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ECONOMIC EVALUATION OF FOREST PEST MANAGEMENT STRATEGIES

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Introduction

The large apparent loss of timber to tree-killing bark beetles, combined with the recognized public nature of the pest problem and the emergence of new strategies for the mitigation of beetle damage, makes the evaluation of the net social benefit of beetle damage-control strategies an important issue for research.

Bark beetle-caused timber mortality is estimated at several billion board feet per year. The earliest estimate of bark beetle damage is that of Keen who estimates that 1.5 billion board feet of timber was lost in 1932 in California alone (Keen). More recent estimates are easily available only on a national basis. The 1952 Forest Resource report claims damage amounting to 4.5 billion board feet, and later Forest Resource reports (U. S. Forest Service, 1958) confirm that estimate: "Bark beetles killed 4.5 billion board feet of sawtimber in 1952, accounting for 90 percent of the insect caused mortality of sawtimber and 63 percent of the growth impact" (U. S. Forest Service, 1965).

The economic impact of the lost timber, however, is less than the estimate arrived at by multiplying the volume lost by the average stumpage value because the lost timber is generally in stands that will not be available for harvest for a number of years. This time lapse affects values in two ways. First of all, because the lost timber was to be available only in the future, the loss must be discounted at a rate of interest to obtain its present value.

Secondly, the board feet calculations do not take the spatial distribution of the lost timber into account. For example, in an overstocked stand an insect infestation may cause trees to die in specific temporal and spatial patterns. If the mortality is evenly distributed within the stand and occurs at a time appreciably before maturity of the trees, the stand may actually yield a higher return with the presence of the insect than it would had the insect been absent (i.e., the insect may be acting to thin the stand). However, if the insect is causing dense, localized mortality or if the mortality occurs just before the stand reaches maturity, then the infestation will cause the future yield of the stand to be smaller than it would have been without the beetles. Such considerations are important when considering the impact of the Western pine beetle since mortality frequently occurs in clumped spatial patterns. Furthermore, the association of this insect with other factors related to tree health such as root pathogens, weather conditions, and atmospheric pollutants should be considered when evaluating the economic impact of beetle infestations.

Evaluating the economic consequences of managing forest pests requires (1) a predictive model of the affected host species which is capable of capturing the damage of the pest and the ameliorating effects of the control strategy and (2) using the predictive model to subsequently evaluate the benefits of various control strategies. The object of this paper is to make a rough estimate of the economic benefits of Western pine beetle control on Ponderosa pine stands on Blodgett Experimental Forest of the University of California. The control mechanism is not specified here; thus, the costs of proposed control strategies are unknown. Nevertheless, in estimating the benefits of mortality reduction alone, it will be possible to ascertain the possible economic impact of control policies before resources are spent developing a specific tactic. If small benefits are all that are available from less than miraculous control strategies, then one should seriously consider a "no action" management strategy. On the other hand, if the potential benefits are quite large, then costly control programs could be justified.

Section 2 of this paper describes the development of the model for evaluating the economic impact of mortality. Section 3 reviews the results and offers some concluding remarks.

Components of the Model

In order to simulate the impacts of pest management strategies, it is necessary to model the growth as well as the mortality of a stand of trees. The following paragraphs outline the methods used to arrive at a workable model for simulation purposes.

Data Description

The data set utilized in this paper consists of measurements by Barr *et al.*, of Ponderosa pine and incense cedar located at Blodgett Experimental Forest. The area in which our 26 tenth-acre plots exist was originally logged around the turn of the century and allowed to regenerate naturally thereafter (Barr). Measurements were first made in 1936-37, and at that time, 40 percent of the stems over 1.0 inches diameter at breast height at the start of the interval (DBH) were incense cedar (the remainder being comprised almost entirely of Ponderosa pine). By 1960, over 90 percent of the stems were identified as Ponderosa pine--the cedar apparently being shaded out. Measurements essential to model development (DBH, height and mortality) are present in every measurement record beginning in 1937 and continuing through 1960 at approximately 10-year intervals. Other measurements such as crown characteristics and boring samples were taken only in certain years, from certain plots, and certain trees in those plots.

