A METHOD FOR ASSESSING ECONOMIC THRESHOLDS OF HARDWOOD COMPETITION

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Abstract-A procedure was developed for computing economic thresholds for hardwood competition in pine plantations. The economic threshold represents the break-even level of competition above which hardwood control is a financially attractive treatment. Sensitivity analyses were conducted to examine the relative importance of biological and economic factors in determining economic thresholds. Growth models were used to determine the level of hardwood basal area (HBA) at which the cost of hardwood control equals the reduction in net present value of the stand due to competition. A basal area prediction model was fit with absolute HBA, rather than percent HBA, and then used to simulate the effects of hardwood competition in loblolly pine plantations. Generalized yield response models at age 25 were developed by site index and HBA, and used to compute HBA when the net present value of the pine response was zero. A hardwood basal area growth model was developed for projecting hardwood basal area to age 3, which is when release treatments would be applied. Sensitivity analyses examined the relative importance of site index, interest rate, pine stumpage value, and treatment cost in determining economic thresholds. The most important biological factor was site index, and interest rate was the most important economic factor. Pine stumpage value and cost of hardwood control treatment were relatively unimportant in determining economic thresholds.

INTRODUCTION

Control of competing vegetation has become a common silvicultural practice for managing pine plantations in the Southeast. Budgetary and environmental considerations require that vegetation management treatment be prescribed on the basis of site-specific analysis of costs and benefits. To be most effective, vegetation treatments must be applied at young ages. However, information on the long-term benefits of vegetation management is inadequate, and response to different treatments cannot be reliably extrapolated to rotation age as required for economic analyses.

Research over the last 25 years has shown substantial increases in pine growth following hardwood control (Clason 1978, Cain and Mann 1980, Glover and Dickens 1985, Glover and Zutter 1993, Miller and others 1995, Quicke and others 1996). Despite these efforts, forest managers have few quantitative tools to assess "how much is too much" for specific site and stand conditions. According to Wagner (1993), developing objective and quantitative systems to evaluate the response to proposed treatments is one of the highest priorities for vegetation management research. Such decision support tools are needed to ensure that treatments are prescribed only when the long-term changes in stand development can be economically justified and balanced with ecological considerations (Wagner 1994).

The economic threshold-the hardwood density at which the discounted value of the gain in timber volume at rotation age following a competition control treatment equals the discounted cost of the competition control treatment (Cousens 1987)—serves as a basis for justifying vegetation treatments. The economic threshold approach involves computing net present value (NPV) for competition control treatments and determining the level of hardwood competition that produces an NPV of $0/ac in the treated stand.

$$NPV = \frac{\text{Volume Gained} \times \text{Stumpage Value}}{(1+i)^r} - \frac{\text{Treatment Cost}}{(1+i)^t} = 0 \quad [1]$$

where i=interest rate (percent), r = rotation age (years), and t = age of hardwood control treatment (years). Estimating the volume gained following competition control is essential to computing the economic thresholds.

The method of determining the economic threshold level of hardwood competition consists of 3 steps, and is demonstrated for loblolly pine plantations. Yield is simulated for various levels of site index, planting density, and HBA. The second step is to use predicted yield, pine stumpage value, hardwood treatment cost, and interest rate to compute the economic threshold level of hardwood competition at rotation age. The final step is to project the economic threshold level of hardwood competition at rotation age to the age when a release treatment would be applied. Sensitivity of biological factors (site index and planting density) and economic factors (interest rate, pine stumpage value, and treatment cost) on the economic threshold level of hardwood competition also is examined.

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METHODS

Predicted Yield

The first step in determining economic thresholds is to predict the yield of loblolly pine plantations with varying amounts of hardwood competition. Three computer models have been developed (Burkhart and Sprinz 1984, Smith and Hafley 1986, and Knowe 1992) to simulate the effects of hardwood competition in loblolly pine plantations. Knowe (1992) compared the assumptions and methodology of these yield systems. Data used to develop the models were obtained primarily from Piedmont and Upper Coastal Plain sites. When hardwood competition is present, all three existing models produce negatively skewed diameter distributions, with predominately small-diameter trees and few large-diameter trees. These models use a negative exponential relationship between pine basal area and percent HBA: greater pine reductions occur at low levels of hardwood competition than at high levels.

