ADAPTATION AND VALIDATION OF THE REGEN EXPERT SYSTEM FOR THE CENTRAL APPALACHIANS

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Abstract.—REGEN is an expert system that predicts future species composition at the onset of stem exclusion using preharvest stand conditions. To extend coverage into hardwood stands of the Central Appalachians, we developed REGEN knowledge bases for four site qualities (xeric, subxeric, submesic, mesic) based on relevant literature and expert opinion. Data were collected from 48 paired stands to calibrate our preliminary REGEN knowledge bases. Data from 17 additional paired stands were used to independently validate the final performance of the model. Predictions for species groups were within 4 percentage points of measured values on average, and model error was typically no more than approximately 20 percentage points for any species group. These independent validation results confirmed the potential of REGEN to predict species composition of stands regenerated using the clearcut method in the Appalachians of Virginia and West Virginia.

INTRODUCTION

The mixed hardwood forests of the Appalachians are diverse and complex ecosystems (Braun 1950, Miller and Kochenderfer 1998, Yarnell 1998). Recent inventories have shown that many of these forests across the Appalachian Region are maturing (Oswalt and Turner 2009). Given the many species assemblages that occur throughout the Appalachians (Eyre 1980), several silvicultural systems can potentially be used to regenerate these maturing forests. Prior to implementing the silvicultural action aimed at fostering regeneration, however, an estimate of regeneration potential should be obtained to ensure landowner objectives can be met. Several approaches have been used to model regeneration in the historically oak-dominated ecosystems of the eastern United States (Rogers and Johnson 1998). Probabilistic models and management guidelines have been developed to evaluate regeneration potential in the Missouri Ozarks (Sander and others 1984), the Alleghenies (Marquis and others 1992), the Southern Bottomlands (Belli and others 1999), and the Central Appalachians (Steiner and others 2008). In some cases, multi-species, regional predictive models have been developed (e.g., Waldrop and others 1986, Dey 1991), but such models are not available for all areas.

REGEN, a multi-species, regional predictive model, has been developed for the Southern Appalachians (Loftis 1989). The REGEN model is an expert system designed to predict the future species composition of dominant and codominant stems at the onset of stem exclusion using a numerical ranking system of species' competitiveness in conjunction with preharvest stand characteristics. To generate predictions in REGEN, a fixed-radius plot survey of advance reproduction is required. Advance reproduction is categorized into five pre-defined size classes: germinant (newly germinated seedlings), small seedlings (<2 feet tall), medium

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seedlings (2-4 feet tall), large seedlings (>4 feet tall), and potential stump-sprouts (trees >4 feet tall and ≥2 inches diameter at breast height [d.b.h.]).

Each size class of advance reproduction for each individual species in REGEN is assigned a competitive rank, ranging from one to eight. Stems that are given a rank of one are considered to be the most competitive, and stems given a rank of eight are considered to be the least competitive. During the prediction process, a predetermined number of the highest-ranked stems of existing advance reproduction at each plot are selected as "winners." These winning stems are expected to be in a dominant or codominant crown position when the stand reaches stem exclusion following a regeneration harvest. Constant or logistic probabilistic parameters are used to establish stump-sprouts, root-suckers, and new seedlings that germinate following harvest. A REGEN Knowledge Base (RKB) contains the competitive rankings and probabilistic parameters used to process input data. These RKBs are modular, which allows REGEN to be adapted to different scenarios by creating custom RKBs. Boucugnani (2005) describes the development of the computer adaptation of REGEN and provides documentation for the underlying framework of the model in greater detail.

Efforts are currently under way to expand REGEN applicability throughout the Appalachians. The focus of this article is our assessment of REGEN's potential to predict future species composition in the Appalachian hardwood forests of Virginia and West Virginia following clearcutting.

STUDY AREA

This study was conducted on the Appalachian Plateau and Ridge and Valley Physiographic Provinces (Fenneman 1938) of Virginia and West Virginia (Fig. 1). Sample sites were located within four counties in Virginia (Craig, Giles, Montgomery, Wise) and six counties in West Virginia (Fayette, Greenbrier, Nicholas, Randolph, Tucker, Webster).

