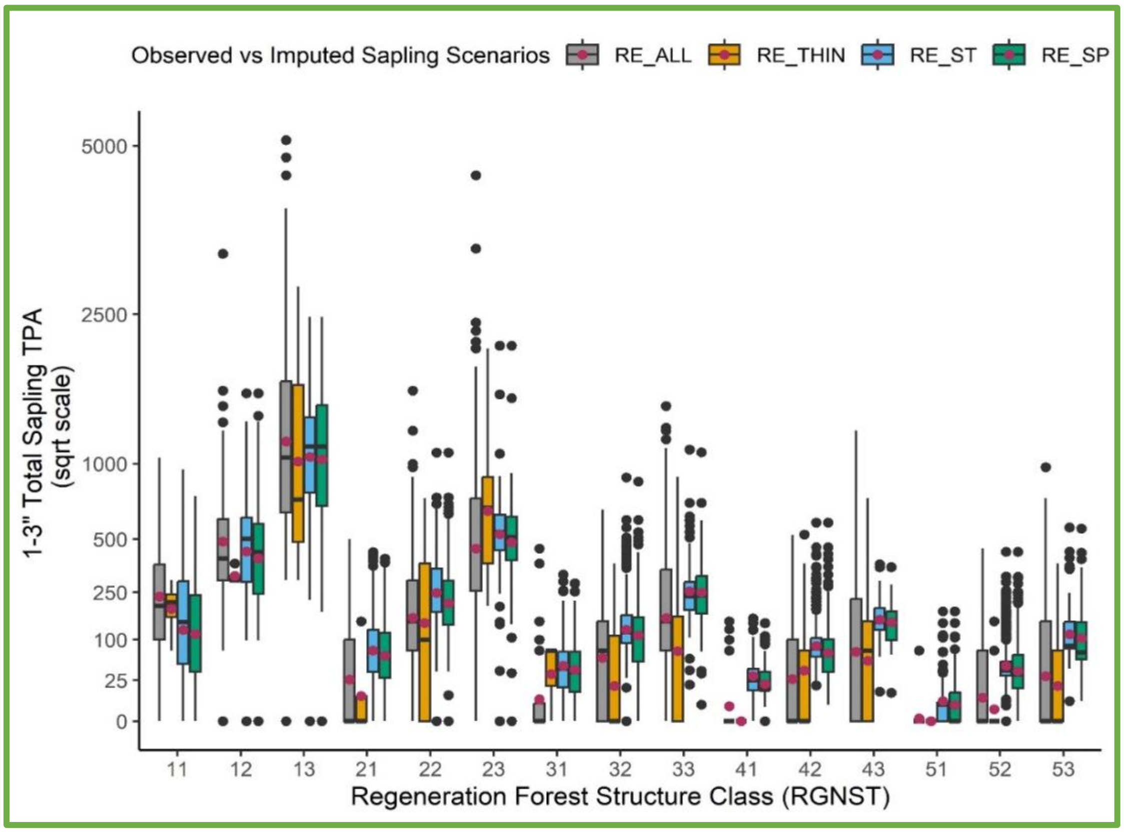




**Figure 2—**Boxplots (maroon dot in the box is the mean) comparing the distribution of empirically observed small (1-3” diameter) sapling density (trees per acre; TPA) across all WC variant stands (RE_ALL; n = 3799), stands that experienced a thinning treatment 10-20 years prior to FIA measurement (RE_THIN; 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).

# Acadian Variant of the Forest Vegetation Simulator (FVS-ACD)

Aaron Weiskittel[1*], John Kershaw[2], Nick Crookston[1,3], Ben Rice[4], Ian Prior[5]

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**Overview:**

- The Acadian Region of North America is a complex transitional ecosystem that spans numerous ecoregions, forest types, and management regimes with a high diversity of owners.
- The Acadian Variant of the Forest Vegetation Simulator (FVS-ACD) development initiated in 2008 and has been continually refined since.
- General modeling architecture and approach like other variants of FVS, but with some important differences.
- Implementation of FVS-ACD within FVS-Online is viable framework for the development, refinement, and extension of future FVS variants.

**Summary:**

The Acadian Region of North America, which includes Maine and the Maritime Provinces of eastern Canada, is a complex transitional ecosystem that bridges the more hardwood-dominated temperate forests of the southern U.S. with the more softwood-dominated boreal forests of northern Canada. The region also has a long history of private ownership and mixed management, which has created a highly mixed landscape of forest conditions. Since 2008, the University of Maine has led the development of the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD), which has seen continued development and use since its initial inception. In recent years, particular focus has been on the refinement of the diameter/height increment and mortality equations, while additional enhancements for simulating the effects of spruce budworm defoliation and hardwood stem form or risk have also been included. Consequently, model projection behavior has evolved over time yet shows reasonable alignment with regional expectations and available long-term benchmarking data. Future efforts will focus on refining stand-level growth along with regional estimates maximum stand density index and site productivity. FVS-ACD is available as stand-alone R package or an option under the NE Variant of FVS within FVS-Online.

**Key Concepts for FVS Users:**

- Robust and flexible modeling approach applicable to existing or new variants of FVS
    - Annualized, realized, and species-specific increment outperforms periodic potential times multiplier approaches.
    - Use of a climate-sensitive measure of potential site productivity allows for the use of more consistent estimates, while avoiding the need for species conversions and addressing possible future conditions due to climate change.
    - Multi-stage approach to mortality predictions outperforms more traditional approaches including methods currently used by other FVS variants.
    - Constraint of growth by stand-level equations is helpful in ensuring proper behavior especially for long-term projections (50-100 years).
    - Growth and mortality modifiers are helpful for modeling effects of management or other novel conditions such as tree form or risk.
    - Ingrowth is a critical component for regions dependent on natural regeneration.
- Novel incorporation into FVS-Online based on available Open-FVS framework and custom R function.
- Development of a broader framework for model testing and deployment within the existing FVS structure, which may help with the speed and ease of getting new growth models and model improvements into users' hands.

**Management Applications/Future Directions:**

- Flexible modeling approach for capturing the dynamic effect of alternative management regimes, climate change, and potential influences of disturbances like spruce budworm defoliation in a complex region.
- Regional inventories should be expanded to include assessments of tree-stem form and risk using the developed protocol given their influence on tree-level growth and mortality trends.
- Future efforts will focus on better constraining tree-level growth predictions, improved representation of high-resolution site productivity differences, and development of additional modifiers, particularly extending form and risk to a greater number of species in the region.

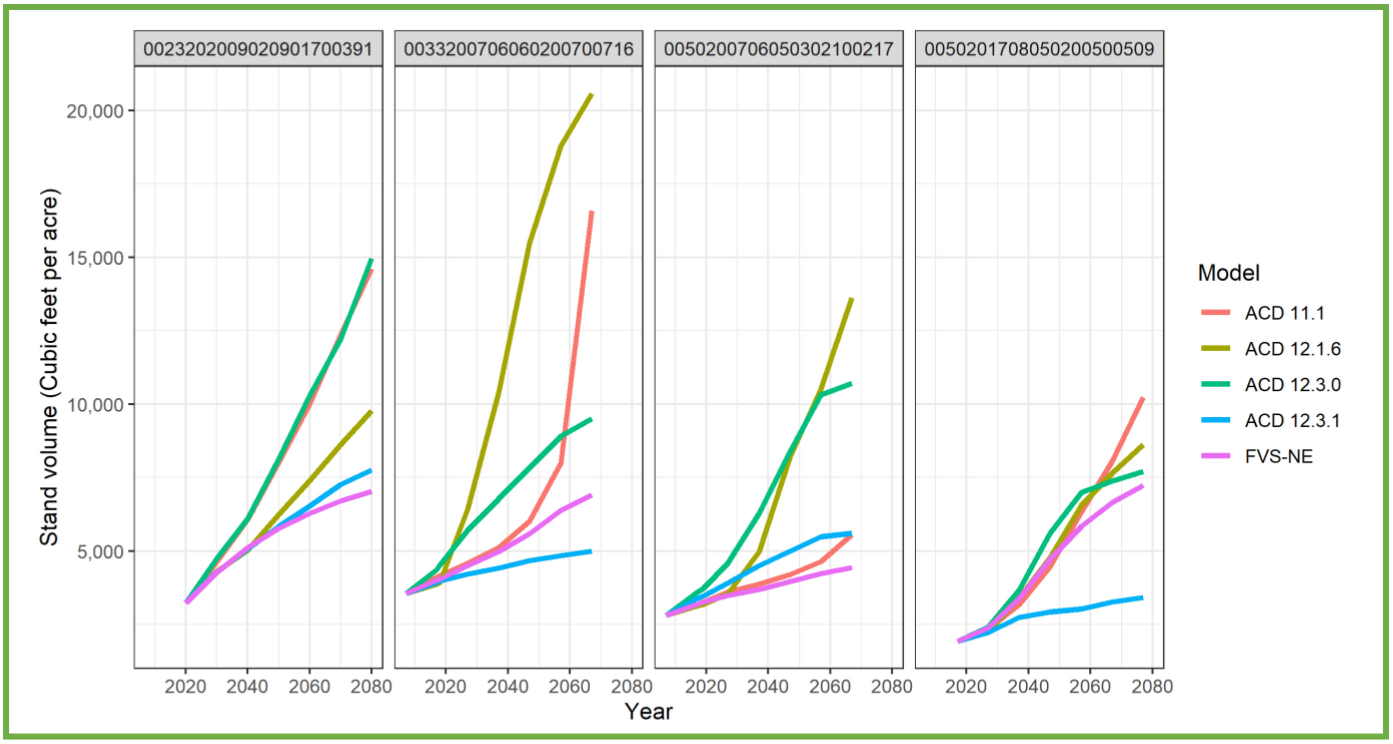


**Figure 1—**Fifty-year projections of stand total volume (ft$^3$ ac$^{-1}$) for selected USDA Forest Service, Forest Inventory & Analysis plots in Maine covering the range of typical conditions across different versions of the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD).

**Table 1—**Comparison of key equations for the previous and current version of the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD) with key references provided. The 2017 version was described in Weiskittel et al. 2018.

| Equation | FVS-ACD Version | |
|---|---|---|
| | **2017** | **2023** |
| ***Base Equations*** | | |
| Climate site index | Weiskittel et al. (2011) | |
| Crown width | Russell and Weiskittel (2011) | |
| Total tree height | Rijal et al. (2012a) (Modified) | |
| Height to crown base | Rijal et al. (2012b) (Modified) | |
| Diameter increment | Weiskittel et al. (2012) | Kuehne et al. (2022) |
| Height increment | Russell et al. (2014) | Kuehne et al. (2022) |
| Crown recession | Russell et al. (2014) | |
| Mortality | Weiskittel et al. (2012) | Chen et al. (2023) |
| Ingrowth | Li et al. (2011) | |
| Stem taper | Li et al. (2012); Weiskittel and Li (2012) | |
| Bark thickness | Li and Weiskittel (2011); Weiskittel and Li (2012) | |
| ***Modifier Equations*** | | |
| Spruce budworm | Chen et al. (2017) | Chen et al. (2018) |
| Hardwood form and risk | — | Castle et al. (2018) |

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# Accessing and Using Forest Inventory and Analysis (FIA) Data in FVS

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## Overview:

- The USDA Forest Service, Forest Inventory and Analysis (FIA) program maintains a network of more than 135,000 forested permanent sample plots that are measured on a rotating basis at 5- to 10-year intervals on all ownerships across the U.S.
- As the FIA dataset has grown, so too has the interest and demand for FIA data to be made available in "FVS-ready" format. Beginning in 2019, the FIA program released data for all 1.6 million plot visits recorded in the FIA database (FIADB) in FVS-ready format, distributed with other FIADB tables in SQLite databases through the FIA Datamart (https://research.fs.usda.gov/products/dataandtools/tools/fia-datamart).
- Since the initial release, several minor updates have been applied to the data formatting program, which is known as FIA2FVS. These updates will be applied in a completely refreshed set of tables in the spring of 2024.

## Summary:

Although there has been some level of demand for FIA data in a format usable in FVS for at least two decades, it has accelerated in recent years due to the need for data collected consistently over large geographic areas. These applications are most commonly in support of carbon- and fire-related analyses, but at scales such as individual national forests or potential woodsheds the focus is commonly on timber yield analyses. In the past, a prerequisite to any large-scale analysis was reformatting of FIA or other datasets into an FVS-compatible format.

Several concurrent developments have led to the abundance FVS analyses using FIA data: (1) compared to 20 years ago, FIA data are much more abundant and consistently collected across the U.S.; (2) FIA has been on an annualized inventory cycle, with new data collected in every state every year; (3) FVS implemented a database extension, which replaced the earlier text file format; ( 4), the FIA and FVS programs, in some coordination, adopted SQLite as a common database format for data distribution and FVS function; and (5) FVS was released as a new, browser-based interface, replacing the Suppose interface. Advances in computing power also led to the feasibility of doing simulations involving thousands of stands, since the core modules of FVS remained computationally efficient and therefore did not offset increasing CPU speeds.

The development of FIA2FVS and storage of pre-translated (FVS-ready) data in the FIA Datamart eliminated a major burden from users wanting to run FIA plot data through FVS. The data are now "plug-and-play"—i.e., users need only download the desired FIA SQLite database(s) and import the FVS-tables through the FVS interface. In addition, FVS-ready FIA data can be run in three different modes: FIA condition (stand), the whole FIA plot, usually

comprising 4 subplots, and individual FIA subplots, in contrast to the traditional stand and plot formats previously possible in FVS (figs. 1, 2; Shaw and Gagnon 2020).

**Key Concepts for FVS Users:**

- User demand and innovative use of FIA data in FVS has been important to the recognition and support of continued maintenance of FVS-ready FIA data in the FIA Datamart.
- Due to the large amount of data, varied history of FIA plot design, presence of undocumented variations in data content and formatting in FIADB, and other factors, user feedback is essential to improving and maintaining data quality. Users who discover or suspect that problems running FIA data in FVS might be data-related should contact the author (john.d.shaw@usda.gov).
- As with any downloadable dataset, users should make note of the download date(s) for the database(s) they are using. Each State is updated separately as new plot data are loaded to FIADB. In addition, State-level updates generally cover only the most recent 5 years. The planned comprehensive database refresh will synchronize State-to-State versioning more closely.

**Management Applications/Future Directions:**

- With easy access to FVS-ready data, the number and variety of applications continues to grow. The linkage of TreeMap (Riley et al. 2022) to FVS-ready FIA data now allows users to “grow pixels” in FVS simulations, allowing for analyses that were not previously possible.
- Following the implementation of the most recent changes to FIA2FVS and the upcoming database refresh, an updated user guide will be released. This will cover advanced topics, such as connecting FVS tables to the core FIA tables for different purposes.

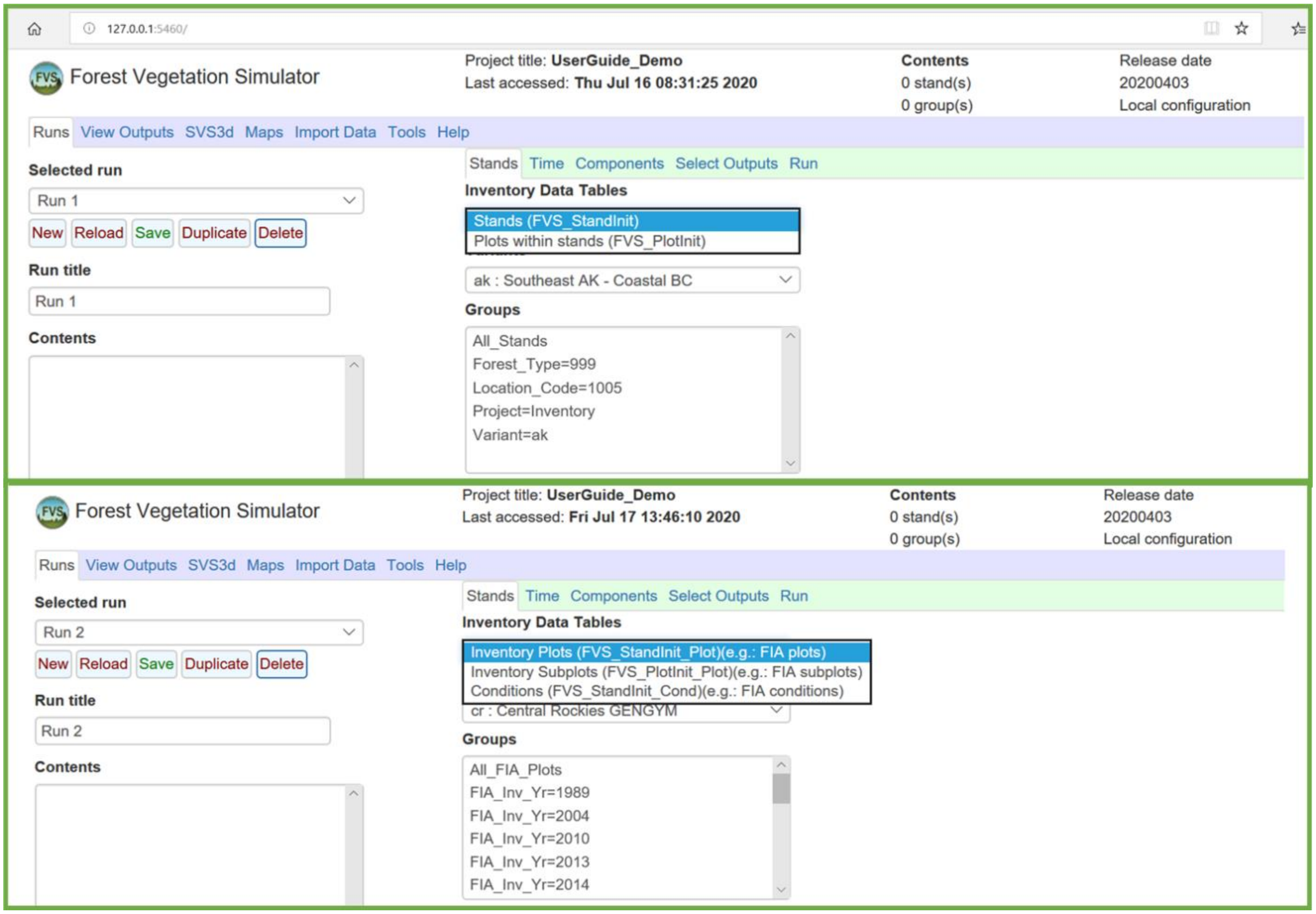


**Figure 1—**Comparison of stand selection options when using conventional data in FVS (top) and FVS-ready FIA data (bottom). Because FIA2FVS produces standardized output, FVS recognizes the format on the input step and automatically provides the option of projecting FIA conditions, whole plots, or subplots.

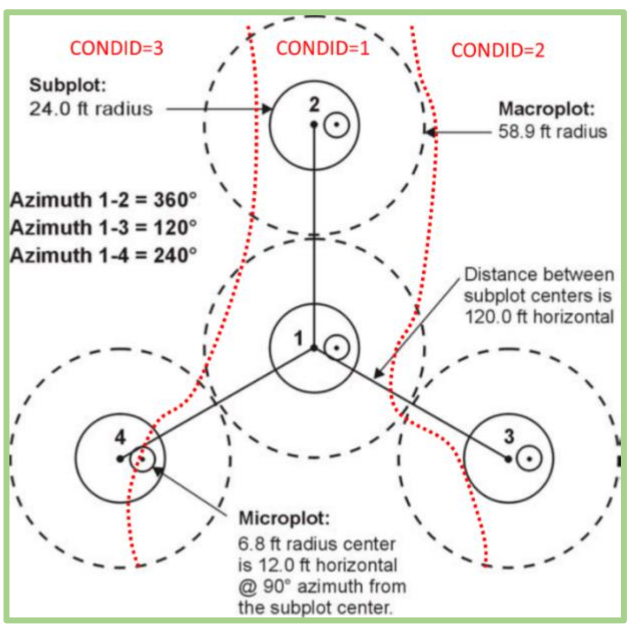


**Figure 2—**Diagram of the current FIA plot design, showing the mapping of conditions (CONDIDs). Conditions in FIA data are equivalent to "stands" as they might be mapped in preparation for a conventional inventory for the purpose of stratification and plot layout. In the methodology used since about 2000, FIA does not rearrange subplots to accommodate natural stand boundaries; the plot is located at the theoretical position, and any existing boundaries, which may exist between different forest types or forest and nonforest, are mapped in the dataset. Condition-level data, in FVS_StandInit_Cond, are most true to traditional stand delineation and the FIA data structure. Plot-level data (FVS_StandInit_Plot) ignore condition boundaries and therefore certain compromises in the data structure. For example, assuming that condition #1 is forested, the variables populated in FVS_StandInit_Plot (e.g., site index or PV_Code) will be those that are recorded for condition #1 because it occupies the majority of the plot footprint. Attributes for conditions #2 and #3 are ignored.

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# FVSOnline Server Software Components, Installation, and Management

Nicholas Crookston[1*] and Philip Radtke[2]

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**Overview:**

- FVSOnline is an R-shiny (RStudio 2023) application used to build FVS (USDA Forest Service 2023) simulations, run, and display results. The system has a client-server architecture where the server is a specialized R (R Core Team. 2021) package that is running in an R session and the client is a graphical user interface running in a web browser.
- The installation at Virginia Tech was done with open-source software and is free of software license fees. The routine maintenance of the system is done with scripts that automatically update the software and management user projects with little day-to-day intervention. It takes about 8 hours per month to operate the system.
- The Virginia Tech installation does not include any special components that provide information security and is therefore most appropriately used for training and testing purposes. It is generally not suitable for the storage of proprietary information. It could be useful, however, to replicate the system described here for use on a private network where proprietary information can be safely stored.

