PREDICTING THE REGENERATION OF APPALACHIAN HARDWOODS: ADAPTING THE REGEN MODEL FOR THE APPALACHIAN PLATEAU

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Abstract—The difficulty of achieving reliable oak (*Quercus* spp.) regeneration is well documented. Application of silvicultural techniques to facilitate oak regeneration largely depends on current regeneration potential. A computer model to assess regeneration potential based on existing advanced reproduction in Appalachian hardwoods was developed by David Loftis of the U.S. Forest Service, Bent Creek Experimental Forest. REGEN is a competition-based, expert system which predicts dominant and codominant species composition at the onset of stem exclusion. A knowledge base containing competitive rankings for each species and size combination of advance reproduction is used to make predictions. REGEN was initially developed for hardwood forests in the Blue Ridge Physiographic Province of the Southern Appalachians and is only applicable for predicting regeneration following a heavy disturbance, such as a clearcut. We have developed preliminary REGEN knowledge bases for hardwood forests in the Appalachian Plateau Province.

INTRODUCTION

Hardwood Regeneration

Successfully regenerating oak (*Quercus* spp.) is difficult in eastern hardwood forests when using traditional regeneration systems (Loftis and McGee 1993). Oak is often displaced by more aggressive shade-intolerant species following clearcutting or by more shade-tolerant species in partial harvesting systems. Site quality has been identified as a primary driver of upland oak regeneration potential (Weitzman and Trimble 1957). The influence of site quality on regeneration potential is perhaps most evident in the Southern Appalachians, resulting in increased site specificity in techniques prescribed to foster oak regeneration (Loftis 1990b). The most promising techniques are modifications of the shelterwood system (Brose and Van Lear 1998, Loftis 1990a). Efforts to foster development of large oak advance reproduction often require an extended regeneration period, perhaps up to 20 years or longer (Sander 1972). Complex relationships between species and site further hinder implementation of landscape level oak regeneration improvement efforts, and the extended planning horizon required by those techniques can only increase management uncertainty. Therefore, identification of individual stands where oak regeneration will be inadequate and their potential for improvement should assist land managers in allocating limited resources. Estimates of regeneration potential may be achieved preharvest using regeneration prediction models. Several regeneration models have been developed for eastern hardwoods (Gould and others 2006, 2007; Loftis 1990b; Sander and others 1984).

Regeneration Models

Regeneration models are generally categorized as either qualitative or quantitative (Rogers and Johnson 1998). Qualitative models are often presented as decision charts or guidelines and usually offer interpretation and prescriptions. A qualitative model has been published for the central Appalachians (Steiner and others 2008). Quantitative models are often computer based and have historically provided estimates of regeneration potential for a single species or perhaps a species group. Quantitative models are often presented as equations and are typically more limited in adaptability. Regional quantitative models such as the ACORn model for the Ozarks are available in some areas (Dey 1991). Currently a multispecies regional quantitative regeneration prediction model for the Southern Appalachians has not been published. Interest in such a tool has led to the development of the REGEN model by Research Forester David Loftis of the U.S. Forest Service, Bent Creek Experimental Forest (Loftis 1989).

REGEN Model

The REGEN model is an expert system designed to predict dominant and codominant species composition following heavy disturbance. The expert user assigns competitive rankings based on species and size of advance reproduction in a predefined scenario. A key feature of REGEN is the categorization of advance reproduction species-size combinations, which are separated as—germinant, small (<2 feet tall), medium (2 to 4 feet tall), large (4 feet and taller), and potential stump sprouts (taller than 4 feet and >2 inches d.b.h.). Each species-size combination is given a ranking, thereby increasing the specificity of the model. Rankings range from 1 to 20 decreasing in competiveness. Given that sources of successful regeneration are often not present as advance reproduction, REGEN allows for the probability of establishment for these unobserved sources, as well as vegetative forms of reproduction, to be included as a constant or logistic parameter. Stems are rewarded based on relative rankings of the population of propagules in each sample plot. The stochastic feature of the model permits numerous runs of the input data thus allowing summary statistics to be included with the results.

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A REGEN knowledge base (RKB) is used to process input data collected from field sample plots. Competition is simulated at the plot level and "winning" stems per plot are later scaled to stems per acre. REGEN populates the predicted plot by adding up to six "winning" stems based on competitive ability per 0.01-acre plot. If one stump sprout is chosen, the number of "winners" per plot is reduced to four; if two or more sprouts are chosen there can be only three "winners" per plot. These rules are intended to compensate for the increased space requirements of stump sprouts as opposed to seed origin regeneration.

RKB's are modular, allowing for the expansion of REGEN to different scenarios by creating an RKB unique for that scenario. The original RKB was developed for the Blue Ridge Physiographic Province of the Southern Appalachians. The objectives of this study were to evaluate the adaptability of the REGEN model framework to the Appalachian Plateau, create RKBs for that region, and field test the predictions from REGEN against data collected across the Appalachian Plateau.