A major limitation of all three existing models is that percent HBA is used as a predictor variable. Pine basal area can be obtained from total basal area and percent HBA. Furthermore, total basal area must be known in order to compute percent HBA. Therefore, using percent HBA implies that the basal area of both the pine and hardwood components is known. In addition, the long-term dynamics of percent HBA are not well documented, with one notable exception (Glover and Zutter 1993), and it cannot be reliably predicted (Harrison and Borders 1996).

A major difference in the loblolly pine plantation yield prediction systems is the amount of pine basal area displaced by hardwood competition. The Burkhart and Sprinz (1984) model implies that 1 ft^2/acre of HBA replaces 1.26 ft^2/acre of pine basal area at 10 percent HBA and 2.11 ft^2/acre of pine basal area at 30 percent HBA. The model developed by Smith and Hafley (1986) implies replacement ratios of 0.88 ft^2 and 0.93 ft^2 of pine basal area per ft^2 of HBA at 10 and 30 percent HBA, respectively. The Knowe (1992) model implies a replacement ratio of 0.97:1 (ft^2 pine basal area/ft^2 hardwood basal area) at 10 percent HBA and 0.99:1 at 30 percent HBA.

The pine basal area and diameter distribution models developed by Knowe (1992) were chosen for demonstrating the method of computing economic threshold level of hardwood competition. The pine basal area model was refit by using absolute HBA rather than percent HBA. The resulting equation accounted for only 1.5 percent less of the variation in observed pine basal area than the model with percent HBA. Dominant height, survival, individual tree height, and volume were predicted by using the functions developed by Borders and others (1990).

Loblolly pine yield at age 25 years was simulated using 0, 5, 10, 15, 20, and 25 ft^2/acre of HBA in stands with site index (base age 25) values of 50 to 80 feet, in 5-foot increments, and planting densities of 500-900 trees/acre, in increments of 100 trees/acre. The relationship between loblolly pine yield and hardwood basal area was linear for all combinations of site index and planting density, so simple linear regression models were developed for each level of site index and planting density:

$$Y = b_0 - b_1 HBA \qquad [2]$$

where Y = loblolly pine yield (tons/acre) at age 25 and HBA = hardwood basal area (ft^2/acre). Inspection of the intercepts (b_0) and slopes (b_1) for all 30 combinations of site index and planting density indicated a linear relationship with site index but no relationship with planting density.

The final step is to project the economic threshold level of hardwood competition at rotation age (25 years) to an age when a release treatment would be applied. In this example, release treatments were applied at age 3 years. As previously mentioned, long-term data on hardwood basal area growth in loblolly pine plantations is very limited. The one notable exception involves a well-documented site preparation study in the upper Coastal Plain of Alabama