**Summary:**

FVSOnline runs in the free version of the R-Shiny server: https://posit.co/download/shiny-server/. That version does not support secure network traffic, that is, only http and not https protocols are supported. Therefore, we use the Apache web server to provide https service and enable Apache to route traffic between the public network and the R-Shiny server which is set to only accept connections from "localhost" (fig 1). The server we use is running Ubuntu Server 22.0 4 LTS on a 32 core Intel-based Dell computer. The management of software and a user's project spaces is accomplished using bash scripts that run every night as scheduled using the Linux cron system. Contact the authors for copies of the scripts and configuration files that manage the system.

**Key Concepts for FVS Users:**

- You can use the Virginia Tech installation of FVSOnline by creating an FVS project at https://charcoal2.cnre.vt.edu/FVSOnline/ [1]
- The system will send you an Email with a link to your project. Anyone with the link can access the project. Using the features in FVSOnline, you can load your own data, make

simulations, view and download the results without installing FVS on your own computer.
- Government agencies and other organizations are free to use this software for their own purposes.

## Management Applications/Future Directions:

- We intend to maintain this service for the foreseeable future and will help others who wish to replicate our installation on other computer systems.

```
server {
listen 3838;
      location /FVSwork {
      site_dir /home/shiny/FVSwork;
      log_dir /var/log/shiny-server;
      directory_index off;
      simple_scheduler 25;
      app_init_timeout 60;
      }
...some more lines for other
purposes...
}
```

Tech details for Shiny web server (key additions):

```
<Proxy *>
Allow from localhost
</Proxy>
Redirect /FVSOnline /FVSOnline/
ProxyPass /FVSOnline/
http://localhost:3838/FVSOnline/
ProxyPassReverse /FVSOnline/
http://localhost:3838/FVSOnline/
Redirect /FVSwork /FVSwork/
ProxyPass /FVSwork/
http://localhost:3838/FVSwork/
ProxyPassReverse /FVSwork/
http://localhost:3838/FVSwork/
```

Tech details (Apache):

**Figure 1—**Technical details for the (a) Shiny web server and (B) the Apache server.

[1] At the time of publication, FVS Online was not functioning on the Virginia Tech platform due to 3rd-party software issues. FVS Online functionality will be restored after the issues have been resolved. As an alternative, Climate-FVS data can be prepared using other functions at Climate-FVS Ready Data Requests (https://charcoal2.cnre.vt.edu/climate/customData/fvs_data.php) and downloaded for use with a local installation of FVS.

## References:


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# A Bottom-up Approach for National-devel Projections of Forest Growth in Canada

Mathieu Fortin[1,*], Juha Metsaranta[1], Jean-François Lavoie[2], Derek Sattler[1], Joanne White[1], Werner Kurz[1], Jason Edwards[1], Adam Dick[1], Winnifred Hays-Byl[1], Roxanne Comeau[1]

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**Overview:**

- In Canada, empirical models of forest growth have been developed by provincial and territorial agencies, with FVS being used in Ontario and British Columbia.
- Given the diversity of models, it is difficult to obtain regional or national forest growth projections.
- The Canadian Forest Service has launched an initiative with the aim of integrating the different models into a common framework to enable regional and national projections of forest growth.

**Summary:**

Canada has a large proportion of public lands whose management falls under the jurisdiction of provincial and territorial governments. Since the 1970s, provincial and territorial agencies have been developing growth models for their own needs, making the Canadian modelling landscape a diversified one (fig. 1). Two variants of FVS are currently being used, one in Ontario and the other in British Columbia.

While this diversity can be seen as beneficial, it poses a major challenge when it comes to producing national or regional forest growth projections. These national projections are critical to carbon estimation and reporting, the national forest inventory, and the evaluation of climate change mitigation options.

Since 2020, the Canadian Forest Service has undertaken a project with the aim of integrating the different models into a framework that would allow for national and regional growth projections. This framework is based on a bottom-up approach. The growth models are used to produce predictions for different management units. Localized meta-models are then fitted to these predictions (Fortin and Lavoie 2022) and made available in a repository. This framework is based on multiple components that interact with each other through Web Application Programming Interfaces (API, see fig. 2).

So far, three models, FVS-BC, OSM and ARTEMIS, have been integrated into this framework allowing for projections in Quebec, New Brunswick, Nova Scotia, and British Columbia. As new models come into this framework and more meta-models become available, users will eventually be able to retrieve all the meta-models that apply in a particular region to produce large-area projections of forest growth.

**Key Concepts for FVS Users:**

- In our framework, the FVS model (BC variant) is wrapped into a C# Web API and will be deployed on the Web in the months to come.
- A client for this Web API will be available in an R package on GitHub. It will make it possible to send a list of trees to FVS, which will predict growth and return the results to the client.
- In this first step, these simulations will be run without any consideration for human-made or natural disturbances.

**Management Applications/Future Directions:**

- Using plot- and tree-level models, such as FVS, for large-area projections is challenging because the model input information, typically the tree lists, is not available wall-to-wall. Using a meta-model instead of the original model enables generation of a simpler model based on available wall-to-wall data inputs, while still capturing the behavior of the original model.
- Given their simplicity, meta-models are compatible with forest management applications such as linear programming.
- Climate-sensitive models will be integrated into this framework in the years to come. This will increase the spatial coverage of growth projections and enable climate-sensitive projections.


**Figure 1—**Some of the empirical growth models used in Canada. Each box represents a single model and its location on the map represents the province and territory where it is being used. This is not an exhaustive list.

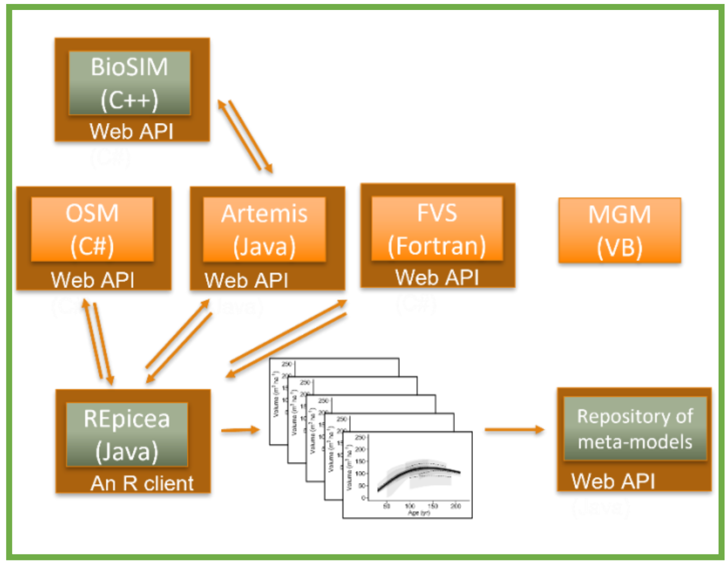


**Figure 2—**Flowchart of the framework under development. The orange boxes stand for the empirical growth models. The green boxes are pre- and post-processing tools. The brown boxes represent Web APIs or clients.

## References:

Fortin, M.; J.-F. Lavoie. 2022. Reconciling individual-based forest growth models with landscape-level studies through a meta-modelling approach. Canadian Journal of Forest Research. 52: 1140-1153. https://doi.org/10.1139/cjfr-2022-0002 [Accessed 25 October 2024]

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


Courtney L. Giebink[1,*], R. Justin DeRose[2], Mark Castle[3], John D. Shaw[4], Margaret E.K. Evans[1]

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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.

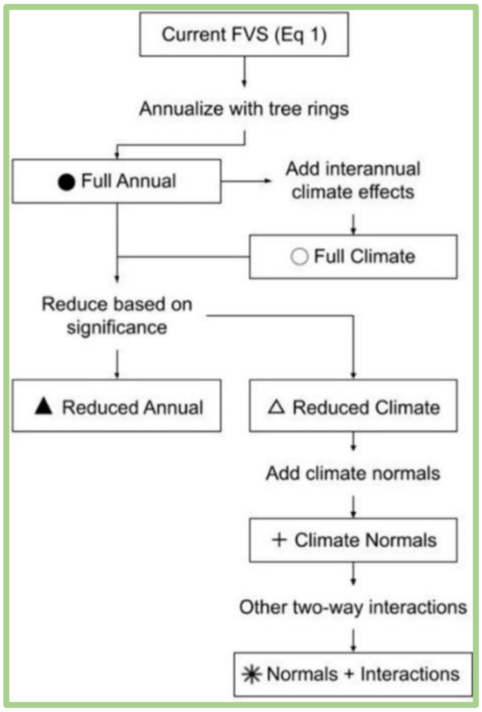


**Figure 1—**Alternative diameter growth models progressively diverged from the current large-tree diameter growth model in FVS. First, tree rings were used to convert the model to a one-year time step (annualization), creating the Full Annual model. Second, interannually varying climate variables were 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.

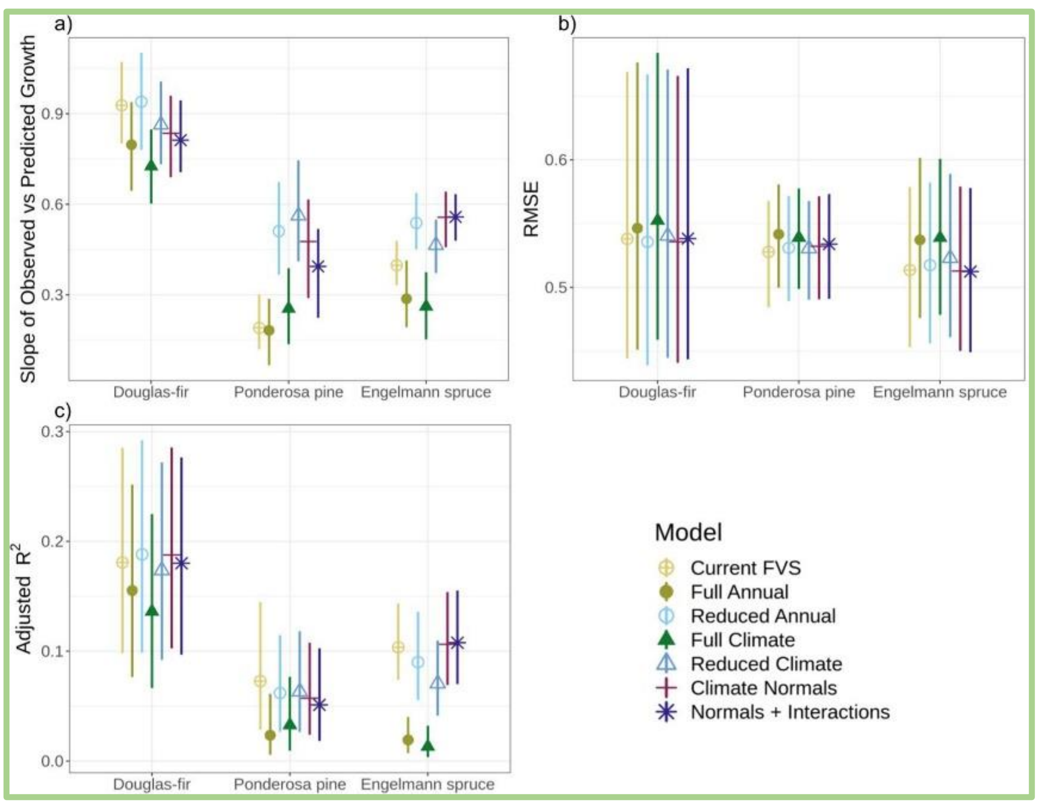


**Figure 2—**Validation of six alternative diameter growth models for Douglas-fir, ponderosa pine, and Engelmann spruce. Model performance is assessed in terms of adjusted $R^2$, root mean square error (RMSE), and the slope of the linear regression of observed vs. predicted diameter growth increment.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

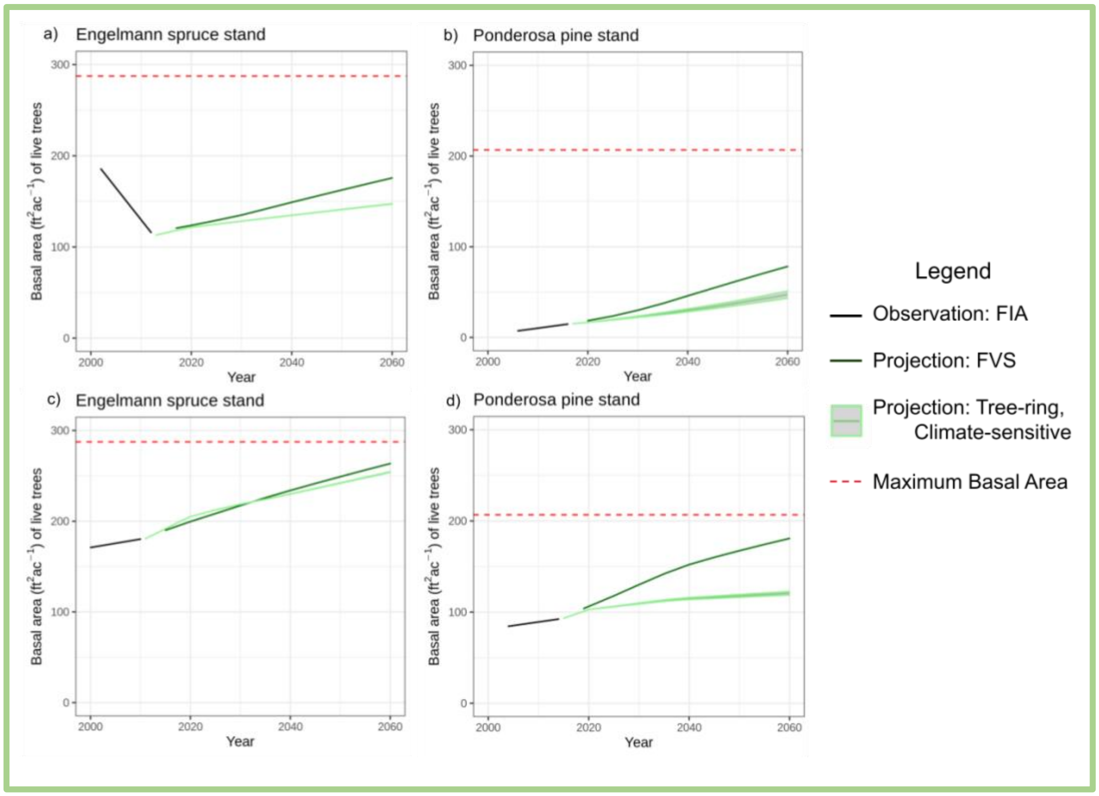


**Figure 3**—Observed and projected basal area (ft$^2$ac$^{-1}$) of live trees with and without the effect of climate. Total basal area (ft$^2$ac$^{-1}$) of live trees in pure Engelmann spruce or ponderosa pine stands in Utah as observed by the Forest Inventory and Analysis (FIA) program (black line), 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).

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DeRose, R.J.; Shaw, J.D.; Long, J.N. 2017. Building the forest inventory and analysis tree-ring data set. Journal of Forestry. https://doi.org/10.5849/jof.15-097

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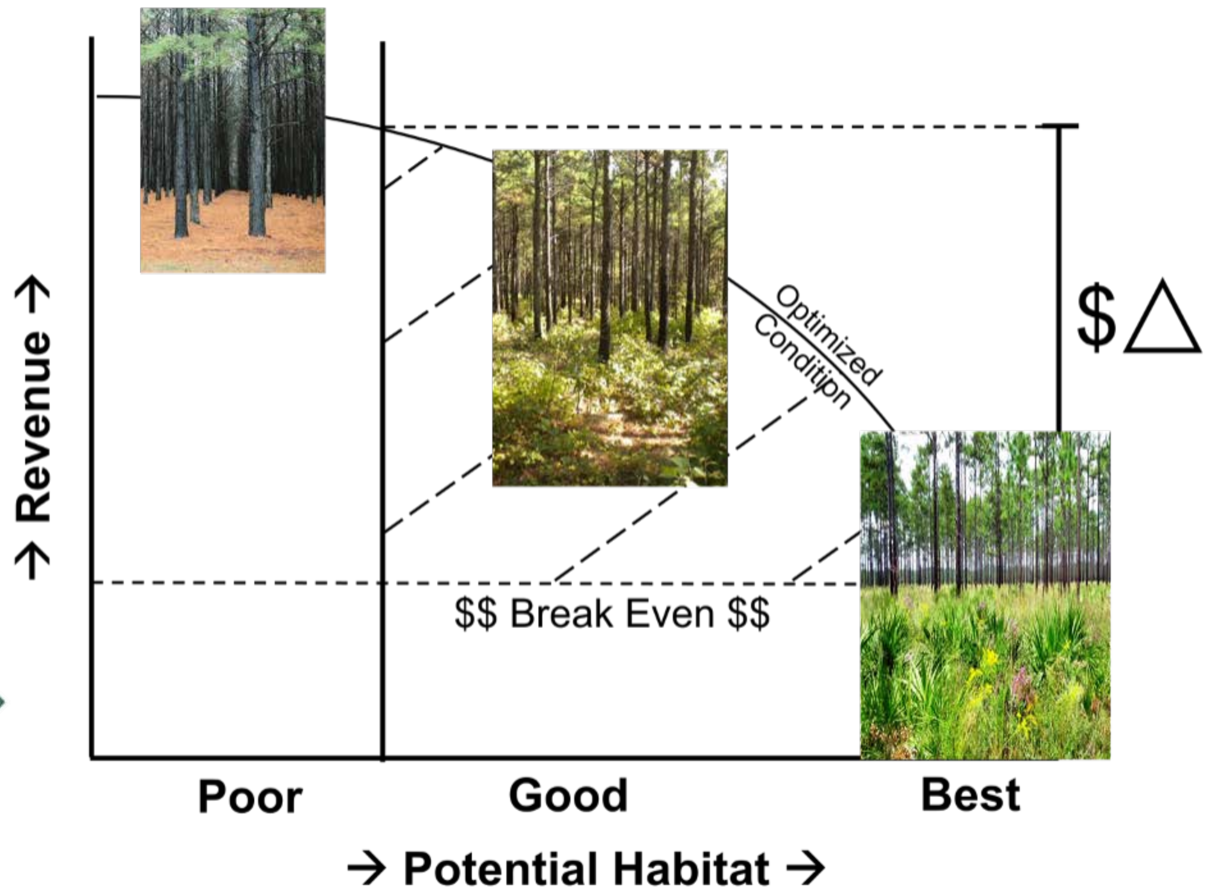
# Project Application



# Modeling Outyear Treatments for Large-Scale Landscape Restoration in FSVeg Spatial Data Analyzer

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**Overview:**

- FSVEG Spatial Data Analyzer is an effective tool for modeling outyear treatment effects across large-scale project areas.
- Imputation of Common Stand Exam (CSE) data allows for "wall to wall" modeling of treatment effects across large scale planning areas, without collecting more data.
- Users should thoughtfully develop their modeled treatments and alternatives and carefully select their temporal settings and output metrics based on the nature of the project under analysis.

**Summary:**

Effects analyses are an important requirement in federal land management. However, requirements are vague, so specialists must determine how to represent the effects of their treatments. FSVeg Spatial Data Analyzer is an effective tool in completing effects analyses for large-scale landscape restoration projects. The model, which imputes Common Stand Exam (CSE) data, allows users to model FVS treatments, analyze alternatives, and visualize treatment effects for every stand in a project area. In order to model treatment effects in FSVeg Spatial Data Analyzer, one must determine how to group treatments (prescriptions), apply appropriate treatments to represent the proposed action, establish temporal settings, identify output metrics to adequately describe changes to the forest vegetation resource, and identify alternatives. FSVeg Spatial Data Analyzer was used to model treatment effects on the forest vegetation resource within the Green Ridge Landscape Restoration Project Area on the Sisters Ranger District of the Deschutes National Forest. The process of modeling the effects of that proposed project and the associated challenges are discussed.

**Key Concepts for FVS Users:**

- Due to the spatial extent of the project area under analysis, an accelerated timeline, and the complex nature of the proposed treatment treatments, the modeled treatments were simplified from the prescriptions and the proposed action.
- Users should be cognizant of the establishment and regeneration parameters in any given variant, as that has a measurable effect on the model's outputs over an extended timeframe.

**Management Applications/Future Directions:**

- If utilized by planning silviculturists, FSVeg Spatial Data Analyzer has the potential to expedite forest vegetation effects analyses required for large-scale landscape restoration project areas and provide more comprehensive predictions across large planning areas.
- Forest Service planning staff would benefit from the development of a standard methodology for modeling treatments effects to improve clarity of expectations and expedite the process.
- Software and Versions Used:
  - FSVeg Spatial Data Analyzer
    - Product Version 3.9 – 3.15
    - Imputation Software yaImpute (SORNEC Version 1/8/2018)
  - Forest Vegetation Simulator
    - SORNEC (South Central Oregon and Southeastern California) Variant
    - Executable version 9/30/2021
- Project start date was 2/20/2019

# Using FVS to Update Inventory Data to Improve Prescribed Treatments and Timber Sale Decisions

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**Overview:**

- Taking old inventory data and running it through FVS to grow out stands to evaluate old silviculture prescriptions and make timber sale decisions.
- The FVS run for the 13 stands that make up the Blue Creek Timber Sale proved to be accurate and represented what was within these stands. When compared to the National Timber Cruise Program the difference in volume was around 1 percent; trees per acre, 3 percent; and basal area, 6-7 percent.
- Having an increased confidence in FVS growth and yield models allows us to update old stand data, have better timber sale planning, and use profitable timber sales to continue restoring Southern Coastal Plain Pine Ecosystem.

