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SIMULATION OF HOW JACK PINE BUDWORM (LEPIDOPTERA: TORTRICIDAE) AFFECTS ECONOMIC RETURNS FROM JACK PINE TIMBER PRODUCTION IN MICHIGAN[1]

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ABSTRACT

The impact of jack pine budworm on economic returns from jack pine timber production in Lower Michigan and management actions that might be taken to reduce this impact were evaluated with a simulation model. Results indicate that current jack pine rotation ages are excessive and should be reduced. Insecticide application is not a viable strategy for reducing jack pine budworm impact.

Forest managers often make decisions to prevent or suppress pest-caused damage that could reduce economic returns. In these situations, forest managers need the tools and information to make the decisions that would minimize economic injury. For this pest-caused effects are expressed in relevant economic terms and potential actions are evaluated by their costs and expected benefits (Leuschner and Newton 1974). This information requires a knowledge of the growth and value of pest-damaged and undamaged stands through the length of a management rotation. Often, however, such information has been based on pest damage assessments which have enumerated numbers of trees killed or have measured short-term growth reductions. Such measures often exaggerate losses and may lead to erroneous management decisions (Mattson and Addy 1975, Miller et al. 1978, Waters and Stark 1980).

While data are rarely available for comparing damaged and undamaged stands, with systems analysis and modelling, comparisons can be made. A system is a set of interconnected elements organized toward a goal or set of goals. A model is an abstraction of a system. While models are usually simpler than the real system they mimic, they can predict the behavior of a complicated and poorly understood system. They allow us to study a complex system under conditions we are unable or would never want to create in the real world. Also, when a management scheme for a particular system has been established, we can use models to optimize this management by adding some value judgments.

Models of systems and systems analysis must be objective-oriented. Therefore, the first phase of systems analysis is to formulate a statement of the problem to be solved. This statement must include the criteria used in evaluating system performance (Manetsch and Park 1979).

The problem we sought to solve was how to minimize the economic impact of jack pine budworm (*Choristoneura pinus* Freeman). This insect regularly defoliates large acreages of jack pine (*Pinus banksiana* Lamb.) in Michigan, resulting in growth loss and tree mortality. The criteria for evaluating system performance were economic returns on investments in jack pine timber production.

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MODEL DESCRIPTION

The system was divided into three discrete elements: (1) stand growth, (2) budworm dynamics and impact, and (3) evaluation of timber investment returns as influenced by the first two components. Figure 1 portrays the interrelationships of these elements. System dynamics were simulated with a Monte Carlo procedure, i.e., randomness within and between runs, being incorporated into the values of system parameters to estimate uncertainty in system performance. Basic model structure is presented in the following text. Details of the model are given in the appendix.

Stand Growth. Jack pine growth was simulated with a nonlinear deterministic stand growth model based on data collected in Lower Michigan.[6] In a deterministic model, all parameters are assumed constant. Independent variables were site index, basal area, and stand age. The model requires a minimum stand age of 20 years. The current year's basal area was calculated by adding basal growth to the previous year's basal area. Height was determined from the site index and stand age. Volume was a function of basal area and height.

Jack Pine Budworm. The jack pine budworm component was modelled by generating two stochastic variables: (1) the time interval between budworm outbreaks, and (2) the effect of budworm defoliation on jack pine growth. Stochastic variables are defined by a probability distribution and, therefore, are not constants. They were used to determine the effect of variability in these parameters on system output. Representing the budworm component as two stochastic variables is a simplification; however, it adequately captures the important properties of this part of the system.

The expected time interval between budworm outbreaks (10 years) was based on ca. 40 years of data collected by the Michigan Department of Natural Resources (MDNR). The distribution of time periods between outbreaks was described by an exponential distribution (used to portray time intervals between random events).

The impact of budworm defoliation was recorded as a percentage reduction in basal area growth. In addition, this impact was distributed over time beginning with the intiation of a budworm outbreak. Mean percentage reductions in basal area due to budworm defoliation were site and age dependent (Table 1) and were approximated from a number of sources (Benjamin 1953; Benjamin et al. 1954, 1961; Graham 1935; Kulman et al. 1963;

[6]Data source: Paul Laidly, USDA Forest Service, Northern Conifers Laboratory, Grand Rapids, MN.