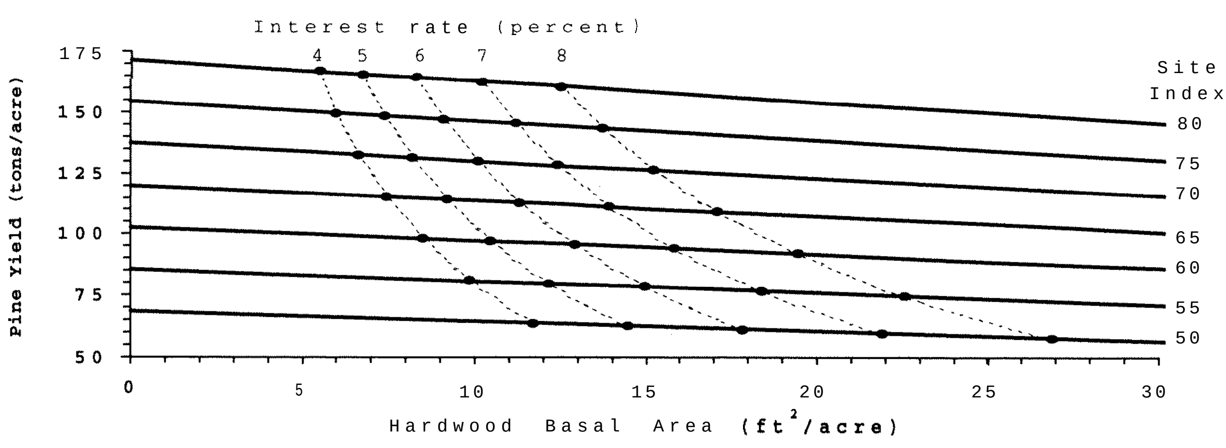

Figure l-Relationship between loblolly pine yield and hardwood basal area at age 25 for site index between 50 and 80. The dashed lines represent the economic threshold level of hardwood basal area for interest rates between 4 and 8 percent. Additional inputs: pine stumpage value = $30/ton and hardwood control treatment cost = $60/acre.

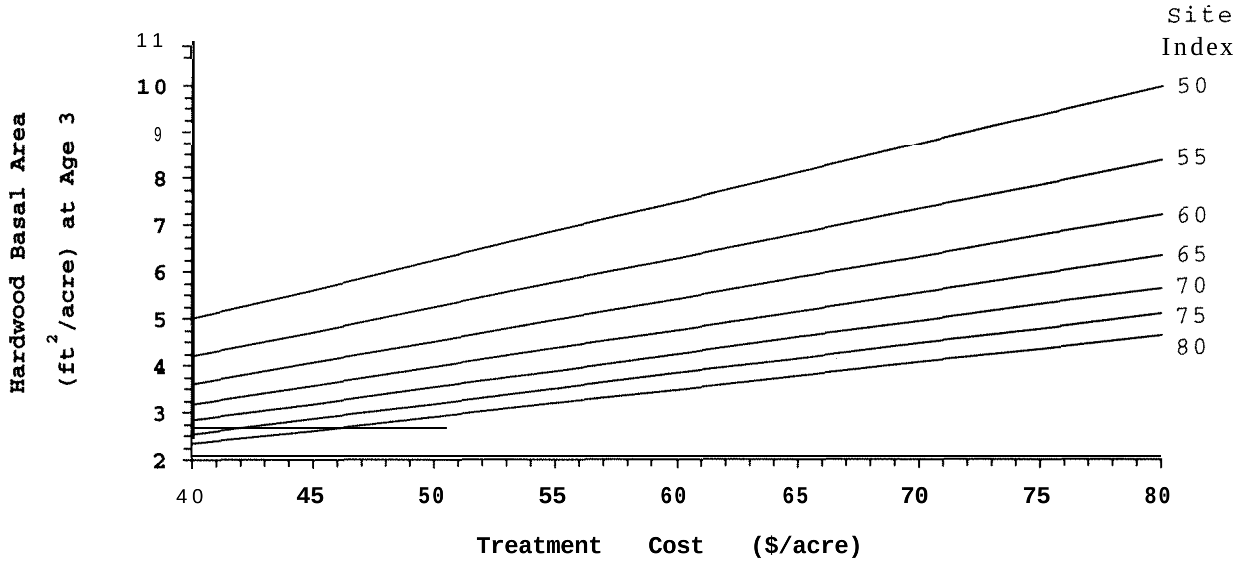

Figure Z-Economic threshold level of hardwood basal area at hardwood control treatment age 3 years for interest rates between 4 and 8 percent. Additional inputs: pine stumpage value = $30/ton and hardwood control treatment cost = $60/acre.

(Glover and Zutter 1993). This study included 5 replications of an untreated check plus chemical (injection and two methods of cut-surface treatment), mechanical (bulldozer scarification), and manual (girdling) treatments. Surviving hardwoods and resprouts developed along with the planted loblolly pine for 27 years after treatment.

Fifty observations of average HBA for each of the six site preparation treatments at ages l-4, 6, 11, 13, 22, and 24 years were used in the analyses. Data for age 27 were excluded from the regressions because hardwood basal area growth was negative between ages 24 and 27 years for several treatments, and a more complex equation would be required to describe this downward trend. In addition, hardwood data were not available for one of the cut-surface treatments at plantation ages 11 and 13 years. Observed HBA-age pairs for each treatment were arranged into 45 non-overlapping growth intervals (e.g., ages 1-2, 2-3, 3-4, 4-6, 6-11, etc.). Graphs of these data suggested several potential equations for describing the observed patterns of HBA growth. Tests for differences in the growth rates among site preparation treatments were also conducted by incorporating indicator variables into the equation that best fit the observed data.