**Summary:**

The timeframe from project planning and data collection to project implementation can span several years. Having updated stand data sufficient to validate silviculture prescriptions before implementation is critical in making sure the desired conditions and goals from the project are met. For the Blue Creek timber sale located on the Ocala National Forest, the original data was collected in 2008 and 2014 before implementation in 2022. Decisions on which stands to harvest, and silviculture prescriptions were finalized in 2015 based on the original data. Another challenge in this process is having enough silviculture and timber staff to recollect data and balancing workloads between multiple on-going large vegetation projects across the district.

The Forest Health Environmental Assessment is a project that identified overstocked southern yellow pine stands across the district to thin addressing the increased potential of a Southern Pine Beetle outbreak following a drought, fire, or storm event. Implementing thinnings is the first step in moving these stands to an uneven- age management which is a primary Forest Objective. The Blue Creek timber sale consists of 13 planted, even-age slash pine stands. In 2022 we needed to validate and possibly update our decision and silviculture prescriptions from 2015. Using FVS we were able to use the original data collected and do a simple run for slash pine with the Southern Variant. The results from FVS validated what we were seeing within the stands in our walk throughs and were later compared to the outputs from the National Cruise Processing Program (NatCruise). After comparing the outputs from FVS and NatCruise we found that standing volume fell within 1-2 percent, trees per acre fell within 3-4 percent, and basal area 6-7 percent. These results increased our confidence in FVS as a

planning tool and allowed for better timber sale planning and packaging to meet our objective, while having a competitive sale that a timber purchaser will buy.

**Key Concepts for FVS Users:**

- The ability to update old Common Stand Exam data using FVS.
- The Southern Variant of FVS produced accurate estimates of growth for even-age slash pine in central Florida.
- The ability to set a common starting year and bring multiple years of collecting data to the same point in time to view.
- The FVS_Summary2_East table allows users to easily assess stand changes over a simulation timeframe. This output can be exported to Microsoft Excel which facilitates analysis and comparisons to other data sources.
- This project demonstrated that FVS produced accurate estimates of stand volume that were comparable to the production cruise data for the Blue Creek timber sale.

**Management Applications/Future Directions:**

- This project increased the confidence in the use of FVS as a management planning tool.
- Being able to see the change in stands overtime to have an idea of what a stand may look like since you last visited it.
- Instead of re-inventorying a stand, previous inventory data can be grown to a common starting year in FVS. These results can be used in the field to determine if additional data should be collected for stand exams. This can increase efficiency and allow for better prioritization of stands where additional data should be collected.
- A timber sale has to cover a higher cost per activity for the Agency and the timber purchaser buying the sale. Timber Sale Planning is highly important so that stands are selected and grouped together so that there is enough volume in the sale to cover the cost and be profitable to the timber purchaser.
- The Ocala National Forest silviculture and timber shops will incorporate FVS into future southern yellow pine thinning and treatments. It has shown to be an effective decision making and planning tool.
- Comparison of FVS results with the National Cruise Processing Program will continue across even and uneven aged southern yellow pine stands. This analysis will hopefully build further confidence in the FVS program.

**Table 1—**Comparing the original data to the common starting year using FVS.

| Comparison of Selected Stands | | |
|---|---|---|
| **Measure** | **2008/ 2014** | **2022** |
| Avg BA | 102 | 140 |
| Avg QMD | 6.7 | 8.4 |
| Avg Height | 60.4 | 69.7 |
| Total CCF | 11,314 | 21,173 |

**Table 2—**Comparing FVS Output to the NatCruise Outputs.

| Measure | FVS | NatCruise | Difference |
|---|---|---|---|
| TPA | 369 | 357 | 3.3% |
| BA | 140 | 131 | 6.5% |
| Total CCF | 21,173 | 21,409 | 1.1% |

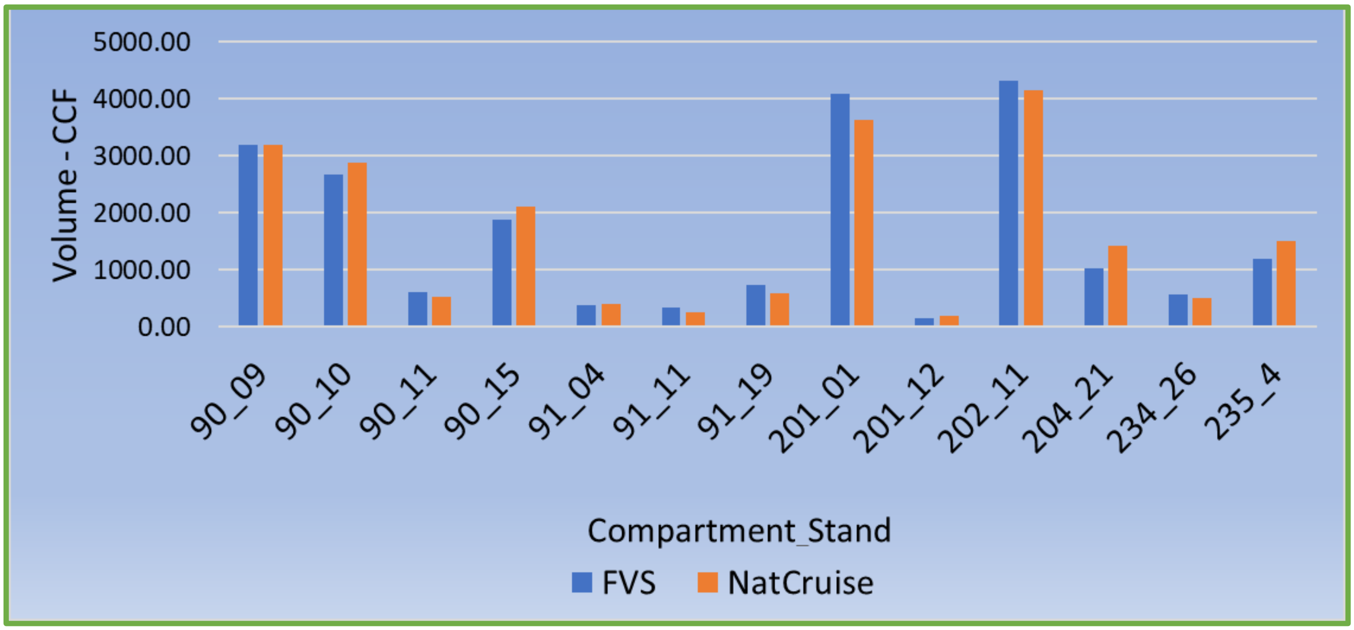


**Figure 1—**Comparing the volume in Hundred Cubic Feet (CCF) per stand between FVS and NatCruise

# Using FIA Data and FVS to Develop Yield Streams and State-and-Transition Models for National Forest Planning

John D. Shaw[1*], Eric Henderson[2], Gunnar Carnwath[2], Sheryl Gunn[3]

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**Overview:**

- Decision support systems (DSS) and optimization models have been part of the National Forest planning process for several decades, and the amount of data and analytical complexity has grown with advances in tools and computational power.
- Current planning projects, such as the Lolo National Forest plan revision, are using the PRISM DSS in conjunction with state-and-transition models to evaluate a wide variety of management scenarios and their outcomes as they relate to a wide variety of forest management objectives (figs. 1, 2).
- The primary goal of this project is to develop a process and information to inform landscape-scale vegetation models with stand-level vegetation change projections under different management regimes. This process has been done in different ways for various forest plans, but it has not been documented to the extent that it is reproducible, and previous efforts did not use the currently available data and tools. As a result, the secondary goal is to document the process in sufficient detail such that the important elements that are likely to be common in other forest plans can be replicated. This should make for efficient completion of this component of forest planning.

**Summary:**

DSSs have become an essential part of forest planning. FORPLAN was the primary analysis tool for Forest Service land management planning starting in 1980. Although it was cutting edge at the time, there were many criticisms, including it not being user friendly, being difficult for analysts, managers, and the public to understand models and explain results, and expensive to run in terms of computer resources. Computing power has grown independently, and FORPLAN has been succeeded by a long line of alternatives, including SPECTRUM, SIMPPLLE, VDDT, and LANDIS. In most cases, this has resulted in “starting over” with respect to the user experience with scenario setup and analysis, including the preparation of large amounts of input data for the models. As a result, carry-over of methods from forest plan to forest plan is minimal.

The forest plan revision for the Lolo National Forest represents the current step in the evolution of this process, with the PRISM model (Nguyen et al 2022) being used for scenario evaluation and optimization, ST-Sim providing state-and-transition data (Daniel et al. 2016) for use in PRISM, and FVS providing yield stream data for PRISM and state-and-transition input data for ST-Sim. Potential source data include the Forest Inventory and Analysis database

(FIADB) and the Field Sampled Vegetation database (FSVeg). The use of FVS to produce yield stream data as optimization model input has a relatively long history of use in forest planning, but documentation of methods is sparse and sometimes specific to particular forest plans. As a result, there is a documentation need.

Because all of the necessary modeling and evaluation steps would have to be done in support of the Lolo plan revision, the opportunity was used to explore a range of methodological approaches. During the evolution of the process many alternatives were either tried and rejected or implemented and possibly improved upon in later parts of the process. Although there are many parts to the process, documentation of the explored and adopted alternatives is focused on the use of FVS as a primary source of input data for the other models.

**Key Concepts for FVS Users:**

- Data acquisition was the first step. We considered FIADB and FSVeg as the primary data source candidates. FSVeg can include FIA data, but inclusion at the National Forest level is "on demand" at the request of the Forest. Early in the process we rejected FSVeg in favor of FIADB, partly due to a technical issue with FSVeg Spatial, which has since been resolved, and some other limitations. However, lessons learned from the use of FIA data might be useful for a future re-evaluation of FSVeg as a primary data source.
- We used a number of techniques to expand the dataset and streamline simulation runs. For example, there are fewer than 400 FIA plots on the Lolo, so the number of plots included in the simulation dataset was expanded by using plots from surrounding forests with PV_Codes (habitat types) common with those found on the Lolo. Another method involved "replicating" plots in the input database, which was accomplished by appending Stand_CNs and Stand_IDs with a suffix corresponding to silvicultural scenarios that would be applied in the simulations. This approach replaced the need to select groups of stands and apply keywords; KCP files were simply added to the AddFiles column in the StandInit tables according to the prescription applied to each replicate. As a result, replicates of each stand were easily identifiable in output and output tables.

**Management Applications/Future Directions:**

The timing of this project coincided with the beginning of implementation of Forest Service Planning Service Centers, which are intended to streamline many aspects of forest planning and plan revision. Although the results of our process could be applied by other individual National Forests with plan revisions scheduled for the near future, we recognized that the successful implementation of Planning Service Centers could especially benefit from a well-documented process. Among the potential benefits would be higher consistency of the yield steam components among new forest plans, and Planning Service Centers serving as "institutional repositories" for the methods and documentation we developed. The potential for institutionalization of the process is especially attractive because we found that the sparse amount of existing documentation also came from disparate sources, and frequently left open questions that required follow-up investigations.

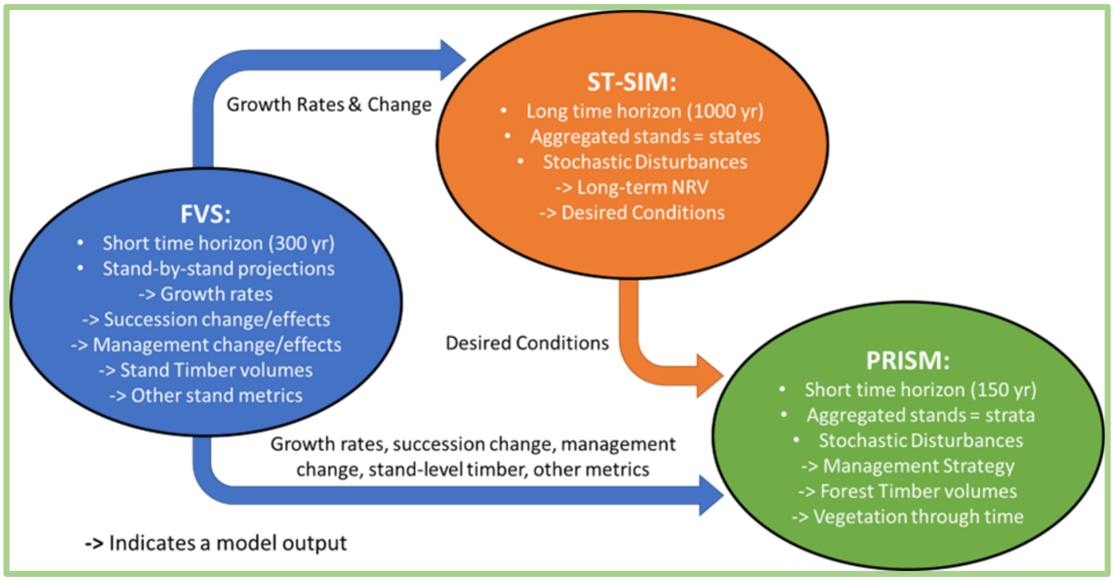


**Figure 1—**General framework for running alternative scenarios through FVS to produce state-and-transition and yield stream data.

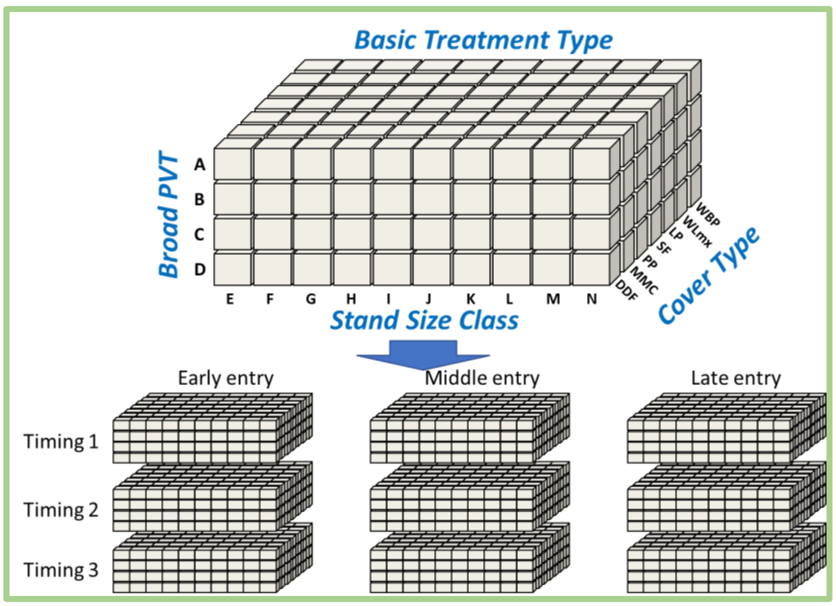


**Figure 2—**Graphic illustration of how a basic silvicultural treatment type expands into a potentially large number of treatment options when different combinations of entry timings (e.g., precommercial thinning, commercial thinning, final harvest) are needed to supply alternative yield stream data to optimization programs such as PRISM.

## References:


Daniel, C.J.; Frid, L.; Sleeter, B.M.; [et al.]. 2016. State-and-transition simulation models: A framework for forecasting landscape change. Methods in Ecology and Evolution. 7(11): 1413-1423.

Nguyen, D.; Henderson, E.; Wei, Y. 2022. PRISM: A decision support system for forest planning. Environmental Modelling & Software. 157, Issue C, p. 105515. https://doi.org/10.1016/j.envsoft.2022.105515

# FVS Modeling for the Devils Hens Nest Vegetation Management Project

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**Overview:**

- Timber harvesting operations often have high costs associated with them, especially when topography necessitates advanced harvesting systems for operating on steep slopes.
- For operations to be commercially viable, the timber harvest volume associated with the silvicultural prescription must be sufficient to offset costs and still produce a profit.
- FVS was used to assess commercial viability of each planning unit in the Devils Hens Nest Project by modeling the prescribed harvests and analyzing outputs of associated harvest volumes.
- This type of preliminary analysis has the potential to significantly reduce costs associated with project planning and implementation, as well as to better inform decision-makers, managers, and specialists.

**Summary:**

The lengthy process of planning and preparation that precedes the advertisement of a federal timber sale comes with significant costs in resources and time. After this process is complete, many proposed timber sales ultimately go “no bid” because the value of the prescribed harvest would be insufficient to offset the costs of operations. This problem demonstrates a need for preliminary analysis of the commercial viability of proposed silvicultural treatments prior to sale preparation and implementation. To conduct such an analysis for the Devils Hens Nest Vegetation Management Project, located on the Clinch Ranger District of the George Washington and Jefferson National Forests, FVS was used to model the prescribed treatments of 134 planning units over 97 stands (35 units proposed for coppice with reserves; 97 units proposed for thinning). FVS outputs of harvest volume were processed in Microsoft Excel to extrapolate values by unit acreages, make unit conversions, calculate weighted means, produce charts and graphs, calculate volumes and harvest percentages by product class, etc. Local guidelines were used as quantifiable thresholds for commercial viability: sawtimber harvest volume > 5 MBF/ac for conventional (ground-based) units; sawtimber harvest volume > 8 MBF/ac for units that require advanced harvesting systems. As expected, coppice with reserves treatments tended to have greater commercial viability; all conventional units met the criteria for viability, and only one advanced unit failed to meet the criteria. Of the units proposed for commercial thinning, 50 percent failed to meet the criteria for viability: 18 conventional and 31 advanced.

**Key Concepts for FVS Users:**

- By only changing the year of harvest, the same workflow can be used to determine when a silvicultural prescription would become commercially viable for a given stand.
- Similarly, commercial viability of different silvicultural prescriptions (alternatives) can be compared by having multiple runs in FVS for the same stands.

**Management Applications/Future Directions:**

- Preliminary analysis of commercial viability for proposed silvicultural treatments has the potential to significantly reduce planning and implementation costs associated with forest management.
- Additionally, this type of workflow can be used to compare commercial viability of alternative prescriptions or determine when a prescription will become commercially viable in the future (due to tree growth and subsequent increased harvest volume).