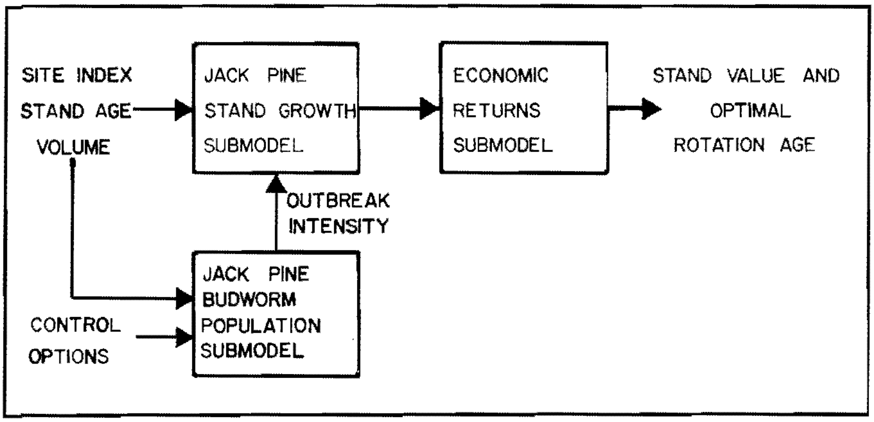

Fig. 1. Conceptual model for the jack pine-jack pine budworm system.

Table 1. Mean annual loss due to budworm defoliation by site and stand age. Loss is based on growth reduction and mortality.

Site index	Stand age	Mean growth loss
40	< 50	17%
40	> 50	20%
50	< 50	7%
50	> 50	10%
60	< 50	5%
60	> 50	6%

MacAloney and Drooz 1956). The Poisson distribution was used to describe the dispersion of growth reductions since no evidence suggested another distribution.

Returns on Timber Investment. Maximum rotation age was selected as the point in time when returns on timber investments were maximized. Establishment costs for existing stands are historic and are irrelevant to alternate courses of action.

The optimum age to harvest existing stands was set at the point in time where the opportunity cost of holding the stand one more year equaled the stand value if harvested in the beginning of that year. Mathematically, this is expressed as:

$$DISVAL_{N+1} - DISVAL_N = 0$$

where DISVAL is the discounted present worth of timber of stand age N.

Discount rates were set equal to the rate of return that the MDNR anticipated for jack pine reforestation investments. These rates of return are site-specific and are based on planatations of 800 trees per acre. All returns, or real returns, were adjusted with the effect of inflation removed. The rates used are: site index 40-1.4%, site index 50-2.67%, and site index 60-4.00%.

Prices for stumpage were based on the price function:

$$PRICE = 6.15 + .39\ VOL\ (r^2 = 0.65)$$

where VOL is the volume per acre in cords. This function was determined from MDNR auction sales.

SIMULATION RESULTS

The model was used to answer two questions: (1) Are current jack pine management strategies optimal when timber is the major objective and jack pine budworm outbreaks are expected? (2) Are insecticide applications to reduce jack pine budworms economically justifiable? Simulations were begun with a stand age of 30 years and basal areas ranging from 60 to 120 feet^2 per acre. Age 30 was chosen as the initial age since it is only beyond this point that stands approach merchantability and are susceptible to budworm damage. Twenty-five Monte Carlo runs were executed for each simulation.

Recommended economic rotations for jack pine by site in Michigan's Lower Peninsula for Forest Management Division Lands are site index 40, 70 years; site index 50, 60 years; and site index 60, 45 to 50 years. These recommendations were made without considering jack pine budworm as a component of the forest management system. Simulation results indicated that these recommended rotations are excessive when budworm is considered.

Model-determined optimal rotation ages (ORA) for defoliated and non-defoliated stands are portrayed in Figure 2. The ORAs for the non-defoliated stands correspond closely to currently recommended rotations. However, when further realism is added to the system by considering the effects of budworm defoliation, the ORAs are greatly reduced. The effect is more pronounced on the poor sites because poor sites have greater budworm susceptibility (Batzer and Millers 1970), and interest rates are higher on the better sites, hence, economic rotations are shorter on these sites regardless of budworm effects.

