AN EVALUATION OF THE HARDWOOD REGENERATION MODEL (REGEN) 16 YEARS POST-HARVEST OF A REGENERATED STAND IN EAST TENNESSEE

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Abstract--The REGEN model (developed by USDA Forest Service, Southern Research Station, Bent Creek Experimental Forest) was used prior to harvest to predict species composition of hardwoods at crown closure. This study evaluates whether the predictive ability of the model was effective by using post-harvest information after 16 years. Regeneration data were collected prior to harvest in February through April 1997 at the University of Tennessee Forest Resources Research and Education Center near Oak Ridge, TN. Five site preparation treatments were implemented to favor desired species and to control undesired species in the future stand: preharvest slash only, preharvest slash with herbicide stump treatment, post-harvest slash only, post-harvest slash and herbicide stump treatment, and control (no slashing or herbicide). Each set of five treatments was replicated six times for a total of 30 treatment plots (0.33 acre per treatment plot). Predictions of overstory composition and number from the REGEN model (using the Southern Appalachian variant) by site preparation treatment are compared to the actual stand data after 16 years to determine the accuracy and utility of the model in forecasting species composition at crown closure prior to harvest. Results indicate that the REGEN model performed well in predicting species composition at crown closure. The model overcompensated for presence of yellow-poplar (*Liriodendron tulipifera* L.), enough to provide reasonable estimations of the number of overstory stems after 16 years. Pre- or post-harvest site preparation techniques had little effect on presence of light-seeded species such as yellow-poplar and black cherry (*Prunus serotina* Ehrh.). About 10 percent of total overstory stems after 16 years were oaks (*Quercus* spp.), regardless of site preparation treatment. The same percentage of advanced oak seedlings was represented in the pre-harvest regeneration inventory.

INTRODUCTION

Ensuring adequate regeneration of preferred species in mixed hardwood stands following a harvest is often a concern to forest managers. A myriad of different species with different site requirements and growth habits and varying sources of reproduction (seed, sprouts, advance regeneration) make prediction of regeneration complex and sometimes unreliable. Often competition from undesirable trees is too great for the commercially important species to overcome.

Encouraging growth of preferred, regenerating species often is accomplished by limiting through site preparation the growth or presence of more undesirable competing species. Slashing and/or herbicides are two methods of site preparation. Little information is available (either pre- or post-harvest treatment) to assess the relative effectiveness of these various site preparation alternatives. Loftis (1978, 1985, 2004) evaluated the effectiveness and costs associated with preharvest practices on Appalachian hardwoods. The results suggest that preharvest treatments reduce the number of stems of undesirable species and increase the proportion of desirable species in the stand.

Subsequently, a forest regeneration model, REGEN, was developed for the southern Appalachians by the USDA Forest Service, Southern Research Station, Bent Creek Experimental Forest near Asheville, NC (Boucugnani 2005, Loftis 1989) to predict species composition at crown closure based on preharvest regeneration sources. Forest managers can use the model as a tool to determine if the predicted regeneration results are satisfactory to meet their objectives. Otherwise, if the results are unsatisfactory, practitioners can take management actions that may lead to more desirable results. These actions typically modify the environment to benefit regeneration and development of desired species and discourage undesirable species. A few examples of actions that could be taken before the harvest that would influence regeneration potential would be a midstory removal to develop greater size of advance reproduction or the use of herbicides to influence competing vegetation.

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REGEN is a probabilistic model based on an expert system using a numerical ranking system of species' competitiveness. The model predicts regeneration outcomes following stand-replacement disturbance events. Regeneration sources (seed, sprouts, or advance reproduction) are specified in a preharvest regeneration inventory by species and size. Probabilities and rankings in the form of knowledge bases (species and propagules) determine the relative likelihood that a species/propagule will be a component of the future overstory at canopy closure. For further information about the REGEN model refer to Boucugnani (2005) or Vickers and others (2011). A web-based version of the model is available at http://www.webregen.org.

The REGEN model is a prospective tool for forest land managers to evaluate regeneration potential. However, the predictive model, based on an expert system, has not been thoroughly tested with actual data because of the 10 to 20 years required for a regenerating stand to reach canopy closure. This study provides an assessment of the REGEN model in one stand in east Tennessee that used several site preparation techniques to influence regeneration.