Statistical differences in hardwood growth rates were detected among the site preparation treatments. Average growth rate for the herbicide treatments (injection only, girdle+herbicide, and chain frill+herbicide) was slower than for the non-herbicide treatments (no treatment, girdle only, and bulldozer scarification). However, this difference was not of practical importance because the equation with treatment-specific growth rates accounted for only 0.3% more of the variation in projected HBA than the reduced model. A single equation can be used to predict hardwood basal area (HBA,) at any plantation age (X) using current hardwood basal area (HBA) and current age (Age):

$$HBA_x = HBA \exp\{0.0395^*(X-Age)\}. \quad [3]$$

This equation accounted for 98% of the variation in projected HBA. In this example, the economic threshold level of hardwood basal at a rotation age of 25 years is projected to a hardwood-control treatment age of 3 years by multiplying HBA at rotation age by 0.4194. This implies that about 42 percent of the HBA at 25-year-old stands is present in 3-year-old stands, when release treatments are applied.

Sensitivity Analyses

The sensitivity analysis was conducted for two reasons. The first is to examine predictions at extreme values of input variables to determine whether the model and assumptions are reasonable. The second reason is to assess the relative importance of biological and economic factors used in determining economic thresholds. Economic factors included in the sensitivity analyses were interest rates of 4 to 8 percent; pine stumpage values of $25/ton to $35/ton; and hardwood treatment costs of $50/acre to $90/acre. The relative importance of the biological and economic factors was examined by varying one factor while holding the remaining factors constant. The more influential factors result in greater variations in the economic threshold level of HBA than the less important factors.

RESULTS

Linear relationships were observed between the intercepts (b,) and slopes (b,) of the yield equation in [2] and site index for all combinations of site index and planting density. Therefore, loblolly pine yield at age 25 in [2] can be generalized as:

$$Y = [-103.0979+(3.4325\ SI)]-[0.3709-(0.0155\ SI)]\times HBA \quad [4]$$

where SI = site index (base age 25) and other terms as previously defined. Volume gained following competition