METHODS

Recognizing the impact site quality can have on the species composition of Appalachian hardwoods, three preliminary RKBs were developed for the Appalachian Plateau in an attempt to capture species variability resulting from site differences. The delineation for application of the three RKBs is based on upland oak site index (base age 50) along the following breaks: site index <65 feet = low quality RKB, site index 65 to 75 feet = medium quality RKB, site index >75 feet = high quality RKB. Rankings were subjective but were based on general silvics and trends reported in available literature as much as possible. Yellow-poplar (*Liriodendron tulipifera*) and black cherry (*Prunus serotina*) were the highest ranked species in all size categories and site qualities, with sweet birch (*Betula lenta*) and red maple (*Acer rubrum*) also being ranked highly. Oaks generally increased in rank with size and decreasing site quality. The more mesic species generally decreased in rank as site quality decreased, while the more xeric species increased in rank. Stump sprouts were ranked as the most competitive source of regeneration when applicable, and rankings generally decreased with smaller size classes.

The RKBs were field tested using a paired stand approach. This approach required that sample sites have a mature hardwood stand relatively free from disturbance for the past 25 years immediately adjacent to a regenerating stand which was harvested via clearcut at least 5 years earlier. Efforts were made to ensure similar site characteristics existed on each component of the paired sample sites; however, a wide range of site quality was desired across sample sites. A total of 41 paired sample sites were located throughout West Virginia on the eastern edge of the Appalachian Plateau in Fayette, Greenbrier, Nicholas, Tucker, and Webster Counties. Of these 41 stands, 7 had a majority of plots in the high-site quality group (site index >75 feet), 23 stands were in the medium-quality group (site index 65 to 75 feet), and 11 stands were in the low-quality group (site index <65 feet).

Sample plots were located using a systematic random grid. A total of up to twenty 0.025-acre regeneration plots were installed at a density of 1 plot per acre on each mature stand to assess regeneration potential. Stand size was variable. At each sample plot in the mature stand, advance reproduction was tallied by species and REGEN height class. Harvested stands were sampled using 0.001-acre plots unless stand development had progressed such that the plots were frequently not populated, in which case sample plots were reestablished as 0.025-acre plots. Sampling was conducted at a density of one plot per acre on a systematic random grid. Stand sizes were variable. Stems were tallied by species, stem origin (seed or sprout), and crown class. At each sample plot on both components of the paired stand slope, aspect, and landscape position were measured to obtain an estimate of site quality using the forest site quality index (Meiners and others 1984).

Although advance reproduction was sampled on 0.025-acre plots, an error was discovered with the scaling algorithm that REGEN uses to adapt data from various plot sizes to the native 0.01-acre plot size. For the purpose of this paper, field data were manually scaled premodel by multiplying each individual advance reproduction propagule by 2.5 and rounded up due to the selection process of the model.

RESULTS AND DISCUSSION

Due to the high floristic diversity found in the Southern Appalachians, species are combined into 10 groups based on either frequency or similarity. The 10 groups created are as follows: black cherry, red maple, sugar maple (*A. saccharum*), sweet birch, yellow-poplar, oaks, mixed mesophytic, subcanopy, pioneer, and miscellaneous. The oaks group consisted of black oak (*Q. velutina*), chestnut oak (*Q. prinus*), northern red oak (*Q. rubra*), scarlet oak (*Q. coccinea*), and white oak (*Q. alba*). Mixed mesophytic species included basswood (*Tilia americana*), American beech (*Fagus grandifolia*), buckeye (*Aesculus octandra*), cucumbertree (*Magnolia acuminata*), Fraser magnolia (*M. fraseri*), and yellow birch (*Betula alleghaniensis*). Subcanopy species found were American chestnut (*Castanea dentata*), American holly (*Ilex opaca*), blackgum (*Nyssa sylvatica*), flowering dogwood (*Cornus florida*), eastern hophornbeam (*Ostrya virginiana*), sassafras (*Sassafras albidum*), serviceberry (*Amelanchier arborea*), sourwood (*Oxydendron arboreum*), and striped maple (*Acer pensylvanicum*). Pioneer species included black locust (*Robinia pseudoacacia*), pin cherry (*Prunus pensylvanica*), and American sycamore (*Platanus occidentalis*). The miscellaneous species group included those that were too few to justify a single group and did not fit well into any other established groups. Species in the miscellaneous group include the ashes (*Fraxinus* spp.), hickories (*Carya* spp.), eastern hemlock (*Tsuga canadensis*), red spruce (*Picea rubens*), and eastern white pine (*Pinus strobus*). Predictions from REGEN were summarized postcomputation into the same 10 species groups.

