Use of the Forest Vegetation Simulator in Determining Optimal Forest Rotation Settings for Abandoned Mined Lands in Appalachia

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Abstract—Approximately 1 million acres of abandoned mined lands exist in the Appalachian coal region. Reclamation and afforestation of these sites may be conducted if it is profitable or if losses can be minimized. Calculating profitability requires a determination of the optimal thinning and harvesting schedule that maximizes financial return. The Forest Vegetation Simulator was used to determine the best management regime by simulating stand growth for northern red oak (*Quercus rubra*). Soil expectation value, calculated with real alternative rates of return ranging from 0.0 to 12.5 percent, was used as the investment criterion. Results indicate that when reclamation costs are low, afforestation can be profitable only when a landowner's real alternative rate of return is 0.0 percent and one thinning is conducted with a final harvest age of 100, at 2.5 percent with two thinnings and a final harvest age of 100, and at 5.0 percent with one thinning and a final harvest at 80 years. Afforestation can be profitable with high reclamation costs only when the alternative rate of return is 0.0 percent and one thinning is conducted with a final harvest at age 100, and at 2.5 percent with two thinnings and a final harvest age of 100.

Appalachia and Abandoned Mined Lands

The Appalachian coal region of the Eastern United States extends from Pennsylvania to Alabama. Of this region, according to the Office of Surface Mining (OSM) (USDI-OSM 2000), there are approximately 1 million acres of land classified as abandoned mined lands (AML) (fig. 1). AML sites are inadequately reclaimed mine sites occurring before passage of the 1977 Surface and Mining Control and Reclamation Act (SMCRA); no Federal or State laws exist that require any further reclamation responsibility to any company or individual (USDI-OSM 2002).

In: Crookston, Nicholas L.; Havis, Robert N., comps. 2002. Second Forest Vegetation Simulator Conference; 2002 February 12–14; Fort Collins, CO. Proc. RMRS-P-25. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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The many problems associated with Appalachian AML sites range from dangerous highwalls causing landslides to underground mine fires causing the release of smoke, haze, heat, or hazardous gases. In an effort to combat the problems present on these lands, OSM has set up the following five AML reclamation priority levels:

- Priority 1—the protection of public health, safety, general welfare, and property from extreme danger of adverse affects of past mining practices.

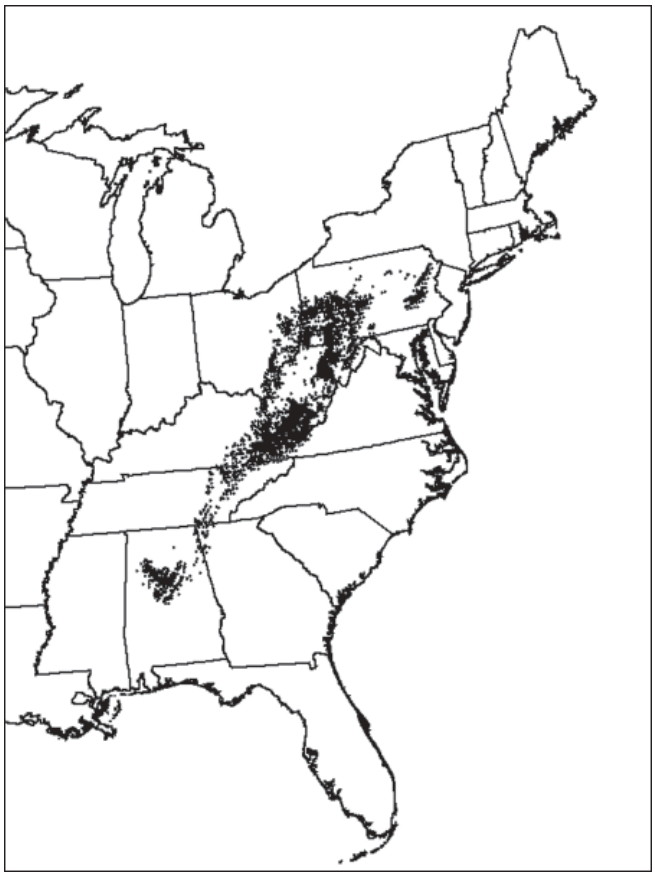

Figure 1—Abandoned mined lands within Appalachia.

- Priority 2—the protection of public health, safety, general welfare, and property from adverse affects of past mining practices.
- Priority 3—the restoration of land and water resources and the environment previously degraded by adverse effects of past mining practices including measures for the conservation and development of soil, water, woodland, fish, wildlife, recreation resources, and agricultural productivity.
- Priority 4—the protection, repair, replacement, construction, or enhancements of public facilities such as utilities, roads, recreation, and conservation facilities adversely affected by past mining practices.
- Priority 5—the development of publicly owned land adversely affected by mining practices including land acquired for recreation and historic purposes, conservation, and reclamation and open spaces (USDI-OSM 2002).