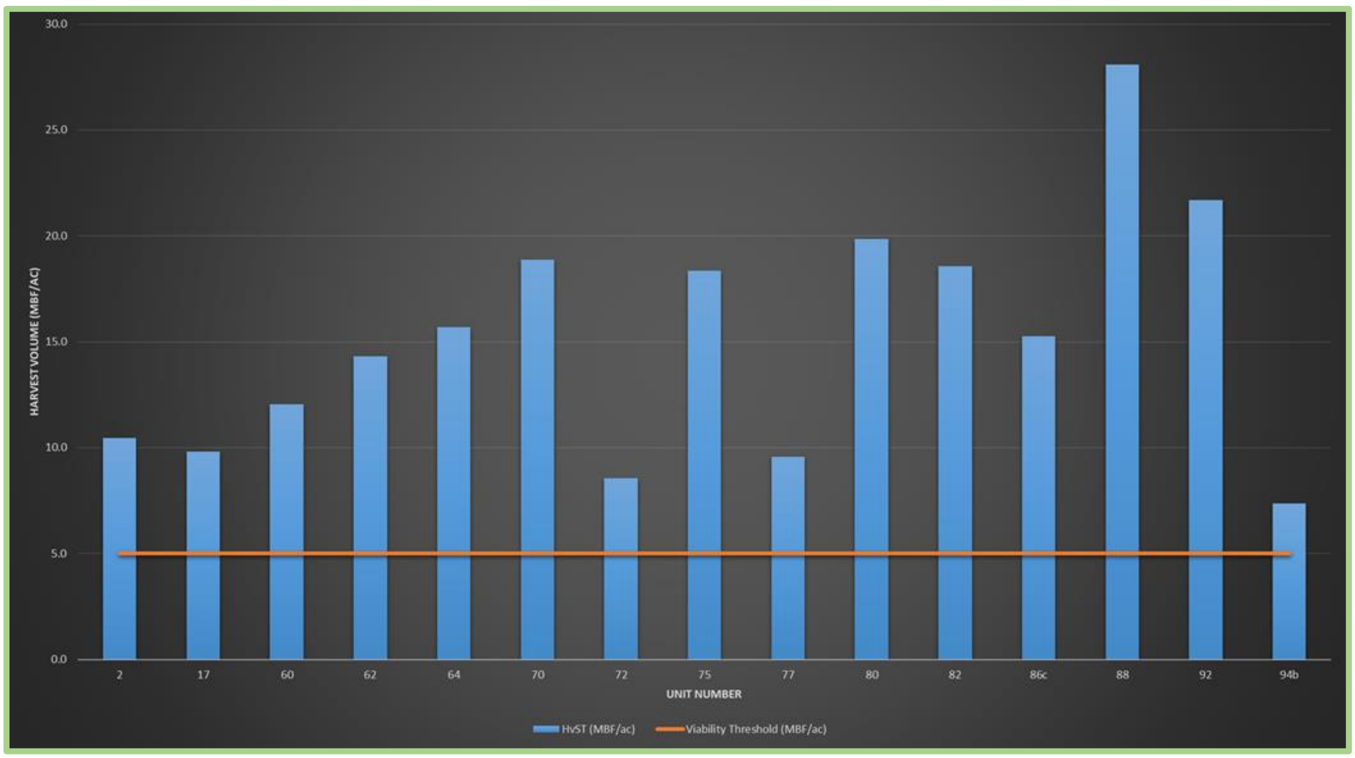


**Figure 1—**Sawtimber harvest volumes for coppice with reserves treatments (conventional logging).

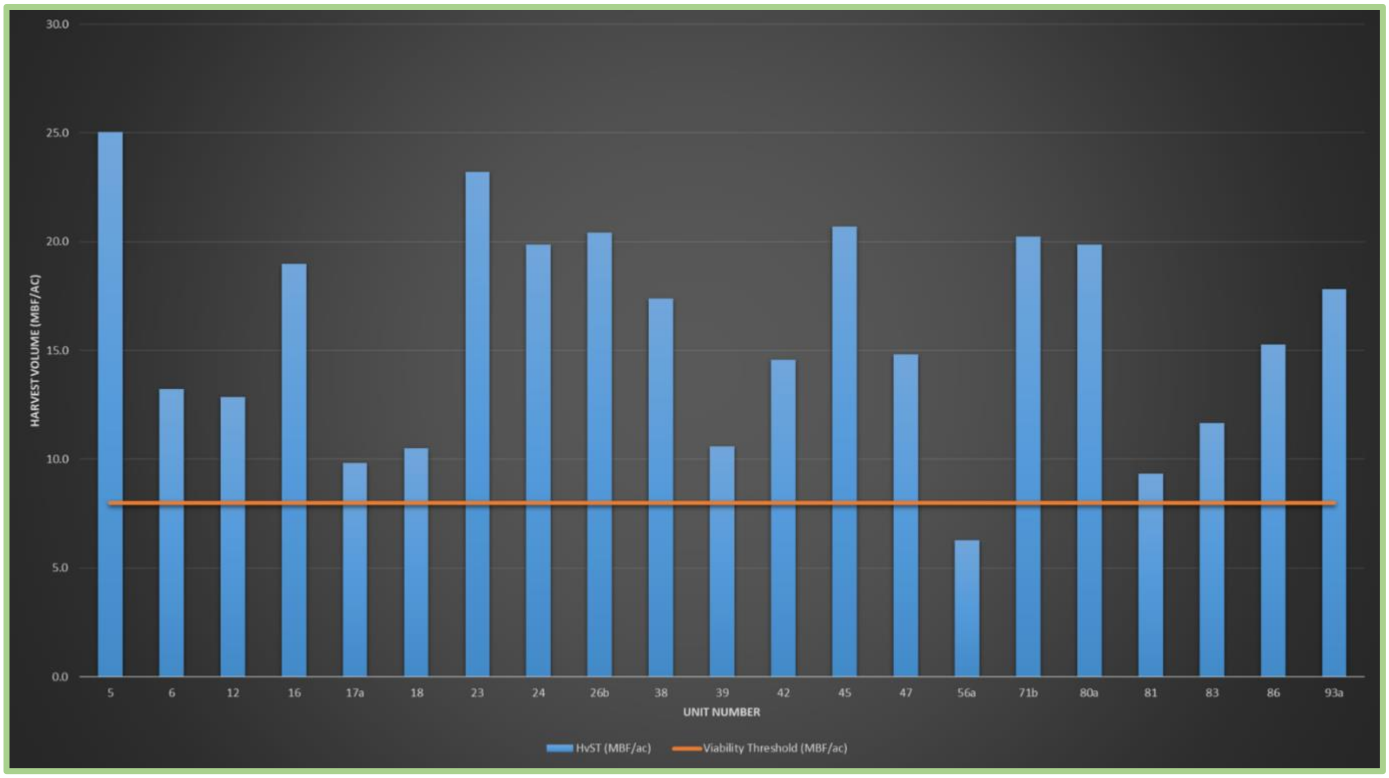


**Figure 2—**Sawtimber harvest volumes for coppice with reserves treatments (advanced logging).

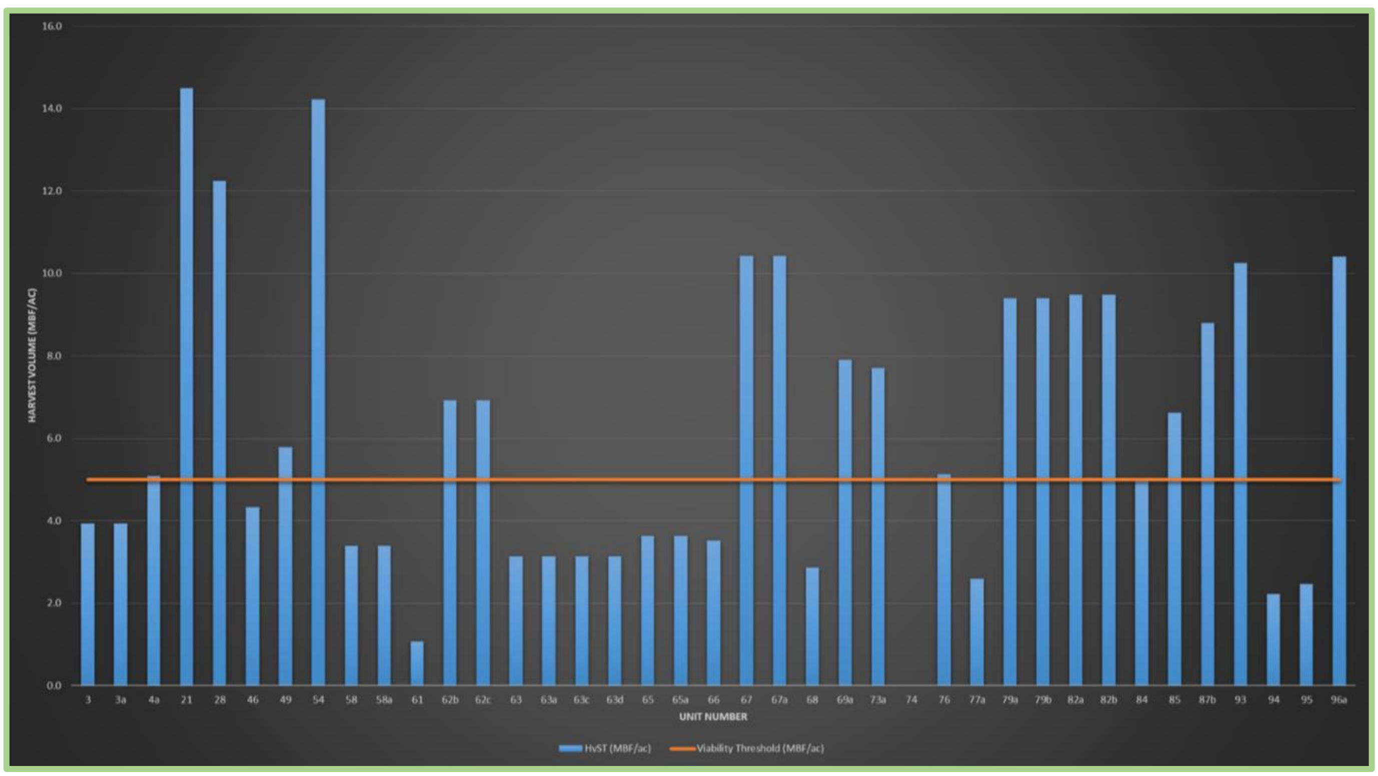


**Figure 3—**Sawtimber harvest volumes for thinning / establishment treatments (conventional logging).

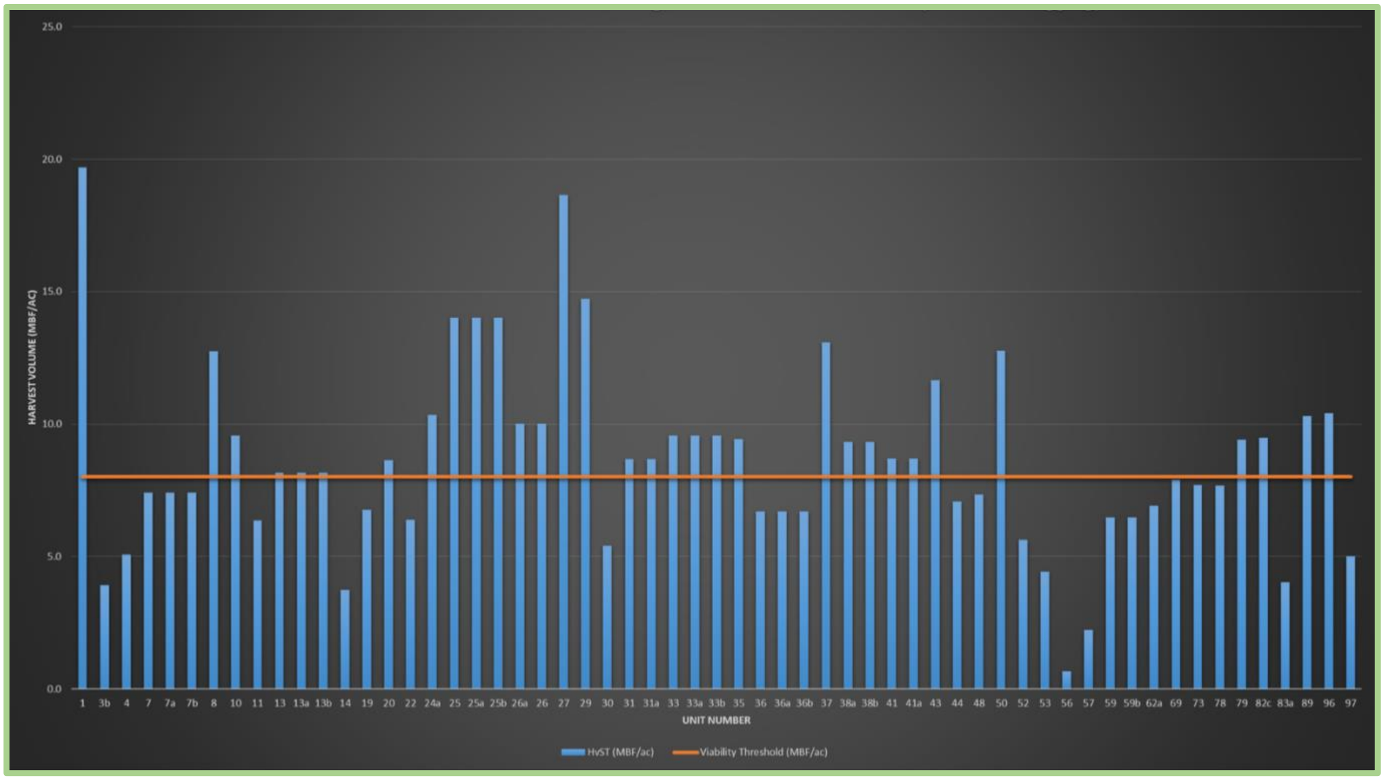


**Figure 4—**Sawtimber harvest volumes for thinning / establishment treatments (advanced logging).

# Integrating Wildlife Habitat Into a Constrained Optimization Strategy on State-Owned Timberlands in North Carolina

Casey E. Phillips[1,2], Joseph P. Roise[2], Christopher E. Moorman, Rachel L. Cook, Rajan Parajuli, Christopher Jordan[1]

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**Overview:**

- Prioritizing wildlife habitat objectives in forest management planning requires quantifying the relationship between the structure and composition of a forest stand and the potential habitat it can offer target wildlife species.
- The Forest Vegetation Simulator (FVS) was used to model habitat indicator metrics in addition to standing and removed timber volumes to evaluate tradeoffs in wildlife habitat and timber production objectives on the timberlands owned and managed by the North Carolina Wildlife Resources Commission.
- Habitat was evaluated for 16 wildlife species, which were identified by agency staff and grouped into four focal guilds (i.e., Open Forest Associates, Longleaf Pine Associates, Shrubland Associates, and Ruffed Grouse), based on commonalities in habitat preference and subsequent targets for forest structure and composition through silvicultural treatments.
- Woodstock models formulated to maximize wildlife objectives tended to thin stands multiple times before scheduling final harvests and production possibilities analyses indicated that worthwhile gains could be achieved in revenue objectives with minimal impacts to wildlife habitat objectives.

**Summary:**

Integrating wildlife management goals into forest planning presents multiple complex challenges. Forest growth and yield models that use different metrics than the habitat suitability models wildlife managers use to estimate habitat quality for wildlife species. Moreover, integrating wildlife habitat requirements into forest management planning requires future forest conditions to be linked quantitatively to the habitat requirements of specific wildlife species. Further, for a methodology to gain widespread acceptance, the analytical platform it is constructed on must be readily available to forest planning practitioners. We used a modified Delphi method to qualitatively relate measured or predicted values within parameterized ranges of 11 vegetation structure and composition metrics (table 1) to the potential of a forest stand to provide habitat for 16 focal wildlife species (table 2). We chose predictive metrics from traditional timber inventory data (e.g., stand and stock data) and simulated outcomes across a 50-year horizon using the Forest Vegetation Simulator. We quantitatively related predicted conditions in a given forest stand to its potential to provide habitat for a combination of the selected focal species using an index

derived from the metrics relevant to the focal wildlife species (tables 3, 4, 5, 6). We integrated the index values as accounting variables in a linear programming framework using the Woodstock Optimization Studio (the standard platform for planning analysis in the forest industry worldwide), which allows them to be tracked over the 50-year model horizon, constrained, or optimized directly as part of the model's objective function. We applied the model to study area of 49,453 hectare across 2,836 timber stands on public lands managed by the North Carolina Wildlife Resource Commission and evaluated the trends in the harvest scheduling, habitat index values, and revenue under 13 formulations of the objective function maximizing habitat (MAX HABITAT) and revenue objectives (MAX CASHFLOW). By scheduling more thinning treatments, index values under the habitat formulation increased faster and higher than those realized under the maximized revenue formulation, which scheduled more final harvest treatments to maximize undiscounted cashflows across the modelled horizon. In the case study, production possibilities analysis indicated worthwhile gains could be achieved for revenue objectives with minimal impacts to wildlife habitat objectives (fig. 1).

**Key Concepts for FVS Users:**

- Prioritizing wildlife habitat objectives in forest management planning requires quantifying the relationship between the structure and composition of a forest stand and the potential habitat it can offer target wildlife species.
- The Forest Vegetation Simulator (FVS) was used to model habitat indicator metrics in addition to standing and removed timber volumes to evaluate tradeoffs in wildlife habitat and timber production objectives on the timberlands owned and managed by the North Carolina Wildlife Resources Commission.
- Habitat was evaluated for 16 wildlife species, which were identified by agency staff and grouped into four focal guilds (i.e., Open Forest Associates, Longleaf Pine Associates, Shrubland Associates, and Ruffed Grouse), based on commonalities habitat preference and subsequent targets for forest structure and composition through silvicultural treatments.

**Management Applications/Future Directions:**

- By including wildlife habitat indices in the harvest scheduling model, thinning final harvest treatments are scheduled at the most appropriate timings and intensities to meet wildlife habitat management objectives.
- Thinning treatments followed by prescribed burning will increase the potential for most forest types in the southeastern U.S. to offer habitat to the focal species described in this study.
- More knowledge is needed to link habitat preferences of potential focal species to the structural and compositional characteristics of forest stands, so habitat objectives could be evaluated for a wider range of wildlife species using FVS.

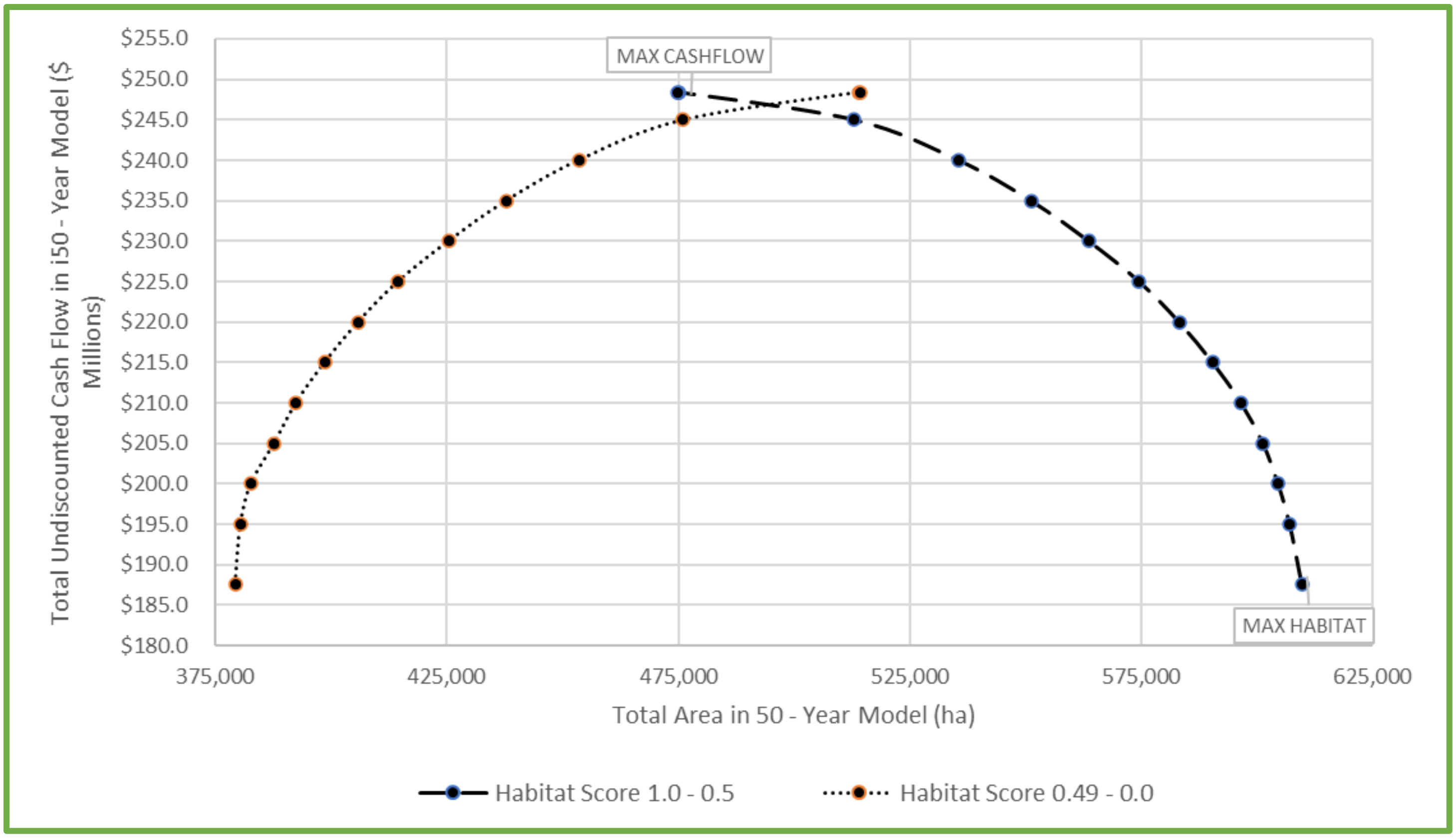


**Figure 1—**Production possibilities frontier comparing the tradeoffs in total revenue and the number of hectares in the top and bottom halves of potential habitat index scores (Q 0.0–2.0) across all 50 years in MAX HABITAT, MAX CASHFLOW, and MAX HABITAT + CASHFLOW constrained by a set cashflow maximums (CFM) in $5 million increments.