Model results using advance reproduction in the mature stand as input were compared to the species composition of the harvested component under the assumption that the mature stand would regenerate very similarly to the developing stand if it were to be harvested today. Comparisons of the model results using the three preliminary RKBs with field-collected data are presented. The average species composition for the seven high-quality harvested stands and the predicted species composition from the high-quality RKB are presented in table 1. The high-quality RKB had the largest discrepancies with the observed composition. The most notable difference was for sugar maple which was overestimated considerably; other species in this RKB were reasonably predicted. The average species composition of the 23 medium-quality harvested stands and the predicted species composition from the medium-quality RKB are displayed in table 2. For the 11 low-quality stands, the average species composition is shown in table 3 along with the predicted species composition from the low-quality RKB. In the medium- and low-quality RKBs, red maple was predicted in higher proportions than what was actually observed, while sugar maple was again overestimated in the low-quality RKB. Given the frequency in which maple is referred to as a potential benefactor to decreasing oak regeneration in the literature, both red and sugar maples were given highly competitive rankings in all three RKBs. Sugar maple was ranked most strongly in the high-quality RKB, and red maple was ranked highly throughout all three RKBs. Results from the field testing suggest that the maples are not as competitive as currently ranked.

Yellow-poplar was observed in similar proportions across all three site quality groups and was predicted similarly in all three RKBs. This is expected as the ranking for yellow-poplar is identical for all three RKBs. Sweet birch was more prevalent in the medium- and high-site quality stands but was underrepresented in the REGEN predictions. Sweet birch, a shade-intolerant species, was very sparse as advance reproduction, and although it was ranked highly, the absence of advance reproduction suggests that the stochastic addition should be increased. Sweet birch is known to have the ability to regenerate very aggressively; however, dominance is often short-lived, and the higher levels found in the medium- and

Table 1—Mean dominant and codominant species composition of seven high-site quality stands

Species group	Species composition	
	Observed	Predicted
	------------------- *percent* -------------------	
Black cherry	27.54	22.44
Miscellaneous	0.00	1.56
Mixed mesophytic	17.85	9.12
Oaks	2.12	0.08
Pioneer	7.55	2.85
Red maple	12.33	13.50
Subcanopy	8.54	3.43
Sugar maple	0.53	33.48
Sweet birch	14.90	4.14
Yellow-poplar	8.64	9.40
Total	100.00	100.00

Table 2—Mean dominant and codominant species composition of 23 medium-site quality stands

Species group	Species composition	
	Observed	Predicted
	------------------- *percent* -------------------	
Black cherry	12.41	13.02
Miscellaneous	1.73	0.98
Mixed mesophytic	16.53	22.30
Oaks	9.73	3.35
Pioneer	9.02	5.03
Red maple	15.96	38.54
Subcanopy	3.57	4.11
Sugar maple	1.44	2.01
Sweet birch	15.08	3.44
Yellow-poplar	14.53	7.22
Total	100.00	100.00

Table 3—Mean dominant and codominant species composition of 11 low-site quality stands

Species group	Species composition	
	Observed	Predicted
	------------------- *percent* -------------------	
Black cherry	4.73	0.81
Miscellaneous	3.12	3.86
Mixed mesophytic	3.77	7.43
Oaks	17.27	4.85
Pioneer	17.53	4.15
Red maple	24.38	36.95
Subcanopy	9.73	15.93
Sugar maple	0.62	7.68
Sweet birch	5.46	6.67
Yellow-poplar	13.39	11.67
Total	100.00	100.00

high-quality groups are expected to gradually decrease as the stand continues through stem exclusion. The pioneer species are expected to perform similarly. This anticipated trend somewhat discourages higher ranking for these species even though the predictions are likely inaccurate at the targeted onset of stem exclusion. Oaks were underestimated by all RKBs but did follow published trends of increasing postharvest competitiveness with decreasing site quality. Other species groups were considered reasonably accurate across the three RKBs for preliminary results.

CONCLUSION

Literature suggests that species composition of postharvest regeneration may react differently somewhere near the aforementioned site quality delineations for the three RKBs in the Southern Appalachians (Smith 1994). For regional modeling purposes it may only be realistic to approximate general breaks in site quality, perhaps within an accuracy of 5 to 10 feet of site index, due to natural uncertainty of forest systems and unreliable methods of estimating site quality. Further investigation of the ranges at which site quality can be assumed to impact regeneration similarly is warranted.

An evaluation of the feasibility of adapting the REGEN model to the Appalachian Plateau based on the results of the preliminary knowledge base tests indicates potential, given refinements and amendments, for REGEN to be developed into a useful tool for the region. Considering that the preliminary rankings are largely subjective, as there are no published numerical competitive rankings compatible with this type of system for the region, future work to amend the now existing knowledge bases for the Appalachian Plateau seems a worthwhile endeavor.

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