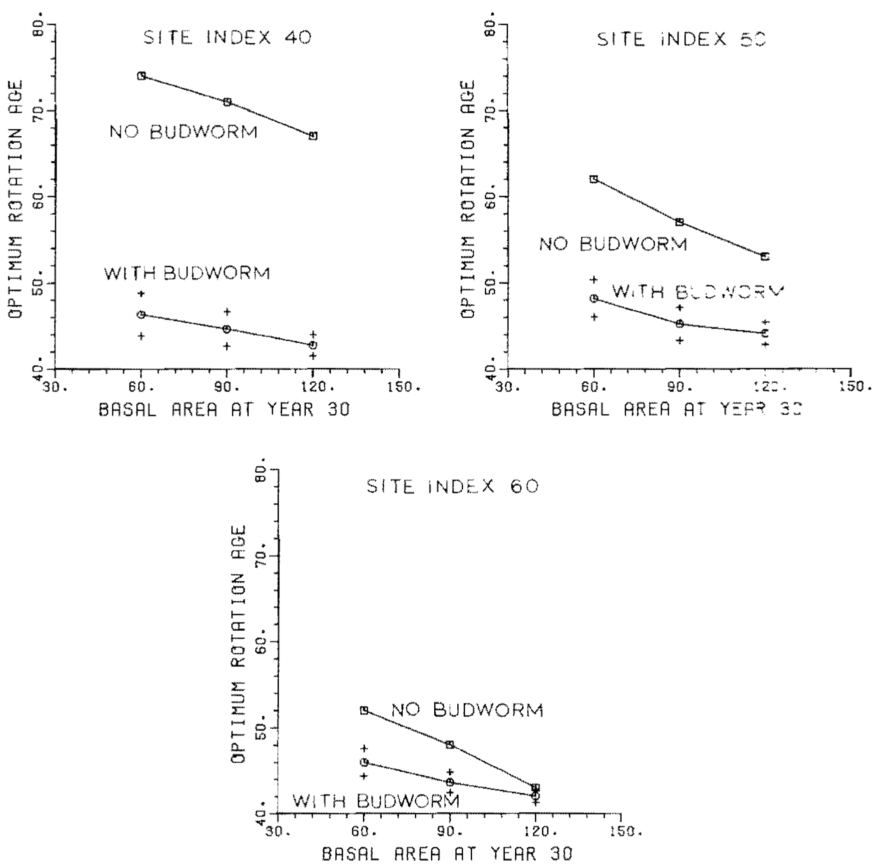

Fig. 2. Comparison of optimum economic rotations for jack pine on sites of index 40, 50 and 60 with and without jack pine budworm defoliation. (+) indicates 95% confidence interval.

Model sensitivity to budworm-induced growth reduction was examined by reducing growth loss rates by 25%. This value was selected based on the variability of reported impact due to budworm defoliation from which growth reduction values in the model were determined. Optimal rotation ages computed with these new rates are compared in Figure 3 with the ORAs of defoliated stands taken from Figure 2. Reducing the growth loss rates by 25% did not produce large changes in the ORAs. In fact, as shown by the overlap of confidence intervals in Figure 3, most means are not significantly different at a 95% confidence level. This suggests that the system is not highly sensitive to these rates and efforts to better determine these parameters may not be warranted.

The economic effectiveness of reducing budworm impact through insecticide application was investigated by comparing the volumes at ORA for a control and no-control strategy. Since the ORA is the point where no additional value is added to the stand, the stand with the greatest volume at rotation is the most valuable. Under the control scheme, a cost of $10 per acre was incurred whenever a budworm outbreak occurred. This amount was based on actual costs per acre in similar production ecosystems to cover both indirect

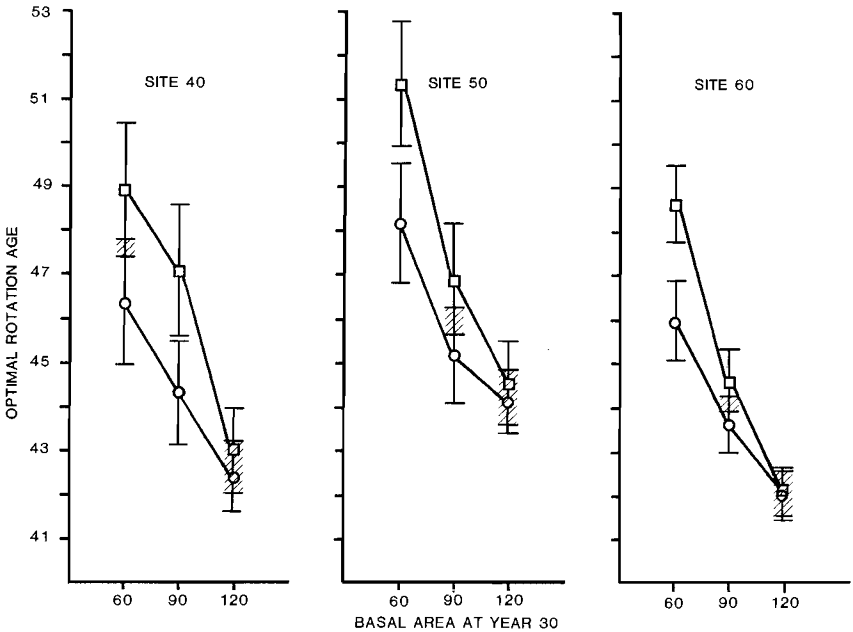

Fig. 3. Comparison of optimum economic rotations for jack pine on sites of index 40, 50 and 60 with full budworm impact (○) and impact reduced by 25 percent (□). Overlap of 95% confidence intervals indicated by cross hatch.