The correction of these problems can be costly, in some cases more than $100,000 per acre. Therefore, OSM has become interested in developing environmentally sound least-cost reclamation methods. Planting trees can be a perfect reclamation tool to achieve this goal for several reasons. First, the Appalachian region has the largest contiguous, temperate hardwood forest in the world (Smith 1995), so restoration with trees can create a landscape that is closer to the premined state. Reclamation with trees can also increase environmental benefits to the surrounding communities by increasing soil pedogenetic processes, enhancing recreational opportunities, and creating more wildlife habitat. Another reason why trees can be presented as a perfect reclamation tool is their ability to withstand pH levels lower than that of other vegetation (Vogel 1981). Trees can also provide landowners with cyclical revenues from forest product sales and effectively reduce the overall cost of reclamation. As a result, economic stimulus can be created within surrounding communities.

Methods

Reclamation and afforestation of AML sites at a least cost requires the determination of the optimal forest rotation setting that maximizes financial return. This study was designed to determine the optimal thinning and harvesting schedules for northern red oak (*Quercus rubra*), one of the major commercial tree species within this region, on AML sites in Appalachia. The Forest Vegetation Simulator (FVS) was used to simulate stand growth data on diameter, height, and volume, for stands from establishment to final harvest. FVS, in conjunction with the Keyword Iteration Navigator (KIN) (an FVS preprocessor that allows a user to input minimum, maximum, and increment values for any one keyword), was combined with an economic program to calculate cash flow tables, net present worths (NPW), and soil expectation values (SEV). This dynamic program was developed to simultaneously determine the financially optimal timing and intensity for thinning(s) and the financially optimal rotation age for northern red oak.

Site index 80 (base age 50) land was examined in this pilot study. The maximum rotation age was set at age 100 with a choice of zero, one, two, or three thinnings during the rotation. The method used for thinnings was a percent of basal area removal from below. The first thinning could not be conducted until the stand was at least 30 years of age. The minimum years between thinnings, or between a thinning and final harvest, could not be less than 15 years. For all of the dynamic computer runs, a "thinning and final harvest" regime would be considered to be operable only if (1) each thinning or final harvest yielded a minimum of 10 cords (960 ft^3), (2) each thinning or final harvest yielded a minimum of 1,500 Doyle board feet (1995 Scribner board feet), or (3) each thinning or final harvest yielded a minimum combination of 5 cords (480 ft^3) and 750 Doyle board feet (997 Scribner board feet). A minimum of 80 residual trees was required after each thinning operation. Four thinning intensities, 25, 30, 35, and 40 percent basal area removal from below, were conducted for each possible thinning regime.

Six real alternative rates of return (ARR) were chosen for the economic analyses: 0.0, 2.5, 5.0, 7.5, 10.0, and 12.5 percent. The annual real price increase of sawtimber and pulpwood were assumed to be 2.5 and 2.0 percent, respectively. The price of sawtimber was assumed to be $255 per 1,000 Doyle board feet ($191.25 per 1,000 Scribner board feet), and pulpwood was priced at $9.00 per cord ($0.09375 per ft^3). The cost for marking and administering a pulpwood or sawtimber sale was assumed to be 10.0 percent of the gross sale. Two sets of establishment costs were used in these analyses. The first set was for the case when little to no reclamation was conducted, and a cost of $225 per acre for seedlings and planting was used. The second set of establishment costs included a $1,100 per acre reclamation cost used to correct erosion and pH problems, and a $225 per acre cost for seedlings and planting. It was assumed that the environmental engineering problems associated with some abandoned mined lands have been corrected, and these lands are ready for forestry practices.

Economic Approach

SEV was used as the efficiency criteria to select the most profitable thinning and harvesting schedule. SEV is the NPW of bare forestland for timber production over a perpetual series of rotations. NPW is the sum of the discounted revenues minus the sum of the discounted costs of a project (Gregory 1987). SEV is used to compare forest investments of different rotation lengths. For each real ARR, the management regime with the highest SEV was chosen as the optimal forest rotation setting.

Results

A total of 144,066 thinning and harvesting combinations, NPWs, and SEVs were calculated. The optimal forest rotation settings that maximize SEV for each real ARR are presented in table 1, and the NPWs for each real ARR with low reclamation costs and high reclamation costs are presented in tables 2 and 3, respectively. All monetary values are presented on a per acre basis.

Table 1—Optimal forest rotation settings that maximize soil expectation value for northern red oak site index 80 (base age 50).