The Growth Model

In this study, growth is identified through tree height and diameter. Growth equations were obtained from the 1950 and 1960 measurements of the Barr plot data using forms similar to those used by Stage. The final form of the basal area increment equation is as follows:

$$\ln(\Delta BA) = 10.45 + \underset{\substack{(7.7)\\ 0.16}}{1.2}\ \ln(TIME) - \underset{\substack{(11.7)\\ 0.089}}{1.1}\ \ln(CCF) + \underset{\substack{(16.5)\\ 0.114}}{1.9}\ \ln(DBH) - \underset{\substack{(6.4)\\ 0.05}}{0.32}\ POS$$

where

BA = basal area of tree
TIME = time interval over which growth prediction is made
DBH = diameter at breast height at the start of the interval
CCF = crown competition factor (basal area per tenth acre)
POS = position in the crown canopy (1 = dominant, 6 = suppressed)
TH = tree height
HG = height growth
DG = diameter growth
$R^2 = 0.66$

and figures in parentheses denote t statistics; standard errors are indicated below.

The signs of all of the coefficients coincide with our empirical knowledge of tree growth. An increase in the diameter breast height will positively affect the basal area of the tree while an increase in the crown competition factor will tend to affect basal area negatively. A movement to a higher position in the crown canopy (1 indicates dominant, 6 indicates suppressed) indicates that the tree is losing ground with respect to the surrounding trees. Thus, the negative sign on the POS variable correctly predicts a detrimental effect on basal area for increases in POS. The positive sign on the TIME coefficent is self-explanatory--longer growth prediction periods are associated with larger changes in basal area. All variables included contribute significantly (at the 1 percent level) to basal area prediction.

Using the above regression for changes in the basal area, the diameter growth is calculated using the relationship: $BA = \pi(DBH/2)$. It follows that:

$$DG = \sqrt{e^{\ln(\Delta BA)}\ DBH^2} - DBH.$$

This diameter growth is then utilized in the following equation for height growth:

$$\begin{array}{lllllllll}
\ln(HG) = 1.47\ + & 0.28 & \ln(DG)\ + & 0.59 & \ln(DBH)\ + & 0.69 & \ln(TIME)\ - & 0.10 & POS \\
 & (6.55) & & (4.41) & & (4.67) & & (2.36) & \\
 & 0.042 & & 0.135 & & 0.147 & & 0.044 &
\end{array}$$

$$\begin{array}{lllll}
- & 0.11 & \ln(CCF)\ - & 0.61 & \ln(TH) \\
 & (1.09) & & (3.7) & \\
 & 0.1 & & 0.164 &
\end{array}$$

where figures in parentheses denote t statistics, standard errors are indicated below and $R^2 = 0.40$.

Using these equations to model the growth of Ponderosa pine, volume equations can then estimate the clear-cut yield in board feet or cubic feet from the timber in any particular year. The following volume equations were developed in 1976 specifically for Ponderosa pine at Blodgett Experimental Forest:

$$\begin{aligned} BDFT &= e^{-8.7461} + 2.7904 \ln(DBH) + 1.3385 \ln(TH) \\ CUFT &= e^{-6.2659} + 2.0839 \ln(DBH) + 0.9175 \ln(TH). \end{aligned}$$

Tree Mortality Prediction

Maximum likelihood estimation can be utilized to arrive at the parameters of the binary logit model on the probability of individual tree mortality:

$$\text{Prob} = \frac{1}{1 + \exp(-XB)}.$$

The global sample consisted of 690 trees on a total of 17 Barr plots in 1950 together with the state of health of each tree in 1960 (1.0 equals dead, 0.0 equals alive). The sample was stratified into 31.30 percent dead trees and 68.70 percent live trees. The logit regression on the mortality variable yielded the following coefficients:

$$\begin{array}{lllllllll} XB = & -3.63 & - & 0.022 \; DBH & - & 0.026 \; TH & + & 0.0000089 \; CCF & + \; 0.29 \; POS \\ & (5.27) & & (3.24) & & (2.07) & & (8.93) & \quad (3.73) \end{array}$$

where figures in parentheses denote asymptotic t statistics; percent correctly predicted, 82.75 percent; and likelihood ratio statistic, 441.18.

For the sample size of 690, the t statistics indicate that all parameters are significantly different from zero at the 1 percent level. In the above equation, each of the parameters possess the expected sign. The coefficient for DBH as well as that for TH are found to be negative indicating that the probability of the tree dying decreases when the tree registers growth. Likewise, the chance of the tree dying increases with an increase in the crown competition factor as noted by the positive sign of the CCF coefficient. An increase in the POSITION code signifies that the tree is moving to subdominant or suppressed conditions. Thus, as the positive sign of the coefficient indicates, the worsening position of the tree will increase the chances of death occurring.