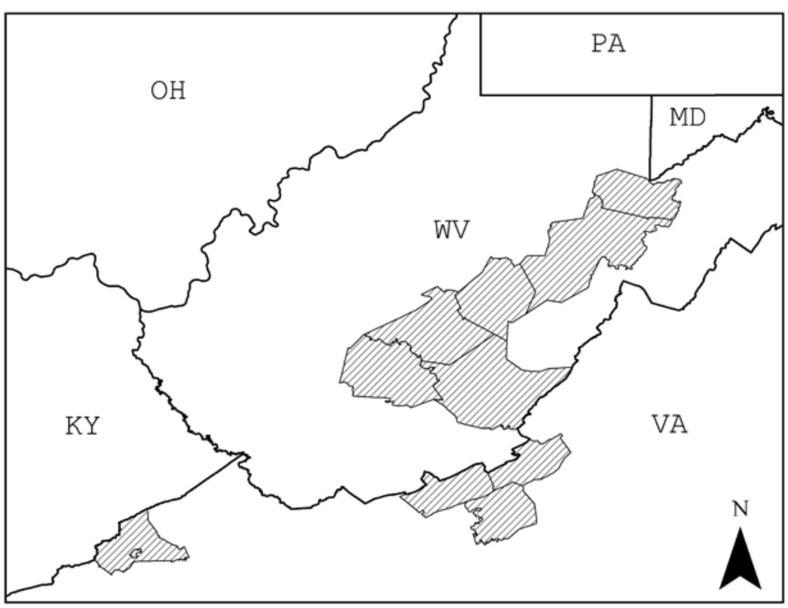

Figure 1.—Location of sample sites in the Central Appalachians. Shaded areas represent counties in which paired stands were located.

METHODS

To adapt REGEN to the Appalachians of Virginia and West Virginia, we created four preliminary RKBs. The four RKBs were designed to predict regeneration on xeric, subxeric, submesic, and mesic sites. The initial rankings and parameters for these four RKBs were based on relevant literature, including silvical characteristics (Burns and Honkala 1990), observed species composition following clearcutting (e.g., Beck and Hooper 1986, Ross and others 1986, Loftis 1989), and site productivity interactions (e.g., Doolittle 1958). The information from these sources and others was modified and supplemented as necessary based on the authors' experience to create rankings and parameters for 33 tree species in the four custom RKBs. These preliminary RKBs were revised based on the results of several iterative trials of model comparisons using field data collected from 48 paired stands across Virginia and West Virginia (Vickers 2009).

Following the calibration and assessment of the four knowledge bases, an additional, independent dataset was collected to validate the performance of REGEN. Field data were collected using a paired-stand sampling approach. This approach utilized sample sites that included both a mature, hardwood-dominated stand free from obvious recent disturbance and an adjacent regenerating clearcut stand with similar site characteristics. According to available landowner records, the mature stands were at least 70 years old, and the regenerating clearcut stands ranged from 5 to 18 years old at the time of sampling. This approach assumed that the two separate management units were once one contiguous stand of similar composition and productivity. Therefore, the mature stands were expected to regenerate in a similar fashion to their paired regenerating clearcut stands if harvested similarly. To ensure similar site productivity between paired mature and regenerating clearcut stands, we obtained estimates of site index using the Forest Site Quality Index (Meiners and others 1984). We also classified paired stands into site classes based on indicator species, as proposed by McNab and others (2002). We applied the species moisture weights from McNab and others (2002) to a list of all tree species present that were ≥2 inches d.b.h. in each mature stand to classify each paired stand into one of four site classes: xeric, subxeric, submesic, or mesic.

Seventeen paired stands were sampled in September and early October 2009. In the mature stands, one fixed-radius plot per acre was established with a maximum of 20 plots per stand. Plots were established using a systematic grid with the distance from the stand boundary to the first plot determined randomly, but no less than 132 feet. Advance reproduction was measured in a 0.01-acre circular plot by species and pre-defined REGEN height class (Large: > 4 feet, Medium: ≥ 2 feet, Small: < 2 feet, Germinant: newly germinated seedlings), and d.b.h. of all stems ≥ 2 inches d.b.h. within the plot was measured to account for potential stump-sprouts. At each fixed-radius plot center, a basal area sampling point was also established, on which the basal area of all stems ≥ 2 inches d.b.h. was measured using a 10 BAF prism. Regenerating clearcut stands were sampled at a density of one fixed-radius plot per acre, using 0.004-acre plots. In the regenerating clearcut stands, regeneration was tallied by species, stem origin (seed or sprout), and crown class (dominant, codominant, intermediate, suppressed). Given the complex assemblages of species that occur across this area, we created eight tree species groups after the data were collected to simplify data analysis and presentation: 1) black cherry, 2) conifers, 3) maples, 4) midstory, 5) oaks, 6) other overstory, 7) pioneer, and 8) yellow-poplar (Table 1). These species groups contain either a single species that was numerous throughout the study area or a collection of species that are expected, for the most part, to occupy similar stand structural positions.