**Table 1—**Forest condition metrics used to assess quality of habitat for focal wildlife species on game lands in North Carolina.

| Forest condition metric | Unit | Definition |
|---|---|---|
| Stand age | Years | Number of years since a regeneration harvest occurred, or a stand was planted, whichever is shorter. |
| Timber regime | Description | Selected timber regime applied to a given stand, which is indicative of the dominant tree species. |
| Aspect | Direction | Degree from which a stand is exposed to environmental factors, as calculated from a digital elevation model. |
| Total basal area | $M^2$/ha | Cross sectional area of stems $\geq$ 2.54 cm DBH. |
| Pine BA >35.56 cm | $M^2$/ha | Cross sectional area of pine stems >35.56 cm DBH |
| Oak BA >25.4 cm | $M^2$/ha | Cross sectional area of Oak stems >25.4 cm DBH |
| Canopy cover | Percent | Percent of the ground area directly covered by overstory tree crowns |
| BA oak >25.4 cm | Percent | Percent of total BA made up of oak stems >25.4 cm DBH. |
| BA midstory | Percent | Percent of total BA consisting of stems > 2.54 cm and < 12.7 cm DBH. |
| Fire return interval | Years | Number of years between planned applications of prescribed fire. |

**Table 2—**Focal species promoted through current forest management practices on NCWRC Game Lands, as determined by agency management staff.

| Focal Species | Associated guild |
|---|---|
| Bachman's sparrow (*Peucaea aestivalis*) | Longleaf pine associates |
| Carolina gopher frog (*Rana capito capito*) | Longleaf pine associates |
| Northern pine snake (*Pituophis melanoleucus*) | Longleaf pine associates |
| Red-cockaded woodpecker (*Leuconotopicus borealis*) | Longleaf pine associates |
| Fox squirrel (*Sciurus niger*) | Longleaf pine associates |
| Northern bobwhite (*Colinus virginianus*) | Shrubland associates |
| E. cottontail rabbit (*Sylvilagus floridanus*) | Shrubland associates |
| Indigo bunting (*Passerina cyanea*) | Shrubland associates |
| Prairie warbler (*Dendroica discolor*) | Shrubland associates |
| American woodcock (*Scolopax minor*) | Shrubland associates |
| Red-headed woodpecker (*Melanerpes erythrocephalus*) | Open forest associates |
| Eastern wild turkey (*Meleagris gallopavo silvestris*) | Open forest associates |
| Timber rattlesnake (*Crotalus horridus*) | Open forest associates |
| White-tailed deer (*Odocoileus virginianus*) | Open forest associates |
| Black bear (*Ursus americanus*) | Open forest associates |
| Ruffed grouse (*Bonasa umbellus*) | Individual evaluation |

**Table 3—**Reported forest structural characteristics important to species in the longleaf pine associate guild and a qualification matrix with ranges for the entire guild across all applicable game lands and timber regimes in North Carolina.

| Characteristic | Best | Good | Poor |
|---|---|---|---|
| Basal area ($m^2$/ha) | 9–13 | 14–18 | < 9 or > 18 |
| Pine BA DBH >35.5 cm ($m^2$/ha) | > 4.5 | 1 – 4.4 | < 4.5 |
| Percent canopy cover | 40–60% | 20–40 % | < 20 or > 60% |
| Percent BA hardwoods | 5–9% | 10–15 % | < 5 or > 15% |
| Oak BA DBH >25.4 cm ($m^2$/ha) | 1–2 | 2.1 -3.5 | > 3.5 or < 1 |
| Percent BA midstory | < 20% | 20–40 % | > 40% |
| Fire return interval (years) | $\leq$ 3 | 4 | > 4 |

**Table 4—**Reported forest structural characteristics related to evaluation metrics for species in the shrubland associate's guild and a qualification matrix with ranges for the entire guild across all applicable game lands and timber regimes in North Carolina.

| Structural Characteristic | Best | Good | Poor |
|---|---|---|---|
| Stand age (years) | 2–4 | 5–6 | 1 and > 6 |
| Basal area ($m^2$/ha) | < 9 | < 13 | ≥ 13 |
| Percent canopy cover | < 30% | 31%–50% | > 50% |
| Fire return interval (years) | 3–4 | 2 or 5 | < 2 or > 5 |

**Table 5—**Reported forest structural characteristics related to evaluation metrics for species in the open forest associate's guild and a qualification matrix with ranges for the entire guild across all applicable game lands and timber regimes in North Carolina.

| Structural Characteristic | Best | Good | Poor |
|---|---|---|---|
| Basal area (m2/ha) | 9–13 | 7–9 OR 13 – 18 | < 7 or > 18 |
| Percent canopy cover | 2550 | 50–60 | < 25 or > 60 |
| Percent of total BA oak >10" | > 20 | 5–20 | < 5 |
| Percent midstory | < 20 | 20–40 | > 40 |
| Fire return interval (years) | 3 | 2 OR 4–5 | < 2 or > 5 |

**Table 6**—Reported forest structural characteristics related to evaluation metrics for ruffed grouse and a qualification matrix with ranges across all applicable game lands and timber regimes in North Carolina.

| Structural Characteristic | Best | Good | Poor |
|---|---|---|---|
| Stand age (years) | 10–15 | 5–10 or 15–20 | < 5 or > 20 |
| Timber regime | Cove Hardwood / Northern Hardwood | Oak Hickory | Pine Regimes / Spruce Fir |
| Oak BA >25.4 cm ($m^2$/a) | 2.25–6 | 1–2.25 | > 6 or < 1 |
| Aspect | North | East or West | South |

# Simulating Potential Carbon Sequestration of Improved Forest Management in Northeastern U.S. Forests

Weier Liu[1,*], Mark Ashton[1], Sara Kuebbing[1]

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**Overview:**

- We used FVS-NE to simulate the effect of forest management on forest stand dynamics and carbon storage in oak-mixed hardwood forests of southern New England. We compared forest stand-level composition, structure, and carbon storage in response to active forest management methods, including selective logging and shelterwood compared to no management, and three natural disturbance regimes combining drought, windstorm, and pests and pathogens.
- By emulating chronic natural disturbances through increased tree mortality of target species in FVS, we found that shelterwood can facilitate forest regrowth after disturbances through regeneration of more diverse tree species than the other management methods. No management and selective logging showed gradual losses of basal area of shade-intolerant trees and the specific species targeted by the chronic disturbances.
- In the 100-year simulation, no management only leads to higher total standing carbon in the absence of simulated chronic natural disturbances. Under chronic disturbances, managed forests had faster carbon sequestration leading to higher carbon storage than unmanaged forests after about 60 years, which is even sooner in about 30 years when we account for carbon stored in harvested wood products.

**Summary:**

Forestry is an important component of natural climate solutions. Some forest advocates argue that the best management option for climate benefits is to maximize growth and stop cutting of all forests. Previous modeling comparisons of the carbon benefits of forest managements have not considered how chronic disturbances or reduced natural regeneration of forests may impact carbon dynamics. Exclusion of common forest disturbances may lead to incomplete conclusions about the impacts of forest managements. Here, we used FVS-NE to simulate the effect of forest management on forest carbon sequestration and storage in comparison with no management, in the absence and presence of chronic natural disturbances. We gathered forest inventory data for the oak-mixed hardwood forests of southern New England and simulated three management scenarios: no-management,

selective logging, and shelterwood. We simulated regeneration in different management regimes using seedling lists informed by existing data. We adjusted tree mortality of specific species groups and size classes to mimic the effect of natural disturbances including drought, windstorm, pests, and diseases. We found that under natural disturbances, shelterwood promotes regeneration of more diverse tree species that leads to faster growth and higher stocking level under impacts of the disturbances. No management and selective logging leads to decrease of total basal area and loss of valuable tree species such as red oak (fig. 1). Forest cutting leads to short term carbon losses, but higher carbon storage in the long term especially when accounting for harvested carbon in wood products (fig. 2).

**Key Concepts for FVS Users:**

- FVS is flexible in mimicking silviculture treatments by combining different cutting regimes. In our case, we performed irregular shelterwood by scheduling three different diameter-limit thinning: no cutting below 2" DBH; 'clearcutting' 2-18" DBH; and thinning with residual basal area of 35 square feet per acre for trees larger than 18" DBH, which represents the canopy trees.
- We can mimic the effect of natural disturbances by manually adjusting mortality rates of specific species, species groups, or trees of different size classes, based on empirical evidence or field observations of the target species under various disturbances.
- FVS-NE's partial-establishment regeneration module makes it challenging to simulate forest stand dynamics under different harvest regimes. Here, we attempted to capture various effects of silviculture treatments on regeneration by making literature-based treatment-specific seedling lists, emphasizing proportional species composition of shade tolerant, mid-tolerant, and intolerant trees. However, the effects of varying numbers of seedlings and the timing of supplying the seedling list to FVS requires additional sensitivity analysis.
- The FVS Fire and Fuel Extension is a powerful tool for simulating the implications of forest stand dynamics, including changes in forest composition and structure, on carbon sequestration and storage. However, we should be aware of the uncertainties in FVS's growth and yield modeling, simulation of management effects, and calculations of biomass and carbon contents, and their potential influences on the accuracy of carbon estimations.

**Management Applications/Future Directions:**

- Chronic natural disturbances are common to forests in this region. Disturbances are predicted to grow in frequency and severity with climate change. Excluding disturbance-related tree mortality from forest growth projections limits the utility of projections to emulate the full range of possible future environmental conditions. In our case study, no management leads to higher carbon storage than managed forests only in the absence of chronic natural disturbances. Given the current trajectory of slow geopolitical response to climate change, this scenario is unlikely for most forests.

- When considering forest management as a natural climate solution, we should emphasize the value of carbon stored in the harvested wood products, especially long-lived wood products. This is especially important considering that natural disturbances will decrease carbon stocks in live tree biomass. There are also co-benefits from wood products, such as the climate benefits of substituting fossil-based energy and material by wood products, and social and economic benefits of a vigorous timber market.
- Our FVS simulation needs to incorporate sensitivity analyses of the timing and severity of natural disturbances, as changing the time of disturbances to different years post management with varying mortality adjustments could impact forest stand dynamics and carbon sequestration.
- The FVS Fire and Fuel Extension can estimate the fate of harvested carbon by partitioning carbon storage into wood product and landfill. However, the default values of conversion rates are based on outdated estimates from 2006. It is conservative in allocating amounts of carbon into wood product according to more recent evidence.

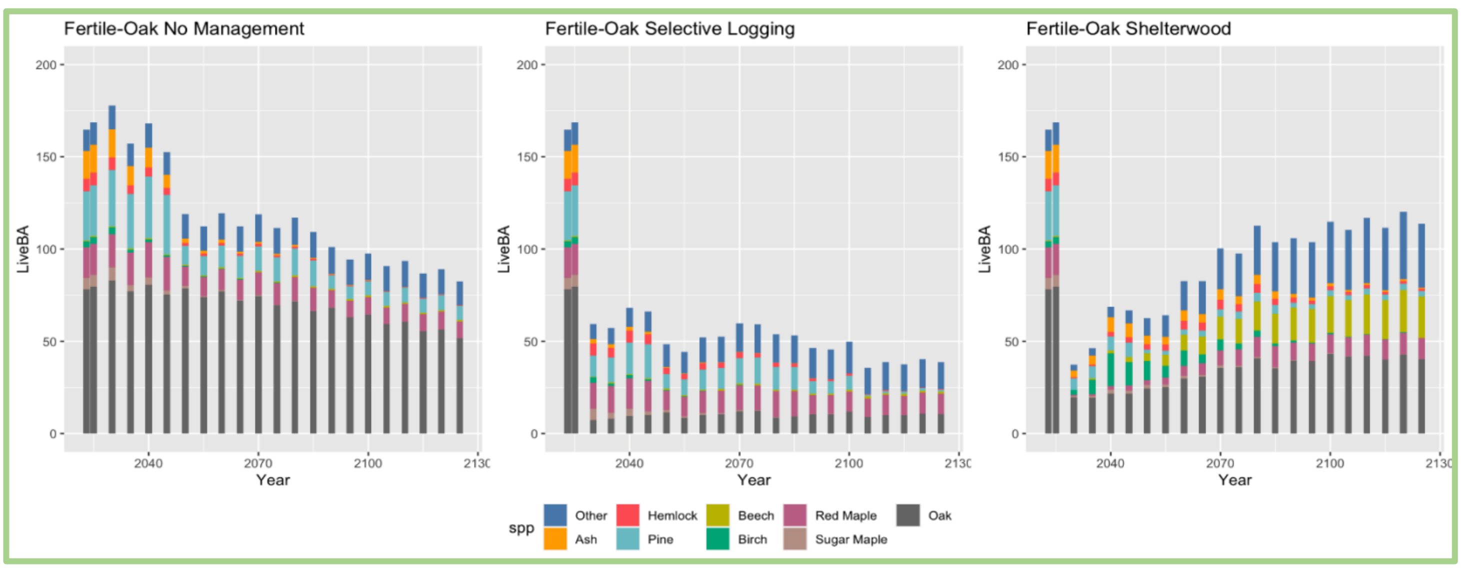


**Figure 1—**Effect of forest management (left to right, no management, selective logging, and shelterwood) and natural disturbances (drought and windstorm) on forest stand composition and structure, represented by total live basal area (square feet per acre).

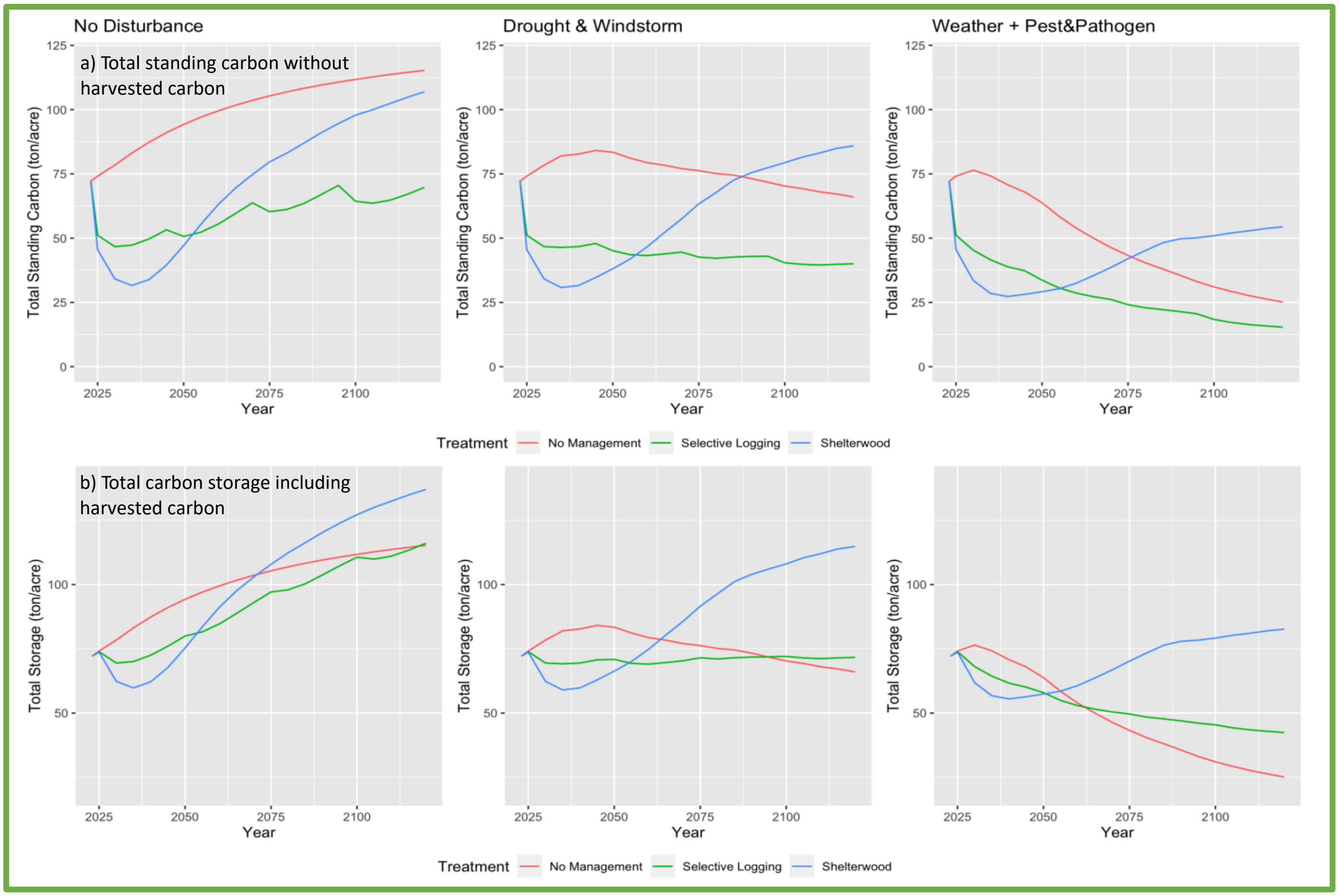


**Figure 2—**Forest carbon storages a) without and b) including harvested carbon in metric tonnes carbon per acre, comparing no management with selective logging and shelterwood, under three different disturbance regimes. Including left – no disturbance, middle – drought and windstorm, and right – drought, windstorm, pests and pathogens (emerald ash borer, beech leaf disease, and spongy moth).

# Automating High-Resolution, Large-Extent FVS Simulations for a Carbon Accounting Protocol

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**Overview:**

- SIG's REM (Reduced Emissions from Megafires) carbon accounting protocol was designed to help provide upfront funding for fuel reduction projects and was approved through the Climate Forward program of the Climate Action Reserve in March 2023.
- REM projects critically depend on several FVS simulations to quantify the effects of proposed fuels treatments on forest growth and yield, carbon stocks, fire behavior, and smoke emissions over the course of a 40-year simulation period.
- We developed a semi-automated and replicable process using TreeMap tree inventory data to facilitate the integration of large-extent (project-scale up to the scale of multi-state regions), high-resolution (as fine as 30-m stands) FVS modeling outputs into Monte Carlo fire behavior simulations with SIG's GridFire model and emissions estimates using FOFEM.

**Summary:**

Manually setting up, executing, and post-processing FVS simulations can be a time-consuming and tedious process. Furthermore, stand polygons appropriate for use in FVS simulations are not universally available, nor is relatively current ready-to-use tree inventory data with which to parameterize those stands. We solved these problems by utilizing the FIA-based TreeMap dataset (Riley et al. 2021) in an innovative collection of scripts that can be executed on-demand through an in-house microservice computing infrastructure.

The REM protocol (Climate Forward 2023) stipulates evaluating a proposed project in terms of its cumulative GHG emissions over a 40-year period that begins when fuels treatments are fully implemented. This involves two sets of FVS simulations: one in which the project treatments are not simulated, and another in which they are (fig. 1). Each set consists of nine individual full-length FVS simulations: a no-wildfire simulation plus eight wildfire simulations (one for each timestep). These wildfire simulations differ in the timing of a simulated wildfire burning under severe weather conditions that affects all stands. Fuels data from these 18 simulations are then fed into SIG's GridFire spatial wildfire behavior simulation software to quantify the indirect effects of the proposed fuels treatments, as well as into the FOFEM model, which is used to quantify several species of wildfire-related emissions (fig. 2).

The FVS modeling required by the REM protocol would be impractical to complete manually, even when using the FVSOnline interface on a high-performance server. We developed a method to streamline these simulations and distribute the computational workload over distributed servers.

**Key Concepts for FVS Users:**

- We developed scripts that process GIS data, set up FVS simulations, execute them using the fvsOL R package, process the outputs for use in the other models, and finally query the outputs to produce the summaries of carbon stocks, fire behavior, smoke emissions, and other outputs required by the REM protocol.
- FVS stands are programmatically created as unique combinations of TreeMap stand ID, past disturbances, and proposed treatments. This allows us to handle individual stands as small as 900 square meters while growing stand conditions forward to the current year and simulating past wildfires, fuel treatments, and timber harvests that may have occurred after the current TreeMap release. Individual phases of this process are handled by separate microservers that idle on distributed Linux servers until receiving a request.
- The primary inputs for the entire process are a vector spatial data file which defines the spatial distribution of the proposed fuels treatments and a collection of FVS addfiles that define the specific keywords needed to simulate those treatments. Project proponents are required to provide an Esri shapefile that defines the location and timing of each proposed treatment type. This shapefile provides a link to a collection of addfiles, built by SIG to define the specifications of these treatments, into the FVS simulations to quantify the effects of the treatments.
- This process allows SIG to efficiently construct and execute complex FVS simulations involving tens or hundreds of thousands of stands that would otherwise be computationally infeasible.

**Management Applications/Future Directions:**

- Although FVSOnline provides a powerful interface to FVS, the fvsOL R package lends itself well to scripted workflows, particularly when many large-extent simulations are required.
- TreeMap's imputed tree inventory dataset is not currently released annually and is typically unable to match the accuracy of local field inventory data; nevertheless, it is an invaluable resource that enables high-resolution FVS simulations on any forested land, regardless of jurisdiction. TreeMap's stand attributes can be grown forward to current conditions when FVS is provided with an adequate spatial record of past forest disturbances.
- Although FFE–FVS only simulates stand-level fire behavior modeling, it can provide the stand-level fuels data (e.g., canopy cover and canopy base height) required for spatial fire behavior modeling. These tabular FVS outputs can provide the attributes for spatial stand information via database queries. Non-forest fuels data can be filled in with LANDFIRE or other sources.
- We are working on improving two key aspects of our approach: the assignment by FFE-FVS of fire behavior fuel models to stands and the simulation of natural forest regeneration in variants that do not include a full establishment model. Currently, we

review the assigned pre- and post-treatment fuel models and intervene only when post-treatment fuel models produce fire behavior that is inconsistent with field experience or the literature. Similarly, stands simulated with no background tree regeneration over a 40–year period are sometimes skewed with respect to metrics like canopy base height that affect simulated fire behavior. We are investigating the use of FIA sapling inventory data to improve these results.