In order to indicate the relative impacts of changes in the variables on the propability of mortality, the median tree in the sample is identified and tested. For a 10 percent increase in DBH, the median tree registered 16.9 percent reductions in probability of death. Similarly a 10 percent increase in TH caused mortality to decrease by 12.8 percent. The same percentage increase in crown competition caused at 30 percent increase in mortality. Finally, increasing the position code in the crown canopy of the median tree by one position (discrete variable) caused a 29 percent increase in probability of death. Thus, although the median tree has a low probability of death (.0734) all variables, and particularly the crown competition factor, appear to be sensitive factors in registering impacts on mortality of changes in tree characteristics.

Simulation Procedure

The model is designed to simulate growth and death of individual trees in an area using data on the characteristics of the trees in a representative subsection of the area. That is, there are data on each tree in the subsection and each tree represents, for example, 1000 trees. The variable, REP, is used to signify the number of trees in the larger area represented by the single tree. The probability of a tree dying is calculated, and this is translated into a corresponding number of dying trees from the larger area. For example, if one tree represents 1000 trees at the outset and the probability of the tree dying is 0.25, then the new REP is 750 (i.e., the single tree is now representing only 750 trees). In this manner, the simulation procedure for growth takes mortality into account without using a Monte-Carlo scheme.

Growth is simulated in intervals of 10 years through 1980 taking the two infestation effects, mentioned in the introduction, into account. First, tree mortality affects the crown competition factor (CCF) in the growth equations and allows for the possible bonus to growth through the lessening of competition. Second, the tree mortality causes a reduction in the board feet yield when the acreage is clear-cut in 1980.

In order to assess the benefits of control strategies for pests, the following question is asked: If we could change the probability of trees being killed by the Western pine beetle by X percent per decade, what would be the present value of the economic benefits resultant? The final phase of the procedure calculates these values using Blodgett Forest Stumpage price data and various interest rates. Per acre benefits of mortality reduction of X percent are then given by the difference between the present values under the two regimes--no reduction *vs.* X percent reduction. These benefits are given in Table 1 under varying interest rates and degrees of mortality reduction.

TABLE 1

Per Acre Economic Benefits of Tree Mortality Reduction Under Various Interest Rates[a]

Mortality reduction	Interest rate	
	8 percent	13 percent
percent		
25	$ 3.03	$1.22
50	6.43	2.59
75	10.27	4.15

[a] It is assumed that control is initiated in 1960 and that the 24 tenth-acre Barr plots are clear-cut in 1980 with the estimated 1980 stumpage price of $110 per thousand board feet obtained.

Table 1 indicates, for example, that a 25 percent reduction in mortality will be a cost-effective strategy only if the per acre application costs are roughly less than or equal to three dollars (provided the rate of interest is pegged at 8 percent). Comparing the two proposed rates of interest, it is evident that the firm is constrained to lower cost strategies when higher discount rates are involved in the decision process.

The relative importance of the two infestation effects was analyzed by separating the two effects in the regime of no mortality reduction, First, if mortality effects on yield are omitted and only possible gains from thinning are taken into account, the final board foot yield rises by 19 percent. On the other hand, if the gains from thinning are ignored, the final yield shows a 2 percent decline. Thus, the mortality effect predominates in this model as expected, although the thinning effect _is_ present in the model and does alter the results slightly.

Some Concluding Remarks

The object of this paper has been to make a rough estimate of the economic benefits of Western pine beetle control on Ponderosa pine stands on Blodgett Experimental Forest. Neither the control mechanism nor the costs of control are specified here. However, the benefits of control, as given in Table 1, indicates the possible economic impact of control policies. The benefits are a function of three variables: (1) the interest rate used in calculating the present discounted values; (2) the stumpage price of Ponderosa pine; and (3) the percent mortality reduction desired. In the case of Blodgett Experimental Forest between 1960 and 1980, an interest rate of 8 percent is likely to be an average figure. The interest rate of 13 percent is included to indicate the sensitivity of the findings to this parameter. In conclusion, if the costs of applying a specific pest control tactic are greater than the benefits detailed in the table, then control programs under these conditions may not be economically justifiable.

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