Initial tests indicated the data were non-normal; therefore, all analyses were conducted using nonparametric tests. These analyses were conducted in SAS® version 9.2 software using the UNIVARIATE procedure (SAS Institute Inc., Cary, NC).

Table 1.—Species groupings used in this study for the Central Appalachians.

Group	Species
Black Cherry	black cherry (*Prunus serotina* Ehrh.)
Conifers	e. white pine (*Pinus strobus* L.), hemlock (*Tsuga* spp.), pitch pine (*Pinus rigida* Mill.), shortleaf pine (*Pinus echinata* Mill.), Table Mountain pine (*Pinus pungens* Lamb.), Virginia pine (*Pinus virginiana* Mill.)
Maples	red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.)
Midstory	Am. beech (*Fagus grandifolia* Ehrh.), blackgum (*Nyssa sylvatica* Marsh.), dogwood (*Cornus* spp.), e. hophornbeam (*Ostrya virginiana* [Mill.] K. Koch.), sassafras (*Sassafras albidum* [Nutt.] Ness.), serviceberry (*Amelanchier* spp.), sourwood (*Oxydendrum arboreum* [L.] DC.), striped maple (*Acer pensylvanicum* L.)
Oaks	black oak (*Quercus velutina* Lam.), chestnut oak (*Q.prinus* L.), n. red oak (*Q. rubra* L.), scarlet oak (*Q. coccinea* Muenchh.), white oak (*Q. alba* L.)
Other Overstory	ash (*Fraxinus* spp.), basswood (*Tilia* spp.), cucumbertree (*Magnolia acuminata* L.), Fraser magnolia (*Magnolia fraseri* Walt.), hickory (*Carya* spp.), yellow buckeye (*Aesculus flava* Aiton), yellow birch (*Betula alleghaniensis* Britton)
Pioneer	black locust (*Robinia pseudoacacia* L.), pin cherry (*Prunus pensylvanica* L.f.), sweet birch (*Betula lenta* L.)
Yellow-poplar	yellow-poplar (*Liriodendron tulipifera* L.)

To assess the overall performance of the model, the predicted future species composition of dominant and codominant stems from REGEN (which was based on advance reproduction from the mature stands) was compared to the measured dominant and codominant species composition (which was taken from regenerating clearcut stands) for each species group at each paired stand as a percentage. For example, if REGEN predicted that black cherry will make up 25 percent of the future dominant and codominant stems following harvest in a given mature stand, and we measured that only 20 percent of dominant and codominant stems were black cherry in the paired regenerating clearcut stand, then the difference (model error) for black cherry at that sample site was 5 percentage points. This type of comparison was completed for each species group at each sample site. The Wilcoxon Signed Rank test, a nonparametric alternative to a paired *t*-test, was used to test for differences between measured and predicted samples for each species group across all paired stands (Ott and Longnecker 2001). Because all paired stands in our study fell on either subxeric or submesic sites, only those two RKBs were tested with field data. Trends observed in the subxeric and submesic site classes were previously extended into the xeric and mesic RKBs according to the authors' expectations, but those RKBs have not been tested.

RESULTS AND DISCUSSION

An example of our final rankings for the most competitive stems of a few common species across all site classes is provided in Table 2. As might be expected, species that are more xerophytic are generally considered more competitive on xeric and subxeric sites, while more mesophytic species are generally ranked higher on mesic and submesic sites. The final competitive rankings did not always progress in rank across the site-quality gradient as we initially assumed, but these final rankings were found to be the best fit to the calibration data that we were able to achieve during the revision process (Vickers 2009). In addition to developing a competitive ranking between species across the four site classes, we also had to develop rankings for the different size classes of advance reproduction within a single species. The rankings within a species are fairly

Table 2.—Example REGEN competitive rankings for the most competitive forms of several common tree species in the Central Appalachians across four site qualities. Species ranked 1 are considered the most competitive on a given site quality, those ranked 8 are considered the least competitive.