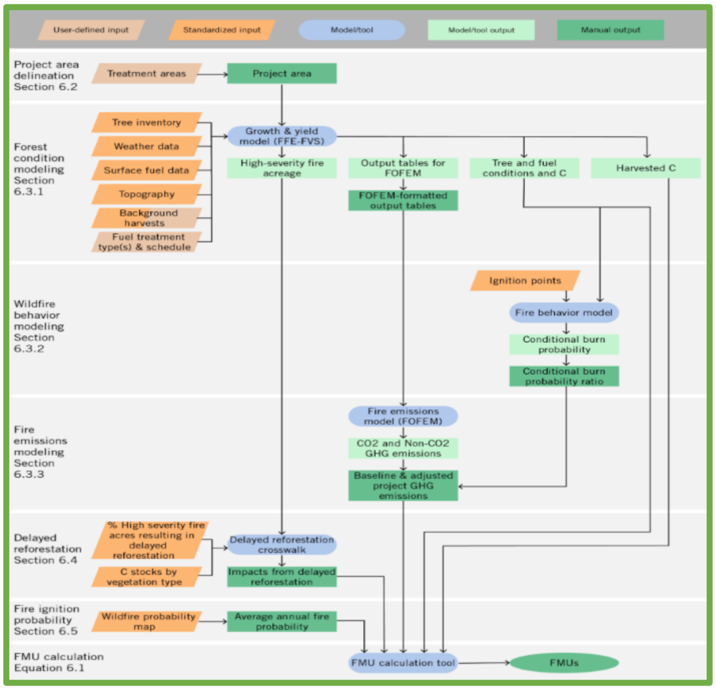


**Figure 1—**Overview of the role of FVS in the REM protocol.

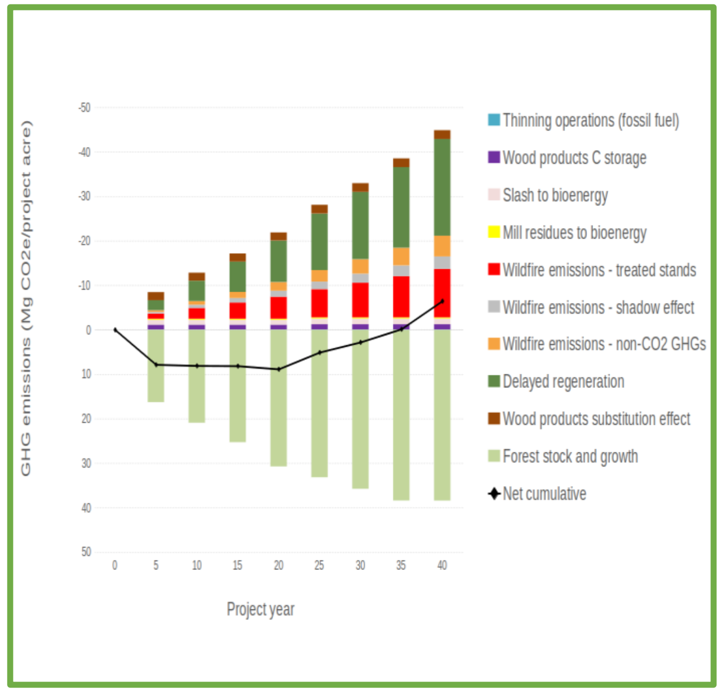


**Figure 2—**Example of REM components.


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# Development of Carbon Entity Guidelines for Wildfire and Prescribed Fire in the Continental United States

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**Overview:**

- This work was conducted for the 2022 update (Murray et al. 2023) of the USDA's 2014 report Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory.
- The objective for the 2022 update is to provide methods and guidance on estimating greenhouse gas (GHG) emissions and carbon removals associated with entity-level activities in managed forest systems across the continental U.S.
- Our contribution to the update was to estimate GHG emissions from wildfire and prescribed fire, which are limited to emissions from consumption of live and dead fuels. This was accomplished using FIA plot data in the Fire and Fuels Extension of the Forest Vegetation Simulator (FFE-FVS), using a range of fires severity settings.

**Summary:**

FIA data from FVS-ready tables packaged with FIADB (Shaw and Gagnon 2020) were used in FFE-FVS to establish prefire carbon pools and fuel loading for trees (live and dead), herbs and shrubs, woody fuels, litter, and duff. FFE was then used to simulate immediate fire effects—tree mortality, fuel consumption, and changes in carbon pools resulting from three wildland fire scenarios (fig. 1). GHG fire emissions were calculated as the product of fuel consumption from the FFE-FVS simulations and pollutant emission factors.

FIA data from about 70,000 plots were used to produce each of the fire severity scenarios. Because FVS is organized as a set of regional variants, subsets of FIA plots were run using the variants in which they were located. FIA plots were attributed with FIA forest type and forest type group classifications and assigned to the geographic regions used in the report framework. For the conterminous United States, over 350,000 combinations of region, forest type, and fire conditions were simulated.

To determine the mortality levels of the fire severity scenarios, FFE simulations were run using a matrix of fire-related parameters (wind speed, fuel moisture, temperature, and burn patchiness; fig. 2). The mortality resulting from a given set of parameters can vary tremendously between forest stands. Region, forest type, and stand composition and structure are critical factors in stand mortality (fig. 3), so variability among regions was not only dependent on the mix of forest types in each region, but different fire behavior in some types

across regions. Tree species and diameter are also important factors; for a given fire scenario, mortality may be highly variable across stands of the same forest type and region (fig. 4). Mortality simulation results were retained for creating estimates of GHG emissions and carbon pools.

**Key Concepts for FVS Users:**

- The goals of the project, as set out by the project organizers, was to achieve constrained levels of mortality that corresponded to each of the fire severity categories. The wide range of responses to similar burning conditions (i.e., FFE-FVS settings) across geographic regions due to different mixes of forest types (fig. 3), and the range of responses of single forest type among regions (fig. 4) made achieving the desired mortality levels a challenging exercise.
- Development of a matrix of FFE-FVS settings, forest types, and other attributes, with associated pre- and post-fire results is essential for data organization and analysis in projects of this scale. Further analysis is needed to test whether certain fire effects are typical of various forest types, or whether the prescribed severity levels are effectively forcing simulation developers to “push” FFE-FVS to produce results that are extreme or highly unusual for certain types in some areas.

**Management Applications/Future Directions:**

- Results of this analysis have been contributed to the development of a public tool, in the form of an MS Excel workbook, that allows users to enter information about their forest land. The tool then queries the data produced by this analysis and returns pre-calculated GHG emissions and carbon fluxes based on the range of severities.
- Landowners or managers need only limited expertise to obtain results from the tool, because it provides a graphical user interface (GUI) and provides limited choices for input.
- The values provided by the tool are approximate, “back of the envelope” calculations, partly owing to the relative coarseness of categories (e.g., forest type group) and limited details about stand structure, composition, etc., and partly due to the aggregation of data over large areas in the analysis, i.e., the values are averaged over a somewhat wide range of conditions.
- A planned improvement is to make the process spatially explicit by integrating TreeMap (Riley et al. 2022), which will use imputed values for various forest attributes in the actual area of interest as an input for the tool. This approach should allow for more locally-specific analysis and a more continuous range of possible outputs (as opposed to class averages). The spatially explicit approach should alleviate some of the challenges encountered when attempting to control fire severity in the simulations, and it will also allow for varying effects within the same parcel of land if there is heterogeneity of fire-related forest attributes.

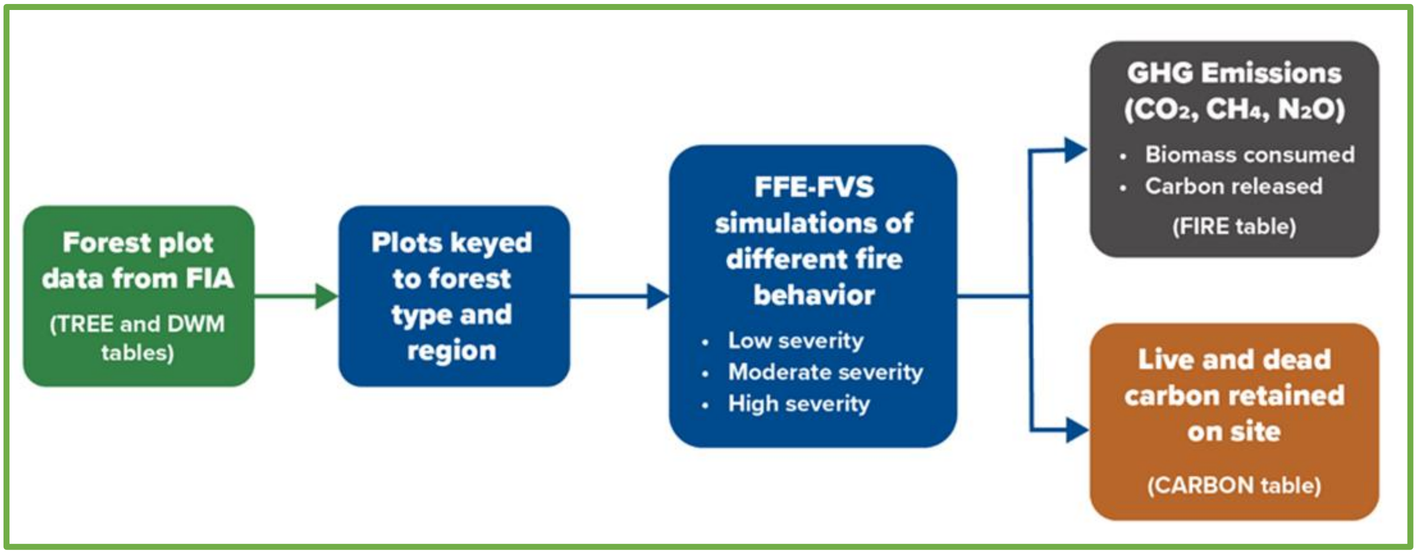


**Figure 1**—Analysis flow, starting with acquisition of FVS-ready FIA data through the FIA Datamart. Only plots on which downed woody material (DWM) was measured were included in the analysis.

| Fire intensity | Moisture level | Wind (mph) | Temp (F) | Percent of stand burned |
|---|---|---|---|---|
| High | Very Dry | 20 | 75 | 100 |
| Moderate | Dry | 15 | 70 | 100 |
| Mod-Low | Moist | 10 | 70 | 100 |
| Low | Wet | 5 | 70 | 90 |
| Very low | Wet | 0 | 65 | 80 |

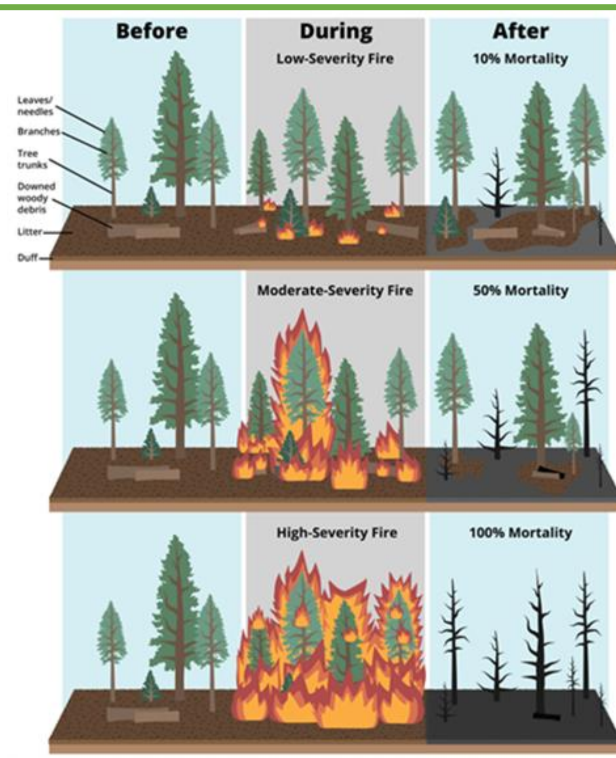


**Figure 2**—Target fire intensity levels and examples of FFE-FVS parameters used to achieve them. Adapted from Murray et al. 2024.

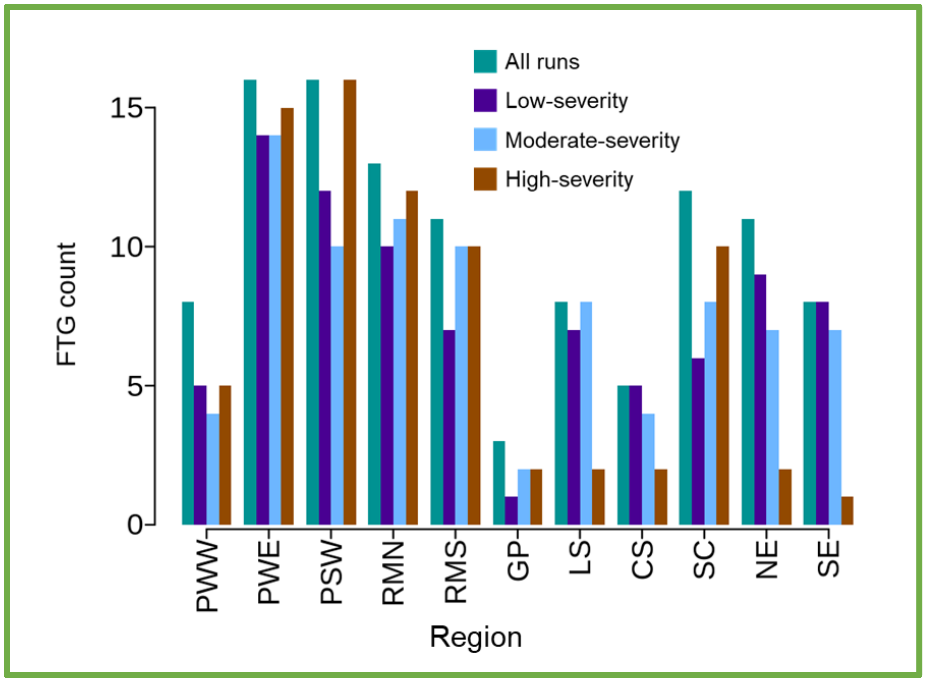


**Figure 3—**Although severity classes were approximately linked to mortality targets, in some cases the range of mortality targets was difficult to achieve, due to the highly variable responses among forest type groups (FTGs) to similar fire conditions. PWW: Pacific Northwest - West; PWE: Pacific Northwest - East; PSW: Pacific Southwest; RMN: Rocky Mountain - North; RMS: Rocky Mountain - South; GP: Great Plains; LS: Lake States; CS: Central States; SC: Southcentral States; NE: Northeast; SE: Southeast

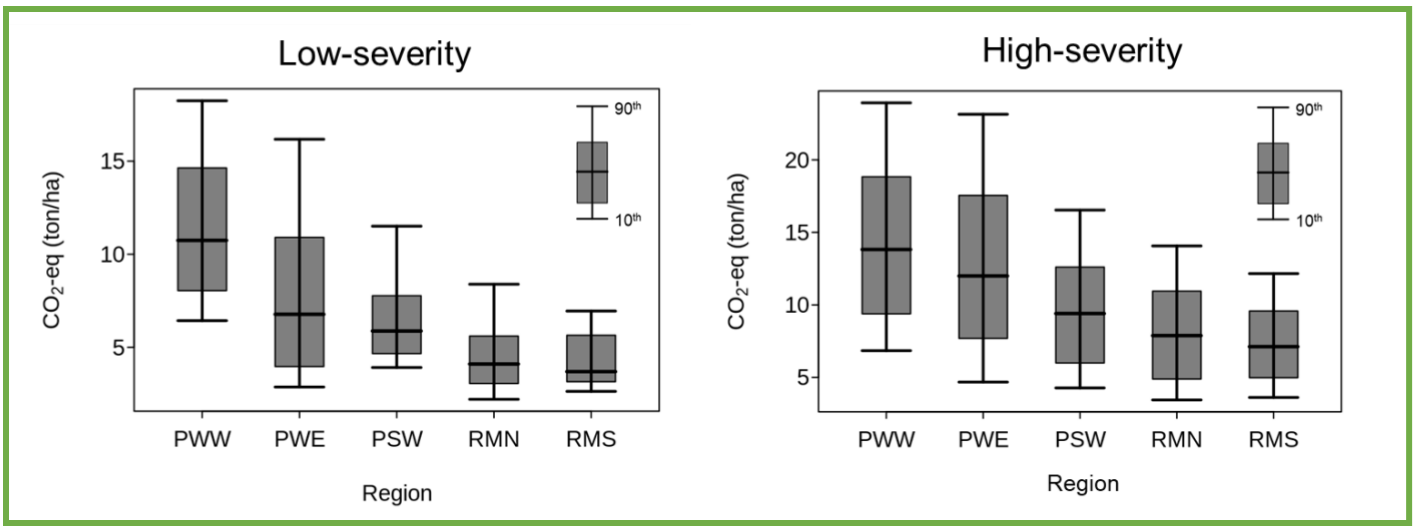


**Figure 4—**Variability in plot-level GHG emissions for the Douglas-fir forest type group in different subregions of the western States.

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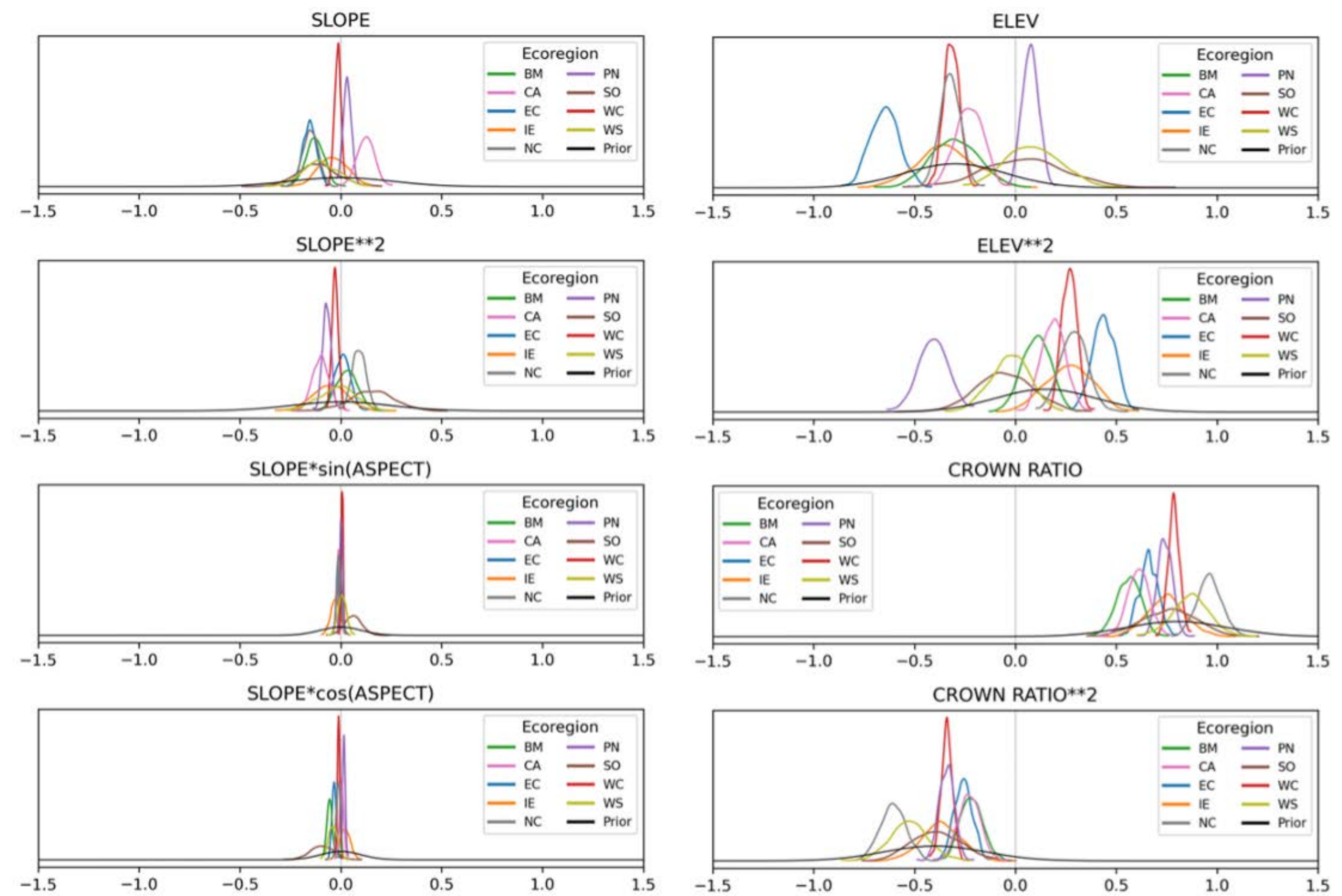
# Model Evaluation




Courtesy image by D. Diaz, Ecotrust.

# Impacts of Precommercial Thinning on Observed Versus FVS-Projected Diameter and Height Increments in the Inland Northwest

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## Overview:

- In the Inland Northwest region of the U.S., precommercial thinning (PCT) of conifer stands typically increases individual tree diameter growth at a faster rate than height growth.
- The Inland Empire variant of the Forest Vegetation Simulator (FVS-IE) allows for effects of reductions in stand density, but links diameter and height growth.
- Region 1 of the U.S. Department of Agriculture, Forest Service (Forest Service) established a broad network of PCT trials that offer a basis for estimating PCT effects and calibrating FVS-IE PCT response.

## Summary:

Precommercial thinning is commonly used in mixed conifer forests of the inland northwest region of the U.S. It is widely understood to increase diameter growth of crop trees, and on some sites can also elicit a height growth response, but growth models are needed to quantify these effects. In principle, FVS-IE can capture PCT effects through reductions in crown competition factor (CCF). However, the model was calibrated to reflect gradual, mortality-driven reductions in CCF as opposed to abrupt changes from active management. Additionally, diameter and height growth are linked in both the small- and large-tree submodels of FVS-IE to an extent that it is unclear whether PCT effects on tree taper can be adequately projected.

The Forest Service Region 1 Permanent Growth Plot (PGP) network was established in the 1980s with randomized PCT and control plots monumented in over 300 stands. Initial analyses based on a subset of the PGP trials remeasured by the Inland Northwest Growth & Yield Cooperative indicate that (1) diameter growth projection errors for Douglas-fir (*Pseudotsuga menziesii*) and western larch (*Larix occidentalis*) are significantly larger for PCT conditions, but that (2) projections errors in height growth are similar under control and PCT conditions. Further work is needed to characterize FVS-IE projection error in diameter growth as a function of PCT timing and intensity, as well as of site productivity and species composition. It is also an open question whether separate small- and large-tree model calibrations would be useful, or if a single calibration function could be applied.

## Key Concepts for FVS Users:

- In the Inland Northwest region of the U.S., precommercial thinning (PCT) of conifer stands typically increases individual tree diameter growth at a faster rate than height growth.
- The Inland Empire variant of the Forest Vegetation Simulator (FVS-IE) allows for effects of reductions in stand density, but links diameter and height growth.
- Region 1 of the Forest Service established a broad network of PCT trials that offer a basis for estimating PCT effects and calibrating FVS-IE PCT response.

## Management Applications/Future Directions:

- The USFS Region 1 PGP program provides a basis for specifying and estimating post-PCT diameter (and, if necessary, height) growth calibration functions using the multi-step method (Weiskittel and others 2011, Ch. 11). Potential effects of PCT intensity, stand age at the time of PCT, time elapsed since PCT will be explored, in addition to effects of initial stand density, site productivity, and species composition.
- Calibration functions for diameter and/or height growth could be implemented outside the core FVSie engine using the event monitor system as is done in the Acadian variant of FVS.