OBJECTIVES

The purpose of this study was to evaluate the predictive outcomes of the REGEN model from pre-harvest regeneration sources by assessing actual overstory composition at canopy closure or stand exclusion 16 years after a commercial clearcut harvest with various site preparation sources.

METHODS

The research was located on a 17-acre watershed at the University of Tennessee Forest Resources Research and Education Center near Oak Ridge, TN in the Ridge and Valley physiographic province. Elevations in the south-facing drainage range from 970 to 1,100 feet above sea level. Soils consist of clayey, kaolinitic, thermic Typic Hapludults from the Fullerton series (Moneymaker 1981). Site index (base age of 50 years) for upland oaks ranges from 65 to 75 feet (Olson 1959). The harvested sawtimber stand was comprised primarily of oaks (*Quercus* spp.) (69 percent by volume), yellow-poplar (*Liriodendron tulipifera* L.) (14 percent), miscellaneous hardwoods (10 percent), and pines (*Pinus* spp.) (6 percent).

Five treatments were implemented: (1) preharvest slash only; (2) preharvest slash with herbicide stump treatment; (3) post-harvest slash only; (4) post-harvest slash and herbicide stump treatment; and (5) control (no slashing or herbicide).

The five treatments were applied to 120- by 120-foot (0.33 acre) plots. This plot size was large enough to distinguish an individual treatment from adjacent treatment while allowing for replications. Each set of five treatments was replicated six times for a total of 30 treatment plots. All treatment plots were located adjacent to each other.

Within each plot, four 1/100 acre subplots were established for sampling. Each subplot was located at a corner of a 60- by 60-foot square contained within each plot. The first subplot was established by running a line bisecting the northern corner of each plot for 42.5 feet. The remaining subplots were positioned by running 60-foot lines parallel to the boundaries of the plot.

Plots were assigned to different replications by establishing groups of plots that were similar in terms of species composition, density, and location. A computer-generated design for incomplete blocks was used to assign treatments to plots.

The initial inventory was conducted in June 1996 before the harvest. All trees above 1 foot in height were measured in subplots during September 1996. Data were collected in several designated classes: 1-foot height classes to 4-feet tall; above 4-feet tall but < 1.5 inches at diameter breast height (d.b.h., 4.5 feet); and by 1-inch diameter class above 1.5 inches. This methodology follows the input data required for the regeneration prediction model (REGEN). The 4 subplots on each of the replicates with the same treatment (24 total subplots for each treatment) were used to predict percentage species composition at crown closure using the REGEN model.

Preharvest treatments were conducted on the designated plots during October 1996. The number of stems cut per plot was recorded as stems > or < 1.5 inches d.b.h. Non-commercial stems >1.5 inches d.b.h. were cut. Garlon® 3A (triclopyr) in a 50:50 mix with water and red dye was used on all non-commercial stumps, primarily red maple (*Acer rubrum* L.), blackgum (*Nyssa sylvatica* Marsh.), sourwood (*Oxydendrum arboreum* DC), dogwood (*Cornus florida* L.), sweetgum (*Liquidambar styriciflua* L.), elms *(Ulmus* spp.), and beech (*Fagus grandifolia* Ehrh.). Herbicide was applied to the stump directly after cutting.

The timber harvest was conducted from February through April 1997. Post-harvest treatments were conducted in August 1997 in the same manner as the preharvest treatments.

All subplots were measured after the second growing season (1999) and the results on species composition and costs associated with pre- and post-harvesting treatments were reported by Hodges and others (2002). Measurements after 10 growing seasons (2006) were collected during December 2006 and January 2007. Data collected on each subplot were stem counts by species for all stems > 4 feet in height. Results after 10 growing seasons were reported by Clatterbuck and Schubert (2010).

Measurements for this study were collected in December 2012 and January 2013. Stems >1.5 inches in d.b.h. on the subplots were defined as overstory stems and were tallied by species. The study area was in the stem exclusion stage with a closed canopy. Data from the subplots were combined by treatment for the six replicates. Percentage species composition was compared between the predicted species composition from the pre-harvest regeneration at stand closure to the actual data 16 years after harvest.