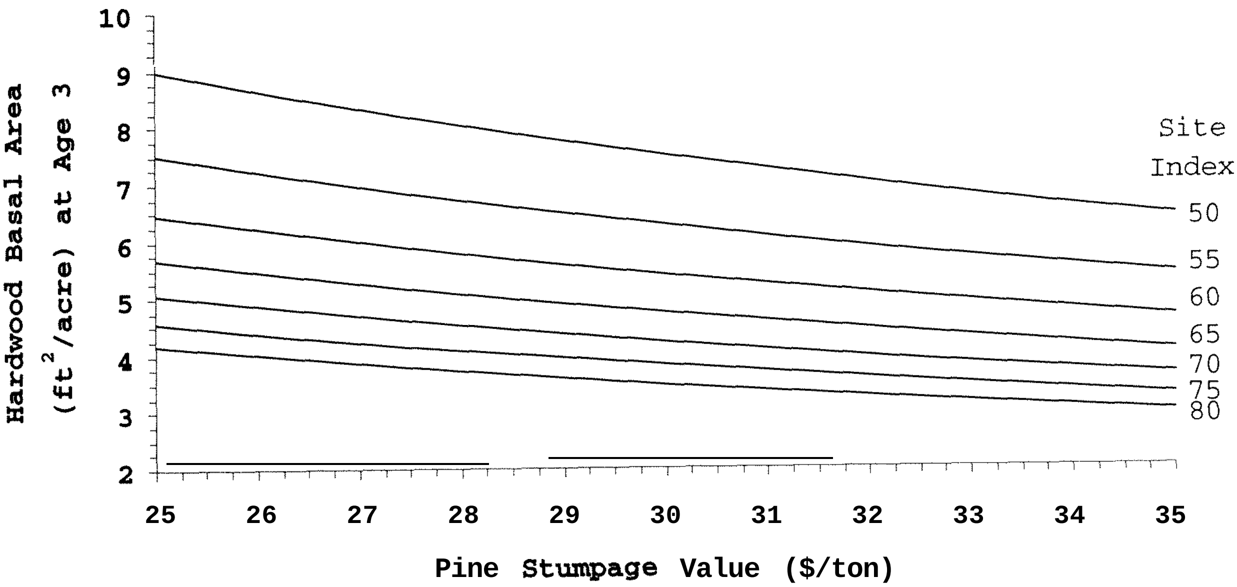

Figure 3-Economic threshold level of hardwood basal area at hardwood control treatment age 3 years for pine stumpage values between $25/ton and $35/ton. Additional inputs: interest rate=6 percent and hardwood control treatment cost=$60/ acre.

control (VG) is the difference in yield for stands without hardwoods (HBA = 0) and stands with hardwoods. Combining [2] and [4], VG is:

$$\begin{aligned} VG &= [b_0-b_1(0)]-[b_0-b_1(HBA)] \\ &= [b_0-b_0]+b_1(HBA) \\ &= b_1(HBA) \\ &= [-0.3709+(0.0155xSI)]xHBA \end{aligned} \qquad [5]$$

Note that the sign of b, changes from negative in [4] to positive in [5], which changes the sign of the component coefficients. When response to hardwood control is expressed as b_1HBA, the economic threshold level of hardwood basal area (HBA,,) for a 25-year rotation (r = 25) and hardwood control treatment at age 3 (t = 3) can be computed by solving [I] for HBA as follows:

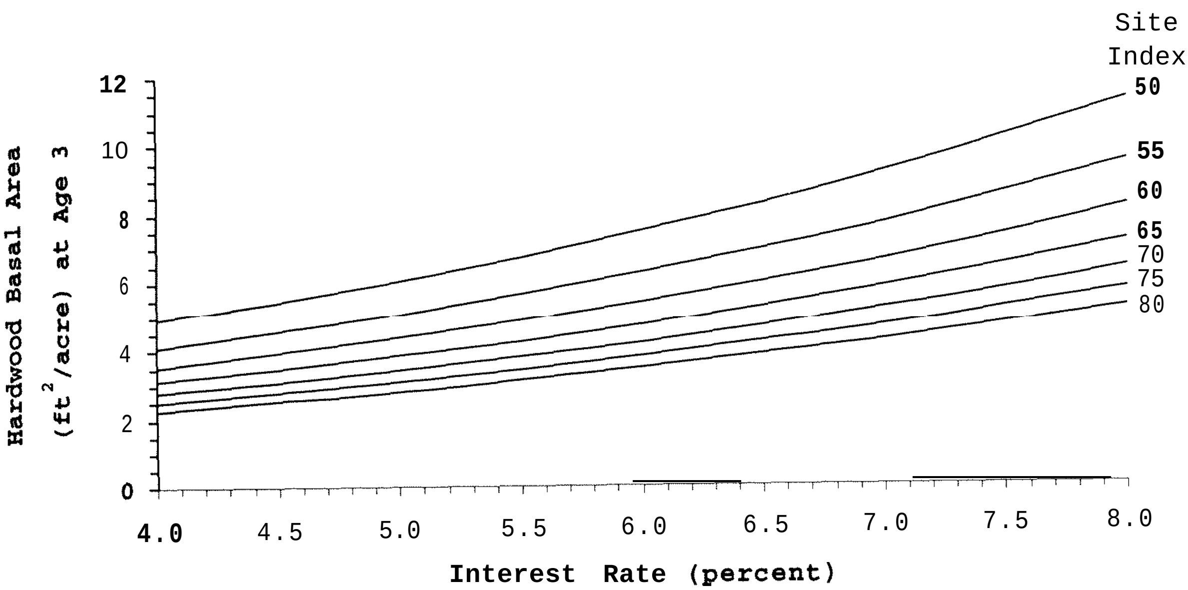

Figure 4-Economic threshold level of hardwood basal area at hardwood control treatment age 3 years for hardwood treatment costs between $40/acre and $80/acre. Additional inputs: interest rate=6 percent and pine stumpage value=$30/ton.