and direct costs.[7] We assumed that an insecticide application reduced the budworm-induced growth loss by 95%, because (1) an insecticide application probably will not kill all budworms, and (2) some damage will occur before the outbreak is detected and control measures are initiated. We felt this value (95%) represented a "best-case scenario" and was used to maximize the benefits of an insecticide application. The simulation showed that insecticide application is not cost effective, since volumes are greater under the no-control strategy (Fig.4).

DISCUSSION

The management of any system can be classified into two broad categories. First, controllable inputs of a system may be manipulated to produce desired outputs. Second, given certain inputs, the system may be redesigned to produce a set of desired outputs. For crop-pest systems, the first approach is portrayed by manipulating pest-host interactions through insecticides. The design approach is more attractive ecologically, and often economical, as shown in the jack pine-jack pine budworm system.

Simulation results indicated that the rotation age on all sites should be reduced. On site 40, however, a rotation of 45 years may not produce a merchantable stand under current pulp-stick harvesting methods. Two approaches may minimize budworm-induced losses on these sites. First, an alternate harvesting method such as whole tree chipping might be

[7]Data source: Greentree Consultants, Inc. P.O. Box 27125, Lansing, MI.

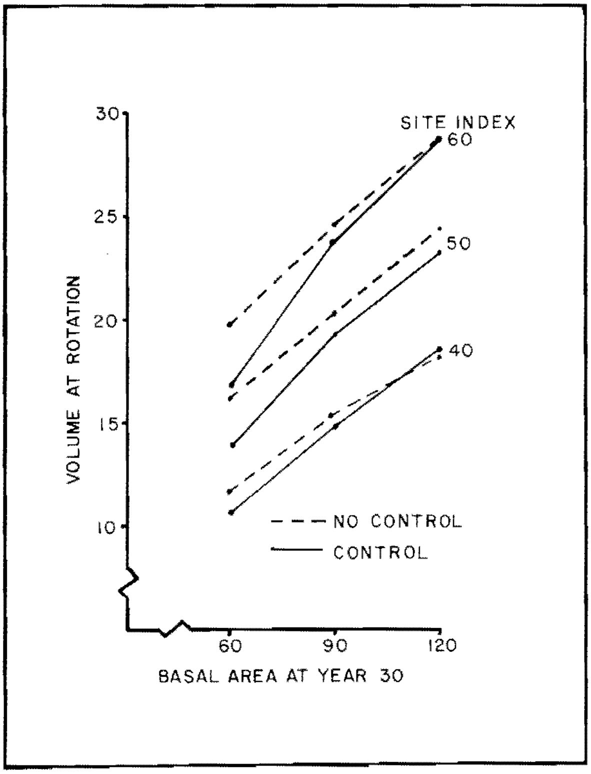

Fig. 4. Comparison of volumes at economic rotation for jack pine on sites 40, 50 and 60 with and without insecticidal control of jack pine budworm.

adopted to shorten the rotation age. Second, since jack pine production on these sites is at best a marginal endeavor, new stands should not be propagated on these areas with the intent of maximizing returns from fiber production. Timber revenues could be maximized on the better sites, with poorer sites being devoted to uses such as recreation or wildlife habitat. This is compatible with a key value approach to forest management.

Rose (1973) also recommended reduced rotation ages and intensified jack pine management after evaluating a complex jack pine-jack pine budworm model. The fact that we reached conclusions similar to Rose's supports both his and our results. Equally important, though, is the contrast between Rose's complex and our simpler approach to modelling these systems.

Broadly speaking, models can take two opposite, yet complimentary, forms: a black box or input-output form, and an internally descriptive form. In the first, information acquired from the data is developed into a model. In the latter, existing theory is used to develop a model which is then tested against experimental data. We used a black box approach to represent the major components of the system (i.e., stand growth and budworm dynamics). These black box models were then tied together in descriptive form to portray system behavior.