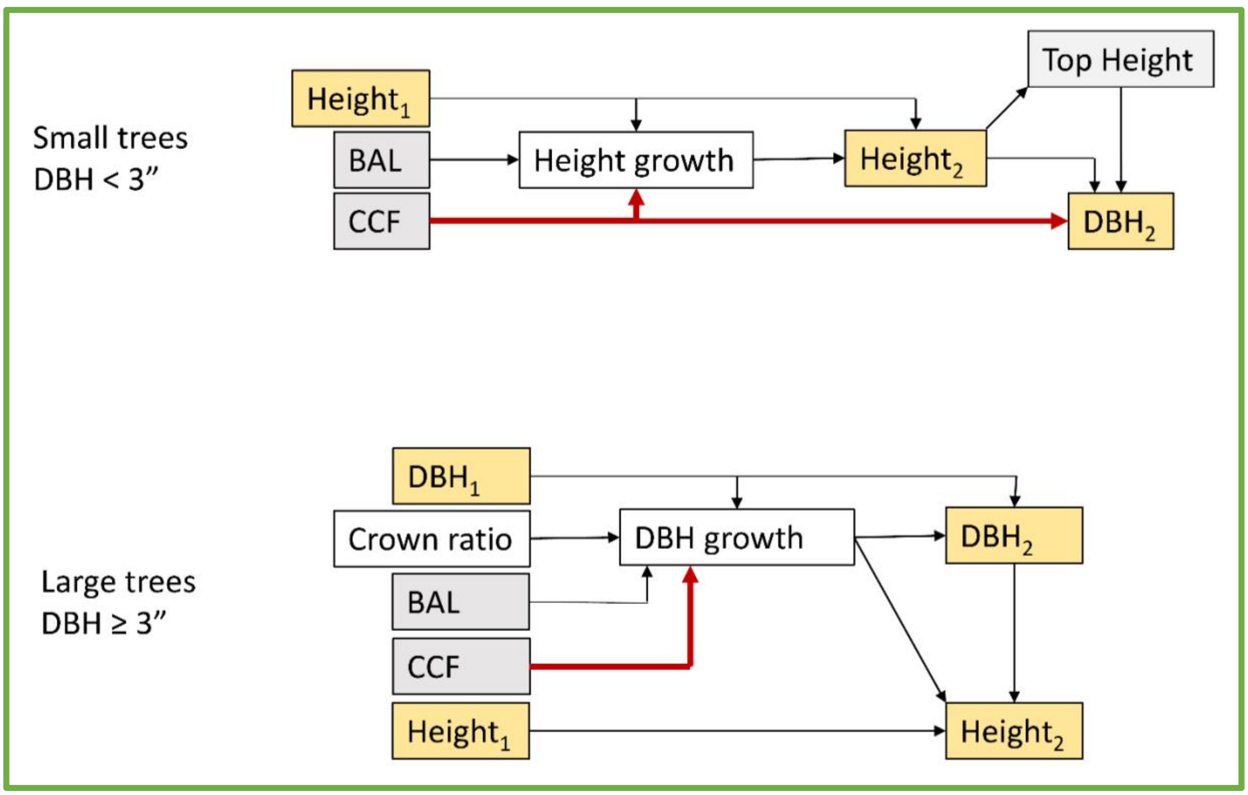


**Figure 1**—Logic underlying tree diameter and height increment in the FVS-IE small- and large-tree growth models. The direct effects of CCF are highlighted in red (DBH: tree diameter at breast-height; BAL: aggregate basal area per acre in trees larger than the subject tree).

## Acknowledgements:

Funding for this work was provided by Inland Northwest Growth & Yield Cooperative and the McIntire-Stennis Cooperative Research Program. Essential logistical support was provided by Forest Service Region 1 staff, including Renate Bush and Tami Fikstad, and by the University of Montana and the Forest Service's National Forest System staff.

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# Using FIA Data and GY Models for State-wide Forest Projections

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**Overview:**

- We consider a case in Maine where statute requires state-wide timber analyses periodically, and models are also requisite to assess impacts from implementing natural climate solutions—climate goals have been set to be carbon neutral by 2045. The Forest Vegetation Simulator (FVS) and other growth and yield (GY) models are being considered for statewide analyses for projecting timber supply and carbon outcomes. We assume and see some evidence that other States are facing similar questions.
- FVS is perhaps the widely used growth and yield model in the U.S., and we wonder if additional work could be done to ensure that it is verified and well calibrated for multiple user needs, across different domains, and at varied scales. Integrating Forest Inventory and Analysis (FIA) data with FVS could serve as the baseline data for many (larger) state and regional analyses and FIA data could be used to improve FVS estimation capabilities.
- As test case, we used FIA2FVS as the starting dataset and grew out Maine's forests. We found that this process was relatively easy, and we could generate "future FIA" estimates using this framework. More work will need to be done to ensure that the Northeast variant (FVS-NE) is well calibrated for Maine.

**Summary:**

In 2019, Maine's forest products industry had a total economic impact of $8.1 billion. The industry employed over 31,000 people, with $1.7 billion in labor income. Ensuring a sustained inventory is the first link in the supply chain that helps the forest sector thrive—namely, that mills stay open, and jobs remain intact. Recognizing that the forest has potential to produce more timber sustainably may allow the industry to grow. On the other hand, acknowledging the limitations of Maine's forests will hopefully reduce the risk of creating overcapacity in Maine's forest products sector. Monitoring and projecting harvest, mortality and the resultant distribution of timber size classes, forest types or species, and other forest conditions is important, as these metrics serve as proxies for overall forest health" (MFS 2022, pp. 2-3). The Maine Forest Service (MFS) periodically conducts Timber Supply Analyses as directed by statute: (i.e., "…project future timber supply using forest models based on growth, harvest, and other dynamic factors affecting the forest." (12 M.R.S. §8877-A (3))). On-going work at MFS uses Woodstock, an optimization modeling platform capable of improving decisions about resource management. One of the key inputs in Woodstock are GY curves which are commonly developed using FVS or some other GY model. To date, efforts have focused mostly

on using FVS-ACD (Weiskittel et. al. 2017) and The Open Stands Model (Hennigar, 2019). Here we project Maine's forests using FIA2FVS tables as input into FVS-NE; compare modeled growth rates to FIA growth rates; and consider approaches for verifying and calibrating FVS for statewide and other modeling efforts.

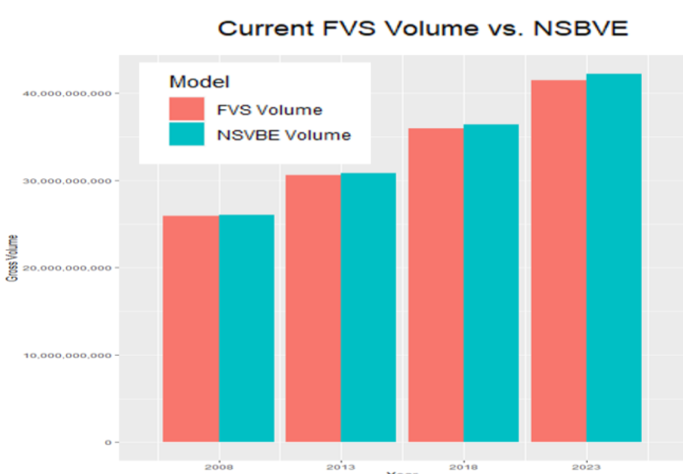
**Key Concepts for FVS Users:**

- Utilizing FIA data could offer a solution for verifying and calibrating FVS.
- FIA2FVS (Shaw and Gagnon 2020) converts the FIA data for ready use in FVS. Users can easily download the FIA database, upload it into FVS, and grow-out stands.
- For users who want results to align with FIA population estimates, the FVS_STANDINIT_COND table allows growth at the plot/condition level. Users can extract FIA inventory year from the GROUPS column (otherwise FVS.INVYEAR == FIA.MEASYR); FVS outputs can then be linked back to FIA tables to match population estimation.
- For verifying FVS-NE we took an approach that grew the first complete annual inventory in Maine forward 15 years (i.e., 3 full cycles) and compared FVS and FIA gross volume growth rates taken as a weighted average at the plot / condition level. FVS growth rates appeared to exceed FIA growth rates.
- Using the publicly available legacy tree database (Radtke et al. (2023), in review) we estimated volume at the tree level (2015) and the resulting NSVB volume equations (https://charcoal2.cnre.vt.edu/nsvb_factsheets/; Westfall et al. The no triples keyword helped consolidate the tree table.). Statewide estimates using NSVB versus the current equation in FVS-NE yielded similar results (fig. 1).
- Preliminary results suggest that FIA mortality estimates exceed FVS-NE mortality estimates resulting in over-estimates of net growth across Maine.
- A solution that we have not fully vetted, but one that does increase mortality, involves modifying maximum density for the stand and the mortality distribution pattern using the BAmax keyword. However, adjusting SDImax directly may ultimately prove a better solution, if base mortality functions in FVS-NE are not refit.
- While FVS growth rates appear high, we observed that FVS maintained the relative growth-rates as they relate between forest types (table 1).

**Management Applications/Future Directions:**

- MFS will continue to explore different methods for projecting Maine's Forests.
- Questions remain about whether the Northeast Variant can be calibrated for Maine's forests, or whether certain models would need re-fit.
- Development of the Acadian Variant of FVS (Weiskittel et al. 2017) continues where models have been re-fit using contemporary data sources. Implementation in the current FVS framework seems likely, yet some obstacles remain.
- Presently the Open Stands Model remains a viable option for projecting Maine's forest.
- The user community might consider whether sub-regional variants using other programming languages (e.g., C# & R) could be a viable option. These sub-variants would need to be generally stable with some reporting of error.

- There seems to be some interest in using FIA data to verify and calibrate FVS variants. With regards to verification, could USDA Forest Service staff (hopefully with assistance from the user-community) provide error statistics at sub-region scale with each update? One starting point might be growing the first cycle of FIA data forward to the most current cycle to compare FVS results on non-harvested lands by State, forest type, physiographic code, and other domains of interest (remeasurement period: FIA.PLOT.REMPER would need to be considered here). Regarding calibration, could keyword files be kept in a repository after users have calibrated a variant or domain within a variant?
- Incorporating NSVB along with estimation procedures for other pools (concurrent with FIA) into the current FVS framework would be very welcome.
- To the extent that other States seek to project timber supply, carbon, and other forest characteristics, the authors wonder if there is potential for between-state collaborations and collaboration with FVS staff, Forest Service Sustainability and Planning staff, particularly as it pertains to Forest Action Plans and FIA analysts as it pertains to 5-year state reports. FIA data could be projected forward to generate future FIA population estimates (fig. 2).
- In addition to considering FVS for large area timber supply and carbon projections. states are considering how other models such as Woodstock, Landis (Simons et al. 2021), RPA (https://www.fs.usda.gov/research/inventory/rpaa/2020), and The Carbon Budget Model ( CBM: https://natural-resources.canada.ca/climate-change/climate-change-impacts-forests/carbon-accounting/carbon-budget-model/13107 ) could be used or integrated into their modeling frameworks to meet their needs.

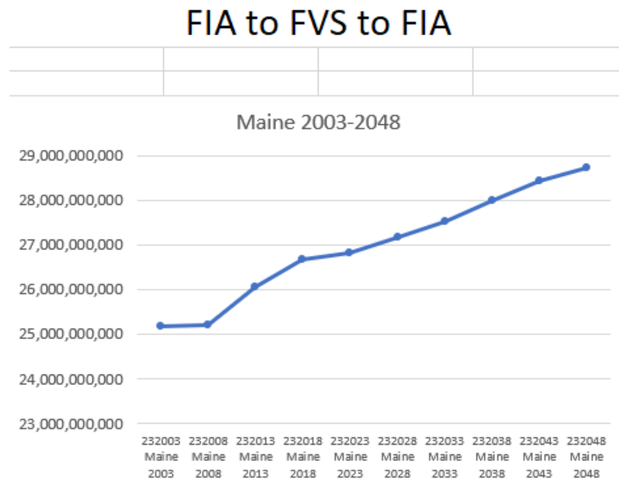



| FIA Forest Type Group | Growth (cords/acre/year) | |
|---|---|---|
| | FIA sound | FVS gross |
| Exotic softwoods group | 1.10 | 1.88 |
| White / red / jack pine group | 0.76 | 1.04 |
| Oak / pine group | 0.71 | 1.08 |
| Oak / hickory group | 0.61 | 0.88 |
| Loblolly / shortleaf pine group | 0.60 | 0.77 |
| Spruce / fir group | 0.51 | 0.73 |
| Aspen / birch group | 0.51 | 0.74 |
| Maple / beech / birch group | 0.49 | 0.70 |
| Elm / ash / cottonwood group | 0.18 | 0.65 |
| Other hardwoods group | 0.10 | 0.29 |

**Figure 1—**Comparison between FVS and NSBVE.

**Table 1—**Comparison between FIA and FVS growth volumes rates by species group.

**FIADB-API v2.0.5 – View Report**
**Estimated parameters**
**Numerator attribute number and description:** 0014 Net merchantable bole volume of live trees (at least 5-inches d.b.h./d.r.c.), in cubic feet, on forest land
**FIADEF** as the forest land definition
**State/EVAL_GRP(S):**
Maine 232003
Maine 232008
Maine 232013
Maine 232018
**Row variable:** EVALID (based on values from the Current inventory)
**Column variable:** Tree class (based on values from the Current)
**Filtering clause(s) applied to numerator and denominator:**
None




| EVALID | Total | Growing Stock | Rough Cull | Total volume w/o rotten cull |
|---|---|---|---|---|
| **Total** | **104,660,362,662** | **96,963,465,536** | **6,212,295,259** | **103,175,760,795** |
| 232003 Maine 2003 | 25,580,251,706 | 23,930,483,273 | 1,263,893,573 | 25,194,376,846 |
| 232008 Maine 2008 | 25,474,349,023, | 23,789,919,608 | 1,432,683,641 | 25,222,603,249 |
| 232013 Maine 2013 | 26,356,383,134 | 24,530,104,531 | 1,534,461,568 | 26,064,566,099 |
| 232018 Maine 2018 | 27,249,378,799 | 24,712,958,124 | 1,981,256,476 | 26,694,214,600 |
| *232023 Maine 2023* | | | | *26,824,493,465* |
| *232028 Maine 2028* | | | | *27,177,040,734* |
| *232033 Maine 2033* | | | | *27,545,165,142* |
| *232038 Maine 2038* | | | | *27,999,675,259* |
| *232043 Maine 2043* | | | | *28,435,769,253* |
| *232048 Maine 2048* | | | | *28,731,069,678* |

**Figure 2—**Conceptual figure showing FIA to FVS to FIA with future FIA estimates.

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# Assessment of Crown Base Recession in Uneven-Aged Ponderosa Pine Forests of Colorado and Arizona

Wade T. Tinkham[1,*], Mike A. Battaglia[1], Lance Asherin[1]

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**Overview:**

- Due to the importance of crown length/crown ratio in capturing forest dynamics, reliable prediction of changes in crown length/crown ratio in future time periods is vital for subsequent processes dependent on these metrics like tree growth or crown fire initiation at future time points.
- The Forest Vegetation Simulator Central Rockies variant seems to provide reasonable estimates of missing crown length observations at the start of simulations (fig. 1). Refitting the model did not provide substantial improvements in prediction accuracy.
- While model prediction accuracies of how crown length will change over time seem to capture general trends (fig. 2), the accuracies substantially worsen as simulations become longer (fig. 3). Literature suggests that revising the model to use a two-step modeling strategy of first predicting the probability of a tree's crown receding and then predicting how much the crown should recede could improve temporal predictions.

**Summary:**

The structure of forest canopies from the individual tree crown to the stand canopy level informs a range of ecologically significant factors from photosynthetic capacity and tree vigor to wildlife habitat quality and crown fire potential. However, the data needed for characterizing the crown length/crown ratio is often, at best, subsampled during forest inventories. Therefore, it is important for forest growth and yield models to estimate these missing forest inventory values and to project future changes in crown structure. However, the wide range of tree and stand attributes impacting crown length and its temporal changes have proven to make this difficult in many forest systems. The work used two long-term research stem maps in Colorado (Manitou) and Arizona (Kaibab) ponderosa pine forests to evaluate the reliability of the Forest Vegetation Simulator Central Rockies (FVS-CR) variant for predicting missing crown lengths and projected changes in crown length. Additionally, we provide preliminary thoughts on alternative modeling strategies. FVS-CR prediction accuracy of missing crown lengths at the start of a simulation differed for the two sites (fig. 1), with mean absolute errors of 1.57 and 3.29 m for the Kaibab and Manitou stands, respectively. These differences might be attributed to the two sites being recommended to use different sub-models from FVS-CR. The fitting of a new model to predict missing crown lengths suggests

modifying to a slightly simpler model form that includes height and the interaction of height and plot basal area as predictors, although accuracies were only mildly improved. The projection of future crown lengths by FVS-CR seemed to capture most crown change dynamics (fig. 2). However, initiating simulations without inventoried crown length data reduced the range of future predicted crown lengths. There were notable increases in mean error through time for both study sites, with these errors seeming to be worst when simulated without the inventoried crown ratio to begin with (fig. 3).

**Key Concepts for FVS Users:**

- FVS-CR is relatively reliable at predicting missing crown length from forest inventory data (fig. 1). However, the use of the Lodgepole Pine sub-model at the Manitou study site resulted in substantially larger errors in crown length predictions.
- Fitting a new crown length prediction model only resulted in small improvements in model accuracy, with most of the improvements seen at the Manitou study site.
- Prediction of future crown lengths by FVS-CR tended to have increased errors as the simulations became longer (fig. 3), with errors tending towards over-predicting the length of a tree's crown.

**Management Applications/Future Directions:**

- Currently, FVS-CR provides reasonable estimates of crown length at the start of a simulation when these observations are missing from forest inventory data (fig. 1). This accuracy provides confidence in the model's ability to describe current crown fire hazard as a function of crown architecture.
- However, FVS-CR projected future crown lengths (fig. 2) tended to be overly long at Kaibab and to have lengths underpredicted at Manitou, with these errors becoming worse the longer a simulation runs. While these errors indicate the model represents general trends in crown length through time, projection trying to understand things like future crown fire hazard should be cautious about the magnitude of changes and more trust the direction of changes.
- Further work is ongoing to test alternative model forms for predicting future changes in crown length to improve model reliability.

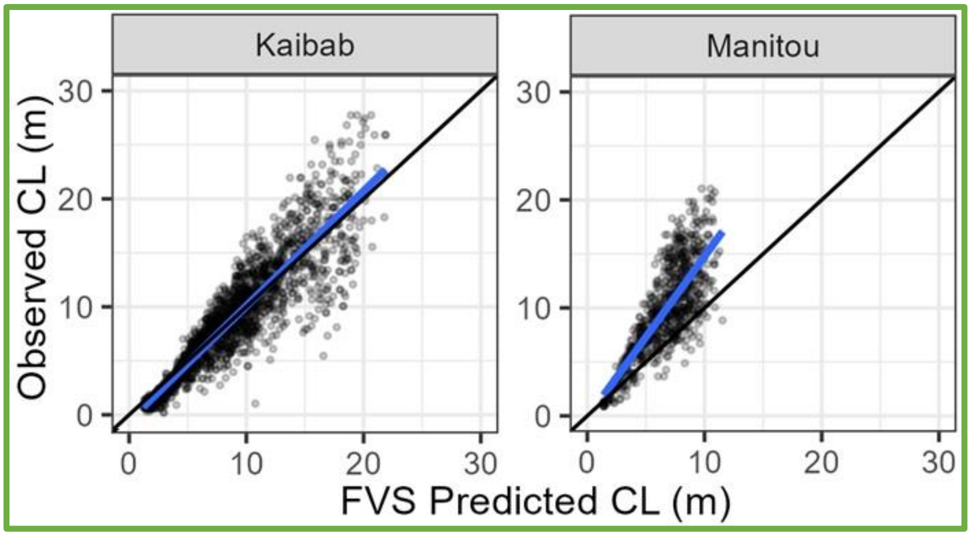


**Figure 1—**Forest Vegetation Simulator predicted crown length (CL) at the start of simulation compared to field-observed values for the two study sites.