REGEN Competitive Rank	Xeric	Subxeric	Submesic	Mesic
1	Virginia pine	red maple sweet birch yellow-poplar	black cherry basswood sweet birch yellow-poplar	black cherry basswood sweet birch yellow-poplar
2	red maple	black cherry	northern red oak	
3	sassafras northern red oak	northern red oak	red maple	red maple
4		Virginia pine		northern red oak
5				
6	black cherry yellow-poplar	sassafras basswood	sassafras	
7	sweet birch			sassafras
8	basswood		Virginia pine	Virginia pine

straightforward; i.e., stump-sprouts are more competitive than large stems, which are more competitive than medium stems, and so forth. However, the distance between size class rankings for a species may not be uniform. For example, in the submesic RKB, the rankings for yellow-poplar range from one to five consecutively from stump-sprouts to germinants. In contrast, for northern red oak, a stump-sprout is given a rank of two, a large stem is ranked five, and a medium stem is ranked eight. Given the limited number of rankings available, smaller stems of northern red oak are not considered to be viable sources of regeneration in the submesic RKB. For a complete set of finalized rankings and parameters for all four RKBs, see Vickers (2009).

The competitive rankings that we developed in the REGEN model for the Central Appalachians performed better than was expected. The predicted and measured values for each species group at each sample site were used to calculate the mean species composition values and mean model error across all 17 sample sites, which are displayed in Table 3 and Figure 2. Across all 17 paired stands, the species composition predicted by REGEN was within about 4 percentage points of the measured species composition, on average, for all eight species groups used in this study (Table 3). Tests for differences in sample distributions indicated that only the yellow-poplar species group's distribution of measured values was statistically different from the distribution of predicted values using $\alpha = 0.1$. The yellow-poplar predictions were likely impacted by the inconsistencies of its presence and importance in the northern portions of this study, which tend to be transitional forests between central, Allegheny, and northern hardwoods (Braun 1950, Stout 1991). Other researchers have also experienced difficulty modeling early successional species, particularly yellow-poplar, on the Cumberland Plateau of Tennessee (Waldrop and others 1986). Attempts to decrease the rank of yellow-poplar in the iterative model revision and calibration process resulted in drastic underprediction of yellow-poplar on many sites.

Table 3.—Comparison of measured and predicted species composition at 17 paired stands in the Central Appalachians. Species composition values expressed as percentages represent mean values. P values < 0.1 indicate significant differences between measured and predicted samples as calculated by the Wilcoxon Signed Rank test.

Species Group	Measured (%)	Predicted (%)	P value
Black cherry	4	5	0.2661
Conifers	2	2	0.6250
Maples	22	22	1.0000
Midstory	11	9	0.6777
Oaks	17	13	0.4037
Other overstory	9	8	0.7119
Pioneer	22	24	0.8209
Yellow-poplar	13	17	0.0413
Total	100	100	