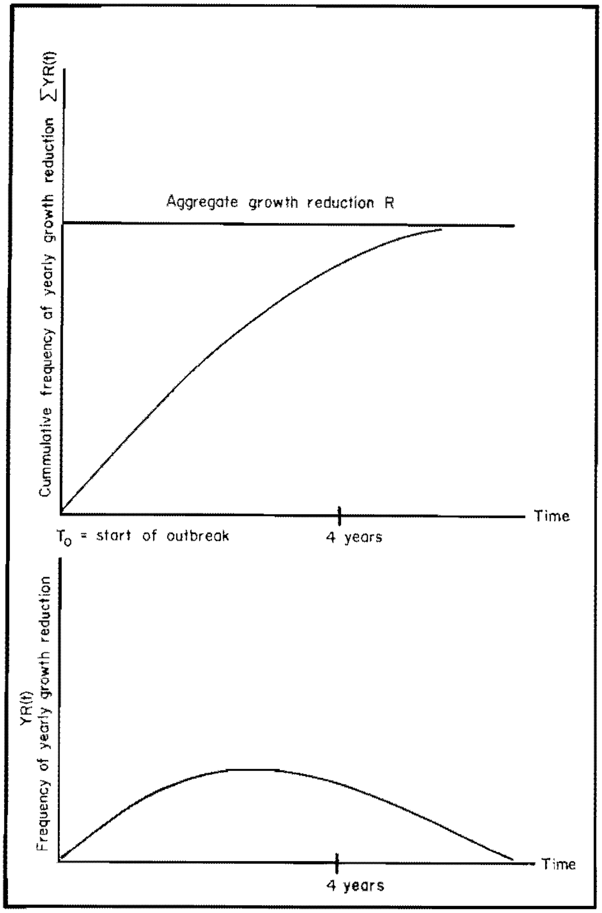

Fig. 5. Approximate frequency and cumulative frequency curves of growth reduction due to jack pine budworm defoliation.

Attempts to comprehensively model all the complexities of a system are futile, since such models are rarely used due to extreme data requirements, unending debugging problems, and nonexistent validation criteria (Clark et al. 1979). Modellers should strive for an economical model that retains system response to management variables. Such models usually are adequate for making management decisions.

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APPENDIX–MODEL EQUATIONS AND DERIVATIONS

Stand growth

The following equations were used to compute jack pine stand growth:

$BG = .276SI^{.63}(2.718\exp(-10.872)\exp(-29.18/SA))(1+.056BA)-.000358BA^2$

$BA_{i+1} = BG + BA_i$

$HT = SI(1.677-(1.8063(2.718\exp(-.0196SA))))$

$VOL = .003958HT(SA)$

BG = Basal growth	SA = Stand age
BA = Basal area	SI = Site index
HT = Height	VOL = Volume

Jack pine budworm

The time interval between budworm outbreaks was described by a truncated exponential distribution having a mean of 10 years and truncation points of 6 and 15 years. A random variable x_i from this distribution may be generated using the inverse transformation method as:

$x_i = -u_x(\ln r_i)$

where u_x is a desired mean and r_i is a uniformly distributed random variate between 0 and 1 (Manetsch and Park 1974).

Jack pine growth reduction following budworm defoliation was modelled as a time distributed process. Total growth loss from a budworm outbreak was described by R. In addition, YR(t) was a set of variables describing growth reductions in the years during and following a budworm attack such that:

$$\sum_{t=1}^{n} YR(t) = R$$

Each YR(t) was thought of as a time-delayed proportion of R. An appropriate model of this process is the series of differential equations:

$$\frac{dr_1}{dt} = \frac{k}{DEL}(R(t) - r_1(t))$$

$$\vdots$$

$$\frac{dr_k}{dt} = \frac{k}{DEL}(r_{(k-1)}(t) - r_k(t))$$

where r_i = a set of intermediate rates and r_k = YR (Manetsch and Park 1974). The constant DEL was the expected value of the transit time of an entity through the process (Manetsch 1966). In this equation, it was the mean length of time a tree suffered reduced growth due to budworm defoliation. The parameter k specifies a member of the Erlang family of density functions that describe the distribution of transit times. Using information from Kulman (1971) and Kulman et al. (1963) the distribution of defoliation effects was described by an Erlang density function with $k=2$ and a mean (DEL) of 4. These relationships are shown in Figure 5.

The total budworm-induced growth loss (R) was described with a Poisson distributed variable. A discrete random variable x_i may be generated by finding x_i such that:

$P(x_{i-1}) < r_i < P(x_i)$

where r_i is a uniformly distributed random variable between 0 and 1 and $P(x_i)$ is the desired cumulative distribution function. In this case $p(x_i)$ is the Poisson distribution. The site and age dependent means for this distribution are presented in Table 1.

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