The purpose of the original study was to evaluate site preparation treatments on species composition after a silvicultural clearcut. The experimental design for that study is not appropriate for testing statistical differences between actual and predicted (REGEN model) species composition since only one stand was sampled, although there were different treatments and the treatments were replicated. Thus, this research should be considered a case study comparing predicted species composition percentages of the REGEN model at the stem exclusion stage of stand development and actual species composition percentage of overstory trees at crown closure measured 16 years after harvest.

RESULTS

The stand prior to harvest was in the stem exclusion stage for many years, resulting in a sparse midstory and understory with few stems or seedlings of desirable species. More than 95 percent of the stems were < 2 feet in height, and most of the species present (red maple, dogwood, sourwood, blackgum, beech) were shade tolerant. Red maple stems composed more than 60 percent of the understory composition. Few yellow-poplar or black cherry, both extremely shade-intolerant species, were present in the advance reproduction. Oak species that were < 2 feet in height averaged about nine stems per 1/100 acre plot.

Stand structure 16 years after harvest was a closed canopy with an average canopy height of 42 feet and mean d.b.h. of 3.9 inches with a wide range of diameter of overstory trees from 1.5 to 8.2 inches.

The predicted species composition at canopy closure of the various site preparation treatments from the REGEN model are shown in table 1. Both yellow-poplar and black cherry have the greater number of stems regardless of treatment. The amount of red maple was reduced in the herbicide treatments. Oak species composed < 5 percent of the stems in any of the treatments.

Table 2 presents actual overstory composition by site preparation treatment 16 years after the harvest at canopy closure (stem exclusion). Generally, more oaks were present in the actual data than in the predicted data, and miscellaneous species were much more robust in the actual data. Red maple was less numerous when herbicide was used in both the predicted and actual datasets. Black cherry had greater proportion of stems in the predicted

Table 1—REGEN model prediction of species composition at canopy closure by site preparation treatment prior to harvest for a hardwood stand at the University of Tennessee Forest Resources Research and Education Center near Oak Ridge, TN. Data for each treatment based on n = 24, 1/100-acre regeneration plot

Site preparation treatment	Yellow-poplar	Black cherry	Red maple	All oaks	Misc. species[a]
	percentage of total stems				
Preharvest slash	38	29	21	2	10
Preharvest slash + herbicide	39	40	12	5	4
Post-harvest slash	51	23	20	2	4
Post-harvest slash + herbicide	49	34	9	1	6
Control - no site preparation	40	30	22	4	4

[a]Miscellaneous species include beech, blackgum, dogwood, elms, hollies (*Ilex* spp.), sassafras [*Sassafras albidum* (Nutt.) Nees], sourwood, sweetgum, pines, sumac (*Rhus* spp.), and white ash (*Fraxinus americana* L.).

model than in the actual data. Yellow-poplar percentages did not range widely between the actual and predicted data, herbicide treatments, or pre- and post-harvest treatments. All species percentages were fairly similar between the actual preharvest and post-harvest treatments.

DISCUSSION

The REGEN model performed well in predicting species composition at crown closure. A few of the discrepancies may be because the knowledge base used was formulated for the southern Appalachian mountains and not the Ridge and Valley province. Black cherry is much more prominent at the higher elevations of the mountains than the Ridge and Valley, where it is much more susceptible to pitch pockets, black knot, rot, and crown breakage from wind and ice damage. The REGEN knowledge base would need to be modified to more correctly classify black cherry in this area.

Species that regenerate readily from seed, particularly yellow-poplar and black cherry, dominate the study area after 16 years (table 2). Pre- and post-harvest slashing and the use of herbicide during site preparation have little impact on the regeneration of these species since they do not regenerate from advance reproduction. The seeds remain viable on the forest floor for several years: yellow-poplar for 4 to 7 years (Clark and Boyce 1964) and black cherry for 3 or more years (Wendel 1977). The viable seeds accumulate in the forest floor after seed dissemination each year forming a seed bank ready to germinate when conditions are favorable, especially after a harvest and site preparation. The numerous, viable seeds in the seed bank often overburden the advance regeneration present on the site prior to harvest shifting the species composition toward these species. The REGEN model estimation of yellow-poplar reflected the actual data. However, the amount of black cherry predicted by the model often was overestimated compared to the actual data.