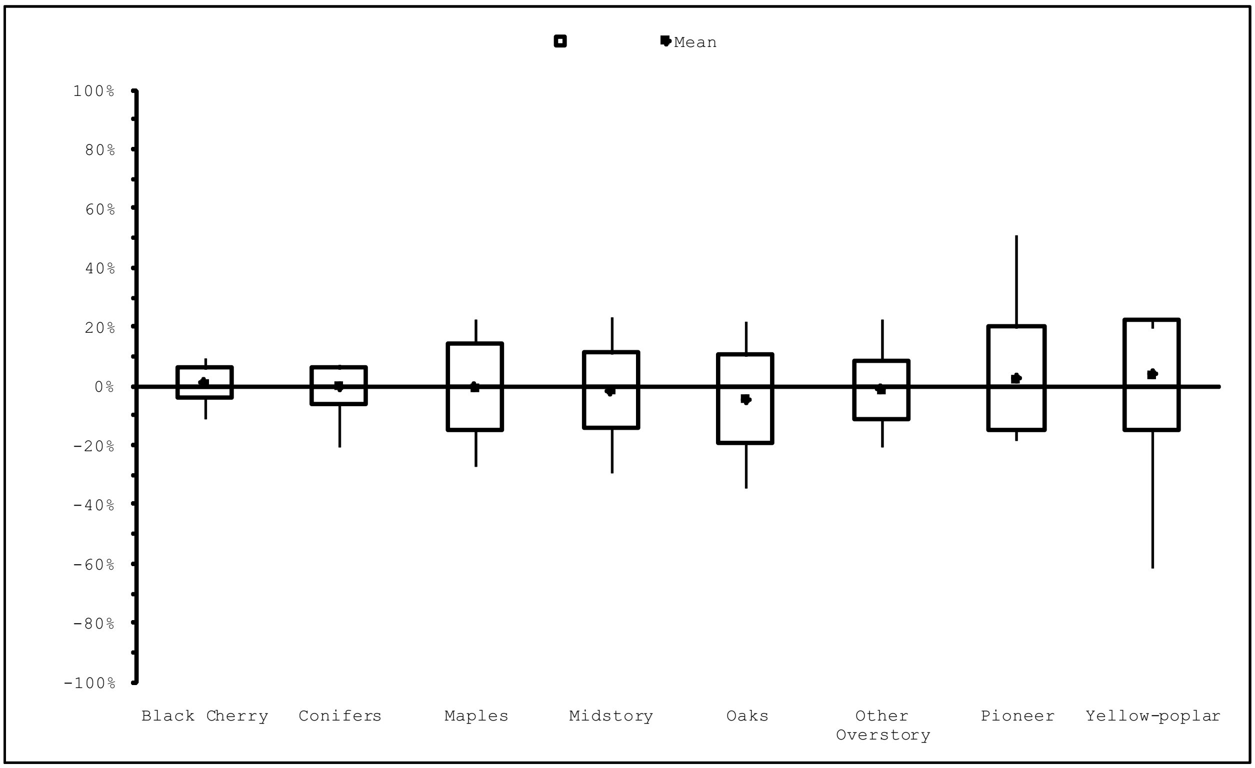

Figure 2.—Mean model error spread for each species group at 17 paired stands in the Central Appalachians. Model error was calculated as predicted – measured. Data points represent mean species group error, open bars represent mean species group error ± one standard deviation, and vertical lines represent species group error range.

Across all 17 paired stands, 1 standard deviation of the model error was not more than approximately 20 percentage points for any species group (Fig. 2). One standard deviation of model error for the pioneer and yellow-poplar species groups was only slightly more widespread than many of the other species groups, but the overall range in error for those two groups was considerably greater. These early-successional species groups were quite variable in their regeneration patterns, and as such, were difficult to parameterize. The model error for the remaining species groups was typically no more than 5 to 15 percentage points.

Results of this study indicated that the REGEN model can be adapted to predict regeneration in various communities with some success. The REGEN model showed potential to provide sufficient information to assist with a variety of management decisions. Although species groups were used in our analyses, the initial predictions in REGEN were, in fact, for individual species. The comparison of mean values between measured and predicted species composition was highly favorable (Table 3), but there was a considerable amount of variation in the degree of accuracy for a given species group on individual stands (Fig. 2). For this reason, REGEN would likely provide a more accurate portrayal of regeneration tendencies across a large ownership rather than for a single stand at this time. The potential to improve these RKBs without long-term studies conducted across the Central Appalachians, however. is limited. Given the highly stochastic nature of Appalachian hardwood regeneration, REGEN predictions should be subject to the scrutiny of an experienced forester prior to basing management decisions on model output. We nonetheless believe REGEN has the potential to be a useful tool in regeneration silviculture and should help identify stands that may be candidates for preharvest manipulation or future ameliorative treatments necessary to meet management objectives.

ACKNOWLEDGMENTS

The authors appreciate the joint funding of this project by the U.S. Department of Agriculture, Forest Service, and the Appalachian Hardwood Forest Research Alliance (AHFRA). The support of the following AHFRA members in identifying and providing access to potential sample sites is greatly appreciated: Jay Engle and Wesley Johnson of MeadWestvaco Corporation, Doug Toothman of Western Pocahontas Properties LP, and Theresa Henderson and Jason Weinrich of The Forestland Group LLC. The authors also thank Bob Radspinner of Plum Creek Timber Company Inc., Glen Jeurgens of the Monongahela National Forest, Thomas Schuler of the Fernow Experimental Forest, and Edward Leonard of the George Washington Jefferson National Forest. The comments of the two anonymous reviewers certainly improved this article and are greatly appreciated.

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