$$\mathrm{HBA}_{,,} = \frac{\mathrm{TC}\times(1+i)^{22}}{\mathrm{SV}\times[-0.3709+(0.0155\times \mathrm{SI})]} \qquad [6]$$

where i = interest rate, SV = pine stumpage value ($/ton), TC = hardwood treatment cost ($/acre), and r-t = 22 years. The economic threshold level of hardwood basal at rotation age is projected to a hardwood-control treatment age of 3 years by multiplying HBA at rotation age by 0.4194.
The effect of varying interest rate on economic threshold level of hardwood basal area at age 25 is shown in figure 1 for fixed pine stumpage value and hardwood treatment cost. As expected, yield increases with increasing site index and decreases with increasing HBA. When interest rate = 6 percent, site index = 65, pine stumpage value = $30/ton, and treatment cost = $60/acre, for example, the economic threshold hardwood basal area is about 11.5 ft^2/acre and expected yield is about 112 tons/acre. The difference in yield between interest rates is not equal, and is larger at lower site index than higher. This implies an interaction between interest rate and site index.

Multiplying HBA at rotation age by 0.4194 provides an estimate of HBA at age 3, which is when hardwood control treatments would be prescribed (figure 2). Using the previous example, the economic threshold hardwood basal area is about 4.7 ft^2/acre at age 3. This is interpreted as the minimum amount of hardwood competition that must be present for a $60/acre release treatment to be financially attractive under those circumstances.

The effect of varying pine stumpage value on economic threshold level of hardwood basal area at age 3 is shown in figure 3 for fixed interest rate and hardwood treatment cost. In this case, the economic threshold level of hardwood basal area decreases with increasing pine stumpage value and site index. For example, when pine stumpage value = $30/ton, site index = 65, interest = 6 percent, and treatment cost = $60/acre, the economic threshold hardwood basal area is about 4.7 ft^2/acre. The difference in economic thresholds across pine stumpage values is nearly linear, and the difference is larger at lower site index than at higher site index.

The effect of varying hardwood treatment cost on economic threshold level of hardwood basal'area at age 3 is shown in figure 4 for fixed interest rate and pine stumpage value. As with interest rates, the economic threshold level of hardwood basal area increases with increasing treatment cost and decreasing site index. When treatment cost = $60/acre, site index = 65, interest = 6 percent, and pine stumpage value = $30/ton, the economic threshold hardwood basal area is about 4.7 ft^2/acre. The difference in economic thresholds across hardwood treatment costs is nearly linear, and the difference is larger at lower site index than at higher site index.

DISCUSSION AND SUMMARY

The concept of economic thresholds was applied to hardwood competition in loblolly pine plantations, and procedures were developed for estimating threshold levels of hardwood basal area. The sensitivity analysis of biological and economic factors affecting the threshold level of hardwood basal area indicated that. both interest rate and site index were more influential factors than stumpage value and treatment cost.

Interest rate has the greatest influence on economic thresholds, especially on poor sites. A 1 percent increase in interest rate increases, threshold by l-2 ft^2/acre on good sites and by 5 ft^2/acre on poor sites. A $5/acre increase in treatment cost increases economic threshold level of hardwood basal area by 0.50 ft^2/acre on good sites and by 0.75 ft^2/acre on poor sites. Increasing loblolly pine stumpage value decreases threshold by 0.5 ft^2/acre on good sites and by 1 .O ft^2/acre on poor sites.Growth models used to simulate hardwood competition may have profound effects on the biological and economic interpretations. The pattern of negative exponential response of pines to hardwood competition implies that low levels of hardwood basal area would produce a greater proportional reduction in pine yield than at higher levels of hardwood competition. Thus, the Burkhart and Sprinz (1984) model may be more appropriate at low levels of hardwood basal area while the Knowe (1992) model may be more appropriate at the higher levels of hardwood competition. Additional considerations are the pine:hardwood replacement ratio and hardwood dynamics. A more comprehensive pine release dataset, with hardwood information, is needed to refine the economic threshold method presented in this study.

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