The site preparation treatments with herbicides, both pre- and post-treatment, reduced the amount of red maple in the model and with the actual data. Red maple was the most common species in the midstory and understory in this closed-canopy stand and was the species that received most of the herbicide applied. However, with the overabundance of yellow-poplar from seed, the growth of red maple into the overstory also was affected by the faster growth of yellow-poplar. Red maple does not appear to be aggressive enough to become a major component of the overstory although more advance reproduction of red maple was present than for any other species.

Oaks were not affected by the site preparation treatments. The same proportion of oaks was present in advance reproduction as the proportion of oaks in the overstory after 16 years. The model estimation for oak species under-represented what actually occurred. Presently about 200 oaks per acre (about 10 percent of total overstory stem) remain at 16 years, and that number will probably diminish with time. Oaks will be a component of the next stand but at a much lower density than in the

Table 2—Actual species composition at canopy closure 16 years after harvest by site preparation treatment for a hardwood stand at the University of Tennessee Forest Resources Research and Education Center near Oak Ridge, TN. Data for each treatment based on n = 24, 1/100-acre regeneration plot

Site preparation treatment	Yellow-poplar	Black cherry	Red maple	All oaks	Misc. species[a]
	percentage of total stems				
Preharvest slash	36	16	21	8	20
Preharvest slash + herbicide	42	23	12	8	15
Post-harvest slash	36	14	16	11	23
Post-harvest slash + herbicide	36	12	13	9	31
Control - no site preparation	50	10	13	7	21

[a]Miscellaneous species include beech, blackgum, dogwood, elms, hollies (*Ilex* spp.), sassafras [*Sassafras albidum* (Nutt.) Nees], sourwood, sweetgum, pines, sumac (*Rhus* spp.), and white ash (*Fraxinus americana* L.).

harvested stand. Most of the oak advance reproduction in this study was < 2-feet tall before harvest. The probability of this diminutive oak advance reproduction becoming an overstory tree is < 2 percent (Loftis 2004).

Most of the miscellaneous species, though a component of the overstory at 16 years, will probably diminish with their slower growth capacity. The exception is the pines, primarily Virginia (*P. virginiana* Mill.) and loblolly (*P. taeda* L.) pines regenerating from wind-blown seed.

These pine stems are few in number but of larger diameters. The REGEN model estimated a lower proportion of miscellaneous species at crown closure than the actual field data after 16 years.

Preharvest site preparation treatments compared to post-harvest treatments had little effect on species composition (tables 1 and 2). Seasonality of when these treatments were conducted was similar, October for the preharvest site preparation and August the following year for the post-harvest. More than three times as many stems were treated in the preharvest plots than recorded in the post-harvest plots (Clatterbuck and Schubert 2010). The harvesting operation resulted in many of the stems in the post-harvest plots being severed before the treatment being applied. Thus, the miscellaneous species category for post-harvest with herbicide was greater because the herbicide was not applied to those stems impacted by the harvest. The preharvest treatments were more costly to conduct than the post-harvest because more stems were treated in the pre-harvest treatments (Hodges and others 2002).

FUTURE CONSIDERATIONS

If the REGEN model is to be used effectively in the Ridge and Valley of east Tennessee, the black cherry rankings and probabilities in the model should be adjusted accordingly to reflect conditions of the study area. The southern Appalachian knowledge base was used in this study and probably reflects conditions in the area where it was developed rather than the Ridge and Valley. The proportion of black cherry in the overstory at canopy closure was often overestimated by the model compared to the actual data. Familiarity with the model and the knowledge base is necessary to make species modifications in the model. Practitioners should realize the silvics of a particular species differs gradually from locality to locality and region to region. The silvics of black cherry in western Pennsylvania is different from the southern Appalachians of North Carolina and different from the Piedmont. The knowledge base of the model should reflect those local conditions where the model is applied.

Hardwood regeneration models are complex and difficult to develop because of the variation in species, sites, reproductive sources, regeneration methods, competitive interactions among and between species, and temporal and spatial scales. Even with this inherent variation, Vickers and others (2011) suggested that model development and information or knowledge contained within the model are responsible for most of the divergence involved between predicted and actual values. The discrepancies encountered in this study, especially those with estimating the proportion of black cherry in the overstory at crown closure, reflect inconsistencies in the knowledge base for black cherry in the Ridge and Valley area. Otherwise, the REGEN model provided reasonable predictions of species composition at canopy closure when compared to actual data 16 years after harvest.

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