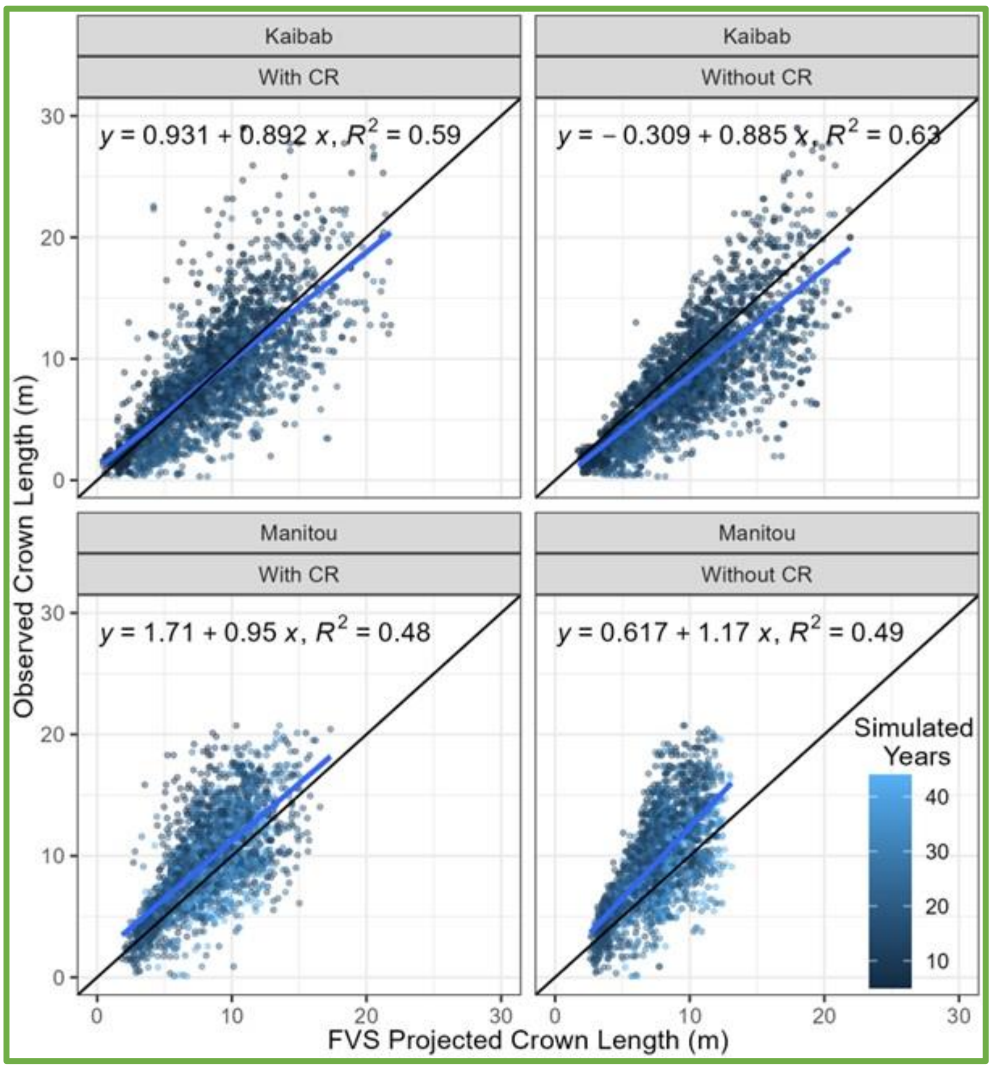


**Figure 2—**Forest Vegetation Simulator predicted crown length (CL) at different points in the future compared with field-observed crown length for the same trees. Additionally, this compares the effect of initiating the simulations either (left) with crown ratio (CR) or (right) without crown ratio information for the two study sites.

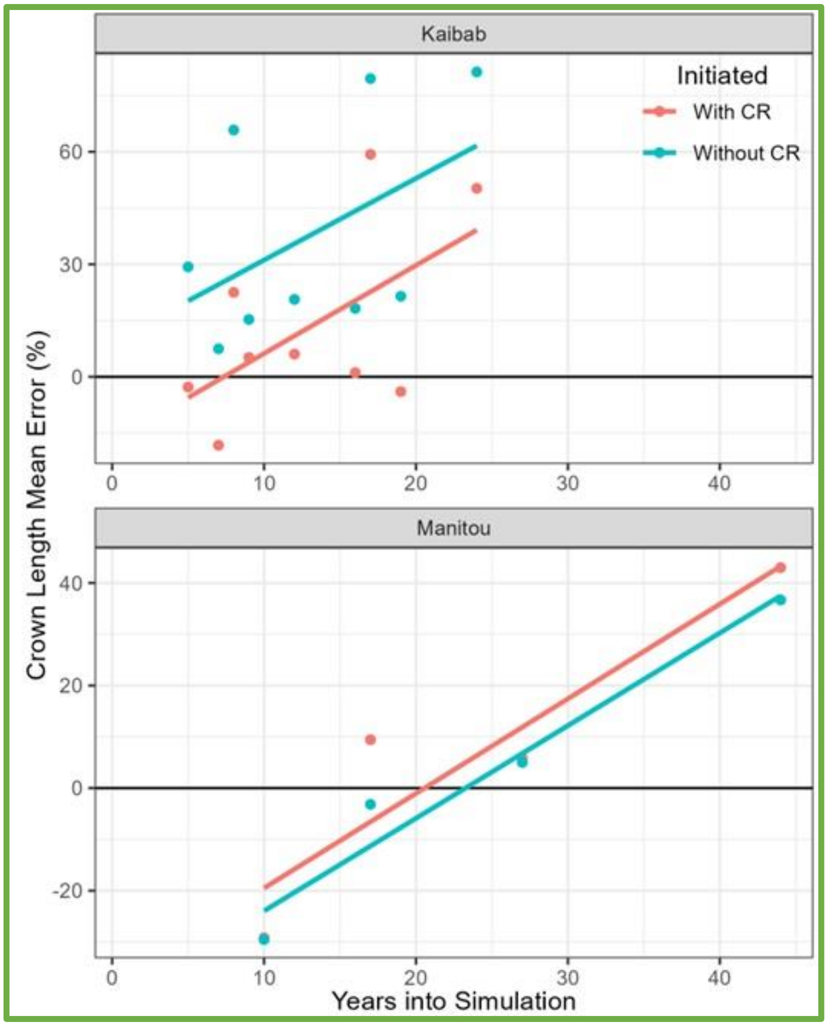

**Figure 3—**Relative mean error in Forest Vegetation Simulator predicted crown length at different future time points for the two study sites, comparing the effect of initiating the simulations either (red) with crown ratio (CR) or (blue) without crown ratio information.

# A Reproducible Workflow to Refit FVS using the FIA Data Stream

David D. Diaz[1,2,*] and Gregory J. Ettl[2]

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## Overview:

- The emergence of FIA as a data stream motivates the development of a reproducible FVS refitting workflow to deliver calibrated software for management decisions and scenario comparisons based on the best available contemporary datasets.
- This opportunity is timely given a clear need for refitting Pacific coast variants given strong overpredictions of net growth under default FVS settings compared to traditional yield curves, FIA chronosequences, and long-term research plot records.
- The implementation of the Wykoff diameter growth function as hierarchical Bayesian state space model allows for FIA observations (and measurement errors) of both DBH and increment cores to be leveraged. This enables model parameters to be learned across ecoregions and confers several advantages compared to historical data selection and regression practices used to refit FVS variants.
- Using Douglas-fir as an illustrative example, we demonstrate the opportunity to simplify and consolidate the variety of diameter growth equations currently employed across Washington, Oregon, and California that are more difficult to interpret and maintain without offering any meaningful benefit in predictive performance.

## Summary:

Forest conservation and management plans, decisions, and policy analyses are commonly developed and reported using the Forest Vegetation Simulator (FVS) software without substantial investment or attention to ensuring FVS is well-calibrated or unbiased for the decision(s) at hand. The emergence of repeated measurements from plots across the Forest Inventory & Analysis (FIA) network of the United States provides a unique opportunity for ensuring predictions of forest conditions and dynamics are grounded in software that is calibrated frequently against the best available contemporary data, particularly given broad and diverse interests in learning as quickly as possible about the effects of our changing climate on forest growth, mortality, disturbance, and regeneration.

We introduce a reproducible turn-key workflow that can be used to recalibrate FVS simultaneously across multiple regional FVS variants using FIA data. We illustrate the application of this workflow using both repeated DBH and radial increment measurements to recalibrate the FVS large tree diameter growth model on a five-year timestep using more than 40,000 repeated measurements of Douglas-fir trees across Washington, Oregon, and California. We find that the current variety of equations among eleven FVS variants across these three states employed to predict Douglas-fir growth appear to offer no benefit in predictive performance compared to a consolidated and simplified model. We advocate for the adoption of this simplified form of the Wykoff diameter growth model to improve

ecological interpretability, enable the propagation of uncertainty in model predictions, and facilitate the more frequent recalibration of FVS against the best available data.

**Key Concepts for FVS Users:**

- Default calibrations of FVS in Washington and Oregon (Diaz et al., 2018), as well as California (Herbert et al., 2023) have shown significant overpredictions of net volume growth compared to benchmarking datasets. These biases are likely to translate into substantially misleading estimates of timber, economic, and carbon sequestration potential among these forests if FVS adjustment or recalibration is not undertaken.
- We recommend a good practice of benchmarking FVS calibration by growing stands from bare ground for 50-100 years and comparing how FVS simulations compare to chronosequences from yield curves, permanent plot records, and/or observations of FIA plots of similar composition and productivity at each 5- or 10-year age class. See supplementary information in Diaz et al. (2018) and Hoover et al. (2021) for examples of this benchmarking approach. Supplementary information in Diaz et al. (2018) also provides an example of using BAIMULT and SDIMAX keywords to adjust FVS behavior to better align with benchmark datasets.
- The recalibration of basic growth, mortality, and other routines in the FVS software using equations that balance interpretability, predictive performance, and maintainability can and should be planned for as a frequent and recurring need and opportunity given the streaming nature of FIA data.

**Management Applications/Future Directions:**

- The reproducible model fitting approach illustrated here can be easily extended to annualized predictions of diameter growth, taking advantage of the increasing collection of tree cores from FIA plots and release of more precisely measured annual ring width data.
- The fundamental form of the Wykoff diameter growth equation can also be extended to incorporate climatic effects which could be introduced to FVS at runtime during each growth cycle through the use of BAIMULT or FIXDG keywords. This would be a significant advance and more direct approach to capturing climatic influences on forest growth compared to the current implementation of Climate-FVS.
- Open-source Python code to reimplement the findings and workflow presented are available on GitHub: https://github.com/d-diaz/refit_fvs.

**References:**

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# Power-user Features of FVS and FVSOnline

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**Overview:**

- FVS power-users are those that have may have analysis needs beyond those easily fulfilled using the FVSOnline graphical-user interface.
- Software tools are described here that support building, changing, and running FVSOnline using scripts to automate repetitive tasks and support using FVSOnline as a component in other systems.
- The FVS model can be manipulated using a second set of functions that interact with the model itself, modifying growth and mortality rates, simulating regeneration or harvests, and so on, thereby allowing a user to alter the FVS model without modifying the Fortran and C code it is written in.
- These tools are written in the R programming language (R Core Team 2021). The most reliable source of detailed information on how to use them is provided with the related R packages available from the USDA Forest Service FVS web site https://www.fs.usda.gov/fvs/index.shtml.

**Summary:**

FVSOnline is an R-shiny (Rstudio 2023) application that can be used to build FVS (USDA Forest Service 2023) simulations, run, and display results. The system has a client-server architecture where the server is a specialized R package that is running in an R session and the client is a graphical user interface running in a web browser. In addition to the components that are accessed via the web browser, there are R functions contained in the FVSOnline package that support manipulation of FVSOnline projects. Projects can contain several FVS runs and each run can contain several simulation units (forest stands) and management alternatives. Table 1 lists the R functions designed for this purpose.

FVS itself is the simulation model that projects forest stand development. There exists a set of internal functions in FVS that can be called by another program and thereby manipulate the projected results, perhaps replacing them completely with predictions made with different models. While those functions can be called by programs other than R, there is an R package called rFVS that is designed to interact with these internal functions (table 2). Note that the Acadian growth model (Weiskittel and others 2017) is implemented within the FVSOnline system using the rFVS functions to interact with FVS. In that case, growth, mortality, and regeneration establishment are modeled using functions in rFVS and the Acadian model. One of the motives of building rFVS is to provide a system where modelers can try new approaches to predicting forest stand dynamics. Those new methods and then be tested and delivered to others within FVS without changing that model's internal code.

## Key Concepts for FVS Users:

- FVSOnline can be a component in other systems.
- FVSOnline can handle large tasks, and repetitive tasks can be automated.
- FVS can be modified without first learning the FVS computer program and languages (mostly Fortran) thus empowering innovation.

## Management Applications/Future Directions:

- The future direction is to maintain this software and enhance it as needs are discovered.

**Table 1—**Functions in FVSOnline designed to be used externally from the web browser interface.

| Function name | Description |
|---|---|
| addNewRun2DB | Add the output from a run into the master FVSOut.db |
| extnAddComponentKwds | Add Keyword Components to a run |
| extnAddStands | Add Stands to a run |
| extnDeleteComponents | Delete FVS keyword components from a run |
| extnDeleteRuns | Delete one or more FVS Runs |
| extnDeleteStands | Delete specific stands from a run |
| extnDuplicateRun | Duplicate a run and assign the duplicate a new title and new management ID |
| extnErrorScan | Scan an FVS output file for errors |
| extnFromRaw | Convert a raw vector to an R object |
| extnGetComponentKwds | Get FVS keyword components from a run |
| extnListRuns | Get a list of FVS Runs |
| extnListStands | List the stands in a run |
| extnLoadFVSRun | Fetch a run into the R session |
| extnMakeKeyfile | Generate the FVS .key file for a run |
| extnMakeRun | Build an FVS run in a project |
| extnSetRunOptions | Set FVS output and timing options |
| extnSimulateRun | Simulate (run) a run's .key and RScript |
| extnStoreFVSRun | Store a run that is in an R session into the FVS project database |
| extnToRaw | Convert an R object to a raw vector |
| fvsOL | Run fvsOL (FVS OnLine/OnLocal) |

**Table 2—**Functions in rFVS.

| Function name | Description |
|---|---|
| fvsAddActivity | Add an FVS Activity to the activity schedule |
| fvsAddTrees | Add new tree records to the simulation |
| fvsCompositeSum | Build a composite summary statistics table |
| fvsCutNow | Specify a thinning/harvest by setting the proportion of each tree record's sampling weight (trees/acre) that will be "cut" in the current cycle |
| fvsGetDims | Get the dimensions of important FVS data storage |
| fvsGetEventMonitorVariables | Get values of Event Monitor variables |
| fvsGetRestartcode | Get the current FVS restart code. See fvsRun for a list of the stop codes |
| fvsGetSpeciesAttrs | Get the values of species-specific data |
| fvsGetSpeciesCodes | Get a data.frame of species codes |
| fvsGetStandIDs | Get stand identification codes |
| fvsGetSummary | Get a data.frame of the summary statistics |
| fvsGetSVSDims | Get the max dimensions of important Stand Visualization System data storage |

| Function name | Description |
| --- | --- |
| fvsGetSVSObjectSet | Get the Stand Visualization System objects |
| fvsGetTreeAttrs | Get attributes of trees |
| fvsInteractRun | Run FVS and specify the R-script code that will be run at each stop point (where specified) |
| fvsLoad | Load the desired FVS program as a shared library |
| fvsMakeKeyFile | Make an FVS keyword file suitable for running FVS using fvsLoad, fvsSetCmdLine and fvsRun |
| fvsRun | Run FVS up to a designated stop point, year, or both. See fvsGetRestartcode for a way to find out the current stop point code |
| fvsSetCmdLine | Set the command line |
| fvsSetEventMonitorVariables | Set Event Monitor variables |
| fvsSetSpeciesAttrs | Set the values of species-specific data |
| fvsSetTreeAttrs | Set attributes of trees |
| fvsSetupSummary | Modifies the "summary" statistics so that it is ready to plot |
| fvsUnitConversion | Get FVS units conversion factor |

## References:

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Weiskittel, A.; John Kershaw, J.; Nicholas Crookston, N.; [et al.]. 2017. The Acadian variant of the Forest Vegetation Simulator: Continued development and evaluation. In: Keyser, C.E.; Keyser, T.L. eds. Proceedings of the 2017 Forest Vegetation Simulator (FVS) e-Conference. e-Gen. Tech. Rep. GTR-SRS-224. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. p. 10-13.

## Conference Program

| Tuesday, March 7th, 2023 | | |
|---|---|---|
| **Time** | **Topic** | **Speaker/Location** |
| 7:30 – 8:30 am | Registration | Lobby |
| 8:30 – 9:00 am | Welcome and Keynote Address | Troy Heithecker, Associate Deputy Chief–National Forest Systems |

| Session 1: Model Development<br>Morning Moderator: Mike Shettles / Afternoon Moderator: Mark Castle | | |
|---|---|---|
| **Time** | **Topic** | **Speaker/Location** |
| 9:00 – 9:30 am | Functional diversity effects on individual-tree growth, crown ratio, and tree mortality in California forests: Implications for FVS modeling | Christopher Looney |
| 9:30 – 10:00 am | Evaluating long-term seedling growth across densities using Nelder Plots and the Forest Vegetation Simulator (FVS) in the Black Hills, South Dakota, USA | Wade Tinkham |
| 10:00 – 10:30 am | Coffee Break | |
| 10:30 – 11:00 am | Use of FVS to evaluate competing vegetation control and fertilization effects on reforestation | Katherine Wood |
| 11:00 – 11:30 am | How long was that treatment effective? An FIA-based imputation procedure to account for natural tree regeneration post-treatment in FVS | Sebastian Busby |
| 11:30 – 12:00 pm | REGEN2FVS: Linking REGEN3 to the Forest Vegetation Simulator in project analyses | Chad Keyser |
| 12:00 – 1:30 pm | Lunch Break | |
| 1:30 – 2:00 pm | The Acadian Variant of the Forest Vegetation Simulator: Evolution, assessment, and future development | Aaron Weiskittel |
| 2:00 – 2:30 pm | Accessing and using Forest Inventory and Analysis (FIA) data in FVS | John Shaw |
| 2:30 – 3:00 pm | FVSOnline server software components, installation, and management | Nicholas Crookston |
| 3:00 – 3:30 pm | Coffee Break | |
| 3:30 – 4:00 pm | A bottom-up approach for national-level projections of forest growth in Canada | Mathieu Fortin |
| 4:00 – 4:30 pm | Climatic sensitivities derived from tree rings improve predictions of the Forest Vegetation Simulator growth and yield model | Courtney Giebink |
| 5:00 – 6:00 pm | Social at Hilton – no host bar | |

| Wednesday, March 8th, 2023<br><br>Session 2: Project Application<br>Morning Moderator: Lance David / Afternoon Moderator: Mike Battaglia | | |
|---|---|---|
| **Time** | **Topic** | **Speaker/Location** |
| 8:30 – 9:00 am | Improving postfire management decision-making by understanding the consequences of passive and active forest management following large stand-replacing wildfires | Morris Johnson |
| 9:00 – 9:30 am | Modeling outyear treatments for large-scale landscape restoration in FSveg Spatial Data Analyzer | Haley Anderson |
| 9:30 – 10:00 am | Using FVS to update old stand data to improve, prescribed treatments and timber sale decisions | Jared Nobles |
| 10:00 – 10:30 am | Coffee Break | |
| 10:30 – 11:00 am | Using FIA data and FVS to develop yield streams and state-and-transition models for National Forest planning | John Shaw |
| 11:00 – 11:30 am | FVS modeling for the Devils Hens Nest Vegetation Management Project | Joseph Elliott |
| 11:30 – 12:00 am | Integration of wildlife habitat into a constrained-optimization timber management strategy | Casey Phillips |
| 12:00 – 1:30 pm | Lunch Break | |
| 1:30 – 2:00 pm | FVS and natural climate solutions: Initial feedback from Forest Carbon Modeling Group engagement | Christopher Woodall |
| 2:00 – 2:30 pm | Simulating potential of improved forest management for carbon sequestration on Northeastern U.S. forests | Weier Liu |
| 2:30 – 3:00 pm | Automating high-resolution, large-extent FVS simulations for a carbon accounting protocol | Dave Schmidt |
| 3:00 – 3:30 pm | Coffee Break | |
| 3:30 – 4:00 pm | Development of carbon entity guidelines for wildfire and prescribed fire in the continental United States | Shawn Urbanski |
| 4:00 – 4:45 pm | Panel Discussion: Carbon modeling | Chris Woodall,<br>Weier Liu,<br>Dave Schmidt |

| Thursday, March 9th, 2023<br><br>Session 3: Model Evaluation<br>Morning Moderator: John Shaw / Afternoon Moderator: Dan Wagner | | |
|---|---|---|
| **Time** | **Topic** | **Speaker/Location** |
| 8:30 – 9:00 am | Impacts of Early Stand Density Treatments on Observed vs Projected Diameter and Height Increments in Mixed Conifer Stands of the Inland Northwest | David Affleck |
| 9:00 – 9:30 am | Growth and Yield Modeling for the State of Maine | Jereme Frank |
| 9:30 – 10:00 am | Using an Automated, High-Resolution FVS Workflow for Regional Planning in California. | Carrie Levine |
| 10:00 – 10:30 am | Coffee Break | |
| 10:30 – 11:00 am | Assessing the Accuracy of FVS for Evaluating Effects of Landscape Disturbance | Ethan Yackulic |
| 11:00 – 11:30 am | Calibrating FVS Growth and Mortality Multipliers in Northern California from FIA Observations | Sara Loreno |
| 11:30 – 12:00 am | Assessment of Crown Base Recession in Uneven-Aged Ponderosa Pine Forests of Colorado and Arizona | Wade Tinkham |
| 12:00 – 1:30 pm | Lunch Break | |
| 1:30 – 2:00 pm | FVS in the Hands of a Consultant | Clara Clark |
| 2:00 – 2:30 pm | Integrating FIA with a New Approach to Make FVS Climate-Aware in the Pacific Northwest | David Diaz |
| 2:30 – 3:00 pm | Power-user Features of FVS and FVSOnline | Nicholas Crookston |
| 3:00 – 3:30 pm | Coffee Break | |
| 3:30 – 4:15 pm | Panel Discussion: Future FVS Development | Mark Castle, Clara Clark, Nick Crookston, David Diaz, Aaron Weiskittel |
| 4:15 – 4:30 pm | Wrap -up | |

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