Real alternative rate of return	Thinning year(s)	Thinning[b]	Final harvest year
percent		*percent*	
0.0	51	25	100
2.5	47-82[a]	30	100
5.0	59	25	80
7.5	41	40	74
10.0	40-55	40	70
12.5	40-55	40	70

[a]First number indicates first thinning year; second number indicates second thinning year.
[b]Basal area removed from below during thinning(s).

Table 2—Net present worth of the optimal forest rotation settings for northern red oak site index 80 (base age 50) with low reclamation costs.

Real alternative rate of return	Net present worth
percent	*dollars per acre*
0.0	70,470
2.5	6,108
5.0	448
7.5	–110
10.0	–206
12.5	–219

Table 3—Net present worth of the optimal forest rotation settings for northern red oak site index 80 (base age 50) with high reclamation costs.

Real alternative rate of return	Net present worth
percent	*dollars per acre*
0.0	69,370
2.5	5,008
5.0	–652
7.5	–1,210
10.0	–1,301
12.5	–1,319

0.0 Percent Real ARR

The optimal forest rotation setting when the landowner's ARR is 0.0 percent requires that a thinning should be conducted at stand age 51, removing 25 percent of the basal area from below, and the final harvest should be conducted at age 100 (table 1). This optimal management regime would generate an NPW of $70,470 per acre when reclamation costs are low (table 2) and an NPW of $69,370 per acre when reclamation costs are high (table 3). These NPW values indicate that the landowner who followed this management regime, over one rotation, would earn 0.0 percent on every dollar invested plus $70,470 per acre if reclamation costs are low, or 0.0 percent plus $69,370 per acre if the reclamation costs are high.

2.5 Percent Real ARR

For landowner's who have a real ARR of 2.5 percent, the optimal thinning and harvesting schedule requires the first thinning at age 47 and the second thinning at age 82. At each thinning, 30 percent of the basal area should be removed. The final harvest should be conducted at age 100. The NPWs for this thinning and harvesting schedule are $6,108 per acre with low reclamation costs and $5,008 per acre with high reclamation costs.

5.0 Percent Real ARR

For landowners who have real alternative rates of return of 5.0 percent, the optimal thinning and harvesting schedule requires that 25 percent of the basal area should be removed at age 59, and a final harvest should be conducted at stand age 80. With low reclamation costs, the NPW for the optimal forest rotation setting is $448 per acre. If reclamation costs are high, the NPW would be –$652 per acre.

7.5 Percent Real ARR

If a landowner's real ARR is 7.5 percent, the optimal thinning and harvesting schedule requires that a thinning should be conducted at age 41, in which 40 percent of the basal area should be removed. The final harvest should be conducted at age 74. This optimal schedule would generate an NPW of –$110 per acre when reclamation costs are low, and an NPW of –$1,210 per acre when reclamation costs are high.

10.0 Percent Real ARR

If a landowner has a real ARR of 10.0 percent, the optimal forest rotation setting shows that the first thinning should be conducted at stand age 40, a second thinning at age 55 (removing 40 percent of the basal area during thinnings), and a final harvest at age 70. This thinning and harvesting schedule would yield an NPW of –$206 per acre when reclamation costs are low, and an NPW of –$1,301 per acre when reclamation costs are high.

12.5 Percent Real ARR

When 12.5 percent is the landowner's real ARR, the optimal thinning and harvesting schedule is the same as the 10.0 percent ARR; a first thinning is conducted at age 40 and a second thinning at age 55. At each thinning, 40 percent of the basal area should be removed. The final harvest should be at stand age 70. The NPWs for this thinning and harvesting schedule are –$219 per acre for low reclamation costs and –$1,319 per acre for high reclamation costs.

Conclusions

The profitability of reclaiming and afforesting AML sites is highly dependent on the landowner's real ARR and the site's productivity, or site index. The use of the optimal forest rotation setting methodology allows a landowner to answer the two basic questions in any profit-maximizing forestry related project: (1) How should I manage my stand, and (2) How profitable will it be? Results indicate that reclaiming and afforesting AML with northern red oak can be a profitable investment when a landowner's real ARR is 0.0 or 2.5 percent, regardless of reclamation costs, or 5 percent when reclamation costs are low. Although there is a net loss in profit when higher ARRs are used, the positive externalities generated from reclaiming these sites may exceed the negative environmental effects present on these AML sites.

Every site has specific reclamation needs. Successful reclamation and afforestation requires a thorough understanding of critical species-site relationships. Future analyses will investigate the potential of reclaiming AML sites with northern red oak and white oak (*Quercus alba*) for site indices ranging from 40 to 80 (base age 50) across the Appalachian coal region.

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